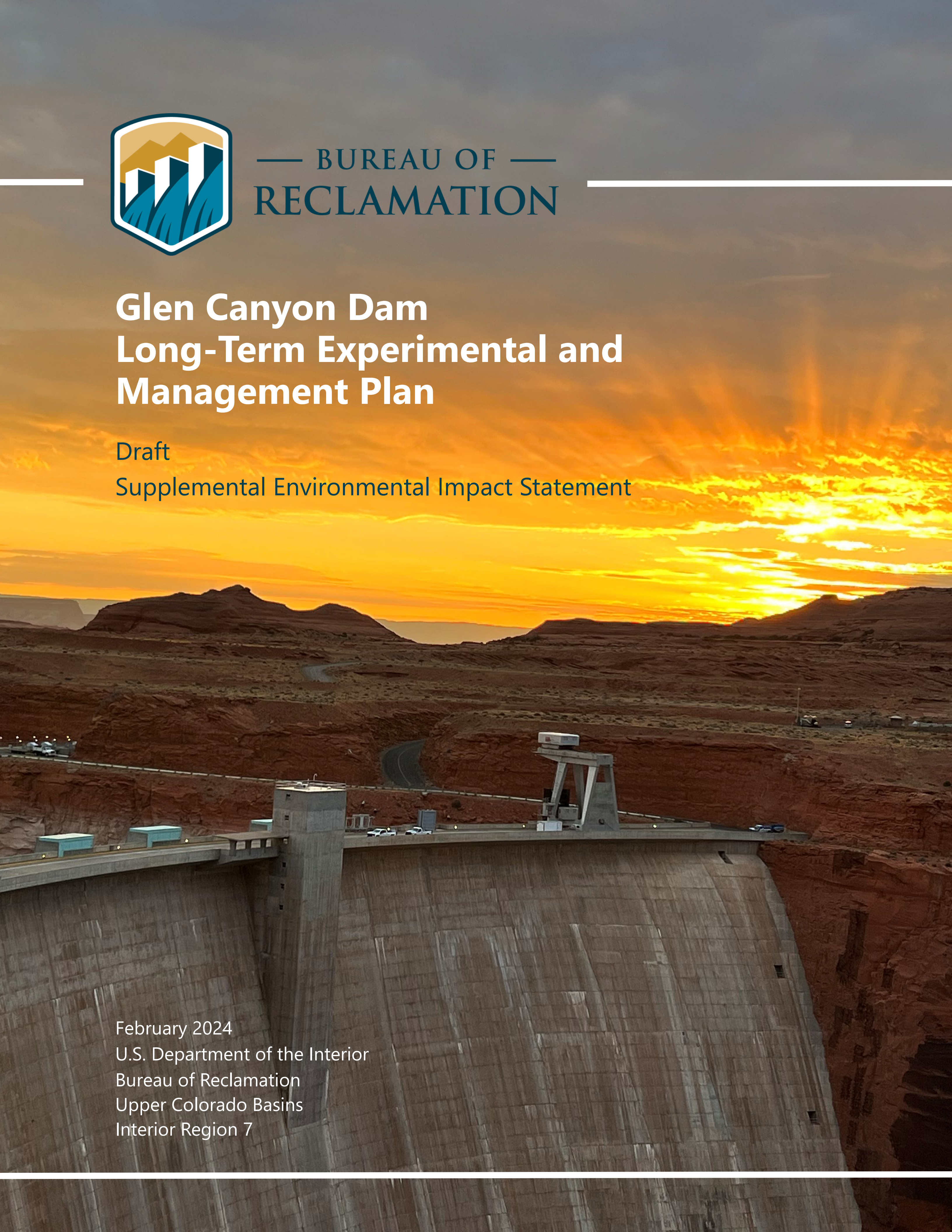

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Glen Canyon Dam Long-Term Experimental and Management Plan

Draft
Supplemental Environmental Impact Statement

February 2024
U.S. Department of the Interior
Bureau of Reclamation
Upper Colorado Basins
Interior Region 7

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Mission Statements

The **Department of the Interior** protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

The mission of the **Bureau of Reclamation** is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Photo by Bureau of Reclamation, Operations Supervisor, Kato Miyagishima, June 2023, Flickr.com, Glen Canyon Dam at sunset

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

Proposed Action:	Reclamation is proposing to revise the 2016 Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam to address the potential impacts from reduced high-flow experiments' (HFE's) frequency and the threat of smallmouth bass below Glen Canyon Dam. Potential impacts from smallmouth bass pose an unacceptable risk to the threatened and endangered species below the dam. The reduction of water temperature and adjustments in flow velocity may serve as essential tools to disrupt the successful spawning and establishment of smallmouth bass. Reclamation has determined that a supplemental environmental impact statement is required to explore the implementation of additional flow options at Glen Canyon Dam. Various reservoir releases with different temperature and velocity combinations will be assessed to disrupt smallmouth bass spawning. This supplemental environmental impact statement will also examine sediment accounting periods and implementation windows related to the HFE protocol analyzed in LTEMP.
Lead Agency:	Bureau of Reclamation, Upper Colorado Basin Interior Region 7
Cooperating Agencies:	Arizona Fish and Game Department Bureau of Indian Affairs Colorado River Board of California Colorado River Commission of Nevada Havasupai Tribe Hopi Tribe Hualapai Tribe Kaibab Band of Paiute Indians National Park Service Navajo Nation Pueblo of Zuni Salt River Project Upper Colorado River Commission US Fish and Wildlife Service Utah Associated Municipal Power Systems Western Area Power Administration

For further information:

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Acronyms and Abbreviations

	Full Phrase
°C	degrees Celsius
°F	degrees Fahrenheit
af	acre-feet
APE	area of potential effect
ASM	Arizona State Museum
AZGFD	Arizona Game and Fish Department
AZ-SGCN	State of Arizona species of greatest conservation need
BGEPA	Bald and Golden Eagle Protection Act of 1940
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CAA	Clean Air Act
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
cfs	cubic feet per second
CH_4	methane
CO	carbon monoxide
CO_2e	carbon dioxide equivalent
CRSP	Colorado River Storage Project
CRSS	Colorado River Simulation System
CV	contingent valuation
DO	dissolved oxygen
EA	environmental assessment
eGRID	Emissions and Generation Resource Integrated Database
EIS	environmental impact statement
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FEIS	final environmental impact statement
GCDAMP	Glen Canyon Dam Adaptive Management Program
GCMRC	Grand Canyon Monitoring and Research Center
GCNP	Grand Canyon National Park
GCNRA	Glen Canyon National Recreation Area
GHG	greenhouse gas
GTMax	Generation and Transmission Maximization Model
GWP	global warming potential
H_2S	hydrogen sulfide
HFE	High-Flow Experiment

IG SEIS	2023 Revised Supplemental Environmental Impact Statement for Near-term Colorado River Operations
Indians	United States for American Indians
Lb/MWh	pounds per megawatt-hour
LMNRA	Lake Mead National Recreation Area
LTEMP	Long-Term Experimental and Management Plan
maf	million acre-feet
MOA	memorandum of agreement
MW	megawatts
MWh	megawatt hours
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NHWZ	new high-water zone
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NPS	National Park Service
NRHP	National Register of Historic Places
OHWZ	old high-water zone
PA	programmatic agreement
Pb	lead
PM	particulate matter
$PM_{2.5}$	particulate matter less than or equal to 2.5 micrometers
PM_{10}	particulate matter less than or equal to 10 micrometers
POM	particulate organic matter
PSD	Prevention of Significant Deterioration
Reclamation	United States Bureau of Reclamation
ROD	Record of Decision
SEIS	supplemental environmental impact statement
Service	United States Fish and Wildlife Service
SGCN	species of greatest conservation need
SHPO	State Historic Preservation Officer
SMB EA	Glen Canyon Dam/Smallmouth Bass Flow Options Draft Environmental Assessment
SO_2	sulfur dioxide
SRM	Sand Routing Model
TCP	traditional cultural place
TDS	total dissolved solids
THPO	Tribal Historic Preservation Officer

UAMPS	Utah Associated Municipal Power Systems
US	United States
USGS	United States Geological Survey
VOC	volatile organic compound
WAPA	Western Area Power Administration
WECC	Western Electricity Coordinating Council
YOY	young of year

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Chapter 1. Purpose and Need

1.1 Introduction

The Colorado River flows from Lake Powell through the Glen Canyon Dam and into the canyons below, where it meanders through sandstone cliffs traversing the Glen Canyon National Recreation Area (GCNRA) and the Grand Canyon National Park (GCNP) before emptying into Lake Mead. The river runs approximately 275 miles from the Glen Canyon Dam to the inlet of Lake Mead and includes some of the country's most unique and rich ecosystems. This stretch of river crosses through Utah, Arizona, and Nevada (**Map 1-1**).

To adaptively manage this stretch of river, the United States (US) Department of the Interior (Department) Bureau of Reclamation (Reclamation), developed the Long-Term Experimental and Management Plan (LTEMP) for operations of Glen Canyon Dam, the largest hydropower-generating unit of the Colorado River Storage Project (CRSP; DOI 2016a).

The National Environmental Policy Act of 1969 (NEPA; 42 United States Code 4321 et seq.), the Council on Environmental Quality's regulations for implementing the procedural provisions of NEPA (40 Code of Federal Regulations [CFR] 1500–1508), and the Department NEPA regulations (43 CFR 46) require the Department to consider the potential environmental impacts of a proposed action before making a decision.

In 2016, Reclamation and the National Park Service (NPS) prepared a final environmental impact statement (FEIS) to evaluate impacts that could result from LTEMP. Since then, environmental conditions and new science have led Reclamation to pursue improvements to the original LTEMP FEIS. Reclamation has prepared this supplemental environmental impact statement (SEIS) to evaluate impacts that could result from the proposed updates to the LTEMP FEIS.

1.2 Background

The proposed updates to the LTEMP FEIS are a result of the extended period of drought, aridification, and low runoff conditions in the Colorado River Basin. Despite an above-average runoff in 2023, the period from 2000 to 2023 is considered one of the driest in over a century and among the driest in the last 1,200 years (Williams 2022). As Lake Powell's water elevation has decreased, the epilimnion,[1] where most fish reside, has drawn closer to the dam's penstocks.[2] The

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[1] Epilimnion – The upper stratum of the water column of a reservoir that is generally warm, circulating, and turbulent.

[2] Penstocks – Dam structures that conduct water from the reservoir through the dam to the turbines of a powerplant. The Glen Canyon Dam centerline penstock elevation is 3,470 feet.

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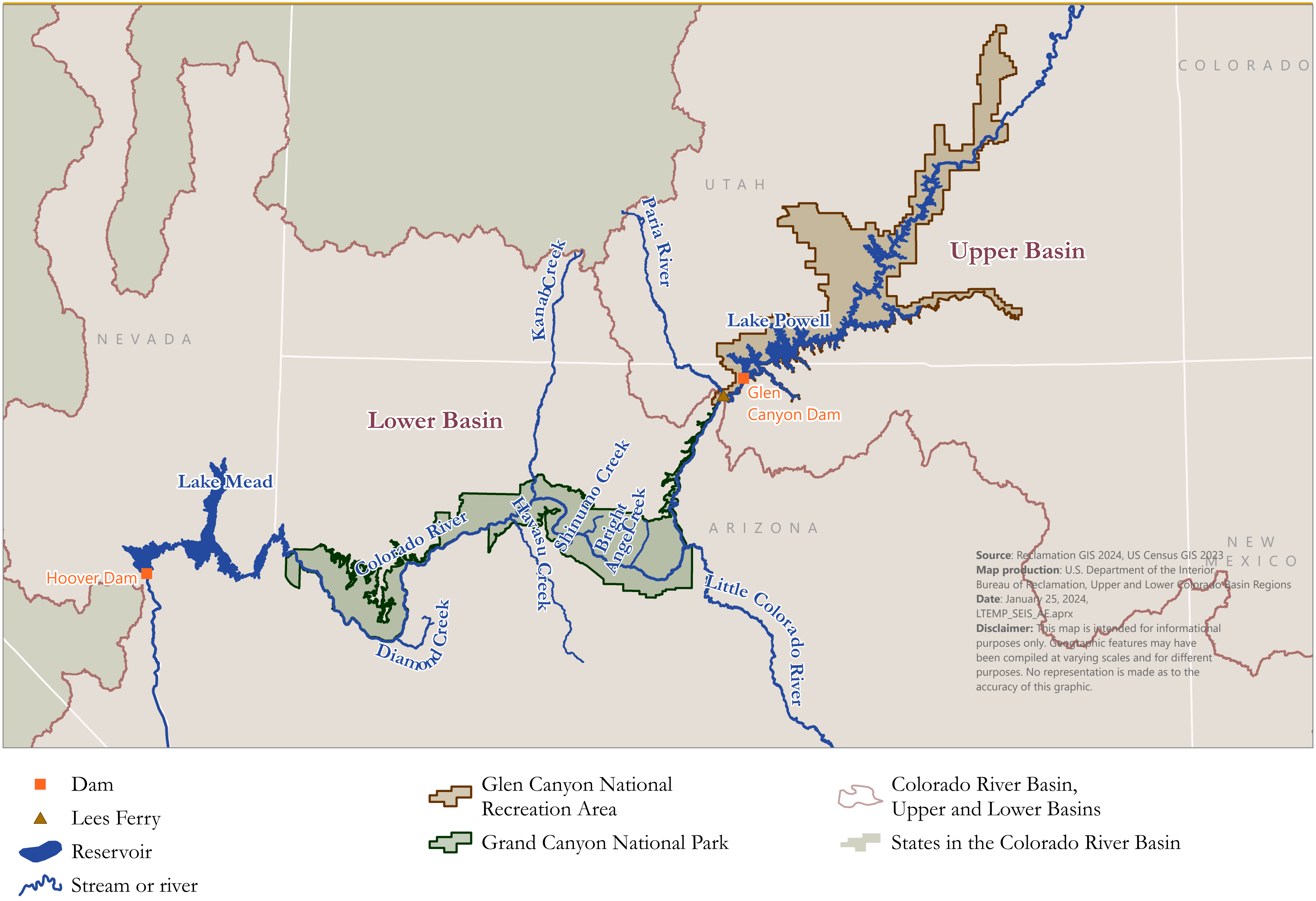
Map 1-1: Project Area

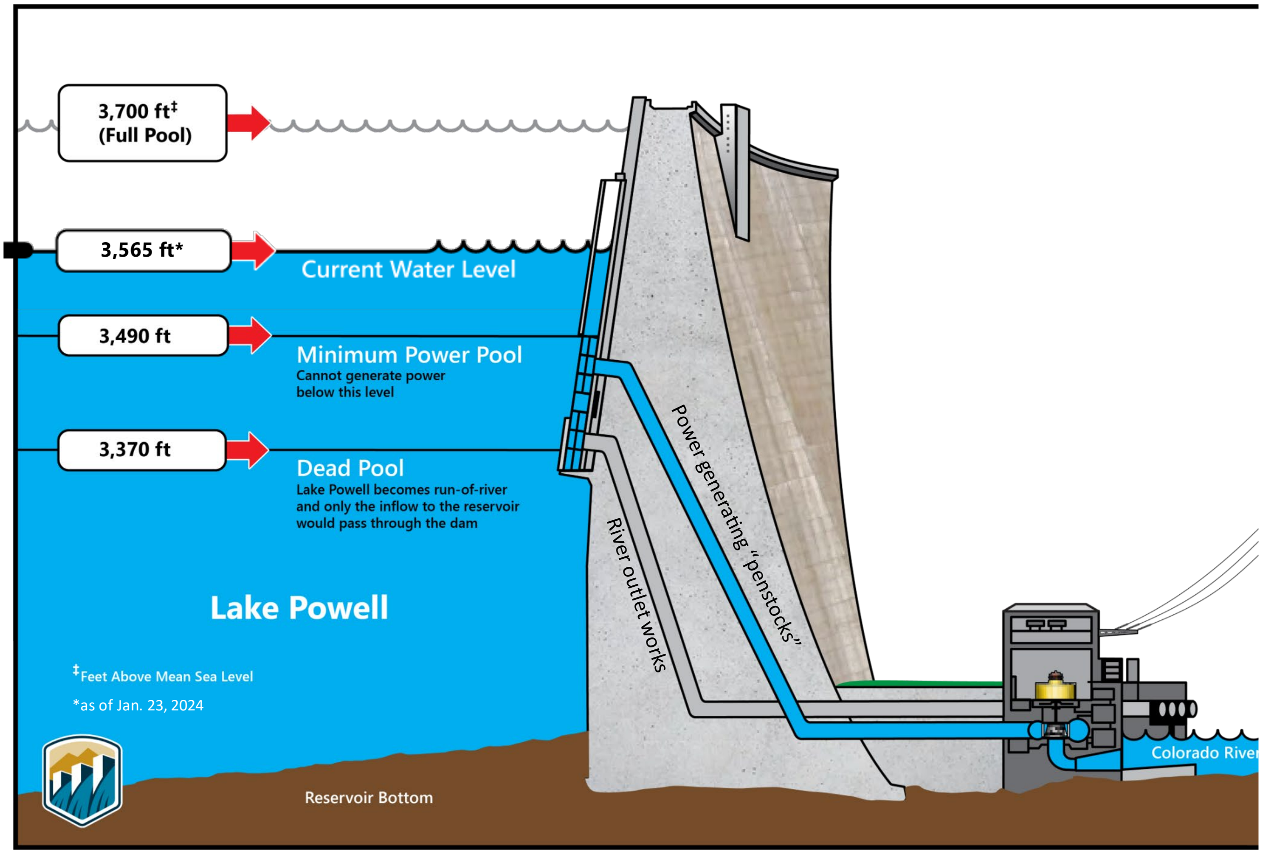


Source: Reclamation GIS 2024, US Census GIS 2023
Map production: U.S. Department of the Interior, Bureau of Reclamation, Upper and Lower Colorado Basin Regions
Date: January 25, 2024,
LTEMP_SEIS_AE.aprx
Disclaimer: This map is intended for informational purposes only. Geographic features may have been compiled at varying scales and for different purposes. No representation is made as to the accuracy of this graphic.

reduction in water elevation increases the likelihood of nonnative fish, such as smallmouth bass, being entrained,[3] passing through the dam, and entering the Colorado River downstream.

As Lake Powell's elevations decline, warmer water from the epilimnion is released from the dam, resulting in increased water temperatures downstream. See **Figure 1-1** for a conceptual representation of Glen Canyon Dam operations. These warmer water conditions facilitate the reproduction and establishment of warmwater nonnative fish that poses a major threat to federally listed fish species and other native and sport fish living downstream of Glen Canyon Dam. If highly predaceous smallmouth bass, which specialize in eating other fish, establish below the dam, removal efforts would be difficult and expensive with potentially limited success. In 20 years of mechanical removal efforts of smallmouth bass in the Upper Colorado River Basin upstream of Glen Canyon Dam, there have been limited success in reducing smallmouth bass densities to benefit native fish populations (Dibble et al. 2021; Bestgen and Hill 2016a).

Figure 1-1
Glen Canyon Dam Operations Guide



Source: USGS and Reclamation 2023

In response to these changing conditions, the Secretary of the Interior's acting designee to the Glen Canyon Dam Adaptive Management Work Group (AMWG) directed Reclamation in August 2022 to identify and analyze operational alternatives at Glen Canyon Dam to disrupt the spawning

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[3] Fish entrainment – The process of fish passing from the reservoir through the dam and into the river below.

of smallmouth bass and other warmwater nonnative fish that pass through the dam. As directed, Reclamation prepared the Glen Canyon Dam/Smallmouth Bass Flow Options Environmental Assessment (SMB EA). NEPA does not specifically require public commenting on a draft environmental assessment (EA). However, given the level of public interest in the project and to engage the interested public to the greatest extent possible, Reclamation provided for a public comment opportunity on the Draft SMB EA.

The Draft SMB EA was released for public review and comment on February 24, 2023. Reclamation accepted public comments on the SMB Draft EA from February 24 through March 10, 2023. Reclamation received 6,953 public comment submissions. Following the in-depth analysis of the SMB EA and upon analyzing and reviewing the comments, Reclamation determined that further analysis was necessary by expanding the EA to an SEIS.

The LTEMP FEIS also includes a proposal to change implementation of High-Flow Experiment (HFE) releases, which were initially implemented under the Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam EA (Reclamation 2011a). Prior to the development of the protocol for HFE releases, three experiments were conducted in 1996, 2004, and 2008 (Wright and Kennedy 2011). HFE releases are triggered based on hydrologic conditions and sediment accumulation in the Colorado River. The source of sediment that facilitates being able to conduct HFE releases is driven by storm activity and the resulting runoff in the Paria River (and other tributaries) that move sediment over time into the Colorado River. Each year, potential HFE releases are evaluated by a planning and implementation team and, if conditions warrant it, this team recommends implementation to the Department.

The 2011 HFE protocol was carried forward into the 2016 LTEMP FEIS. Under the 2016 LTEMP FEIS, HFE releases can be scheduled when conditions permit, within two time frames: in the spring from March through April and in the fall from October through November. Six HFE releases have been conducted since the HFE protocol was initiated in 2012. Under the protocol, those HFE releases occurred in November 2012, 2013, 2014, 2016, and 2018.

The Department also conducted a 3-day spring high-flow experiment that was outside the HFE protocol, but consistent with LTEMP, on April 24–27, 2023. Water releases from the dam during the 3-day 2023 experiment were as high as 39,500 cubic feet per second (cfs). The 2023 experiment's release did not meet sediment trigger requirements for the spring sediment accounting period in the HFE protocol nor was there enough annual volume (greater than 10 million acre-feet [maf]) to initiate a proactive HFE release. However, high fall sediment loads in Marble Canyon and favorable hydrology conditions were present to support a spring experiment consistent with LTEMP. As such, Reclamation analyzed the effects of the unique situation and concluded in a supplemental information report to the LTEMP FEIS that the 2023 experiment would not substantially change the analysis or findings presented in the LTEMP FEIS with regard to other spring HFE releases (Reclamation 2023b).

Since the protocol for HFE releases was initiated in 2012, there have been years in which sediment conditions warranted a recommendation for an HFE release, but an HFE release was not implemented. The Department made the decision not to implement fall HFE releases in 2015, 2021, and 2022, despite reaching input triggers for sediment HFE releases because of increased water temperatures and the higher potential for entrainment of warmwater nonnative fish. Concurrently, analyses indicated reduced transport of fine sediments in years characterized by low release volumes. These developments prompted a comprehensive reevaluation of the scientific data underpinning the HFE protocol.

Over the last quarter century, scientific insights regarding the use and timing of HFE releases have significantly enhanced the understanding of management of sediment supplies derived from tributaries below the dam. The review of HFE releases over the past decade, particularly in the context of lower releases, highlights the need to reassess the HFE sediment accounting period and the implementation window to more effectively improve sediment conditions in the Grand Canyon.

On June 6, 2023, the Secretary of the Interior's acting designee to the AMWG, a federal advisory committee, issued a directive to Reclamation. This directive charged Reclamation with the responsibility of preparing an SEIS. The SEIS will explore potential adjustments to the LTEMP HFE protocol to incorporate the latest scientific findings.

This SEIS serves as an extension of the December 2016 Record of Decision (ROD) for the LTEMP FEIS (DOI 2016b). The core focus of this SEIS is the evaluation of sub-annual flow options designed to prevent the establishment of smallmouth bass and other warmwater nonnative, invasive fish below Glen Canyon Dam by impeding their reproduction. Additionally, this comprehensive analysis will explore changes to the sediment accounting periods associated with the LTEMP HFE protocol using the latest available science.

1.3 Proposed Federal Action

Recognizing the ecological threat that smallmouth bass pose on the Colorado River downstream of Glen Canyon Dam, Reclamation has concluded that immediate actions must be developed to ensure the prevention of population establishment of smallmouth bass and warmwater nonnative, invasive fish. In addition, Reclamation has acknowledged improved ways to assess sediment inputs and sediment retention that may affect the frequency of HFE releases.

Accordingly, Reclamation is proposing to revise the LTEMP FEIS to address the potential impacts from reduced HFE frequency and the threat of smallmouth bass below Glen Canyon Dam. Reclamation has concluded that the potential impacts from smallmouth bass pose an unacceptable risk to threatened and endangered species below the dam.

The reduction of water temperature and adjustments in flow velocity may serve as essential tools to disrupt recruiting smallmouth bass populations from expanding. Therefore, Reclamation has concluded an SEIS is required to explore the implementation of additional flow options at Glen Canyon Dam. A range of reservoir releases with varying combinations of temperature and release volumes will be analyzed to assess their effectiveness in disrupting smallmouth bass spawning and preventing recruiting populations from expanding. Reclamation will also examine the sediment accounting periods and implementation windows associated with the HFE protocol analyzed in the LTEMP FEIS.

Reclamation and its partners have already begun efforts toward additional protections at Glen Canyon Dam. These efforts include guidance provided by the Glen Canyon Dam Adaptive Management Program (GCDAMP) stakeholders. The guidance includes, but is not limited to, fish exclusions, slough modifications, and temperature control devices (GCDAMP 2023). These efforts are considered medium- and long-term solutions and will require additional development and analysis. Reclamation plans to explore these options through future NEPA actions.

1.4 Purpose of and Need for Action

The purpose of the LTEMP SEIS is for Reclamation to analyze additional flow options at Glen Canyon Dam in response to nonnative, invasive smallmouth bass and other warmwater nonnative species recently detected directly below the dam. The need is to disrupt the establishment of smallmouth bass below Glen Canyon Dam by limiting additional recruitment, which could threaten populations of threatened humpback chub below the dam.

The LTEMP SEIS will also consider the HFE protocol by including the latest scientific information to improve Reclamation's ability to implement HFE releases as detailed in the LTEMP FEIS. Specifically, Reclamation is considering adjusting sediment accounting periods and HFE implementation windows.

1.5 Lead and Cooperating Agencies

The Secretary of the Interior is responsible for the operation of Glen Canyon Dam pursuant to applicable federal law. The Secretary is also vested with the responsibility of managing the mainstream waters of the Colorado River pursuant to federal law. This responsibility is carried out in a manner consistent with the Law of the River[4] (Reclamation 2008). Reclamation, as the agency designated to act on the Secretary's behalf with respect to these matters, is the lead federal agency for the development of this SEIS in accordance with NEPA.

Sixteen federal, state, Tribal, and public utility agencies are cooperating for the purpose of assisting with environmental analysis and preparation of this SEIS. State, Tribal, and public utility cooperators include the Arizona Fish and Game Department (AZFGD), Colorado River Commission of Nevada, Salt River Project, Utah Associated Municipal Power Systems (UAMPS), Upper Colorado River Commission, Colorado River Board of California, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and Pueblo of Zuni. The federal cooperating agencies include the US Fish and Wildlife Service (Service), Bureau of Indian Affairs (BIA), NPS, and Western Area Power Administration (WAPA).

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[4] The numerous compacts, federal laws, court decisions and decrees, contracts, and regulatory guidelines used to administer the Colorado River are collectively referred to as the "Law of the River."

The BIA has responsibility for the administration and management of lands held in trust by the United States for American Indians (Indians) and Indian Tribes located within the Colorado River Basin. Developing forestlands, leasing assets on these lands, directing agricultural programs, protecting water and land rights, and developing and maintaining infrastructure and economic development are all part of the BIA's responsibility.

The Service is involved in the conservation, protection, and enhancement of fish, wildlife, and plants and their habitats for the continuing benefit of the American people. The Service manages four national wildlife refuges along the lower Colorado River. Among its many other key functions, the Service administers and implements federal wildlife laws, protects endangered species, manages migratory birds, restores nationally significant fisheries, conserves and restores wildlife habitat such as wetlands, and assists foreign governments with international conservation efforts. It also oversees the federal aid program that distributes hundreds of millions of dollars in excise taxes on fishing and hunting equipment to state fish and wildlife agencies.

The NPS administers areas of national significance along the Colorado River, including GCNRA, GCNP, Baaj Nwaavjo I'tah Kukveni Grand Canyon National Monument, and Lake Mead National Recreation Area (LMNRA). The NPS administers visitor use (including recreation) of cultural and natural resources in these areas from offices located at Page, Arizona; GCNP, Arizona; and Boulder City, Nevada. The NPS also grants and administers concessions for the operation of marinas and other recreation facilities at Lake Powell and Lake Mead, as well as concession operations along the Colorado River between Glen Canyon Dam and Lake Mead.

WAPA markets and distributes hydroelectric power and related services within a 15-state region of the central and western United States, and it is one of four power marketing administrations within the Department of Energy. WAPA's mission is to market and transmit electricity from federal multiuse water projects. WAPA markets and transmits power generated from the various hydropower plants located within the CRSP under the CRSP Act and operated by Reclamation. WAPA customers include municipalities, cooperatives, public utility and irrigation districts, federal and state agencies, and Indian Tribes located throughout the Colorado River Basin. The wholesale customers, in turn, provide retail electric service to millions of consumers within the seven Colorado River Basin States.

1.6 Scope of the SEIS

1.6.1 Affected Region and Interests

The project area encompasses Glen Canyon Dam and the Colorado River downstream of the dam to the inlet[5] of Lake Mead. Lake Powell and Lake Mead are ***not*** within the project area. The analysis area may vary depending on the specific resource being considered. For instance, the cultural analysis will encompass a rim-to-rim area of potential effect (APE), while the socioeconomic and hydropower analyses will examine surrounding counties and communities.

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[5] The inlet of Lake Mead can fluctuate from season to season and year to year. The fluctuations of the inlet do not impact the resource analysis for this SEIS.

1.6.2 Relevant Issues

The following relevant issues will be addressed in this SEIS:

- **Drought and Low Runoff Conditions:** Given the prolonged period of drought, aridification, and low runoff conditions in the Colorado River Basin, it is crucial to assess the impact of these conditions on water levels, water temperature, and fish populations.
- **Entrainment of Nonnative Fish:** The analysis will investigate the risk and consequences of warmwater nonnative fish, especially smallmouth bass, being entrained, passing through Glen Canyon Dam, and entering the Colorado River.
- **Effect of Water Temperature:** The discharge of warmer water downstream due to decreasing Lake Powell elevations will be explored. This issue is significant because it creates conditions conducive to the reproduction and establishment of warmwater nonnative fish, posing a threat to native species downstream.
- **Threat to Federally Listed Fish Species:** The potential threat posed by nonnative, predatory fish, including smallmouth bass, to federally listed fish species and other native fish downstream of Glen Canyon Dam will be examined.
- **HFE Protocol Evaluation:** The evaluation of the HFE protocol will consider factors such as the absence of fall HFE releases in certain years, despite sediment triggers being met; sediment transport in low-release and low-elevation years; use of best available science for sediment accounting; and the need to improve the protocol to utilize the best available science.
- **Modifications to HFE Protocol:** The SEIS will explore potential modifications to the HFE protocol in light of the latest scientific findings and insights, including adjustments to sediment accounting periods and HFE implementation windows.

1.7 Timing Considerations for this SEIS

The NEPA analysis in this process is designed to address river conditions that typically begin to occur in the summer of each year for warmwater nonnative predation and in the spring of each year for potential HFE releases. These timing considerations are pertinent because of a need to evaluate and select, if appropriate, potential solutions to be in place and ready to deploy by summer 2024. Timing considerations are particularly appropriate given the potential effects of nonnative warmwater predators on native and listed fish.

The need to have tools evaluated and, if appropriate, selected to be in place as soon as summer 2024 has compressed the schedule of this NEPA process for the lead and cooperating agencies. Even with a compressed schedule, the information used in this analysis is sufficient to allow comparison among the alternatives. More information may become available to evaluate particular resources as the NEPA process develops.

1.8 Relationship of this Action to Other Colorado River Operations

The actions at issue in LTEMP, and correspondingly in this supplement to LTEMP, concern sub-annual releases from Glen Canyon Dam on hourly, daily, monthly, and experimental timescales. These sub-annual operations are a subset of broader Glen Canyon Dam operations that occur within the larger legal framework governing the Colorado River.

LTEMP does not affect other aspects of Glen Canyon Dam operations. LTEMP cannot affect the hydrology or changes to the hydrology or climate that determine how much water is stored by Glen Canyon Dam. LTEMP does not affect the operations of dams and other facilities upstream of Glen Canyon Dam. LTEMP does not control how much water is released from Glen Canyon Dam on an annual basis; such annual operation releases are currently controlled by the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007), which is currently being supplemented by the 2023 Revised Supplemental Environmental Impact Statement for Near-term Colorado River Operations (IG SEIS; Reclamation 2023c). LTEMP instead controls the timing of annual releases to improve downstream conditions, meeting the requirements of the Grand Canyon Protection Act, and minimizing—consistent with other laws—adverse impacts on downstream natural, recreational, and cultural resources.

1.9 Summary of the Contents of this SEIS

This SEIS describes the proposed federal action, the alternatives considered, the analysis of the potential effects of these alternatives on revised Colorado River operations and associated resources, and environmental commitments associated with the alternatives. The contents of the chapters in this volume are as follows:

- **Chapter 1, Purpose and Need**, includes background information leading to this SEIS, identification of the purpose of and need for the management strategies for Glen Canyon Dam being considered in the proposed alternatives, and the scope of this SEIS.
- **Chapter 2, Description of Alternatives**, describes the process of formulating alternatives and presents a range of reservoir operation strategies and guidelines considered under each alternative, as well as alternatives considered but eliminated from detailed analysis.
- **Chapter 3, Affected Environment and Environmental Consequences**, describes the affected environment for the proposed alternatives and presents evaluations of potential impacts that could result from the implementation of the alternatives under consideration. The discussion also addresses environmental consequences (i.e., potential effects of the action alternatives that could occur compared with the No Action Alternative). A methodology, summary, and discussion of cumulative impacts is also included under each resource topic.

- **Chapter 4, Consultation and Coordination**, describes the public involvement process, including public notices, scoping meetings, and hearings. This chapter also describes the coordination with federal and state agencies, local utilities, and Native American Tribes during the preparation of this document and any permitting or approvals that may be necessary for implementation of the proposed alternatives.

In addition to the above, this document includes a list of acronyms used throughout this SEIS; a glossary of commonly used terms; a list of references cited in the SEIS; a list of persons contributing to the preparation of the SEIS; a distribution list of agencies, organizations, and persons receiving copies of the document; and an index.

Table 1-1
Resources Considered for Detailed Analysis

Resource	Potentially Significant	Issue Areas
Water Resources		
Hydrologic Resources	Yes	Reservoir elevations, reservoir releases, river flows
Water Quality	Yes	Salinity, temperature, dissolved oxygen (DO)
Physical Resources		
Air Quality	Yes	Air pollutant emissions from alternative power sources
Visual Resources	No	Colorado River landscape character between Glen Canyon Dam and Lake Mead
Cultural Resources	Yes	Exposure of and increased visitation to resources (historic properties) as river levels fluctuate; sediment availability for wind-borne transport to protect resources downstream of the dam
Geomorphology and Sediment	Yes	Sediment transport, erosion, deposition, and beach-building conditions
Climate	Yes	Greenhouse gas (GHG) emissions from alternative power sources
Biological Resources		
Aquatic Resources	Yes	Food base, fish
Vegetation	Yes	Riparian and wetland habitat, weeds
Wildlife	Yes	Amphibians, reptiles, raptors, mammals, waterfowl
Special Status Species	Yes	Threatened and endangered species, state and Tribal sensitive species
Human Environment		
Tribal Resources	Yes	Mortality of fish, which are contributing elements to traditional cultural properties (TCPs); exposure and increased visitation to sacred sites and archaeological sites; changes in vegetation important to Tribes
Recreation	Yes	Whitewater boating, fishing
Energy and Hydropower	Yes	Generation, economic analysis, capacity
Socioeconomic Impacts	Yes	Net value from recreation activities, environmental nonuse value, economic impacts from electricity rate changes and hydropower generation capacity changes
Environmental Justice	Yes	Disproportionate effects on minority and low-income populations

Chapter 2. Description of Alternatives

2.1 Development of Alternatives

This chapter discusses the process used to define, develop, and analyze the range of reasonable alternatives for implementing the proposed federal action. As discussed in **Chapter 1**, Purpose and Need, Reclamation received approximately 7,000 public comments following the release of the Draft SMB EA. Many of these comments specifically addressed the potential impacts on Tribal resources, hydropower generation, and the associated economic impacts. In response to the direction from the Secretary of the Interior's acting designee, Reclamation is now transitioning to a more comprehensive SEIS analysis.

For the LTEMP SEIS scoping process, Reclamation envisioned considering the following preliminary six alternatives:

- **(1) No Action Alternative**: This alternative represents the continuation of current operations without implementing any changes.
- **Flow Option Alternatives Initially Analyzed in the SMB EA (February 2023)**: These original action alternatives build on the analysis conducted in the SMB EA (Reclamation 2023a). These alternatives aim to reduce the river temperature below 15.5 degrees Celsius (˚C; 60 degrees Fahrenheit [˚F]) to disrupt smallmouth bass spawning. The two flow spike alternatives include changes in dam releases to implement flows high enough to cool river temperatures in backwater areas (a known spawning location of smallmouth bass). These alternatives were analyzed to cool the river water temperature down to either Lees Ferry (river mile 15) or the confluence with the Little Colorado River (river mile 61). Moving forward, alternatives 2 through 5 may be referred to as the "cold-water alternatives" due to their similarities.
    - **(2) Cool Mix Alternative**
    - **(3) Cool Mix with Flow Spike Alternative**
    - **(4) Cold Shock Alternative**
    - **(5) Cold Shock with Flow Spike Alternative**
- **(6) Non-Bypass Alternative**: This alternative explores a flow option that does not involve the use of Glen Canyon Dam's bypass system. Instead of aiming to reduce river temperatures, this alternative focuses on river stage fluctuations to disrupt smallmouth bass spawning.

These alternatives aim to comprehensively examine a range of options, addressing the concerns raised by the public and stakeholders during the SMB EA process and ensuring a more detailed evaluation of potential impacts and benefits in the upcoming SEIS. The range of alternatives considered reflects input from Reclamation, States, Tribes, cooperating agencies, stakeholders, and other interested parties, including comments submitted during the SEIS public scoping period and the public comment period on the SMB EA.

2.2 Implementation

The Department anticipates adopting the smallmouth bass-related operations through operating year 2027. Reclamation's goal is to implement additional strategies in the future to prevent the establishment of smallmouth bass and other warmwater nonnative fish that were identified in the Invasive Fish Species Below Glen Canyon Dam: A Strategic Plan to Prevent, Detect, and Respond (GCDAMP 2023). In addition, the HFE-related changes to sediment account windows and implementation periods will last through the lifetime of the LTEMP FEIS. The Department may select different parts of any of the alternatives to best meet the purpose and need. The process to determine implementation of the potential actions discussed in this SEIS will be included in the Final SEIS and the ROD. Such implementation process details will not change the assessment of alternatives provided in this SEIS.

2.3 Common to All Action Alternatives

Under all alternatives, operations would continue pursuant to the continued implementation of existing agreements that control operations of Glen Canyon Dam.

In addition, in accordance with the purpose and need (**Section 1.4**), Reclamation will implement changes to the sediment accounting period and implementation windows using the best available science. These changes consist of adjusting the semiannual sediment accounting period to an annual period with the option for a spring or fall HFE release, or both. These changes to the HFE protocol would not change the duration or magnitude of HFE releases as outlined in the LTEMP FEIS; instead, they would adjust the timing to optimize the best available science when implementing HFE protocols.

The detailed changes to the HFE protocol were outlined in the 2023 Proposal to Amend the High-Flow Experiment Protocol and Other Considerations that was developed by the Flow Ad Hoc Group, through the Technical Work Group of the AMWG in partnership with the Grand Canyon Monitoring and Research Center (GCMRC) and Reclamation; that 2023 proposal is incorporated by reference. This document provides detailed changes to the both the sediment account period and implementation window. Reclamation has analyzed adding rollover sediment from one or more years to the current July 1 starting value if a sediment-triggered HFE release was not conducted in the previous annual accounting period, as described below in **Section 2.4**.

Dam operations would allow for the emergency exception criteria to continue as needed and as outlined in the LTEMP FEIS (DOI 2016a).

2.4 Alternatives Assumptions

To accurately model the alternatives described below, Reclamation, in coordination with the GCMRC and WAPA, developed a series of assumptions based on current conditions, operating criteria, system constraints, and the best available science. This section outlines those assumptions and the modeling process that were conducted during the analysis.

Reclamation would like the flexibility to implement temperature-based flow options to target smallmouth bass, depending on where they are found in the river. For the purposes of the modeling effort, cooling was modeled to river mile 15 and river mile 61 (the confluence with the Little Colorado River). Cooling to river mile 15 (approximately 15 river miles below Lees Ferry) would allow Reclamation to target smallmouth bass in the more heavily populated areas, such as the slough. Cooling to river mile 61 would allow Reclamation to target smallmouth bass that have traveled farther downstream. Actual river mile targets for potential implementation could vary depending on where smallmouth bass are located within a given year.

General overview of analyses for the smallmouth bass flow alternatives:

- Reclamation chose to use hydrologic data modeled for the IG SEIS because these data represented the most up-to-date modeling data available at the time of analysis (Reclamation 2023c). A set of 30 hydrologic traces representing a wide range of hydrologic conditions provided a robust range of monthly data for 4 years to match the timescale of the smallmouth bass flow options. Please refer to the IG SEIS for additional details on the hydrologic modeling (Reclamation 2023c).
- An initial run of the smallmouth bass model was made to determine the months in which flow spikes would be expected to be triggered under the operational alternatives that include flow spikes and under the two scenarios in which different river miles (river mile 15 and 61) were targeted. Additional information on the smallmouth bass model can be found in **Appendix A**.
- An initial run of the sediment model was conducted to determine when high flows would be triggered under different alternatives, what the magnitude and duration of a high flow would be, and what the magnitude of a flow spike could be (under alternatives that include flow spikes). This analysis also determined whether water needed to be moved among months to allow for an HFE release. Modified monthly volumes were then reported. Further information on the sediment model can be found below and in **Section 3.4**.
- For traces in which monthly volumes were modified to accommodate HFE releases or flow spikes, updates were made to Lake Powell elevations during the intervening months based on the rules embedded in the Colorado River Simulation System (CRSS) and reported in the revised elevations tab.
- The smallmouth bass model was then rerun to determine the expected smallmouth bass lambda (rate of population growth) and, when appropriate, the monthly bypass required under a given scenario.
- To maximize the value of hydropower, an optimization algorithm was run and given a series of constraints to determine hydropower value in each month that differed among

alternatives. This algorithm required input of monthly outflow volumes and elevations, details regarding potential HFE releases (such as duration and magnitude), potential flow spikes (number and magnitude), and any potential extra bypass for smallmouth bass alternatives. The output was expressed as hourly releases.

- Sediment, riparian vegetation, aeolian transport, recreation economics, and water quality (CE-QUAL-W2) models were then run using the generated hourly releases.
- Smallmouth bass lambda estimates were also modified to include the effects of fine-scale variation in flow, when necessary (that is, when lambda was greater than 1 without these adjustments).
- In addition, WAPA used the modeled monthly hydrologic data to run the Generation and Transmission Maximization (GTMax) model to produce hourly releases. GTMax simulates the dispatch of electric-generating units and the economic trade of energy among utility companies using a network representation of the power grid.

Glen Canyon Dam operational and regulatory constraints considered:

- For the purposes of modeling, the initiation of the action alternatives would only begin if water temperatures either at river mile 15 or at river mile 61 (the confluence with the Little Colorado River) are at or above 15.5°C (60˚F).
- If water temperatures at either river mile 15 or at river mile 61 (the confluence with the Little Colorado River) are below 15.5°C (60˚F), it is not necessary to implement the proposed actions.
- Dam operations would allow for the emergency exception criteria to continue as needed and as outlined in the LTEMP FEIS (DOI 2016a).
- There would be a minimum release of 2,000 cfs through the penstocks at all times.
- Modeling of bypass releases that use the river outlet works would seek to adhere to current guidelines, to the extent possible, recognizing that limits to bypass use are subject to change as Reclamation learns more about the appropriate limits at different elevations.
- For all alternatives, the assumed total release maximum ramp rates are 4,000 cfs per hour up and 2,500 cfs per hour down; these rates are consistent with the LTEMP FEIS.
- A minimum total release of 8,000 cfs during the day (7:00 a.m. to 7:00 p.m.) and 5,000 cfs at night, consistent with LTEMP, is assumed for all cold-water alternatives. A minimum total release of 2,000 cfs is assumed for the Non-Bypass Alternative.
- Per WAPA's requirements, a minimum of 40 megawatts (MW) of generation must be maintained to stabilize electrical grid requirements. The release volume to maintain 40 MW changes depending on the water surface elevations at Lake Powell. Current conversion estimates to maintain 40 MW correspond to a 1,300-cfs minimum discharge. Electrical grid

stabilization releases will average minimum releases of 5,000 or 8,000 cfs,[6] according to the ROD requirements.

General high-flow implementation modeling details:

- The Sand Routing Model (SRM), developed by Wright et al. (2010), is used to calculate sand mass balance. The GCMRC wrote code that selects HFE magnitude and duration, selected via iteration according to the sand mass balance. The code also redistributes monthly volumes, if necessary, and interfaces with the SRM by generating synthetic 15-minute hydrographs.
- HFE releases are implemented in November or April, or both, depending on the alternative. Under the 1-year sediment accounting window, decision-makers can choose to implement an HFE release in fall or spring depending on the information available at that point. For modeling purposes, it is assumed that a spring HFE release is preferred to a fall HFE release; a spring HFE release would be selected if modeling as of November 1 indicates that the release would be equal to or one duration level lower than the fall HFE release would be in that year.

  For the alternatives that include flow spikes, if a spring HFE release is selected and flow spikes are scheduled to occur in May or June, implementation of the HFE on April 15 (default) was compared with the implementation of it in place of the first flow spike, using sediment inputs up to April 1. For modeling purposes, if the durations are equal or within one duration level, the HFE release is implemented in place of the first flow spike.
- It is assumed that no HFE releases would be implemented below a Lake Powell elevation of 3,500 feet, as the HFE magnitude would be below 37,000 cfs, and a release could increase the risk of going below the power pool elevation of 3,490 feet. The power pool elevation is the depth below which the dam can no longer produce power. Under the 1-year window, if an HFE release were triggered but not implemented due to this constraint, and there were no other HFE releases in the accounting window, a positive sand mass balance would be carried over into the next accounting window.
- If HFE or flow spike implementation, plus base releases of 16 thousand acre-feet (kaf) per day (the minimum required under LTEMP), result in a monthly volume higher than the initially specified monthly release volume, volume would be borrowed from other months and added to the implementation month. For the months being borrowed from, flow would be reduced to a minimum of 16 kaf per day. For a fall HFE release, if the reservoir elevation at the end of the implementation month is 3,530 feet or higher, the order in which volumes would be borrowed from other months is April, March, May, February, December, and January. If the elevation is lower than 3,530 feet, the order would be the same; however, May would be excluded. This is because borrowing from May to release water sooner could

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[6] In addition to daily scheduled fluctuations for power generation, the instantaneous releases from Glen Canyon Dam may also fluctuate to provide 40 MW of system regulation. These instantaneous release adjustments will stabilize the electrical generation and transmission system and translate to a range of approximately 1,300 to 1,500 cfs above or below the hourly scheduled release rate. Under the system's typical conditions, fluctuations for regulation are typically short lived and generally balance out over the hour with minimal or no noticeable impacts on downstream river flow conditions.

diminish the April end-of-month elevation. If, after going through all borrowing months, the implementation month still does not have sufficient volume, the adjustment process would be repeated, using LTEMP minimum flows of approximately 13.1 kaf per day. If there is still not sufficient volume, the HFE duration would be reduced to the next duration level as a last resort.

For modeling purposes, for an April HFE implementation, the borrowing-month order would be April, March, May, June, September, August, then July. For implementation in May, June, July, August, or September, the order would be the same as above, except the implementation month would be borrowed from before any other month. Actual borrowing-month order is subject to change based on hydrologic conditions.

- Modeling of HFE releases uses modified combined river outlet works capacity at operating elevations below 3,600 feet, per current operational constraints. When HFE releases exceed 72 hours, the releases would be further reduced, per current operational constraints. Actual implementation may involve slightly different magnitudes based on operational constraints.
- When monthly volumes are altered, CRSS equations for Lake Powell were rerun between the first and last modified month to create elevations that were as accurate as possible; however, for all months after the last modified month, CRSS was not rerun.

Specific high-flow implementation modeling details:

- The initial condition for SRM (bed thicknesses and bed grain size distribution) is based on an SRM model run from September 1, 2002, to October 1, 2023, using sediment inputs and gage discharges downloaded from the GCMRC website (GCMRC 2023a).
- For alternatives that do not include flow spikes, releases are assumed to be implemented on November 15 (the fall HFE) and April 15 (the spring HFE). However, if flow spikes occur in May or June and a spring HFE release has been triggered, the HFE release may be delayed until the first month of flow spike implementation, if the duration for the later implementation date is within one duration level of the earlier date. When selecting HFE duration, Paria River sand inputs up to the first of the implementation month are considered, and a 90 percent multiplier is used on sand inputs to reflect the "lower bound" estimate. For the 1-year accounting window, the initial decision to implement a fall versus spring HFE release is assumed to occur on November 1 based on sediment inputs to that point. If a spring HFE release is selected, the duration is revised based on inputs up to the first of the implementation month. After the appropriate HFE duration is selected, SRM is rerun with the full sediment inputs.
- Possible HFE durations are 250, 192, 144, 96, 72, 60, 48, 36, 24, and 12 hours. The possibility of HFE releases under 12 hours was not analyzed; this is because such short durations are unlikely to be sufficient for sandbar building, and they could result in adverse erosion. Following LTEMP, the 250-hour option is part of the extended-duration, fall HFE releases and cannot occur until a 192-hour HFE release is conducted. If an HFE release longer than 96 hours is run in the fall, no spring HFE releases can be run. The HFE with the longest possible duration resulting in a positive sand mass balance for Marble Canyon for the accounting period is the selected HFE. Under the No Action Alternative, the accounting period runs July 1 to November 30, and December 1 to June 30. For the 1-year window, the

mass balance between July 1 and the termination of the HFE is used when selecting the HFE duration, with the possibility of sediment carryover from the previous year(s) if an HFE release was triggered but not implemented (for instance, due to low reservoir elevation).

- Each of the 30 hydrologic traces is randomly assigned a trace of Paria River sediment inputs derived from the October 1996 to September 2023 record. Assuming that on October 1, 2023, the trace loops back around to October 1996, for the 30 hydrologic traces starting in 1991, the Paria trace starting years are as follows: (1) 1998, (2) 2010, (3) 2022, (4) 2001, (5) 2014, (6) 2000, (7) 2002, (8) 2015, (9) 2008, (10) 1999, (11) 2018, (12) 2003, (13) 2004, (14) 1996, (15) 2012, (16) 2006, (17) 2005, (18) 2013, (19) 2011, (20) 2007, (21) 2019, (22) 1997, (23) 2016, (24) 2020, (25) 2009, (26) 2021, (27) 2017, (28) 1997, (29) 2000, and (30) 2019. Hence, differences between traces are due to a combination of the hydrology and the specific trace of sediment inputs.
- HFE magnitude is based on the combined bypass and penstock capacities. Bypass releases are based on operational constraints. Penstock capacities are taken from the CRSS model.
- SRM uses 15-minute-interval hydrographs. For simplicity, a synthetic dam release hydrograph was generated using hourly data and used within SRM as if it were the discharge at river miles 30 and 61. (SRM uses river mile 87 as well to calculate eastern Grand Canyon mass balance, but this information is not needed in the present modeling because only Marble Canyon mass balance is considered.) The synthetic hydrograph is generated by assuming the maximum discharge fluctuations under LTEMP, with a cap at 25,000 cfs or the maximum penstock release, whichever is lower. The daily pattern is assumed to be 12 hours on a steady daily minimum release, with a 4,000 cfs per hour ramp up and 2,500 cfs per hour ramp down to a steady daily maximum release. If, however, the minimum release based on the above is below 8,000 cfs, the modeling assumes 12 hours on maximum release, with again 4,000 cfs per hour ramp up and 2,500 cfs per hour ramp down to a steady daily minimum release; this is to avoid going below the LTEMP minimum daily releases, which must be at minimum 8,000 cfs for a full 12 hours. The hydrograph defined above is used in the initial modeling to determine HFE dates and durations, but the final resource model runs will use refined hydrographs based on hydropower modeling.

General smallmouth bass modeling details:

- The smallmouth bass flow option alternatives are designed to target smallmouth bass (*Micropterus dolomieu*); however, other warmwater nonnative fish species with similar temperature requirements are likely to be reduced under the temperature-based smallmouth bass flow options.
- Water temperatures of 16°C (61˚F) or greater are typically required for smallmouth bass to lay eggs and for young of year (YOY) to grow significantly, if hatched. Growth of smallmouth bass at temperatures of 16°C (61˚F) is marginal, such that if a fish were hatched and maintained at approximately 16°C (61˚F) for the length of a typical growing season, it would be very unlikely to grow large enough to survive the winter (Shuter et al. 1980; Dudley and Trial 2014). Because of uncertainty in temperature forecasts, target temperatures of 15.5°C (60˚F) are used to trigger the timing and magnitude of flows. All smallmouth bass

flows alternatives, including the Non-Bypass Alternative, were triggered by this target temperature. For the cold-water alternatives, impacts were analyzed under different scenarios in which the target temperature was calculated either at river mile 15 or river mile 61.

- Glen Canyon Dam release temperatures (using the penstocks, bypass, or a combination) used in the smallmouth bass population growth model are estimated for every day of the year using a model that relies on spring inflow (April–July) into Lake Powell, the day of year, and the depth as predictors. The model was fitted to 225 Lake Powell temperature profiles from 2000 through 2021 (Eppehimer et al., forthcoming).[7]
- Downriver warming of water released from Glen Canyon Dam is estimated using a model developed by Dibble et al. (2021) and adapted from a monthly to daily scale by calculating the average daily solar radiation (insolation) and daily air temperatures from the Page, Arizona, weather station. Reservoir release temperatures are most influential above river mile 88, while a combination of discharge, shortwave radiation, and air temperature become more important farther downstream (Mihalevich et al. 2020).
- The amount of water that needs to be released through the river outlet works and the penstocks varies based on the elevation of the lake and the distribution of water temperatures through the water column (factors that determine the temperature of the water being released), the time of year (which affects air temperature and solar radiation), and the daily discharge; all of these determine how quickly a given amount of water warms as it travels downriver (Dibble et al. 2021; Mihalevich et al. 2020).
- For modeling of the cool mix and cold shock alternatives, it was assumed that river outlet works have a capacity of 3,150 cfs and can be operated at half-tube increments.
- The smallmouth bass population growth model is run on a 16-month time step beginning in January. An inflow, outflow, and elevation for October 2027–April 2028 were added to the model. This timeline was necessary due to the 16-month time step required by the model. It was assumed that 8 maf annual inflows follow monthly volumes determined by a log-transformed linear model fit to 2000–2021 historical inflows. The modeling assumed 7.48 maf annual outflows with monthly volumes determined by LTEMP guidelines. Elevations are calculated using the CRSS water balance equation for Lake Powell, given a starting elevation (September 2027) and subsequent monthly inflows and outflows. Given the minimal variation in monthly inflow and outflow during the October to April intervals and the fact that this period is primarily used to calculate starvation days,[8] which are primarily a function of reservoir elevations, the above assumptions have minimal impact on overall lambda and are not expected to change the bypass required under a smallmouth bass alternative.
- For each year, trace, and scenario within an alternative, the predicted population growth, lambda, was calculated based on predicted water temperatures using the model described in Eppehimer et al. (forthcoming). For alternatives that included flows to increase velocities (e.g., the Non-Bypass Alternative or alternatives with flow spikes), the calculations were adjusted based on the calculated amount of spawning habitat available in Lees Ferry during regular operations that would be expected to be disturbed by flows designed to increase

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[7] This source is scheduled to be published before the public draft. The citation will be updated accordingly.

[8] Days that are less than 10° C (50° F)

velocity. Spawning habitat was defined as habitat that remained wetted with velocities less than 0.1 meters per second during normal operations. This habitat was expected to be disturbed if disturbance flows either dried the habitat or increased velocities above 0.3 meters per second. Analyses of velocities and wet/dry status were calculated at a 5- by 5-meter resolution from a discharge water velocity model previously developed for the Lees Ferry reach (Kaplinski et al. 2022; Nelson et al. 2016).

Hydropower modeling assumptions:

GTMax

- GTMax is an optimization model used by CRSP to estimate power availability, forecast and schedule hourly generation, estimate energy purchases and sales, forecast marketable capacity, and assess other changes in operations. GTMax's primary objective is to meet hourly customer demand. The secondary objective is to minimize costs if purchases are necessary to meet contractual obligations or to maximize revenue if WAPA has more energy than the contractual commitments to sell to the market.
- The model is used to maximize the value of the electric system, taking into account not only its limited energy but also firm contracts, independent power producer agreements, and bulk power transaction opportunities on the spot market.
- The GTMax modeling for this SEIS estimated hourly releases at Glen Canyon Dam. For months when no bypass experiment was implemented, the model calculated hourly values for 1 week each month and then replicated those results for every week of the month.
- In months where a bypass experiment took place, every hour of the month was modeled.
- Lake Powell elevations used to estimate a water-to-power conversion factor were calculated by averaging the end-of-month elevation of the current month with the previous month's end-of-month elevation.
- Peak and off-peak pricing data were estimated using Argus Forward Mid-Market power curves for the Palo Verde hub.

GCMRC

- This model was developed based on standard constrained optimization methods (Harpman 1999). Modeling efforts included a constrained optimization model, which optimizes Glen Canyon Dam operations based on the observed load following from November 2020 through November 2023. This model used observed operations as a proxy for the scheduling of energy at Glen Canyon Dam by WAPA customers. Energy production was constrained by water availability and operating constraints.
- Elevations were calculated using end-of-month elevations.
- The estimated costs of changes in energy generation at Glen Canyon Dam were developed using the results of the constrained optimization model.
- Hourly pricing parameters were derived by using historical Argus Forward Mid-Market projections for the Palo Verde hub and actual prices from February 2000 through November 2023. Future monthly energy prices were estimated using Argus Forward Mid-

Market power curves, adjusted using the estimated parameters, for October 2023 through November 2027.

Model Comparison

- Both models used the same 30 hydrologic traces described above.
- Modeling data were analyzed from January 2024 through September 2027 for both models.
- When implementing high-flow or other experiments, GTMax and the GCMRC model may slightly differ in ramp rates or other hydrograph details.

2.5 No Action Alternative

Reclamation analyzed the No Action Alternative, as it provides an appropriate basis against which to compare the effects of the proposed action. Under the No Action Alternative, there would be no changes to operations at Glen Canyon Dam as analyzed in the LTEMP ROD. Sediment accounting and HFE implementation would continue as described in the LTEMP ROD (DOI 2016b).

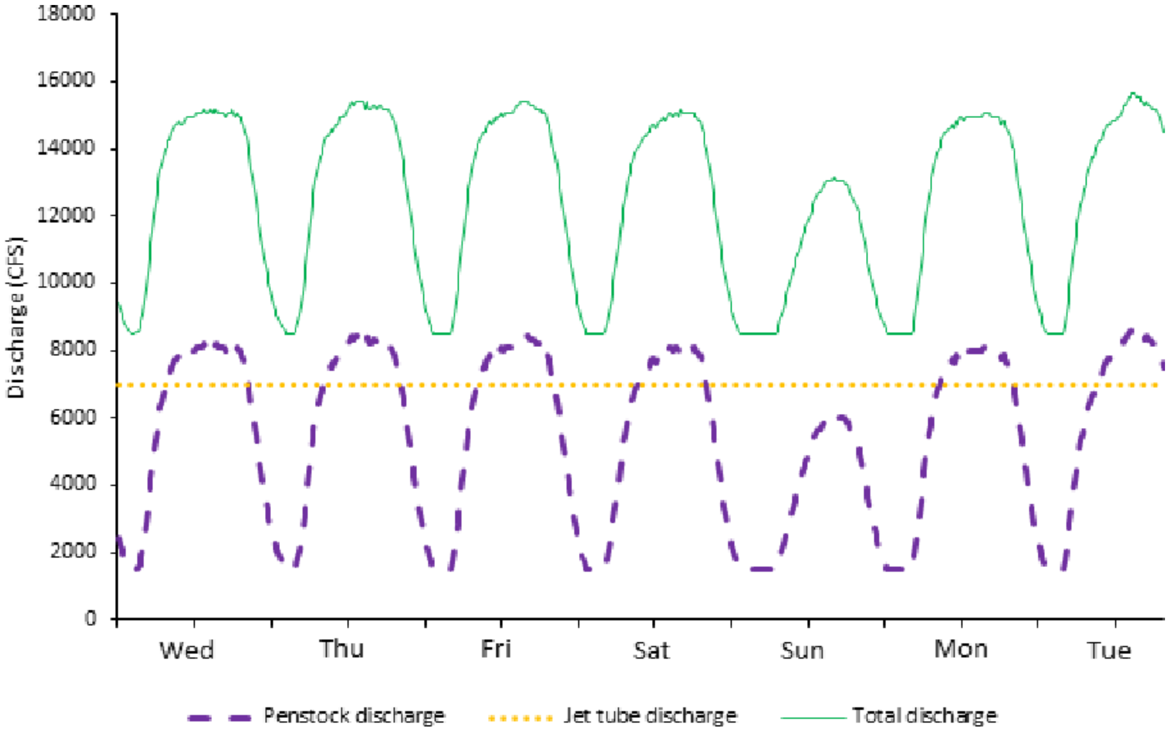
If low reservoir elevations at Lake Powell persist, the No Action Alternative would result in continued warming of water and the spread of smallmouth bass and other warmwater nonnative species in the Colorado River below Glen Canyon Dam. Warmer water temperatures would likely encourage smallmouth bass spawning and would likely result in further population establishment downstream of Glen Canyon Dam. Smallmouth bass are predatory and would likely prey upon native species, including the federally protected humpback chub, potentially impacting the endangered species status of the humpback chub population. Moreover, there is strong evidence from the Upper Basin indicating that smallmouth bass could also have adverse effects on other native fish populations below the dam (Bestgen and Hill 2016b). This includes the small number of federally listed razorback sucker currently in the canyon, along with bluehead suckers, flannelmouth suckers, and speckled dace.

If drought and aridification conditions continue, the No Action Alternative could also result in the continued trend of fewer and smaller HFE releases. The reduced number and magnitude of HFE releases would not optimize the best available science for sediment accounting. The No Action Alternative would not meet the project's purpose or need.

2.6 Cool Mix Alternative

The Cool Mix Alternative would involve strategic water releases from both the penstocks and river outlet works to maintain a daily average water temperature below 15.5°C (60°F) from below the dam to either below Lees Ferry (river mile 15) or the Little Colorado River (river mile 61) (USGS 2022). The quantity of water released through the river outlet works would be determined by predicted temperatures at the river outlet works and penstocks during the flow, ensuring the minimum necessary release to meet the water temperature goal. The release quantity would vary throughout the year, influenced by monthly water volumes and temperature conditions (**Figure 2-1**; USGS 2022).

Figure 2-1
Conceptual Hydrograph for Cool Mix Alternative



Source: USGS 2022

Note: This conceptual hydrograph for the Cool Mix Alternative assumes that a monthly volume of about 740,000 acre-feet (af) is being released. Similar hydrographic shapes would be expected at different monthly volumes. The hydrograph begins at midnight between Tuesday and Wednesday and illustrates a full week of operations.

Within the smallmouth bass model, flows would be triggered when temperatures at the target river mile are predicted to rise above 15.5°C (60°F). This target accounts for variations in water temperature releases and warming rates, increasing the likelihood of maintaining temperatures near or below 15.5°C (60°F) at the target river mile (Dibble et al. 2021; Mihalevich et al. 2020; USGS 2022).

In practice, flow implementation would occur on a weekly scale and would be planned weeks in advance. Adjustments closer to implementation would involve lowering the bypass if less is needed than initially estimated. Notably, differences among weeks in a month are most pronounced during June and early July when the temperature profile in Lake Powell is developing. To align with actual implementation without necessitating multiple weeks of hydropower maximization (that is, the operation of the hydropower system to generate the maximum amount of electrical power) within each month, daily bypass estimates from the smallmouth bass model were post-processed. Flows were simulated to occur all month, if they were triggered before the month's halfway mark, and start in the subsequent month, if they were triggered after the halfway mark. Additionally, all days within a month would have bypass equal to the median of the month, with minimal changes observed in overall bypass across traces (USGS 2022).

Upon triggering, water would be released from both penstocks and river outlet works to maintain a daily average water temperature below 15.5°C (60°F) at the targeted river mile. Closer to the dam, temperatures are cooler in the main river. The amount of water released through the river outlets would be based on predicted temperatures at the river outlet works and penstocks during the flow, representing the minimum amount of bypass required to meet the water temperature goal (USGS 2022).

Achieving the target temperature of 15.5°C (60°F) below river mile 15 or river mile 61 is highly achievable when all four river outlet works are available and average daily discharge exceeds 8,500 cfs (USGS 2022). Challenges may arise under specific conditions, such as average daily discharge below 8,000 cfs and penstock temperatures exceeding 23°C (73°F). In these cases, maintaining daily average water temperatures below 15.5°C (60°F) may be limited to below the dam through river mile 45 in Marble Canyon. Smaller volumes of water warm more quickly, posing difficulties in releasing sufficient cold water to counteract warming.

This alternative has been modeled to show cooling down to river mile 15 and separately, to the confluence of the Little Colorado River. These two scenarios (cooling to river mile 15 and to river mile 61 [the confluence with the Little Colorado River]) have been analyzed as sub-alternatives to show the impacts if smallmouth bass were identified in upper reaches (Lees Ferry) or farther downstream (Little Colorado River).

2.7 Cool Mix with Flow Spike Alternative

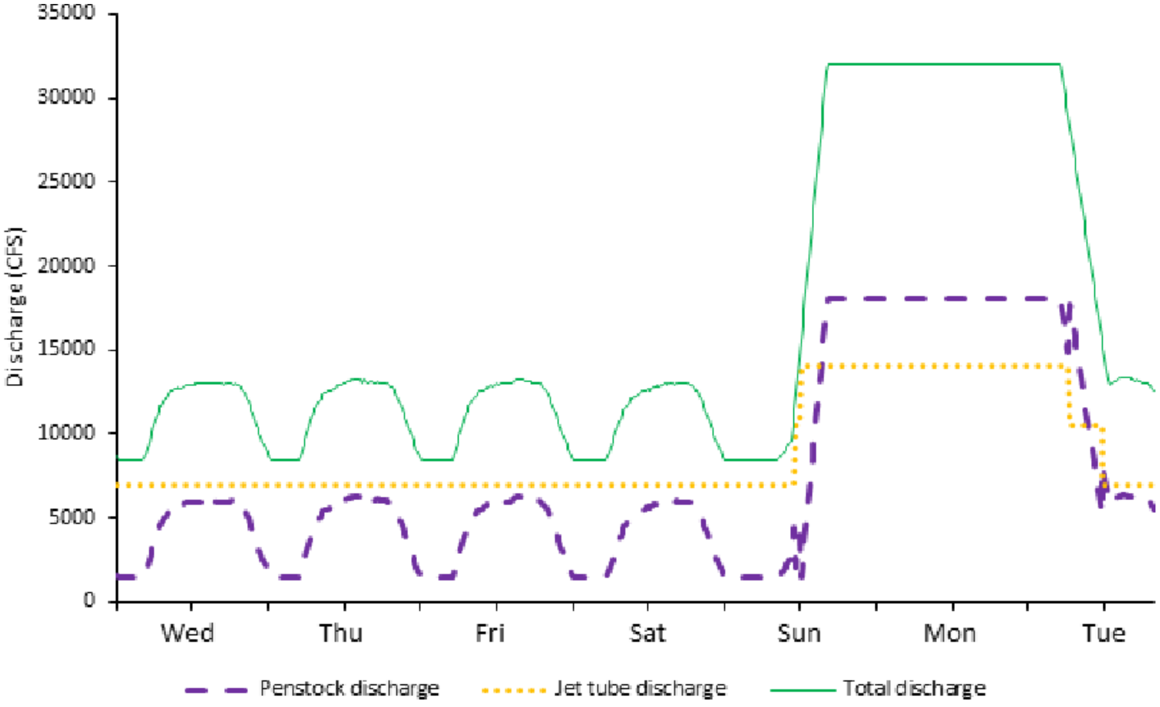
For the Cool Mix with Flow Spike Alternative, water would be released through the penstocks and river outlet works to maintain a daily average water temperature below 15.5°C (60°F) from below the dam to Lees Ferry or the Little Colorado River. In this alternative, up to three 8-hour flow spikes could be implemented if sufficient water is available. The flow spike is anticipated to disrupt spawning in margin habitats that may be warmer than the mainstream river. During a flow spike, as much water as possible (up to 45,000 cfs) would be released through the penstocks and river outlet works. Additionally, an HFE release could replace a flow spike if doing so would maximize benefits to sediment and is timed appropriately to affect smallmouth bass spawning (USGS 2022).

The amount of water released during the cool mix phase of the hydrograph would depend on predicted temperatures at the river outlet works and penstocks. The minimum necessary amount would be released through the river outlet works, varying throughout the year based on monthly volumes. Refer to **Figure 2-2** for a conceptual hydrograph of this flow option.

The required release through the river outlet works and penstocks would vary based on the Lake Powell elevation and the distribution of water temperatures through the water column. The water's temperature upon release and the time of year (which affects air temperature and solar radiation) dictate how quickly the water warms downstream (Dibble et al. 2021; Mihalevich et al. 2020).

The effectiveness of this alternative at achieving temperature goals, given certain river outlet works availability, would be similar to those outlined in the Cool Mix Alternative.

Figure 2-2
Conceptual Hydrograph for Cool Mix with Flow Spike Alternative



Source: USGS 2022
Note: This conceptual hydrograph for the Cool Mix with Flow Spike Alternative assumes a monthly release volume of approximately 740,000 af. Similar hydrographic shapes would be expected at different monthly volumes. The hydrograph begins at midnight between Tuesday and Wednesday and illustrates a full week of operations. During the other 3 weeks of the month, daily releases would be similar to the first 4 days shown on the above hydrograph. If a second flow spike were added per month while maintaining operations, an additional 68,000 af of water would be required. Alternatively, the average daily discharge on nonflow spike days could be lowered from approximately 10,920 cfs to approximately 9,550 cfs to allow two flow spikes while maintaining a monthly release of approximately 740,000 af. While days of the week are depicted in this conceptual hydrograph, they are not fixed and would be determined by the implementation team.

Flow spikes would likely be implemented in spring/early summer due to the available monthly release volumes and the higher potential to disrupt spawning. Modeling assumes two flow spikes in the first month that smallmouth bass flows are triggered in a given year and one flow spike in the following month (if smallmouth bass flows are still triggered in that month).

The assumed peak discharge during the flow spike is up to 32,000 cfs, based on constraints from the current maintenance schedule. A 32,000-cfs flow spike moves approximately 133,000 af of water over 3 days; this is approximately 94,000 af more than the minimum base operations. Consequently, the minimum monthly volume required for two flow spikes would be approximately 590,000 af (USGS 2022). If additional water were available for the flow spike, the volume would need to be recalculated.

This alternative has been modeled to show cooling down to river mile 15 and the confluence of the Little Colorado River. These two scenarios (cooling to river mile 15 and river mile 61, the confluence of the Little Colorado River) have been analyzed as sub-alternatives to show what the impacts would be if smallmouth bass were identified in upper reaches (Lees Ferry) or farther downstream (Little Colorado River).

2.8 Cold Shock Alternative

For the Cold Shock Alternative, the release of water through the river outlet works is designed to induce a short-duration cold shock, targeting temperatures of 13°C (55°F) or below at Lees Ferry or the Little Colorado River to disrupt smallmouth bass spawning and rearing (Henderson and Foster 1957; Rawson 1945; Latta 1963).

In the smallmouth bass model, flows would be activated when temperatures at the targeted river mile are forecasted to rise above 15.5°C (60°F). Flows would aim to disrupt spawning behavior through a rapid and sustained cooling of the river. The actual implementation of flows would be anticipated on a weekly scale, necessitating advanced planning weeks ahead. Adjustments closer to the week of implementation would primarily involve lowering bypass, if the initially estimated bypass is greater than needed. Refer to **Figure 2-3** for a conceptual hydrograph of this alternative.

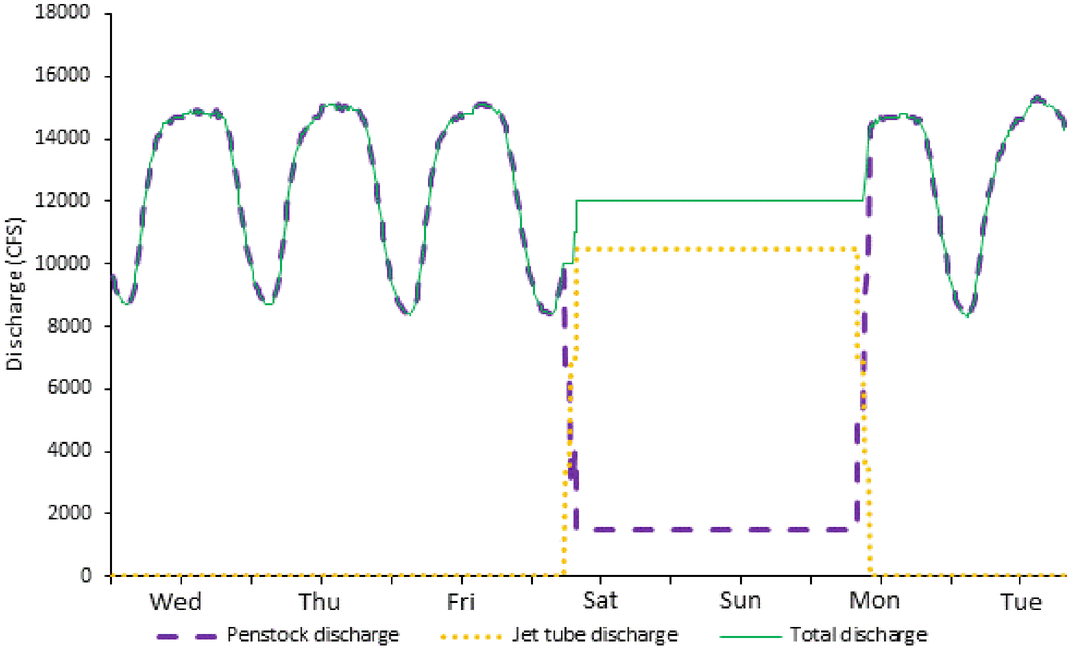
Cold shocks were simulated to occur throughout the entire month if smallmouth bass flows were triggered before the halfway mark of a month. If triggered after the halfway mark, simulations began in the subsequent month.

Upon triggering, cold shocks could be executed every weekend for up to a total of 12 weekends, each lasting 48 hours. The transition to normal flows would occur outside these implementing weekends. In the simulation of the cold-shock alternatives, up to 12,600 cfs was assumed to be released as bypass, recognizing that the actual capacity for long-term releases could vary slightly based on operational constraints. Within a month, the calculated bypass for cold shocks is the minimum required, tested in half-tube increments, to lower the temperature below 13°C (55°F) at the targeted river mile on all weekends or 12,600 cfs if a lesser volume fails to meet this condition. Hydropower releases during the cold shock are consistently assumed to be 2,000 cfs.

Under certain extreme high-temperature scenarios (for example, greater than 23°C [73°F]), it may not be possible to reach desired target temperatures based on release temperatures and the availability of river outlet works (USGS 2022).

This alternative has been modeled to show cooling down to both just below river mile 15 and river mile 61 (the confluence of the Little Colorado River). These two scenarios have been analyzed as sub-alternatives to demonstrate the impacts if smallmouth bass were identified in upper reaches (Lees Ferry) or farther downstream (Little Colorado River).

Figure 2-3
Conceptual Hydrograph for Cold Shock Alternative



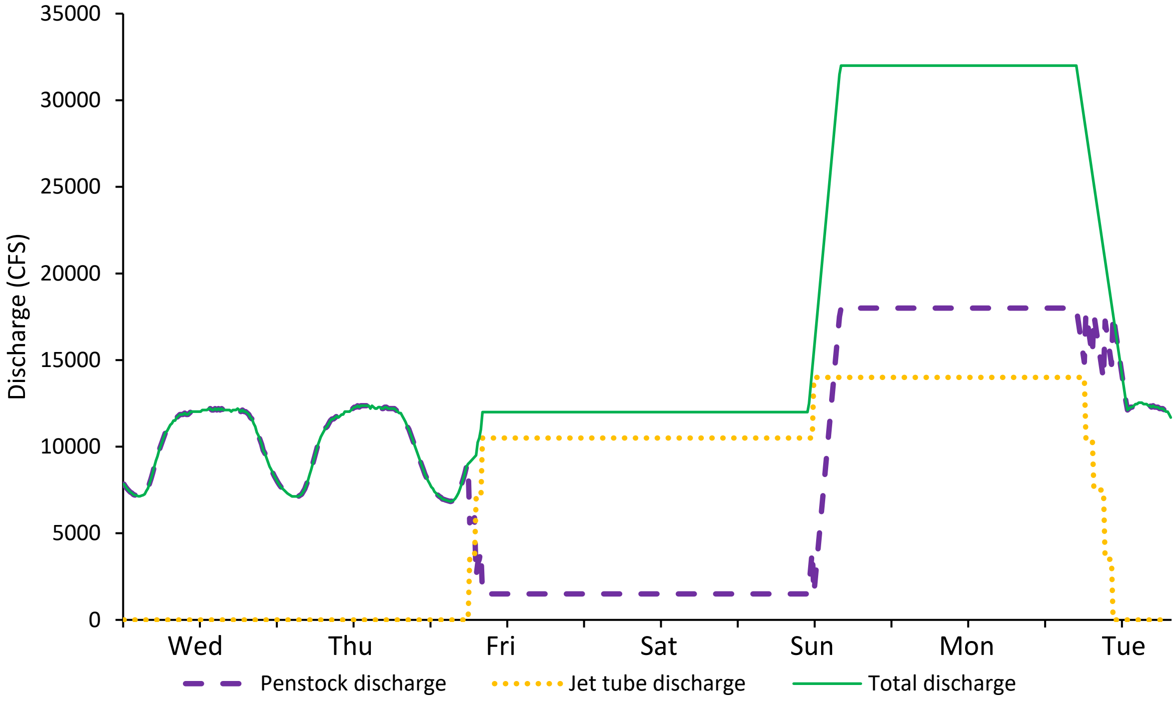
Source: USGS 2022
Note: This conceptual hydrograph for the Cold Shock Alternative assumes that approximately 740,000 af and at least three river work outlets are available in June. Similar hydrographic shapes would be expected at different monthly volumes. The hydrograph begins on the midnight between Tuesday and Wednesday and illustrates a full week of operations. Operations would be the same for all weeks in the month.

2.9 Cold Shock with Flow Spike Alternative

For the Cold Shock with Flow Spike Alternative, water would be released through the river outlet works for a minimum of 48 hours to induce a cold shock downstream to either Lees Ferry or the Little Colorado River. In addition, up to three 8-hour flow spikes could be implemented if sufficient water is available. The flow spikes aim to disrupt spawning in margin habitats, which are potentially warmer than the mainstem river. As much water as possible, up to 45,000 cfs, would be released through penstocks and river outlet works during flow spikes. This flow spike could be replaced by an HFE release if it maximizes benefits to sediment and is appropriately timed to impact smallmouth bass spawning. A conceptual hydrograph is provided for this alternative in **Figure 2-4**.

This option would commence when daily water temperatures at the Little Colorado River reach 15.5°C (60°F), providing weekly 48-hour cold-shock releases and at least one 8-hour spike flow, lasting up to 12 weeks. The cold shock, transitioning into the flow spike for that given week, is integral to this alternative.

Figure 2-4
Conceptual Hydrograph for Cold Shock with Flow Spike Alternative



Source: USGS 2022

Note: This conceptual hydrograph for the Cold Shock with Flow Spike Alternative assumes approximately 740,000 af are available in June, all four river outlet works are available, and there is one flow spike per month. Similar hydrographic shapes would be expected at different monthly volumes. The hydrograph begins on midnight between Tuesday and Wednesday and illustrates a full week of operations. For the other 3 weeks of the month (without flow spikes), the first part of the hydrograph would be the same as the first 4 days of the week (baseline plus cold shock) but would include 3 additional days of baseline releases in place of the flow spike.

The quantity of water released through the river outlet works during the cold-shock phase would be based on predicted temperatures at the river outlet works and penstocks during the flow. The minimum water required to meet the temperature goal would be released through the river outlet works, considering constraints due to operations and maintenance. The release amount could vary throughout the year based on water temperatures at river outlet works and penstock depths. Releases on other days would primarily align with the monthly volume. The water release needed to meet the temperature goal varies based on lake elevation and water temperature distribution through the water column. The released water's temperature and the time of year (which affects air temperature and solar radiation) influence how quickly it warms downstream (Dibble et al. 2021; Mihalevich et al. 2020).

The effectiveness of this alternative at achieving temperature goals, given certain river outlet works availability, would be similar to those outlined in the Cool Mix Alternative.

Under alternatives with flow spikes, these spikes are expected to be most effective if timed earlier in the potential reproductive cycle of smallmouth bass. For modeling purposes, it was assumed that there would be two flow spikes in the first month that smallmouth bass flows were triggered in a given year, and one flow spike in the following month if smallmouth bass flows were still triggered. Flow spikes would only occur during the months of May, June, July, August, and September, as during this period the margin habitat is typically warmer than the mainstream river. These considerations ensure a comprehensive understanding of the flow option's impact on smallmouth bass spawning (USGS 2022).

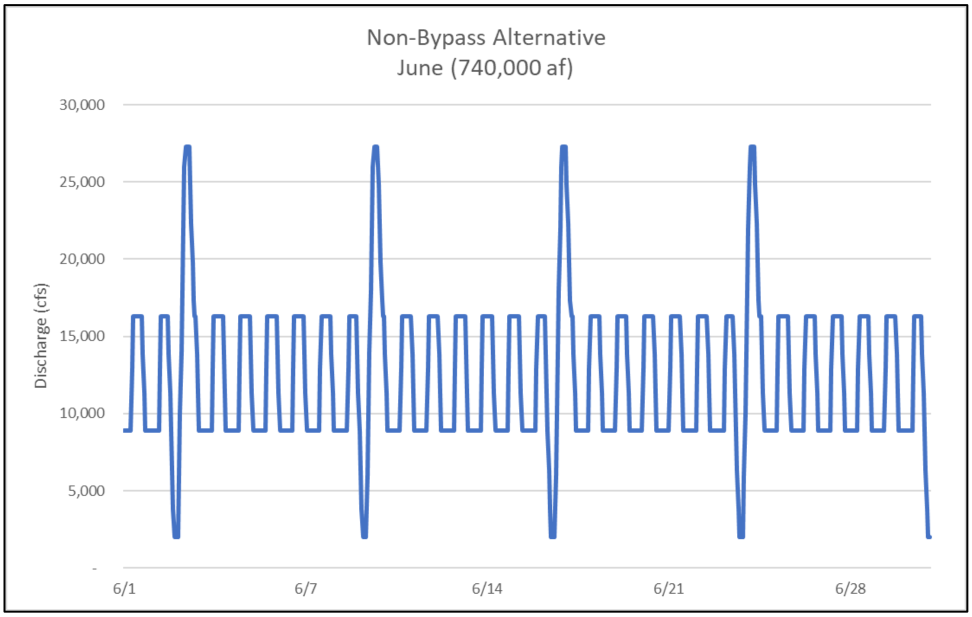
This alternative has been modeled to show cooling down to both river mile 15 and river mile 61 (the confluence of the Little Colorado River). These two scenarios have been analyzed as sub-alternatives to demonstrate the impacts if smallmouth bass were identified in upper reaches (Lees Ferry) or farther downstream (Little Colorado River).

2.10 Non-Bypass Alternative

The Non-Bypass Alternative proposes a hydrograph centered on strategically employing substantial river stage changes that are targeted along the Lees Ferry reach to disrupt smallmouth bass nests and spawning activities below Glen Canyon Dam. This alternative consists of a once-weekly, short-duration, low-flow release immediately followed by a short-duration high flow. The low-flow release is meant to dewater shallow nesting areas along shorelines or in backwaters and sloughs. The high-flow release is meant to increase water velocities in nesting areas in deeper habitats that are not dewatered during the low flow. The design of this alternative is such that the short-duration, low-flow and high-flow releases are largely attenuated by the time the flow wave reaches the confluence with the Little Colorado River. This alternative is predicated on the flow fluctuations that reduced rainbow trout reproduction during the pre-ROD period (1965–1991) to the point where the fishery could only be maintained through stocking (McKinney et al. 1999a).

The low-flow release would begin on Sunday nights at 9:00 p.m. local time and last until 1:00 a.m. Beginning Monday morning at 1:00 a.m., releases would begin ramping up and reach a maximum powerplant release (that is, approximately 27,300 cfs) by 7:00 a.m. Releases would remain at a maximum powerplant release until 11:00 a.m. when releases would begin to down ramp back into normal operations for the rest of the week. The treatment would be repeated weekly once water temperatures are forecasted to rise above 15.5°C (60°F) in areas where smallmouth bass are observed spawning (for example, the 12-mile slough) to disrupt renesting. **Figure 2-5** shows a conceptual hydrograph of the Non-Bypass Alternative.

Figure 2-5
Conceptual Hydrograph of the Non-Bypass Alternative



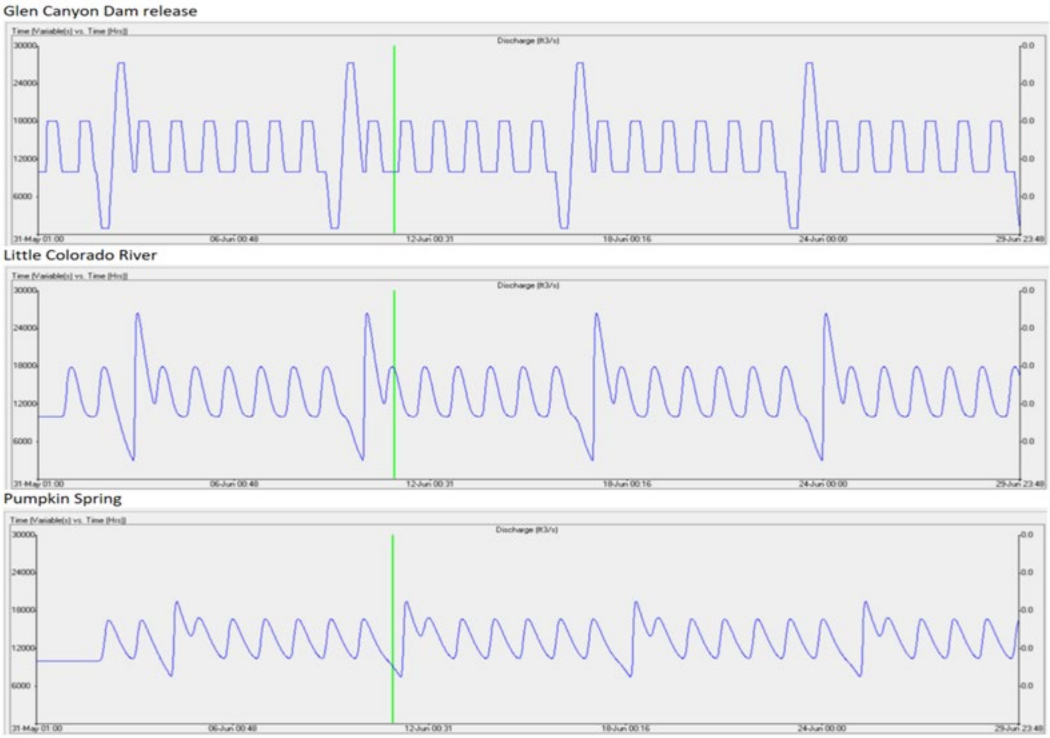
Source: WAPA 2023

Note: This conceptual hydrograph for the Non-Bypass Alternative assumes approximately 740,000 af are available in June. Similar hydrographic shapes would be expected at different annual volumes. This graph shows the repeated low- and high-flow release combinations at the start of each week beginning Sunday night and ending Monday afternoon. The magnitude of the trough and spike would diminish as the releases travel downstream.

Under the Non-Bypass Alternative, flows could drop as low as 2,000 cfs and rise as high as approximately 27,300 cfs. The minimum flows proposed under this alternative fall below those developed in the LTEMP ROD (5,000 cfs at night and 8,000 cfs during the day). This alternative would exceed the maximum daily range of 8,000 cfs analyzed in the LTEMP ROD. Modeled ramp rates were slightly outside the LTEMP requirements. Actual ramp rates would be within the operating range of the LTEMP ROD.

The fluctuations shown in **Figure 2-5** were designed to disrupt the smallmouth bass spawning at river mile 61. As the water from the low-flow and high-flow releases travels downstream, the magnitude of both would diminish due to additional river inputs and the progression of low flow to high flow, which would aid in "collapsing" the trough. This diminishing of the flow magnitude is depicted in **Figure 2-6**.

Figure 2-6
Non-Bypass Alternative Flow Modeling of "Collapsing" Trough



Source: WAPA 2023 using a flow routing model based on Wiele and Smith 1996
Note: Flow modeling using the Colorado River Flow, Stage, and Sediment model showing the release wave created by the Non-Bypass Alternative treatment at Glen Canyon Dam (top panel), at river mile 61 at the Little Colorado River (middle panel), and at river mile 213 at Pumpkin Spring (bottom panel).

2.11 Alternatives Considered but Eliminated from Detailed Analysis

2.11.1 HFE Only Alternative

The HFE Only Alternative describes a set of actions aimed at better implementation of HFE releases, as outlined by the LTEMP ROD, utilizing best available science for sediment accounting. This alternative would change both the sediment accounting windows and HFE implementation periods with the goal of implementing HFE releases at a frequency and magnitude originally projected in the LTEMP ROD. This alternative did not meet the purpose and need because it did not address the issue of smallmouth bass.

2.12 Summary Comparison of Alternatives

Table 2-1
Summary Comparison of Alternatives

Alternative	Description
No Action Alternative	This alternative would maintain existing water release operations at Glen Canyon Dam. This could lead to continued warming of the Colorado River below Glen Canyon Dam. If drought and aridification conditions continue, it could potentially foster smallmouth bass and other warmwater invasive fish species spawning. These warmwater invasive species could negatively impact the federally protected humpback chub through predation or competition for resources. This alternative would not meet the project's purpose or need.
Cool Mix Alternative	The Cool Mix Alternative would strategically release water mixed from the penstocks and river outlet works to maintain a daily average water temperature below 15.5°C (60°F) from Glen Canyon Dam to either Lees Ferry or the Little Colorado River. The release quantity would vary based on predicted temperatures and monthly water volumes. Implementation would occur weekly when river temperatures exceed 15.5°C (60°F) until the river temperatures drop below 15.5°C (60°F). The goal is to interrupt smallmouth bass spawning by reducing water temperature below the level when smallmouth bass initiate spawning.
Cool Mix with Flow Spike Alternative	This alternative would operate in a manner similar to the Cool Mix Alternative, by disrupting smallmouth bass spawning. It would include up to three 8-hour flow spikes to disrupt spawning through a change in water velocity near smallmouth bass nests, in addition to those under the Cool Mix Alternative. If implemented, flow spikes would release water through penstocks and river outlet works to maintain the target temperature in margin habitats, such as the -12-mile slough. Implementation would occur weekly when river temperatures exceed 15.5°C (60°F) until the river temperatures drop below 15.5°C (60°F).
Cold Shock Alternative	The Cold Shock Alternative would induce a cold shock, targeting temperatures of 13°C (55°F) or below at either Lees Ferry or the Little Colorado River to disrupt smallmouth bass spawning. Flows would be triggered when temperatures rise above 15.5°C (60°F) and would occur on a weekly schedule for 12 weekends. The release amount would vary based on temperature conditions and capacity considerations. Implementation would occur weekly when river temperatures exceed 15.5°C (60°F) until the river temperatures drop below 15.5°C (60°F).
Cold Shock with Flow Spike Alternative	Combining cold shocks and flow spikes, this alternative would be initiated when daily water temperatures at either Lees Ferry or the Little Colorado River reach 15.5°C (60°F). It would include weekly 48-hour cold-shock releases and up to three 8-hour flow spikes. The release quantity would be based on predicted temperatures, with flow spikes aiming to disrupt spawning in margin habitats. Implementation would occur weekly when river temperatures exceed 15.5°C (60°F) until the river temperatures drop below 15.5°C (60°F).

Alternative	Description
Non-Bypass Alternative	Focusing on smallmouth bass nesting habits, the Non-Bypass Alternative would propose a hydrograph with substantial stage changes to disrupt smallmouth bass spawning. It would suggest a weekly treatment schedule, combining low and high flows to desiccate nests in shallow water and scour nests in deeper areas. Implementation would occur when river temperatures exceed 15.5°C (60°F) until the river temperatures drop below 15.5°C (60°F).

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2.13 Summary of Potential Effects

Table 2-2
Summary of Potential Effects

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Hydrologic Resources	Operations at Glen Canyon Dam would not change; this means there would be no changes to the hydrology. Reservoir elevations and release volumes would follow current trends.	Impacts on system hydrology under the Cool Mix Alternative would be temporary and would not exceed the cumulative impacts on water resources as identified in the LTEMP FEIS.	Increased flow rates from the flow spikes would temporarily decrease water surface elevations in Lake Powell; however, the elevations would be restored to previous elevations depending on inflows. No long-term impacts on hydrology are anticipated.	Impacts on system hydrology under the Cold Shock Alternative would be temporary and would not exceed the cumulative impacts on water resources as identified in the LTEMP FEIS.	Increased flow rates from the flow spikes would temporarily decrease water surface elevations in Lake Powell; however, elevations would be restored to previous elevations, dependent on inflows. No long-term impacts on hydrology are anticipated.	The minimum and maximum proposed flows would exceed the maximum daily range as developed in the LTEMP ROD. However, monthly and annual release volumes would be the same as those under the cold-water alternatives.
Water Quality	Operations at Glen Canyon Dam would remain unchanged. Therefore, the water released from the penstocks would remain warm, with a lower DO concentration. The increase in temperature and salinity would continue to be negligible.	Cool mix operations would result in decreased total release temperature during summer periods when bypass would be utilized, and temperatures would remain cooler over a longer duration compared to cold shock operations. Cool mix operations would lead to an increase in salinity compared to the No Action Alternative but would remain lower than the early spring concentration peaks so the increase would be minimal. Low DO events would be slightly less probable than the No Action Alternative and the cold-shock operations.	Impacts on temperature, salinity, and DO would be similar to those under the Cool Mix Alternative. The flow spike would further reduce release temperature, but this change would be minimal. The flow spike would also lead to a further increase in salinity but salinity would remain lower than the early spring salinity concentration peaks so the increase would be minimal.	Cold-shock operations would result in decreased total release temperature during summer periods when bypass would be utilized. The duration of cold releases would be more effective at reducing the total release temperature than under the cool mix operations. Cold-shock operations would lead to an increase in salinity compared to the No Action Alternative and cool mix operations but would remain lower than the early spring concentration peaks so the increase would be minimal. Low DO events would be similar to the No Action Alternative.	Impacts on temperature, salinity, and DO would be similar to those under the Cold Shock Alternative. The flow spike would further reduce release temperature, but this change would be minimal. The flow spike would also lead to a further increase in salinity but salinity would remain lower than the early spring salinity concentration peaks so the increase would be minimal.	Impacts on temperature, salinity, and DO would be similar to those under the No Action Alternative since the Non-Bypass Alternative would not involve the use of Glen Canyon Dam's bypass system and would instead focus on changes in release volumes.
Air Quality	Operations at Glen Canyon Dam would not change; this means hydropower generation from the facility would remain consistent with historical levels. No changes in air quality would occur from replacing any portion of the electric generation from the facility with sources that create emissions of air pollutants.	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation on the grid in the impact analysis area, which is the 11-state Western Interconnection region. This region consists of Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. These replacement sources could create increased emissions of air pollutants, compared with the generation at	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation on the grid. These replacement sources could create increased emissions of air pollutants, compared with the generation at Glen Canyon Dam. Compared with the total 2020 emissions within the 11-state impact analysis area, the increased emissions would represent 0.022 percent and 0.015 percent of SO_2 and 0.004	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation on the grid. These replacement sources could create increased emissions of air pollutants, compared with the generation at Glen Canyon Dam. Compared with the total 2020 emissions within the 11-state impact analysis area, the increased emissions would represent 0.011 percent and 0.008 percent of SO_2 and 0.002	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation on the grid. These replacement sources could create increased emissions of air pollutants, compared with the generation at Glen Canyon Dam. Compared with the total 2020 emissions within the 11-state impact analysis area, the increased emissions would represent 0.009 percent and 0.007 percent of SO_2 and 0.002	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be slightly increased. This increase in zero-emission hydropower could result in a small reduction in air emissions from other power generation sources in the air quality analysis area, potentially resulting in a negligible improvement in air quality and visibility in the area.

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Air Quality *(cont.)*	*(See above.)*	Glen Canyon Dam. Compared with the total 2020 emissions within the 11-state impact analysis area, the increased emissions would represent 0.025 percent and 0.016 percent of sulfur dioxide (SO_2) and 0.005 percent and 0.003 percent of nitrogen oxides (NOx) under the Little Colorado River and river mile 15 options, respectively, under the existing grid replacement scenario. The Cool Mix Alternative would result in the largest increase in emissions compared with the No Action Alternative. In the highest emission year under the highest-case emissions scenario, the emissions resulting from the implementation of the Little Colorado River option of this alternative would make up approximately 0.006 percent of emissions of nitrous oxides, 0.022 percent of emissions of lead components, 0.001 percent of emissions of particulate matter smaller than 2.5 microns, 0.052 percent of emissions of SO_2, and less than 0.001 percent of emissions of carbon monoxide, volatile organic compounds, and particulate matter smaller than 10 microns in the 11-state impact analysis area. The additional emissions resulting from the changes proposed under this alternative are not expected to result in any new violation or significant increase in the level of existing violation of any National Ambient Air Quality Standards (NAAQS) or State Ambient Air Quality Standards. The changes are not expected to result in any noticeable increase in the levels of visibility impairment at any Class I or Class II areas, including GCNP, GCNRA, and LMNRA.	percent and 0.003 percent of NOx under the Little Colorado River and river mile 15 options, respectively, under the existing grid replacement scenario. The additional emissions resulting from the changes proposed under this alternative are not expected to result in any new violation or significant increase in the level of existing violation of any NAAQS or State Ambient Air Quality Standards. The changes are not expected to result in any noticeable increase in the levels of visibility impairment at any Class I or Class II areas, including GCNP, GCNRA, and LMNRA.	percent and 0.001 percent of NOx under the Little Colorado River and river mile 15 options, respectively, under the existing grid replacement scenario. The additional emissions resulting from the changes proposed under this alternative are not expected to result in any new violation or significant increase in the level of existing violation of any NAAQS or State Ambient Air Quality Standards. The changes are not expected to result in any noticeable increase in the levels of visibility impairment at any Class I or Class II areas, including GCNP, GCNRA, and LMNRA.	percent and 0.001 percent of NOx under the Little Colorado River and river mile 15 options, respectively, under the existing grid replacement scenario. The additional emissions resulting from the changes proposed under this alternative are not expected to result in any new violation or significant increase in the level of existing violation of any NAAQS or State Ambient Air Quality Standards. The changes are not expected to result in any noticeable increase in the levels of visibility impairment at any Class I or Class II areas, including GCNP, GCNRA, and LMNRA.	*(See above.)*

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Visual Resources	The existing trends of increasing bank armoring and a narrowing lower riparian zone would continue to affect the area’s landscape character; beneficial effects would occur on sandbar building and sediment export when HFE releases are conducted.	Impacts on landscape character would be similar to those described under the No Action Alternative. The HFE releases would continue to contribute to sandbar building and sediment export in the Colorado River, positively affecting the adjacent landscape character.	Increased flow events during flow spikes would be similar to HFE releases and could result in increases in sandbar building, decreases in bank armoring, and more favorable spring germination conditions for riparian vegetation types; these would allow the area’s landscape to appear more natural in character than under the No Action Alternative.	Impacts on landscape character would be similar to those described under the No Action Alternative. During cold-shock flows, periods of elevated steady flows in the Colorado River may benefit riparian species, allowing for higher germination rates with the potential for the landscape character to appear more natural than under the No Action Alternative.	Increased flow events during flow spikes would be similar to HFE releases and could result in increases in sandbar building, decreases in bank armoring, and more favorable spring germination conditions for riparian vegetation types; these would allow the area’s landscape to appear more natural in character than under the No Action Alternative.	The more dynamic river management included under this alternative could allow the area’s landscape character to appear more natural than under the No Action Alternative. The addition of the HFE option under this alternative would further facilitate higher flows, potentially increasing the benefit to sandbar building and decreasing the extent of bank armoring.
Cultural Resources	No additional positive or negative impacts beyond those analyzed in the LTEMP FEIS are expected for archaeological sites. There would be no changes to available sediment for aeolian deposits on archaeological sites.	No additional impacts beyond those analyzed in the LTEMP FEIS are expected for archaeological sites. The available sediment would be similar to that under the No Action Alternative.	No additional impacts beyond those analyzed in the LTEMP FEIS are expected for archaeological sites. The available sediment would be similar to that under the No Action Alternative.	No additional impacts beyond those analyzed in the LTEMP FEIS are expected for archaeological sites. The available sediment would be similar to that under the No Action Alternative.	No additional impacts beyond those analyzed in the LTEMP FEIS are expected for archaeological sites. The available sediment would be similar to that under the No Action Alternative.	Low flows may expose previously inundated historic properties. The available sediment would be similar to that under the No Action Alternative.
Geomorphology and Sediment	No additional impacts beyond those analyzed in the LTEMP FEIS are expected for HFE releases, mass balance, and sandbar building.	Under the 1-year sediment accounting period, HFE releases would typically be triggered and implemented in the spring. Fall HFE releases would likely be rare. Mass balance at Marble Canyon would decline more slowly compared with under the No Action Alternative, and this would be reflected in relatively gradual sandbar growth and smaller sandbars.	Under the 1-year sediment accounting period, HFE releases would typically be triggered and implemented in the spring. Fall HFE releases would likely be rare. Mass balance at Marble Canyon would decline more slowly compared with under the No Action Alternative. This would be reflected in relatively gradual sandbar growth and overall smaller sandbars. In some years, flow spikes would cause sand export in the lead up to HFE implementation, which would reduce the resulting HFE duration. Flow spikes would decrease mass balance at Marble Canyon to a slightly greater extent relative to the alternatives without flow spikes, while contributing slightly more volume to sandbars.	Under the 1-year sediment accounting period, HFE releases would typically be triggered and implemented in the spring. Fall HFE releases would likely be rare. Mass balance at Marble Canyon would decline more slowly compared with under the No Action Alternative. This would be reflected in relatively gradual sandbar growth and smaller sandbars.	Under the 1-year sediment accounting period, HFE releases would typically be triggered and implemented in the spring. Fall HFE releases would likely be rare. Mass balance at Marble Canyon would decline more slowly compared with under the No Action Alternative. This would be reflected in relatively gradual sandbar growth and overall smaller sandbars. In some years, flow spikes would cause sand export in the lead up to HFE implementation, which would reduce the resulting HFE duration. Flow spikes would decrease mass balance at Marble Canyon to a slightly greater extent relative to the alternatives without flow spikes, while contributing slightly more volume to sandbars.	Under the 1-year sediment accounting period, HFE releases would typically be triggered and implemented in the spring. Fall HFE releases would likely be rare. Mass balance at Marble Canyon would decline more slowly compared with under the No Action Alternative. This would be reflected in relatively gradual sandbar growth and smaller sandbars. Overall, HFE regimes and sediment transport patterns would resemble those modeled under the smallmouth bass flow alternatives.
Climate Change	Operations at Glen Canyon Dam would not change hydropower generation from the facility. There would be no change in climate change trends as a result of GHG emissions that would occur from replacing any portion of electric generation with power generated from sources that emit GHGs (for example, coal, oil, and natural gas).	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation within the 11-state Western Interconnection region. Replacement sources, which could include higher-cost sources such as coal, natural gas, and oil, would result in increased GHG emissions compared with the generation at Glen Canyon Dam. Under the Little Colorado River and river mile 15 options, increased	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation within the 11-state Western Interconnection region. Replacement sources, which could include higher-cost sources such as coal, natural gas, and oil, would result in increased GHG emissions compared with the generation at Glen Canyon Dam. Under the Little Colorado River and river mile 15 options, increased	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation within the 11-state Western Interconnection region. Replacement sources, which could include higher-cost sources such as coal, natural gas, and oil, would result in increased GHG emissions compared with the generation at Glen Canyon Dam. Under the Little Colorado River and river mile 15 options, increased	Due to the changes proposed under this alternative, the amount of hydropower generated at the Glen Canyon Dam Powerplant would be reduced. The reduction in generation would need to be replaced by other sources of generation within the 11-state Western Interconnection region. Replacement sources, which could include higher-cost sources such as coal, natural gas, and oil, would result in increased GHG emissions compared with the generation at Glen Canyon Dam. Under the Little Colorado River and river mile 15 options, increased	Under the Non-Bypass Alternative, the implementation of high release volumes routed through the generation facility would result in an increase in hydropower generation, compared with the No Action Alternative. The increase in generation could replace other sources of generation within the 11-state Western Interconnection region, which would result in reduced emissions. Reduced emissions would represent 0.0007 percent of total 11-state analysis area emissions, assuming power generated would replace

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Climate Change *(cont.)*	*(See above.)*	emissions would represent 0.0039 and 0.0024 percent of total emissions, respectively, under a composite grid scenario, and up to 0.0122 and 0.0077 percent, respectively, under a coal-powered generation scenario. The Cool Mix Alternative would result in the largest increase in emissions compared with the No Action Alternative.	emissions would represent 0.0034 and 0.0023 percent of total emissions, respectively, under a composite grid scenario, and up to 0.0109 and 0.0075 percent, respectively, under a coal-powered generation scenario.	emissions would represent 0.0017 and 0.0012 percent of total emissions, respectively, under a composite grid scenario, and up to 0.0055 and 0.0037 percent, respectively, under a coal-powered generation scenario.	emissions would represent 0.0014 and 0.0011 percent of total emissions, respectively, under a composite grid scenario, and up to 0.0044 and 0.0035 percent, respectively, under a coal-powered generation scenario.	a composite of sources, and up to 0.0022 percent of emissions, assuming the power generated would replace coal-powered generation sources.
Aquatic Resources	Smallmouth bass would likely continue to pass through the dam and expand their range and numbers from Glen Canyon Dam to Lake Mead, with an increased risk of predation on native fish. All other resources would be as described in the LTEMP FEIS but with lower Lake Powell elevations and warmer releases.	Cool temperatures could delay or disrupt maturation and spawning by smallmouth bass, but shoreline pockets of warm water could still provide suitable spawning conditions. Other fish species and the aquatic food base have experienced cool releases; therefore, they are not expected to be negatively affected.	Cool temperatures could delay or disrupt maturation and spawning by smallmouth bass, and flow spikes would potentially displace adults, eggs, and fry, lowering survival. Native fish species may also be affected, but they exist mostly downstream of Glen Canyon.	Cold shocks could disrupt and possibly delay maturation and spawning by smallmouth bass, as well as eggs and fry; however, the cold shocks may not affect warm pockets along shorelines. Native fish species may also be affected, but they exist mostly downstream of Glen Canyon where cold shocks would be ameliorated.	Cold shocks could disrupt and possibly delay maturation and spawning by smallmouth bass, as well as eggs and fry. Flow spikes could displace adults, eggs, and fry in areas where a velocity change results in lower survival. Native fish species may also be affected, but they exist mostly downstream of Glen Canyon where cold shocks and spikes would be ameliorated.	The Non-Bypass Alternative could disrupt smallmouth bass spawning by changing the water velocity. This would lead to nest abandonment and mortality of smallmouth bass eggs and larvae. Native fish species would likely not be affected because they exist mostly downstream of Glen Canyon, and flow changes would be ameliorated.
Vegetation	Water volumes in the Colorado River would continue to decrease in response to regional aridification and drought conditions. Frequent, extended high flows would result in an overall decrease in native plant communities and decrease in wetland habitat. Upper riparian zones would likely transition to desert ecosystems.	Total vegetation cover would increase slightly compared with the No Action Alternative in Marble Canyon and eastern Grand Canyon. In western Grand Canyon, the proportion of native vegetation cover would decrease slightly, and species richness and total vegetation cover would increase slightly compared with the No Action Alternative.	Impacts on riparian vegetation in Marble Canyon would be negligible. Total vegetation cover would increase slightly in eastern Grand Canyon, and the proportion of native vegetation cover would decrease slightly in western Grand Canyon (depending on the flow spike scenario).	Impacts on riparian vegetation would be similar to those described for the Cool Mix with Flow Spike Alternative.	Impacts on riparian vegetation would be the same as those listed for the Cool Mix with Flow Spike Alternative	In Marble Canyon, this alternative would result in a small increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative. In eastern Grand Canyon, this alternative would result in a small increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative. In western Grand Canyon, the effects of this alternative would be most pronounced and would result in a moderate increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative.
Wildlife	There would be no impacts for most wildlife species that use riparian habitats.	Adverse impacts for most wildlife species that use riparian habitats would be temporary or negligible, or both.	Wetland-obligate species could benefit due to periods of elevated, steady flow. Flow spikes could provide water resources to species at higher elevations during summer months.	Wetland-obligate species could benefit due to periods of elevated, steady flow.	Wetland-obligate species could benefit due to periods of elevated, steady flow. Flow spikes could provide water resources to species at higher elevations during summer months.	Reduced shoreline stability could lead to a decrease in the abundance of aquatic invertebrates and greater disruption to shoreline wildlife habitat.

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Special Status Species	The risk of smallmouth bass predation on special status fish species (that is, humpback chub, razorback sucker, flannelmouth sucker, and bluehead sucker) is expected to increase if smallmouth bass become established in areas occupied by native fish, potentially negatively affecting populations.	The risk of smallmouth bass negatively impacting special status fish species would be reduced if the alternative reduces smallmouth bass populations, compared with under the No Action Alternative. The cool temperature is not expected to negatively affect special status fish. No impacts are expected for special status species that use riparian habitats.	The risk of smallmouth bass negatively impacting special status fish species would be reduced if the alternative reduces smallmouth bass populations, compared with under the No Action Alternative. The cool temperature and spikes would be ameliorated downstream where most of these species exist. Increased shoreline instability could impact the endangered northern leopard frog.	The risk of smallmouth bass negatively impacting special status fish species would be reduced if the alternative reduces smallmouth bass populations, compared with under the No Action Alternative. The cold shock would be ameliorated downstream where most of these species exist. Increased shoreline instability could impact the endangered northern leopard frog.	The risk of smallmouth bass negatively impacting special status fish species would be reduced if the alternative reduces smallmouth bass populations, compared with under the No Action Alternative. The cold shock and spikes would be ameliorated downstream where most of these species exist. Increased shoreline instability could impact the endangered northern leopard frog.	Increased shoreline instability could impact the endangered northern leopard frog.
Tribal Resources	Operations at Glen Canyon Dam would not change, and there would be no change in fish mortality. There would be no additional impacts on archaeological or sacred sites than those analyzed in the LTEMP FEIS. Riparian vegetation would follow current trends.	The Cool Mix Alternative would not result in fish mortality. There would be no additional impacts on archaeological or sacred sites than those analyzed in the LTEMP FEIS. Differences in vegetation communities would be minor.	The Cool Mix Alternative with Flow Spikes may result in fish mortality. There would be no additional impacts on archaeological or sacred sites than those analyzed in the LTEMP FEIS. Differences in vegetation communities would be minor.	The Cold Shock Alternative may result in egg or larval fish mortality. There would be no additional impacts on archaeological or sacred sites than those analyzed in the LTEMP FEIS. Differences in vegetation communities would be minor.	The Cold Shock Alternative with Flow Spikes may result in egg or larval fish mortality. There would be no additional impacts on archaeological or sacred sites than those analyzed in the LTEMP FEIS. Differences in vegetation communities would be minor.	The Non-Bypass Alternative would result in the loss of life of eggs and fry. Low flows could result in the exposure of archaeological sites or sacred sites. Differences in vegetation communities would be minor.
Recreation	Under the No Action Alternative, Glen Canyon Dam operations would remain unchanged, following the guidelines set in the LTEMP FEIS. In the Glen Canyon reach, implementation of HFE releases would continue to result in reduced short-term angler satisfaction, lost opportunities for the concessionaire from visitors rafting, and increased erosion of campsites on terraces. In the Grand Canyon, daytime flows would continue to be above the safe whitewater minimum of 8,000 cfs, with good river conditions (between 20,000 and 26,000 cfs) occurring most of the time. HFE releases would result in a potential increase in camping areas in the Grand Canyon.	Under the Cool Mix Alternative, reduced water temperatures would improve water quality for rainbow trout, which would likely increase angler satisfaction in the short and long term. Impacts on boating, the rafting concessionaire, and camping in the Glen Canyon reach and whitewater boating and camping in the Grand Canyon would be similar to those described under the No Action Alternative.	Under the Cool Mix with Flow Spike Alternative, benefits to the rainbow trout fishery resulting from reduced water temperatures would be the same as described under the Cool Mix Alternative. Flow spikes would reduce catchability during the peak fishing months, thereby reducing angler satisfaction in the short term. Flow spikes would also temporarily disrupt boating in the Glen Canyon reach and the ability of the rafting concessionaire to operate. The spikes also would contribute to increased erosion of campsites, compared with under the No Action Alternative. Flow spikes would likely improve whitewater boating conditions in the Grand Canyon, but they could temporarily limit beach usability for camping during implementation. In the long term, flow spikes have the highest potential to increase camping areas in the Grand Canyon.	Under the Cold Shock Alternative, cold shocks would likely have adverse impacts on fry and early juveniles, which could decrease angler satisfaction in the short term; however, cooler water temperatures would likely improve the water quality for rainbow trout in the long term, thereby increasing angler satisfaction in the long term. Impacts on boating, the rafting concessionaire, and camping in the Glen Canyon reach and whitewater boating and camping in the Grand Canyon would be similar to those described under the No Action Alternative.	Under the Cold Shock with Flow Spike Alternative, short-term reduced angler satisfaction could occur, which would be similar to under the Cold Shock Alternative. Flow spikes would reduce catchability during the peak fishing months, thereby reducing angler satisfaction in the short term. Flow spikes would also temporarily disrupt boating in the Glen Canyon reach and the ability of the rafting concessionaire to operate. They also would contribute to increased erosion of campsites, compared with the No Action Alternative. Flow spikes would likely improve whitewater boating conditions in the Grand Canyon, but they could temporarily limit beach usability for camping during implementation. In the long term, flow spikes have the highest potential to increase camping areas in the Grand Canyon.	Under the Non-Bypass Alternative, fry and juveniles would be negatively affected by both the high and low flows. The rapid fluctuations in water levels could also disrupt fishing during the flows' implementation. The Non-Bypass Alternative would also be less likely to benefit the rainbow trout fishery by reducing water temperatures, compared with the cold-water alternatives. The low flows under the Non-Bypass Alternative could limit the ability of boats to freely navigate in the Glen Canyon reach, which would adversely impact boating and the rafting concessionaire in the short term, compared with under all other alternatives. In the Grand Canyon, minimum flows would be below the safe whitewater minimum, which would adversely affect whitewater boating.

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Energy and Hydropower	Under the No Action Alternative, no changes would be made to Glen Canyon Dam operations. The power generation and economic value of electric energy would continue, similar to historical levels; there would be slight variations, depending on water availability and the constraints outlined in the LTEMP FEIS.	The Cool Mix Alternative would result in a total loss of approximately 130 GWh–145 GWh from 2024 to 2027 when modeled to river mile 15 and a loss of approximately 215 GWh–230 GWh when modeled to river mile 61. Relative to the No Action Alternative, this is equivalent to a 0.9 to 1.0 percent loss and a 1.5 to 1.6 percent loss, respectively. The loss in economic value of electric energy would be approximately $12.8–$15.3 million for river mile 15 and $19.4–$26.2 million for the Little Colorado River. These are equivalent to a 1.2 to 1.3 percent loss and a 1.8 to 2.2 percent loss, respectively, relative to the No Action Alternative.	The Cool Mix with Flow Spike Alternative would result in a total loss of approximately 132 GWh–140 GWh from 2024 to 2027 when modeled to river mile 15 and a loss of approximately 200 GWh–205 GWh when modeled to river mile 61. Relative to the No Action Alternative, these are equivalent to a 0.9 to 1.0 percent loss and a 0.7 to 1.4 percent loss, respectively. The loss in economic value of electric energy would be approximately $12.5–$15.5 million for river mile 15 and $17.8–$25.8 million for the Little Colorado River. These are equivalent to a 1.1 to 1.3 percent loss and a 1.6 to 2.1 percent loss, respectively, relative to the No Action Alternative.	The Cold Shock Alternative would result in a total loss of approximately 66 GWh–70 GWh from 2024 to 2027 when modeled to river mile 15 and a loss of approximately 102 GWh–103 GWh when modeled to river mile 61. Relative to the No Action Alternative, these would be equivalent to a 0.5 percent loss and a 0.7 percent loss, respectively. The loss in economic value of electric energy would be approximately $6.5–$8.8 million for river mile 15 and $8.4–$13.8 million for the Little Colorado River. These are equivalent to a 0.6 to 0.7 percent loss and a 0.8 to 1.1 percent loss, respectively, relative to the No Action Alternative.	The Cold Shock with Flow Spike Alternative would result in a total loss of approximately 65 GWh–66 GWh from 2023 to 2027 when modeled to river mile 15 and a loss of approximately 83 GWh–105 GWh when modeled to river mile 61. Relative to the No Action Alternative, these would be equivalent to a 0.5 percent loss and a 0.6 to 0.7 percent loss, respectively. The loss in economic value of electric energy would be approximately $6.1–$9.2 million for river mile 15 and $7.3–$15.0 million for the Little Colorado River. These are equivalent to a 0.6 to 0.8 percent loss and a 0.7 to 1.3 percent loss, respectively, relative to the No Action Alternative.	The Non-Bypass Alternative would result in a total gain of approximately 9 GWh from 2024 to 2027 when modeled to river mile 15 and a gain of approximately 20 GWh–42 GWh when modeled to river mile 61. Relative to the No Action Alternative, these would be equivalent to a 0.1 percent gain and a 0.1 to 0.3 percent gain, respectively. The gain in economic value of electric energy would be approximately $1 million for river mile 15 and $0.2–$0.7 million for the Little Colorado River. These are equivalent to a 0.1 percent gain and a 0.0 to 0.1 percent gain, respectively, relative to the No Action Alternative.
Socioeconomic Impacts	Under the No Action Alternative, the estimated net value for the 50-month analysis period was calculated at $366.76 million for whitewater boaters and $19.03 million for anglers. Nonmarket values associated with the humpback chub may decrease in the long term. Other nonmarket values may also be impacted in the long term. HFE releases could continue to impact sandbar development and the associated values. It should also be noted that nonmarket values may differ for different groups. Respondents who are supportive of hydropower, concerned about the health effects of air pollution, and concerned about ways of life for Native American Tribes and rural western communities are more likely to support the continuation of current patterns of dam operations and assign a higher value to this operation. Additionally, individuals owning property in the region around Glen Canyon Dam are considerably more likely to support continuation of dam operations.	As compared with the No Action Alternative, this alternative would result in minimal changes to the net value for anglers and whitewater boaters for all reaches. Nonmarket values associated with humpback chub are not likely to be negatively affected. In terms of sandbars and the associated values, this alternative would result in the potential for slight increases in the associated nonmarket value. For values associated with climate change, nonmarket values would be impacted by an increase in carbon emissions. This alternative represents the greatest level of increased emissions. Similarly, this alternative represents the greatest potential for impacts to other values associated with rural ranching and farmers, or other area residents who may value continued current operations of the dam.	Estimates for the net value for anglers include a 17 percent increase in value in the Glen Canyon reach and a 1.5 percent increase in the lower Grand Canyon reach, compared with the No Action Alternative. A minimal change would occur for the whitewater boating value. Impacts on the values associated with the humpback chub from the Cool Mix with Flow Spike Alternative would be the same as described under the Cool Mix Alternative. Values associated with sandbars would be increased compared with under the No Action Alternative. Values associated with continued current operations of the dam could be impacted under this alternative.	Under the Cold Shock Alternative, some long-term increases in angler satisfaction would likely occur. Compared with the No Action Alternative, boating would have minimal changes in terms of satisfaction and value. Under the Cold Shock Alternative, potential impacts would occur for values associated with the humpback chub. Sandbar increases would support increased values compared with the No Action Alternative. Compared with the No Action Alternative, increased carbon emissions would occur, resulting in impacts on climate change–associated values; however, these increases under the Cold Shock Alternative would be lower than those increases described in the Cool Mix Alternative. Impacts on the people who value continued dam operations would occur, but at a lower level than under the Cool Mix Alternative.	Impacts on angler and boating net economic values would be the same as those described in the Cold Shock Alternative. Under the Cold Shock with Flow Spike Alternative, impacts on humpback chub values would be similar to those under the No Action Alternative. Values associated with sandbars would be increased compared with the No Action Alternative. Values associated with continued current operations of the dam could be impacted under this alternative.	Some short-term impacts could occur for angler satisfaction. The high and low fluctuations of water could impact the boater experience in both the Glen Canyon and Grand Canyon reaches. This could adversely impact the associated value. Under the Non-Bypass Alternative, there is the potential for short-term impacts on humpback chub juveniles from flow changes; however, the effect of these high flows is expected to be minimal; no long-term changes to the associated value are expected. No change is anticipated to carbon emissions or values associated with continued dam operations under this alternative.

Resource	No Action Alternative	Cool Mix Alternative	Cool Mix with Flow Spike Alternative	Cold Shock Alternative	Cold Shock with Flow Spike Alternative	Non-Bypass Alternative
Environmental Justice	Under the No Action Alternative, operations at Glen Canyon Dam would not change, and hydropower generation would continue at historical levels. There would be no impacts on environmental justice communities because of changes to power generation.	Reduced energy generation and increased replacement energy would result in financial impacts, changes to air quality emissions from replacement power, changes to Tribal resources, changes to regional economic activity related to recreation, and changes to use and nonuse values. The Cool Mix Alternative would result in the most impacts on power generation, the second-most financial impacts, and the most impacts on air quality. These impacts could disproportionately impact environmental justice communities.	Impacts on environmental justice communities would be similar to those described for the Cool Mix Alternative; however, the Cool Mix with Flow Spike Alternative would result in the second-most impacts on power generation and the most financial impacts on environmental justice communities. The quality of the angling experience in terms of angling access would result in potential impacts on environmental justice communities.	The Cold Shock Alternative would result in the third-most potential financial impacts on environmental justice communities.	The Cold Shock and Flow Spike Alternative would result in the second-fewest potential financial impacts on environmental justice communities. Impacts on environmental justice communities because of changes to angling access would be the same as those described under the Cool Mix with Flow Spike Alternative.	The Non-Bypass Alternative would result in the least impacts on hydropower generation and the least financial impacts. Under this alternative, there would be a gain in economic value of electric power. This could benefit communities, including environmental justice communities. However, this alternative would result in the most potential impacts on recreation and Tribal resources (through fish mortalities). These impacts would result in potential disproportionate adverse impacts for environmental justice communities.

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Chapter 3. Affected Environment and Environmental Consequences

3.1 Introduction

This chapter describes the affected environment and environmental consequences for the resources that could be significantly affected by the alternatives, as described in **Table 1-1**. The affected environment sections describe and update the current conditions, focusing on those that have changed since 2016. The environmental consequences sections provide analysis of the No Action and Action Alternatives, as described in **Chapter 2**. The analysis is issue based, addressing the specific relevant concerns identified during scoping for a particular resource. For brevity and to avoid redundancy, the 2016 LTEMP FEIS (Reclamation 2016) is incorporated by reference. To supplement the 2016 LTEMP FEIS (DOI 2016a), these sections provide a summary of the affected environment from the original 2016 document, modified as necessary to include changes that have occurred since 2016.

3.2 Hydrology

3.2.1 Affected Environment

The Colorado River headwaters begin in the Rocky Mountains of Colorado. The river flows southwesterly until its terminus in the Gulf of California. It benefits approximately 40 million users in seven western states and the Republic of Mexico. Peak inflow flow at Glen Canyon Dam occurs in late spring to early summer, although flows in late summer through autumn sometimes can increase following monsoonal rain events (Reclamation 2007. Snowmelt during spring and early summer months is the main contributor to the river's flow, but inflow is also driven by precipitation within the basin and controlled by upstream dams and diversion structures.

The Upper Colorado River Basin, which is defined as the area above Lee Ferry, is mainly classified as semiarid and the Lower Basin, which is below Lee Ferry, is classified as arid. The climate, however, can vary from cold and dry in alpine environments at high elevations to dry-temperate west of the mountains and arid to the southwest. Average annual precipitation totals in the alpine regions of the Upper Colorado River Basin range from 30 to 60 inches. Near Glen Canyon Dam, rainfall in this area averages between 6 and 8 inches, mostly in the form of cloudburst storms during late summer and early fall. The arid climate of the region around Lake Powell leads to significant evaporation rates, especially during summer months.

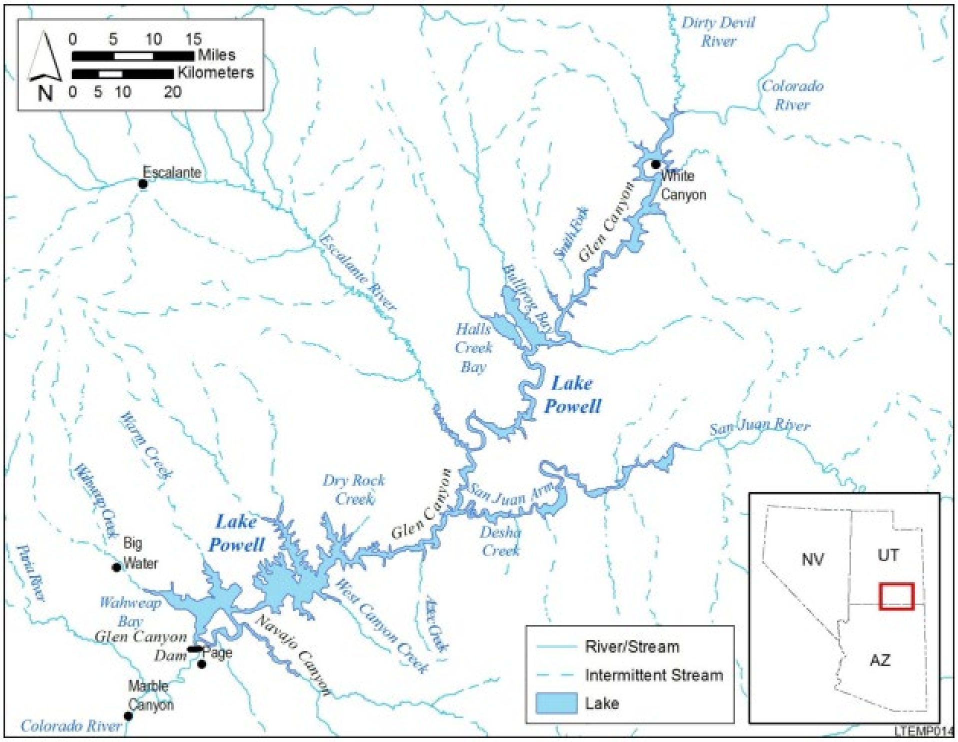
In 2021, Reclamation updated climate and hydrology projections across the western United States to better align with new techniques, data, and analyses (Reclamation 2021a). Under all GHG scenarios, average temperatures are projected to continue to increase overall across the west; in the past 40 years, the climate of the Colorado River Basin has become increasingly warmer, mainly due to anthropomorphic changes to the atmosphere. In addition, precipitation is projected to trend toward lower total annual precipitation but greater fluctuation in timing, frequency, and magnitude of storm events (Zhang et al. 2021). The continued warming and subsequent aridification of the Upper Basin leads to reduced snowpack; this warming has been shown to disproportionately impact snowpack regions, causing runoff to decline at double the rate compared to regions without snowpack (Bass et al. 2023). Studies have also found that a hotter climate has led to a reduction in runoff efficiency in both wet and dry years. Therefore, future flows will be less than anticipated both from precipitation and snowmelt (Woodhouse and Pederson 2018), yielding lower water levels in Lake Powell. Climate experts and scientists suggest droughts of this severity occurred in the past and are likely to continue to occur.

The Upper Colorado River Basin experiences significant year-to-year hydrologic variability. Unregulated inflow into Lake Powell, which is a good measure of hydrologic conditions in the Colorado River Basin, has ranged between approximately 5.4 and 25.4 maf over the 105-year full record of flow (1906–2010) (Reclamation 2007, 2013). The 2000–2022 period is the lowest 23-year period since the closure of Glen Canyon Dam in 1963, with an average unregulated inflow of 8.29 maf, or 93 percent of the 30-year period of record (1991–2021) inflow of 9.6 maf. Additionally, 2000–2011 was the driest 11-year period in recorded history, and 1999–2010 was the second driest 11-year period (Holdren et al. 2012; GCMRC 2015).

Lake Powell is the second-largest reservoir in the Colorado River system. It was created following the construction of Glen Canyon Dam in 1963 through the CRSP. Overall, approximately 95 percent of the reservoir's inflow originates from the Colorado River and two of its major tributaries: the San Juan River and the Green River (Stanford and Ward 1991; Reclamation 1995, 2007; Wildman et al. 2011). Lake Powell has a maximum storage capacity of 25.27 maf as of October 2023. When storage is full, it has an average depth of 165 feet and a depth of 560 feet near the dam. Water levels in Lake Powell can fluctuate based on seasonal variations in inflow as well as operations of the dam. Releases from Glen Canyon Dam are pursuant to the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead and the 2016 LTEMP ROD. Lake Powell storage assists the Upper Colorado River Basin States in meeting Colorado River Compact obligations, generates hydroelectric power through the Glen Canyon Dam powerplant, and provides recreational benefits. **Figure 3-1** shows Lake Powell and its major tributaries.

The outflow from Lake Powell is regulated by the Glen Canyon Dam. Monthly release volumes are based on anticipated power demands, forecasted inflows, and other factors such as storage equalization between Lake Powell and Lake Mead. High release rates do not always coincide with peaks in reservoir inflow; instead, they typically occur during times of increased power demands or during HFEs. Colorado River flows at the Lees Ferry gaging station, or river mile 0 (located approximately 15.5 miles downstream of Glen Canyon Dam and approximately 1 mile upstream of the Paria River mouth), have been monitored since May 1921, prior to the Dam's construction (DOI 2016a). This record provides an outlook comparing pre- and post-dam conditions. The average pre-dam annual peak flow was approximately 92,000 cfs throughout the period of record.

Figure 3-1
Map of Lake Powell and Associated Major Tributaries



Source: Department 2016a

Additionally, paleoflood research has determined that during the last 4,500 years, 15 floods at Lees Ferry had peak discharges greater than 120,000 cfs. Of these floods, 10 had peak discharges greater than 140,000–150,000 cfs during the last 2,100–2,300 years, and one flood that occurred 1,200–1,600 years ago had a peak discharge exceeding about 300,000 cfs (Topping et al. 2003). Since the installation of the dam, both peak flows and the frequency of very low flows have been reduced (DOI 2016a). Long-term and annual release volumes from Lake Powell are detailed in the LTEMP FEIS (Department 2016a). Releases can also fluctuate beyond those scheduled in accordance with ROD section 1.2B (DOI 2016b).

3.2.2 Environmental Consequences

Methodology

The analysis presented in this section was informed by hydrologic models showing the impacts of monthly flow alterations at Glen Canyon Dam on Lake Powell and the Colorado River extending from Lees Ferry at river mile 15 through river mile 61 (at the Little Colorado River confluence), where the largest concentration of humpback chub can be found. These two locations were analyzed as sub-alternatives to show what the impacts would be in smallmouth bass where identified in the upper reaches or further downstream. The initiation of the action alternatives would only be triggered if water temperatures at either location are at or above 15.5~~6~~ degrees Celsius (°C) (60 degrees Fahrenheit [˚F]). The flow alternatives were verified to ensure their alignment with release volumes as established in the LTEMP FEIS (DOI 2016a).

The operational alternatives were modeled using a set of 30 ensemble streamflow prediction monthly traces to capture a range of hydrologic conditions. An initial run of the smallmouth bass model was made to determine the months in which flow spikes would be expected to be triggered under operational alternatives that include flow spikes. Additional information on the smallmouth bass model can be found in **Appendix A**. Subsequently, a sediment model was run to identify the timing, magnitude, and duration of an HFE. If, during months where a HFE or flow spike event were marked to occur, monthly volumes from Glen Canyon Dam and Lake Powell elevations were reallocated and adjusted between months, such that the annual release volume from Lake Powell remains unchanged from the No Action Alternative.

Impact Analysis Area

- The impact analysis area for the hydrologic analysis extends between Lake Powell to river mile 61 downstream on the Colorado River.

Assumptions

- Inflow into Lake Powell would follow existing trends; action alternatives would not influence inflows.
- Total annual release volumes from Lake Powell would remain consistent with the 2007 Interim Guidelines.
- Under all alternatives except for the Non-Bypass Alternative, Reclamation would adhere to operational and regulatory constraints outlined in the LTEMP FEIS (DOI 2016a).

Impact Indicators

Changes in Lake Powell water surface elevations (in feet) and release volumes from Glen Canyon Dam (in af).

Issue 1: How would flow alterations at Glen Canyon Dam affect the hydrology at Lake Powell and the Colorado River downstream?

No Action Alternative

Under this alternative, operations at Glen Canyon Dam would remain unchanged. The flow regime would occur as dictated in the LTEMP FEIS. Specifically, water would continue to be discharged primarily through the penstocks, and HFEs would most likely occur in the fall with low likelihood of HFEs in the spring.

Figure 3-2
Monthly Lake Powell Elevations for the No Action Alternative

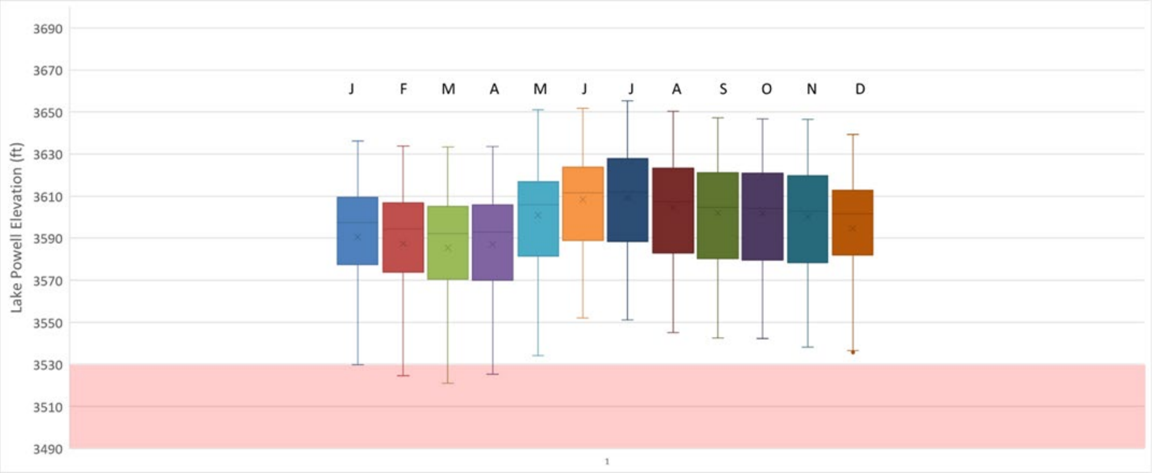


Figure 3-3
Monthly Glen Canyon Dam Release Volumes for the No Action Alternative

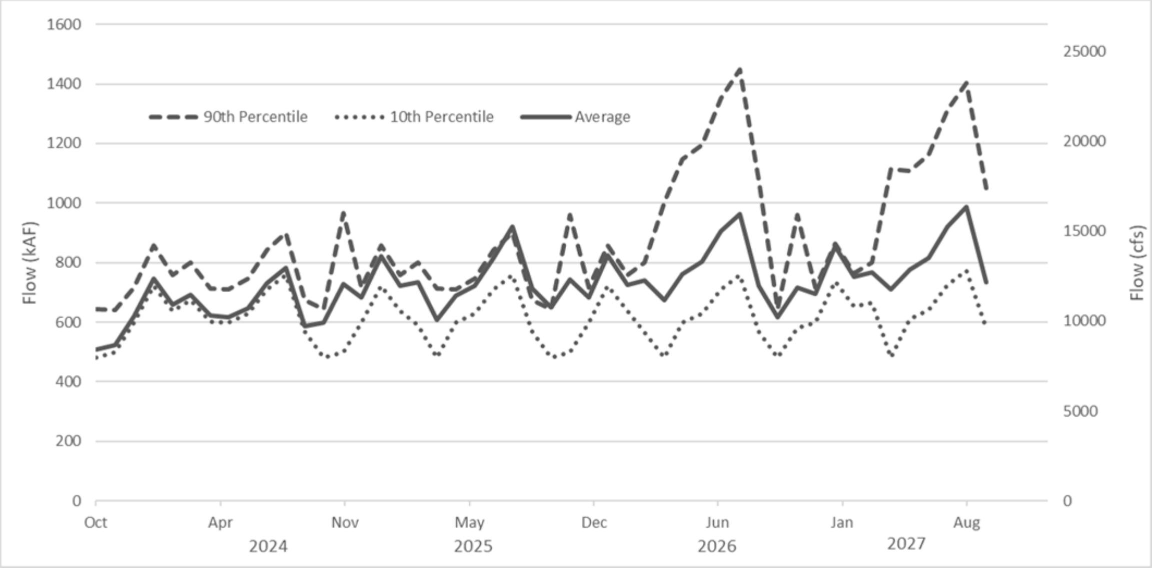


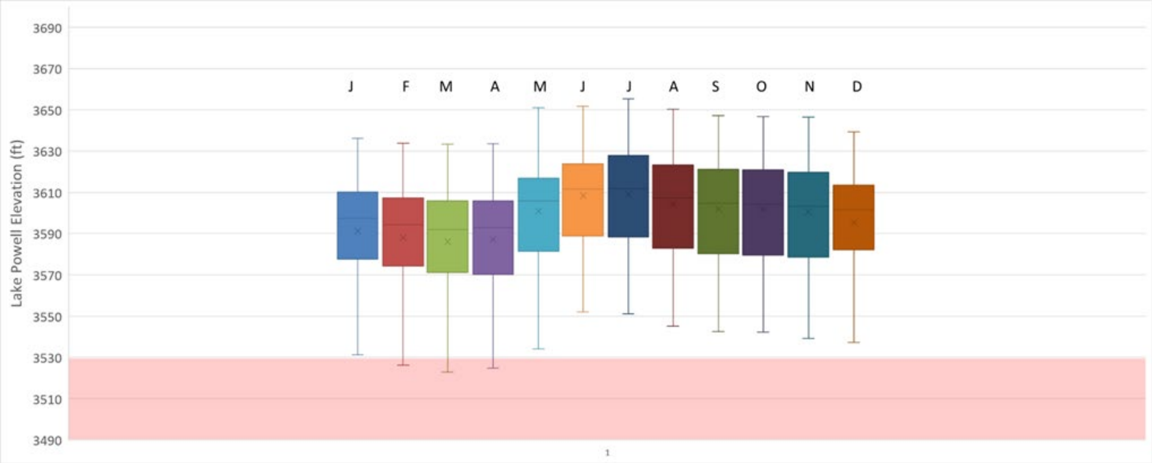
Table 3-2
HFE Occurrence Summary per Water Year for the No Action Alternative

	HFE Flows		
WY	**Maximum**	**Mean**	**Minimum**
2024	1	1	1
2025	2	1	1
2026	2	1	1
2027	2	1	1

Cool Mix Alternative

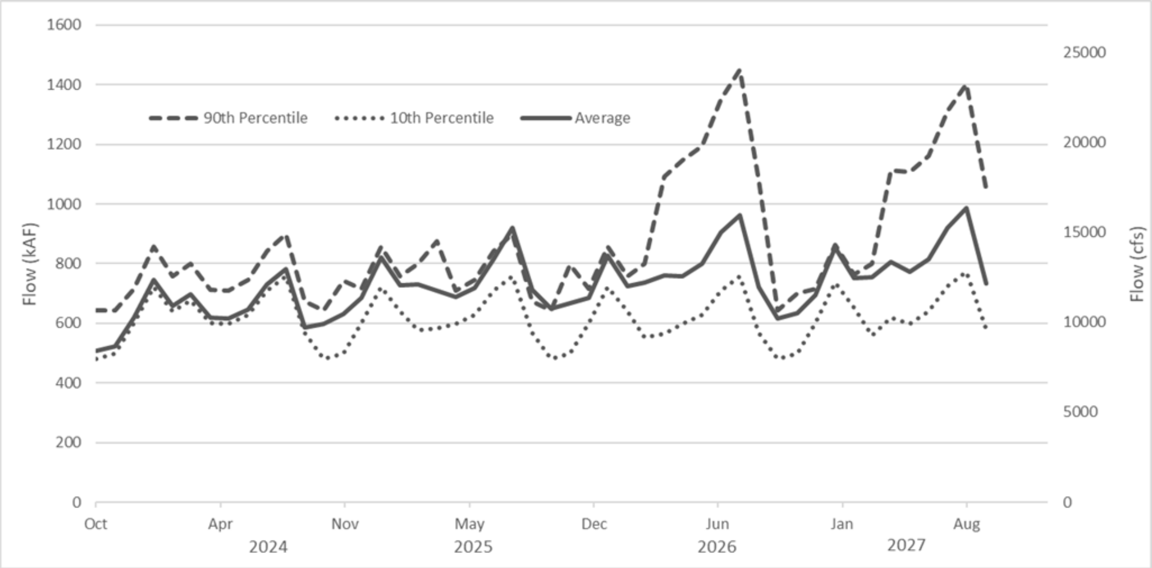
Consistent releases from the river outlet works aim to cool the river to 15.5 °C (60°F) at the target locations of river mile 15 or river mile 61. The volume of water released through the river outlet works and penstocks would vary based on the elevation of Lake Powell, monthly water releases, and water temperatures in the reservoir. Under this flow option, discharges from the dam would continue to operate at the same levels described in the LTEMP FEIS. The only change would be the release point of flows from the dam, whether from the penstocks or the river outlet works. There was no discernable difference in monthly reservoir elevations or GCD release volumes between the river mile 15 and river mile 61 sub-alternatives.

Figure 3-4
Monthly Lake Powell Elevations for the Cool Mix Alternative



The red zone below elevation 3,530 feet indicates where the warmer thermocline zone begins as opposed to the cooler hypolimnion zone above. The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Figure 3-5
Monthly Glen Canyon Dam Release Volumes for the Cool Mix Alternative



The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Table 3-4
Experimental Smallmouth Bass Flow and HFE Occurrence Summary per Water Year for the Cool Mix Alternative

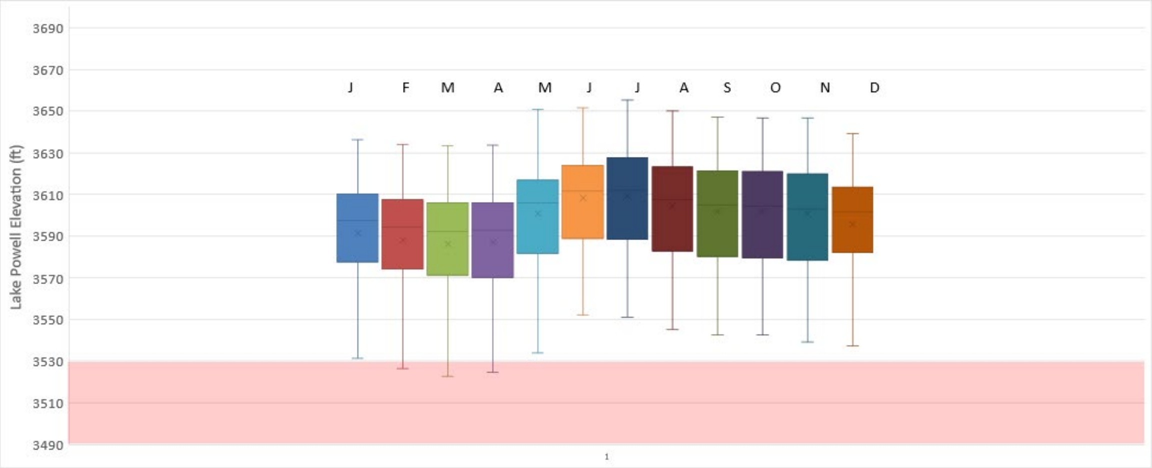
Experimental Smallmouth Bass Flows						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	2	1	1
2025	5	3	1	5	3	1
2026	6	3	1	7	3	1
2027	5	1	2	6	1	1

HFE Flows						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	1	1	1
2025	2	1	1	2	1	1
2026	2	1	1	2	1	1
2027	1	1	1	1	1	1

Cool Mix with Flow Spike Alternative

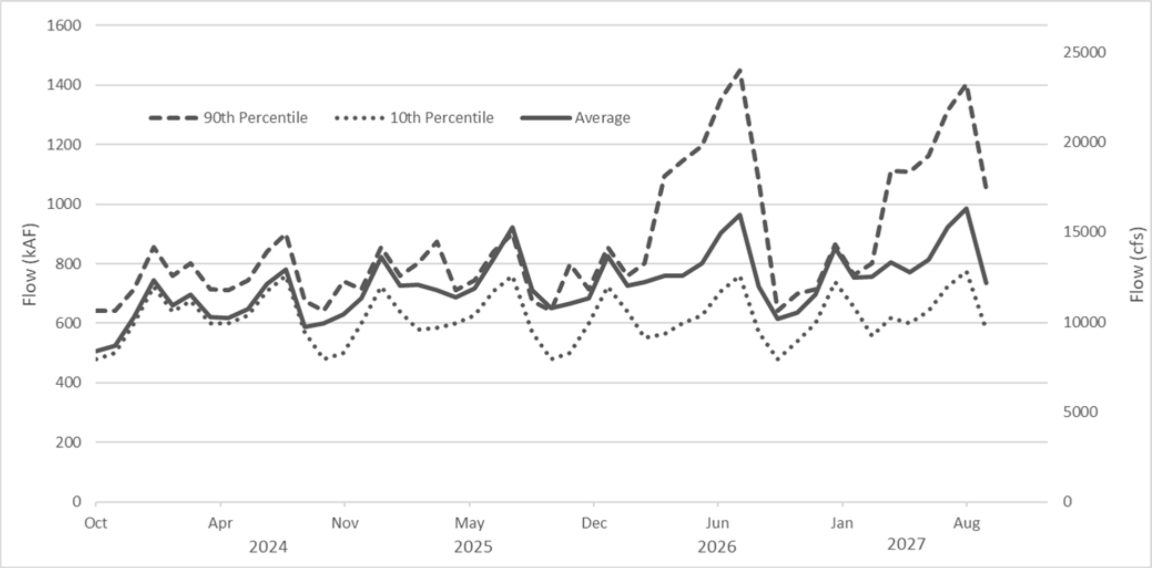
This alternative is similar to the Cool Mix Alternative but includes the implementation of up to three 36-hour flow spikes that aim to increase flows and decrease temperatures in backwater areas. These flow spikes would be added between late May and mid-July if sufficient water is available in Lake Powell. Under this alternative, increased flow events during flow spikes would be similar to HFEs. The volume of water released during flow spikes would be higher than during typical operations; however, they would still be within the range as analyzed in the LTEMP FEIS. Flow spikes could yield lower water elevations in Lake Powell immediately after the event. The time to restore the water level to normal levels would vary, depending on the inflow into the reservoir. There was no discernable difference in monthly reservoir elevations or GCD release volumes between the river mile 15 and river mile 61 sub-alternatives.

Figure 3-6
Monthly Lake Powell Elevations for the Cool Mix with Flow Spikes Alternative



The red zone below elevation 3530 indicates where warmer thermocline zone begins as opposed to the cooler hypolimnion zone above. The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Figure 3-7
Monthly Glen Canyon Dam Release Volumes for the Cool Mix with Flow Spikes Alternative



The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Table 3-6
Experimental Smallmouth Bass Flow and HFE Occurrence Summary per Water Year for the Cool Mix with Flow Spike Alternative

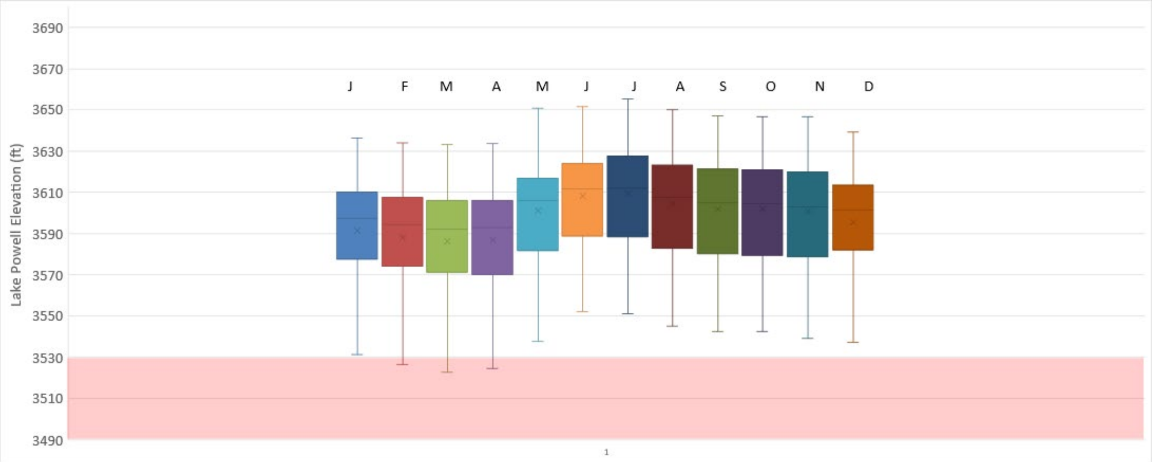
Experimental Smallmouth Bass Flows						
	River Mile 15			River Mile 61		
WY	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**
2024	1	1	1	2	1	1
2025	5	3	1	5	3	1
2026	6	3	1	7	3	1
2027	5	1	2	6	1	1

Flow Spikes						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	2	1	1
2025	2	2	1	2	2	1
2026	2	2	1	2	2	2
2027	2	0	2	2	0	2
HFE Flows						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	1	1	1
2025	2	1	1	2	1	1
2026	2	1	1	2	1	1
2027	1	1	1	1	1	1

Cold Shock Alternative

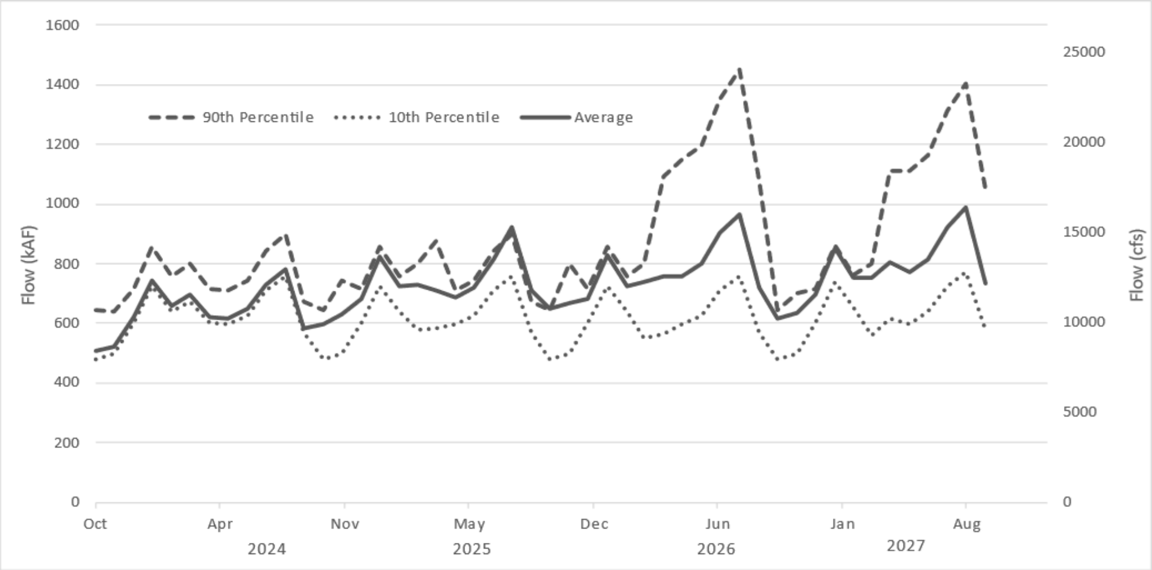
Under this alternative, a large, 48-hour weekly release from the river outlet works aim to reduce water temperatures in the river to 13°C (55.4°F) at the target locations of river mile 15 or 61. Under this flow option, discharges from the dam would continue to operate at the same levels described in the LTEMP FEIS. The only change would be the release point of flows from the dam, whether from the penstocks or the river outlet works.

Figure 3-8
Monthly Lake Powell Elevations for the Cold Shock Alternative



The red zone below elevation 3,530 feet indicates where the warmer thermocline zone begins as opposed to the cooler hypolimnion zone above. The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Figure 3-9
Monthly Glen Canyon Dam Release Volumes for the Cold Shock Alternative



The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Table 3-8
Experimental Smallmouth Bass Flow and HFE Occurrence Summary per Water Year for the Cold Shock Alternative

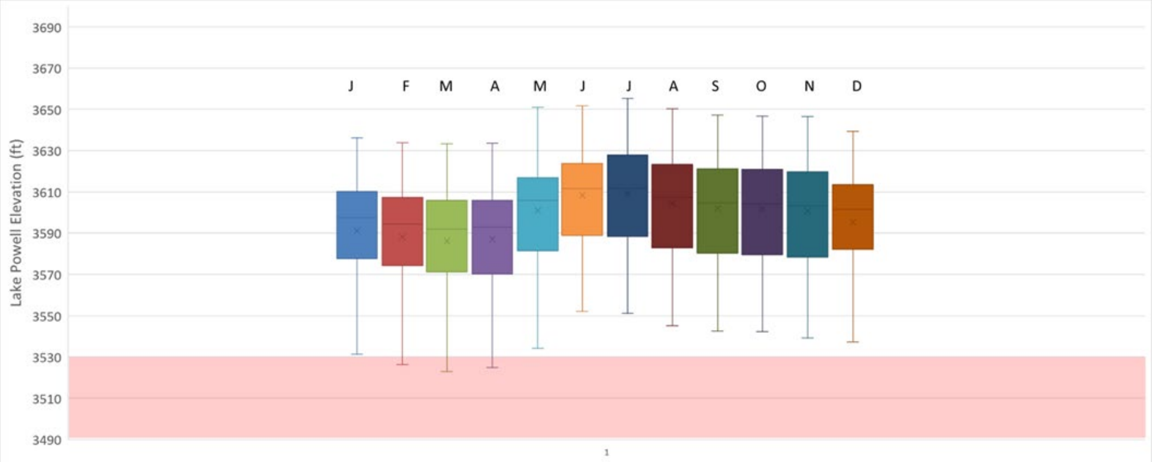
Experimental Smallmouth Bass Flows						
	River Mile 15			River Mile 61		
WY	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**
2024	1	1	1	2	1	1
2025	5	3	1	4	2	1
2026	4	3	1	4	2	1
2027	4	1	2	4	1	1

HFE Flows						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	1	1	1
2025	2	1	1	2	1	1
2026	2	1	1	2	1	1
2027	0	1	0	1	1	1

Cold Shock with Flow Spike Alternative

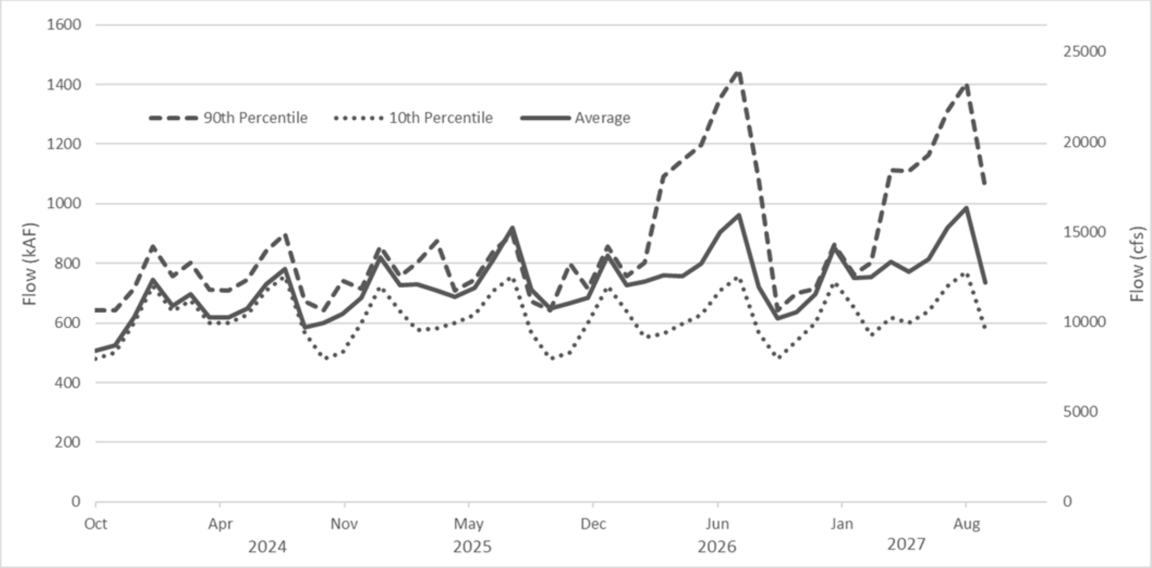
Under this alternative, weekly releases from the river outlet works are coupled with increased flow events that act similar to HFEs, intended to increase sediment movement and decrease temperatures at backwater areas. These flow spikes would be added between late May and mid-July if sufficient water is available in Lake Powell. The volume of water released during flow spikes would be higher than during typical operations; however, they would still be within the range analyzed in the LTEMP FEIS. Flow spikes could yield lower water elevations in Lake Powell immediately after the event. The time to restore the water level to normal levels would vary, depending on the inflow into the reservoir.

Figure 3-10
Monthly Lake Powell Elevations for the Cold Shock with Flow Spike Alternative



The red zone below elevation 3,530 feet indicates where the warmer thermocline zone begins as opposed to the cooler hypolimnion zone above. The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Figure 3-11
Monthly Glen Canyon Dam Release Volumes for the Cold Shock with Flow Spike Alternative



The figures presented are based on estimates out of 30 modeled traces. Differences in results between sub-alternatives at river mile 15 and river mile 61 are not discernable.

Table 3-10
Experimental Smallmouth Bass Flow and HFE Occurrence Summary per Water Year for the Cold Shock with Flow Spike Alternative

Experimental Smallmouth Bass Flows						
	River Mile 15			River Mile 61		
WY	Maximum	Mean	Minimum	Maximum	Mean	Minimum
2024	1	1	1	2	1	1
2025	5	3	1	4	2	1
2026	4	2	1	4	2	1
2027	4	1	2	4	1	1

Flow Spikes

	River Mile 15			River Mile 61		
WY	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**
2024	1	1	1	2	1	1
2025	2	2	1	2	2	1
2026	2	2	1	2	2	2
2027	2	0	2	2	0	2

HFE Flows

	River Mile 15			River Mile 61		
WY	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**	**Minimum**
2024	1	1	1	1	1	1
2025	2	2	1	2	1	1
2026	2	2	1	2	1	1
2027	2	0	2	1	1	1

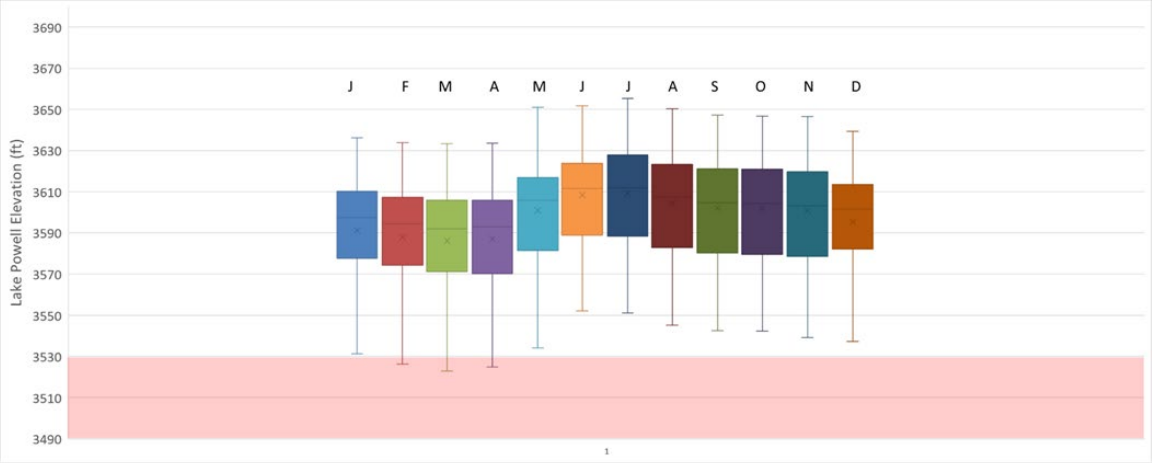
Non-Bypass Flow Alternative

This alternative proposes a hydrograph centered on employing higher velocities to disrupt existing nests rather than preventing spawning.

The approach involves a detailed analysis of timing, duration, magnitude, and frequency, capitalizing on the susceptibility of male bass to changes in their environment that cause the males to abandon their nest. On a weekly basis, flows would drop to a minimum of 2,000 cfs followed by a quick increase to ~27,300 cfs over an approximate 8-hour window at Glen Canyon Dam. Low-flow events are uncommon downstream of Glen Canyon Dam. In the early 1990s research flows as low as 1,000 cfs were imposed. The mass movement of water released at this lower rate travels at a slower rate. When the high flow is then later released, this slug of water is expected to overtake the low flow wave by the time it reaches river mile 61 (confluence with the Little Colorado River) (downstream The effects on water levels within Colorado River under this alternative would be most intense near Glen Canyon Dam, with the effect of the high- and low- volume releases on river water levels diminishing further downstream.

Figure 2-5 shows a conceptual hydrograph for the Non-Bypass Alternative. The graph shows repeated high- and low-flow release combinations on Sunday night through Monday afternoon. The 2016 LTEMP ROD defines maximum ramp rates as 4,000 cfs per hour up, and 2,500 cfs per hour down. The drop between the low flow (2,000 cfs) and the high flow (~27,300 cfs) over the 8-hour window does not violate ramp rates. However, both the minimum and maximum proposed flows exceed the maximum daily range as developed in the LTEMP ROD.

Figure 3-12
Monthly Lake Powell Elevations for the Non-Bypass Alternative



The red zone below elevation 3,530 feet indicates where the warmer thermocline zone begins as opposed to the cooler hypolimnion zone above. The figures presented are based on estimates out of 30 modeled traces.

Figure 3-13
Monthly Glen Canyon Dam Release Volumes for the Non-Bypass Alternative

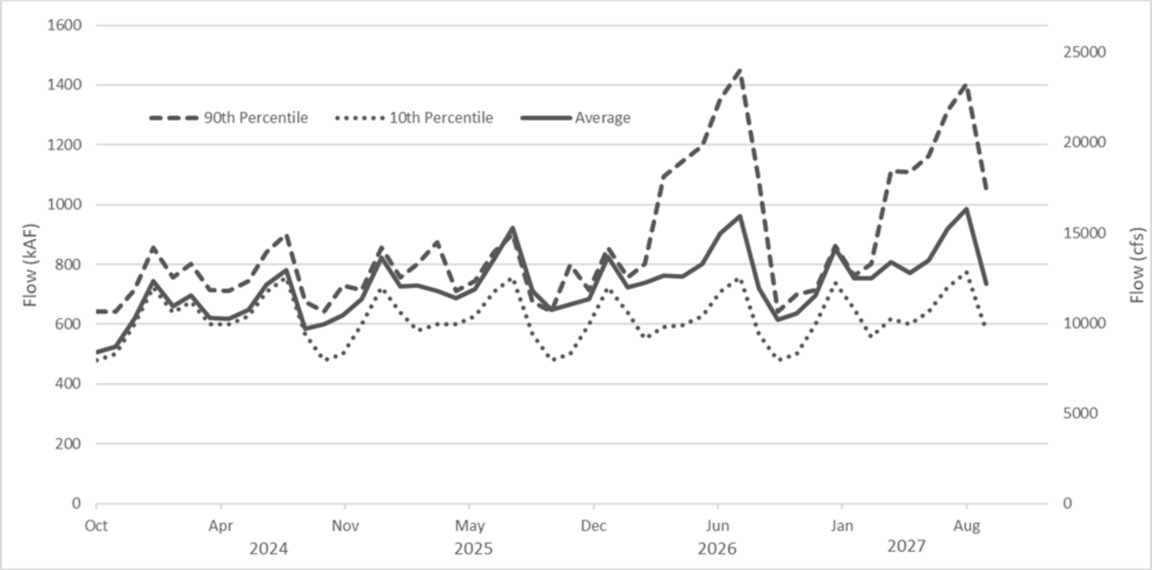


Table 3-12
HFE Occurrence Summary per Water Year for the Non-Bypass Alternative

	HFE Flows		
WY	Maximum	Mean	Minimum
2024	1	1	1
2025	2	1	1
2026	2	1	1
2027	1	1	1

Cumulative Effects

Direct impacts on the Colorado River downstream of Glen Canyon Dam and at Lake Powell stemming from alternate monthly water releases are likely to be temporary and are not anticipated to have major impacts on the local hydrology. Overall elevation changes in Lake Powell under the action alternatives are relatively minor, and water. On an annual basis, release volumes to the Lower Basin would remain unchanged. All proposed flow options except for the Non-Bypass Alternative would operate within the spatial and temporal bounds and under the assumptions of the existing analysis in the LTEMP FEIS.

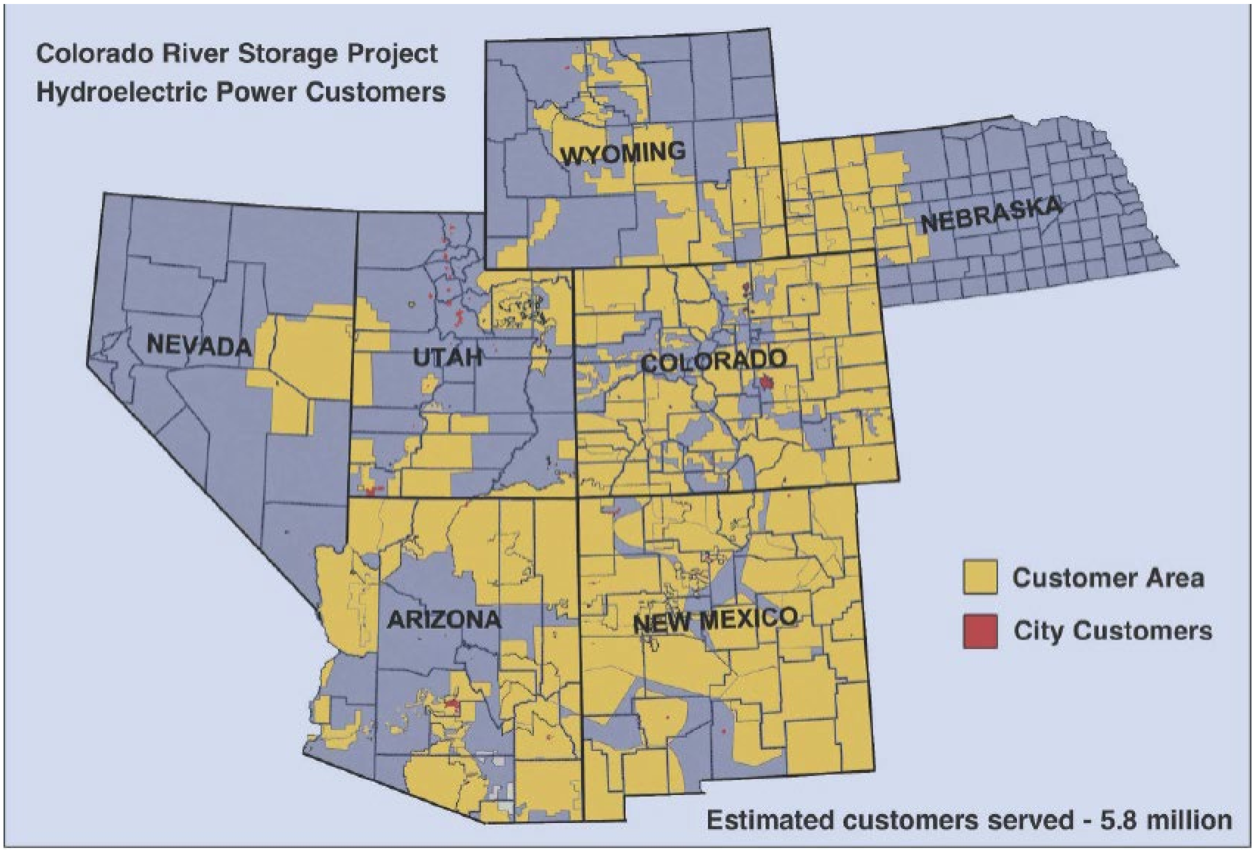
3.3 Energy and Power

3.3.1 Affected Environment

This section describes Glen Canyon Dam and the Glen Canyon Powerplant's power operations and power marketing. Additional information on the socioeconomic environment relating to hydropower and additional resources, including baseline economic conditions for the seven-state CRSP hydropower customer area, can be found in **Section 3.15** and **Section 3.16**, Socioeconomics and Environmental Justice, respectively.

The powerplant is connected to the Western Power Grid via a regional transmission system. Power generated at Glen Canyon Dam provides electricity for the US Department of Energy's WAPA customers. WAPA is responsible for providing electricity to a 15-state region of the western United States. Glen Canyon Dam is a major contributor to the transmission system and typically provides electricity to Wyoming, Utah, Colorado, New Mexico, Arizona, Nevada, and Nebraska (DOI 2016a, p. 3.221). Glen Canyon Dam also provided emergency power supplies to California in 2020 (Stone 2020). **Figure 3-14** shows a map of CRSP hydroelectric power customers.

Figure 3-14
CRSP Hydroelectric Power Customers Map



Operations at Glen Canyon Dam affect the Basin Fund[9], consumers, and government agencies. Revenues from power generation are deposited into the Basin Fund, which authorized revenues toward other programs, as dictated by the CRSP Act of 1956 and the Grand Canyon Protection Act of 1992.

Power Operations

Power operations are the physical operations of an electrical power system, including hydropower generation and control, operational flexibility, scheduling, power generation load-following, regulation, reserves, transmission, and emergency operations. These are discussed in the sections below. Glen Canyon Dam operations directly impact power generation. The amount of water discharged through the generator units and the elevation of the reservoir dictate the amount of electricity generated. Typical operations at Glen Canyon Dam result in power generation at the powerplant, with electricity moving from the plant and along the transmission system to the customers. A simplified diagram of the powerplant's operations is provided in **Figure 3-15.**

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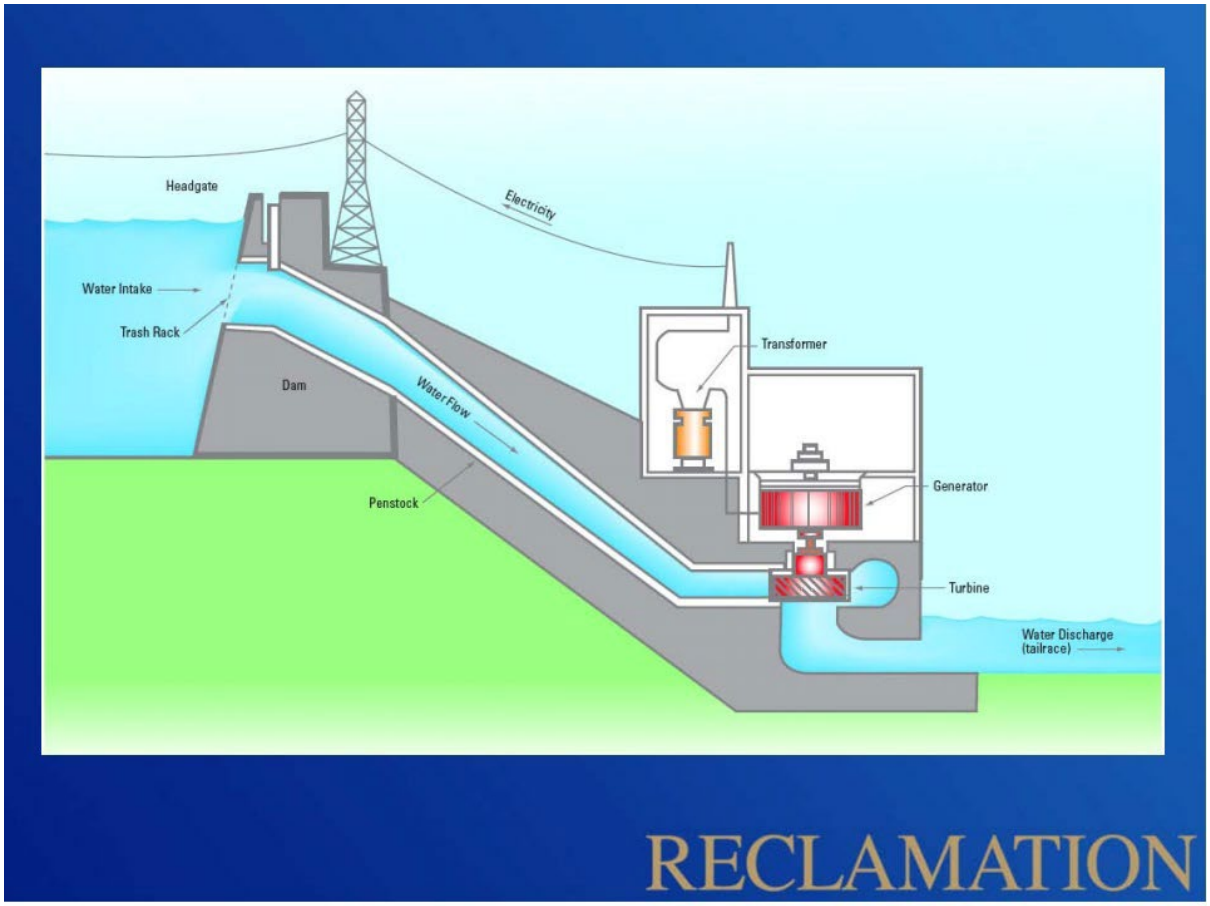
[9] https://www.usbr.gov/uc/rm/crsp/index.html

Figure 3-15
Powerplant Operations Diagram



Hydropower Generation

Glen Canyon Dam has eight generators with a maximum combined capacity of 1,320 MW when the reservoir elevation is 3,700 feet (DOI 2016a). The powerplant requires a minimum Lake Powell elevation of 3,490 feet to operate. Reclamation reported a net generation of 3,345 gigawatt-hours in fiscal year 2021 and 2,583 gigawatt-hours in fiscal year 2022 (Reclamation 2022). The LTEMP FEIS provides additional historical power generation data, such as annual net generation, and is incorporated by reference (DOI 2016a, pp. 3.199–3.200). Power generation varies on daily, seasonal, and yearly scales as a result of contract obligations, water release schedules, power needs, reservoir levels, and other operational requirements. Releases through the river outlet works do not generate power, and therefore, have no power system economic value (DOI 2016a).

Basin Fund

The CRSP Act of 1956 established the Basin Fund, 43 U.S.C. § 620d, which remains available until expended to carry out the project's purposes and operations. Maintaining a sufficient Basin Fund balance is critical to operating and maintaining reliability of CRSP facilities in delivering water to water users and generating and transmitting power to power customers. WAPA and Reclamation use this fund to pay operations and maintenance expenses of CRSP facilities, provide power for WAPA customers, provide the Basin States' Memorandum of Agreement (MOA) funds, support environmental and salinity programs, and return the cost of constructing the CRSP system to the U.S. Treasury. Other than the Basin Fund, WAPA does not have a non-reimbursable funding source that can be used for this experiment. Additionally, a Cost Recovery Charge (CRC) cannot be implemented to cover non-reimbursable purchase power expenses.

WAPA provides wholesale power to small utilities, municipalities, and tribal reservations who fold this power into the rest of their portfolio to fulfill their load requirements. Under WAPA's current rate structure, WAPA provides its long-term firm power customers with a set amount of power on a quarterly basis. The amount of power is based on the amount of water Reclamation forecasts to release from the CRSP units during that quarter. If CRSP units do not generate enough power to fulfill these contractual obligations, WAPA must purchase power and transmission on the energy market to make up the difference. WAPA uses cash from the Basin Fund to make those purchases.

Under the Grand Canyon Protection Act of 1992, Pub. L. 102-575 (GCPA), WAPA records the financial costs of environmental experiments as non-reimbursable by accounting for such costs as a constructive return to the U.S. Treasury, rather than an operations and maintenance expense to be recovered through WAPA's cost-based power rates.

By bypassing the electrical generators at Glen Canyon Dam, the experiment will reduce hydropower generation. Accordingly, WAPA will be required to purchase replacement power to fulfill its contractual obligations to customers. The experiment would markedly increase the amount of non-reimbursable costs drawn from the Basin Fund and returned to the Treasury.

Because the Basin Fund is used to fund ongoing operating expenses, its balance significantly fluctuates due to the ongoing purchase and sale of energy and transmission. WAPA must maintain a sufficient balance in the Basin Fund to pay for operations and maintenance despite these fluctuations. WAPA projects that if the Basin Fund balance falls below $70 million, it would result in increased impacts to its ability to adequately fund project needs and environmental programs, including the Glen Canyon Dam Adaptive Management Program (and related experiments), the Upper Colorado River Recovery Implementation Program (and related experiments), water quality programs, consumptive use studies, and other functions it supports.

This could lead to immediate impacts, such as WAPA becoming unable to purchase sufficient energy or transmission to fulfill its contractual obligations. Such a reduction in the Basin Fund would also carry longer term impacts resulting from WAPA cancelling or deferring maintenance and replacement of critical electrical infrastructure due to insufficient funds to fulfill those project needs. This could ultimately compromise reliability of the CRSP system.

Scheduling

Power scheduling occurs by matching available power generation to seasonal, daily, and hourly system energy and capacity needs. At Glen Canyon Dam, power scheduling is affected by the temporal distribution of monthly water release volumes, restrictions in water release patterns, availability of generator units (due to maintenance), availability of other CRSP hydropower units, power allocations, and peak and off-peak power demand periods. Scheduling to meet power requirements typically results in higher water releases via the powerplant in the peak power demand months of December, January, July, and August.

Load-/ Generation-Following and Regulation

Hydropower generation can change instantaneously in response to changes in the load (demand) or unanticipated changes in the power generation resources within the operating region. This ability to respond to rapidly changing load conditions is called load- and/or generation-following (DOI 2016a, p. 3.203).

Typically, power demand, or power load, increases during daylight hours and decreases during nighttime hours. The load is similar from Monday through Saturday, but the load drops considerably on Sunday. This type of operation (load following) creates large fluctuations in water releases, which has negative impacts on environmental resources (DOI 2016a, p. 3.204). The 1996 ROD (Reclamation 1996) narrowed the range of operation for fish and wildlife and GCPA purposes, and thereby reduced the ability of power generation at Glen Canyon Dam to respond to customer load.

Changes in WAPA's scheduling guidelines typically occur slowly over a period of months, not only because of the operational constraints originally imposed by the 1996 ROD (Reclamation 1996) but also due to changing market conditions. The LTEMP FEIS also further reduced the load-following capability, despite increasing down-regulation rates, and it followed more natural flows (DOI 2016b), reducing operational flexibility. Operational flexibility has been affected by persistent drought and aridification, electricity market disruptions in 2000 and 2001, and extended experimental releases that have large daily flow-rate fluctuations (DOI 2016a, p. 3.204). Operational conditions are further affected by the frequency, season, and time-of-day limitations that may be in effect; physical and environmental operating restrictions at other CRSP generating facilities and within the interconnected electric system; and the availability and price of replacement power (DOI 2016a, p. 3.201).

Capacity Reserves/Emergencies and Outage Assistance

WAPA operates a balancing authority[10] for the region and is required to maintain sufficient generating capacity to continue serving its customer load. This is to ensure reliable power availability and uninterrupted service. Total available capacity, in turn, is determined by the minimum and maximum allowable releases from other unit powerplants and is particularly important for emergency situations (DOI 2016a).

In the event of a large loss of generation capacity, the North American Electric Reliability Corporation's reserve standards require that available generation capacity be used to return the electric generation to normal operating conditions within 10 minutes following the disturbance. Typically, these reserves are only needed for an hour or less. WAPA's ability to supply emergency assistance is limited by available transmission capacity and available generation capability. The ability to deliver emergency assistance varies on an hourly basis, depending on the firm[11] load obligations and available generation from project resources (DOI 2016a, p. 3.205). WAPA will continue to operate under the emergency exception criteria, as stipulated under the 1996 ROD, which allows

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[10] The control agency responsible for ensuring a balance between energy demand and supply

[11] Capacity and energy that is guaranteed to be available.

Glen Canyon Dam to be operated outside of minimum and maximum flow limits, daily change constraints, and both maximum hourly up-and-down ramp rates in the event of a power system emergency (Reclamation 1996).

Transmission System

Glen Canyon Dam is connected to a transmission system that allows for power to serve users such as municipal, residential, tribal, agricultural, and commercial consumers. Glen Canyon Dam's generation can affect transmission limitations when lines do not have enough capacity to transmit electricity from the point of generation to the point of demand. Actual transmission refers to the measured flow of power on the line. The North American Electric Reliability Corporation requires monitoring of the actual and scheduled power flow for system operation (DOI 2016a).

Power Marketing

WAPA markets wholesale CRSP Act power to preference entities (WAPA, n.d.), serving approximately 5.8 million retail customers in the operating region (DOI 2016a, p. 3.206). Sales of electric power in fiscal year 2021 were $195.9 million (WAPA 2021). Additional information about power marketing, including wholesale and retail rates, is included in the LTEMP FEIS. This information is incorporated by reference (DOI 2016a, pp. 3.206–3.209).

WAPA modified firm power rates for fiscal year 2022[12] in response to continued drought conditions and aridification, Lake Powell's reservoir level, associated reductions in power production caused by lower Glen Canyon Dam water releases, and increasing market prices for firming power. Under this new rate, WAPA delivers only power and energy produced from CRSP resources to a subset of customers, and deliveries are directly affected by Glen Canyon Dam operations and water releases.

3.3.2 Environmental Consequences

Methodology

GCMRC

The models for GCMRC are based on standard energy economic analysis methods (Harpman 1999). Modeling efforts included a constrained optimization model, which optimizes electricity production based on water availability and operating constraints. Modeling consists of 30 different traces to account for variability of future generation.

GTMax

The GTMax SL model simulates operation of the dams and powerplants. The GTMax SL model is well suited for this application because it uses a systemic modeling approach to represent all system components while recognizing interactions among supply, demand, and water resources over time. GTMax SL represents FG, BM, MP, and CY in the same manner they are operated and marketed by WAPA. It simulates the system on an hourly time step as a large set of mathematical equations that are solved using linear programming software. All operations are within component limitations and system dispatch goals that are formulated as a set of linear constraints and bounds.

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[12] Internet website: https://www.wapa.gov/regions/CRSP/rates/Pages/rate-order-199.aspx

In each study, the model formulation contains a single objective function that maximizes the value of the electricity generated by the powerplants over a 1-week time period (1 day for the factual case of the FG Study). All hours are solved simultaneously, allowing the model to recognize that the dispatch of supply resources in any one hour affects the dispatch during all other times in a simulated week.

Impact Analysis Area

Modeling from GCMRC was conducted for the planning horizon, October 2023 through November 2027. Model results produced the energy generation (MWh) and economic value of electrical energy from operational differences at Glen Canyon Dam for each flow option.

Modeling from GTMax was conducted for the planning horizon, October 2023 through September 2027. Model results produced the energy generation (MWh) and economic value of electrical energy from operational differences at Glen Canyon Dam for each flow option.

To match results with GCMRC and GTMax, only results from January 2024 to September 2027 are summarized below. Omitting t hese few months does not impact the overall results because no experiments took place in 2023.

Assumptions

For GCMRC, the estimated cost (impact to economic value of electrical energy) of changes in energy generation at Glen Canyon Dam were developed using a constrained optimization model. Historical load based on hourly releases at Glen Canyon Dam from September 2020 through August 2023 were used to optimize energy generation (HDP Online Data Query). Historical locational marginal price at the Palo Verde Hub from February 2020 to August 2023 was used to estimate the price vectors over the planning horizon (California ISO OASIS). Future monthly energy prices were estimated using Argus Forward Mid-Market Power Curves for October 2023 through November 2027 (Argus Media).

GTMax SL takes into account the topology of the electric power system analyzed. The model and topology can consider historical power plant and reservoir information, environmental constraints, electricity market prices, and scheduling objectives. GTMax SL topology nodes can represent hydropower plants and river flow gauges. Each node contains information about the specific attributes of the entity that it represents. For example, hydropower plants in the topology contain information about reservoir water releases, operating constraints, and the power plant specified at weekly, daily, and hourly time scales. The flow of energy between connected grid points and water channel flows are represented in the model by links that connect node objects. In the FG Study, water links along with gauge nodes are used to estimate flows at specific points on river channels for environmental monitoring and compliance. GTMax SL can also account for the spatial dependencies among power plants that are at cascaded reservoirs, as is the case for the three reservoirs that compose the Aspinall Unit.

For months with no experiments, the GTMax SL model is run for one typical week per month for all months during the study period. Weekly simulations are scaled up so that each run represents a 1-month time period. In months where there were experiments, every hour of that month was modeled. These results, along with actual operations that occurred during spring peak periods, are used to evaluate the economic impact of the operational constraints.

Impact Indicators

Model results produced the energy generation (MWh) and resulting projected economic value of electrical energy from operational differences at Glen Canyon Dam for each flow option.

Alternatives

No Action Alternative

Under the No Action Alternative, no changes would be made to Glen Canyon Dam operations. Therefore, water would continue to be released primarily through the penstocks, as described in the LTEMP FEIS. Power generation would continue, similar to historical levels, with slight variations, depending on water availability and constraints outlined in the LTEMP FEIS. Economic value of electrical energy from energy sales would also continue to be generated, similar to historical levels, with slight variations, depending on consumer demands, generation levels, and constraints outlined in the LTEMP FEIS.

Action Alternatives

Modeling from GCMRC was conducted for the planning horizon, October 2023 through November 2027. Model results produced the energy generation (MWh) and economic value of electrical energy from operational differences at Glen Canyon Dam for each flow option. Modeling from GTMax was conducted for the planning horizon, October 2023 through September 2027. Model results produced the energy generation (MWh) and economic value of electrical energy from operational differences at Glen Canyon Dam for each flow option.

In order to match results with GCMRC and GTMax, only results from January 2024 to September 2027 are summarized below. Omitting these few months does not impact the overall results because no experiments took place in 2023.

Impacts on Power Generation

Compared with current conditions, all four cold water flow options would include passing more water through the river outlet works where energy is not generated. Energy generation effects would vary, depending on the flow option implemented. Each flow scenario studied would reduce the energy generation and increase the amount of replacement energy required to meet demand in the interconnected transmission and distribution system.

Based on average energy generation estimates over the 30 modeled traces, the Cool Mix Alternative and the Cool Mix with Flow Spike Alternative would result in the most impacts on power generation, with a total loss of approximately 145 GWh and 140 GWh at river mile 15, respectively, and a loss of approximately 230 GWh and 205 GWh at river mile 61, respectively. These estimated losses are for the model period from January 2024 through September 2027. Cool Mix results in a higher loss because water would be consistently released through the river outlet works, with large amounts released during the flow spikes. The Cold Shock Alternative would have the third-fewest impacts on modeled power generation, with an average loss of approximately 70 GWh because water would be released periodically during weekends. The Cold Shock with Flow Spike Alternative would have the second-fewest impacts, with a river mile 15 loss of approximately 65 GWh and a river mile 61 loss of approximately 83 GWh. It would mirror the Cold Shock Alternative but would include flow spikes, which would result in large releases of water through the river outlet works during those events. The Non-Bypass Alternative would have the fewest impacts, with a river mile 61 gain of approximately 42 GWh because the bypass system would not be used; but instead, there would be changes in release volumes. **Table 3-13** outlines the total loss of generation from each flow alternative.

Table 3-13
Potential 45-Month Flow Impacts on Power Generation, as Estimated by USGS

Alternative	Total Lost Production - river mile 15		Total Lost Production - river mile 61	
-	(GWh)	% Loss from No Action	(GWh)	% Loss from No Action
Cool Mix Alternative	145.12	1.00%	229.82	1.58%
Cool Mix with Flow Spike Alternative	139.90	0.96%	205.01	1.41%
Cold Shock Alternative	70.05	0.48%	102.86	0.71%
Cold Shock with Flow Spike Alternative	65.05	0.45%	83.10	0.57%
No Bypass Alternative			(41.75)	0.29%

Source: GCMRC 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces.

As a percentage of total power generation under the No Action Alternative over the modeled period from January 2024 through September 2027, the percentage of power lost from the remaining alternatives ranges from 0.3 percent for the No Bypass Alternative at river mile 61 to 1.6 percent for the Cool Mix Alternative at river mile 61. The percentage lost for each alternative is provided in **Table 3-13** above. For comparison, the average annual change in generation for the No Action Alternative over the 3 modeled years from 2024 to 2027 is 9.1 percent. The percentage loss for each of the alternatives is roughly one order of magnitude lower than the year-over-year variation for the No Action Alternative.

Results from a similar analysis on generation conducted by WAPA are provided in **Table 3-14** below. The results are different, but have similarities to the GCMRC data, with the Cool Mix Alternatives having the most impacts, the Cold Shock Alternatives having the second-most impacts, and the No Bypass Alternative having the least.

Table 3-14
Potential 50-Month Flow Impacts on Power Generation, as Estimated by WAPA

Alternative	Total Lost Production - river mile 15		Total Lost Production - river mile 61	
-	(GWh)	% Loss from No Action	(GWh)	% Loss from No Action
Cool Mix Alternative	130.43	0.90%	214.73	1.47%
Cool Mix with Flow Spike Alternative	132.17	0.91%	200.58	1.38%
Cold Shock Alternative	65.84	0.45%	101.58	0.70%
Cold Shock with Flow Spike Alternative	66.09	0.45%	104.71	0.72%
No Bypass Alternative	(8.71)	0.06%	(20.36)	0.14%

Source: WAPA GTMax Model 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces.

In addition, the timing of these releases would impact the overall total energy generated during the modeled time period. For the Cool Mix Alternative and Cool Mix and Flow Spike Alternative, water would constantly be released through the river outlet works, regardless of demand. These options would result in less power generation, even during peak demand hours. Flow Options Cold Shock and Cold Shock with Flow Spike Alternative would mostly impact generation during weekends, when demand is lower. More detailed summary statistics for each option are provided in the following two tables.

Table 3-15
Potential 45-Month Flow Impacts on Power Generation, River Mile 15 (Loss in GWh), USGS

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	145.12	4.94	(46.22)	(39.31)	866.07	1,371.70
Cool Mix with Flow Spike Alternative	139.90	5.33	(26.68)	(17.38)	755.11	1,347.60
Cold Shock Alternative	70.05	4.94	(46.22)	(39.31)	388.04	612.12
Cold Shock with Flow Spike Alternative	65.05	5.33	(26.68)	(17.38)	327.91	532.67
No Bypass Alternative						

Source: USGS and Reclamation 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are power generation estimates out of 30 modeled traces.

Table 3-16
Potential 45-Month Flow Impacts on Power Generation, River Mile 61 (Loss in GWh), USGS

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	229.82	7.75	(46.22)	(39.31)	1,276.58	1,906.06
Cool Mix with Flow Spike Alternative	205.01	0.56	(28.79)	(20.53)	1,160.76	1,871.25
Cold Shock Alternative	102.86	7.75	(46.22)	(39.31)	462.01	648.57
Cold Shock with Flow Spike Alternative	83.10	0.56	(26.68)	(17.39)	382.91	564.60
No Bypass Alternative	(41.75)	(22.62)	(212.64)	(143.54)	7.03	24.56

Source: USGS and Reclamation 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the power generation estimates out of 30 modeled traces. Results from a similar analysis on generation conducted by WAPA are provided in **Table 3-17** and **Table 3-18** below.

Table 3-17
Potential 45-Month Flow Impacts on Power Generation, River Mile 15 (Loss in GWh), WAPA

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	130.43	0.00	(157.89)	(63.75)	868.12	1,281.08
Cool Mix with Flow Spike Alternative	132.17	0.00	(157.89)	(63.75)	831.35	1,242.89
Cold Shock Alternative	65.84	0.00	(157.89)	(63.75)	404.53	584.43
Cold Shock with Flow Spike Alternative	66.09	0.00	(157.89)	(63.75)	436.90	601.19
No Bypass Alternative	(8.71)	0.00	(157.89)	(63.75)	40.92	79.18

Source: WAPA GTMax Model 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the power generation estimates out of 30 modeled traces.

Table 3-18
Potential 45-Month Flow Impacts on Power Generation, River Mile 61 (Loss in GWh), WAPA

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	214.73	41.06	(157.89)	(63.75)	1,279.25	1,844.87
Cool Mix with Flow Spike Alternative	200.58	45.00	(271.11)	(75.11)	1,282.32	1,780.57
Cold Shock Alternative	101.58	36.18	(156.88)	(64.23)	538.62	733.33
Cold Shock with Flow Spike Alternative	104.71	44.80	(271.11)	(75.11)	572.36	783.85
No Bypass Alternative	(20.36)	(2.54)	(331.86)	(75.11)	41.15	79.18

Source: WAPA GTMax Model 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the power generation estimates out of 30 modeled traces.

Impacts on Economic Value of Electrical Energy

The action alternatives would have financial impacts that would vary to a large extent based on reservoir elevation and temperature conditions, as well as which river mile is targeted for cooling, based on the distribution of smallmouth bass. Less power generated would mean a reduction in the economic value of electrical energy generated from power proceeds that would be transferred into the Basin Fund. Replacement energy sources would need to cover the decrease in power generation. WAPA would purchase replacement power using funds from the Basin Fund. All of this replacement power would be generated from other sources. Replacement power would most likely be provided from natural gas powerplants, with a smaller portion supplied by coal-fired powerplants. Renewable generation such as wind, solar, or other environmentally friendly sources may also be used for replacement power. The decrease in funds available in the Basin Fund could result in increased costs to customers, and in some cases, may trigger a cost-recovery charge.

Financial impacts are directly correlated to impacts from reduced power generation. Therefore, the Cool Mix Alternative would have the most financial impacts, with an average estimated economic value of electrical energy loss of around $12.8 million for river mile 15 and $19.4 million for river mile 61 over the period from January 2024 to September 2027. The Cool Mix with Flow Spike Alternative would have the second-most financial impacts, with an estimated economic value loss of $12.5 million for river mile 15 and $17.8 million for river mile 61. The Cold Shock Alternative would have the third-most financial impacts, with an estimated economic value loss of $6.5 million for river mile 15 and $8.4 million for river mile 61. The Cold Shock with Flow Spike Alternative would have the least financial loss, with an estimated economic value loss of $6.1 million for river mile 15 and $7.3 for river mile 61. The river mile 61 No-Bypass Alternative has almost the same results as the No Action Alternative, with a slight gain of $0.15 million over the entire period from January 2024 to September 2027. The following table outlines the total loss of economic value due to electrical energy from each flow alternative.

Table 3-19
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, as Estimated by USGS

Alternative	Total Lost Economic Value - river mile 15		Total Lost Economic Value - river mile 61	
-	($ million)	% Loss from No Action	($ million)	% Loss from No Action
Cool Mix Alternative	$12.82	1.16%	$19.38	1.76%
Cool Mix with Flow Spike Alternative	$12.52	1.14%	$17.78	1.61%
Cold Shock Alternative	$6.48	0.59%	$8.38	0.76%
Cold Shock with Flow Spike Alternative	$6.08	0.55%	$7.25	0.66%
No Bypass Alternative			($0.15)	(0.01%)

Source: USGS and Reclamation 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the average Economic Value of Electrical Energy estimates out of 30 modeled traces.

As a percentage of total economic value under the No Action Alternative over the modeled period from January 2024 through September 2027, the percentage of economic value due to electrical energy lost from the remaining alternatives ranges from 0.55 percent for the Cold Shock with Flow Spike Alternative at river mile 15, to 1.8 percent for the Cool Mix Alternative at river mile 61. The percentage lost for each alternative is provided in **Table 3-19**. For comparison, the average annual change in economic value for the No Action Alternative over the 3 modeled years from 2024 to 2027 is 13.3 percent. The economic value percentage loss for each of the alternatives is roughly one order of magnitude lower than the year-over-year variation for the No Action Alternative.

Results from a similar analysis on economic value due to electrical energy conducted by WAPA are provided in **Table 3-20**. The results were similar to the USGS GCMRC data, with the Cool Mix Alternatives having the highest impacts, the Cold Shock Alternatives having the next-highest impacts, and the No Bypass Alternative having the least impact.

Table 3-20
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, as Estimated by WAPA

Alternative	Total Lost Economic Value - river mile 15		Total Lost Economic Value - river mile 61	
-	($ million)	% Loss from No Action	($ million)	% Loss from No Action
Cool Mix Alternative	$15.26	1.27%	$26.20	2.18%
Cool Mix with Flow Spike Alternative	$15.48	1.29%	$25.75	2.14%
Cold Shock Alternative	$8.76	0.73%	$13.05	1.08%
Cold Shock with Flow Spike Alternative	$9.21	0.77%	$15.04	1.25%
No Bypass Alternative	$0.97	0.08%	$0.67	0.06%

Source: WAPA GTMax Model 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the average Economic Value of Electrical Energy estimates out of 30 modeled traces.

The amount of bypass needed will vary based on the elevation of Lake Powell, the inflows that can affect release temperature and the monthly outflow volumes, and whether the flows are conducted during months when alternate/ replacement power is more expensive. The costs in **Table 3-21** were calculated based on the average of 30 traces. More detailed summary statistics over the 30 traces are given in the two tables below.

Table 3-21
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, River Mile 15 ($ million), USGS

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	$12.82	$1.45	($0.45)	$0.08	$67.59	$105.12
Cool Mix with Flow Spike Alternative	$12.52	$2.69	($0.38)	$0.12	$59.06	$103.17
Cold Shock Alternative	$6.48	$1.45	($0.45)	$0.08	$27.29	$44.55
Cold Shock with Flow Spike Alternative	$6.08	$2.58	($0.45)	$0.05	$22.20	$37.94
No Bypass Alternative						

Source: USGS and Reclamation 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the Economic Value of Electrical Energy estimates out of 30 modeled traces.

Table 3-22
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, River Mile 61 ($ million), USGS

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	$19.38	$2.61	($0.45)	$0.08	$99.82	$145.96
Cool Mix with Flow Spike Alternative	$17.78	$3.30	($1.86)	($0.40)	$92.85	$144.25
Cold Shock Alternative	$8.38	$2.61	($0.45)	$0.08	$30.70	$47.06
Cold Shock with Flow Spike Alternative	$7.25	$3.39	($1.00)	($0.05)	$26.49	$41.88
No Bypass Alternative	($0.15)	$0.67	($7.41)	($4.93)	$2.95	$3.49

Source: USGS and Reclamation 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the Economic Value of Electrical Energy estimates out of 30 modeled traces.

Results from a similar analysis on economic value due to electrical energy conducted by WAPA are provided in **Table 3-23** and **Table 3-24** below.

If replacement power is required, it could put pressure on parts of the transmission system. Replacement power is likely to travel along the transmission system in the reverse direction of historical operations. This reversal of power along the transmission system could result in congestion not previously experienced and potential additional maintenance costs on the transmission system. The extent of impacts would correlate with the amount of replacement power purchased.

Table 3-23
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, River Mile 15 ($ million), WAPA

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	$15.26	$0.64	($5.34)	($1.48)	$94.00	$137.73
Cool Mix with Flow Spike Alternative	$15.48	$0.64	($5.34)	($1.48)	$92.39	$137.69
Cold Shock Alternative	$8.76	$0.64	($5.34)	($1.48)	$50.27	$76.20
Cold Shock with Flow Spike Alternative	$9.21	$0.64	($5.34)	($1.48)	$55.69	$82.30
No Bypass Alternative	$0.97	$0.16	($5.34)	($1.48)	$5.24	$8.77

Source: WAPA GTMax Model 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the Economic Value of Electrical Energy estimates out of 30 modeled traces.

Table 3-24
Potential 45-Month Flow Impacts on Economic Value of Electrical Energy, River Mile 61($ million), WAPA

Alternative	Average	Median	Min	10th %	90th %	Max
Cool Mix Alternative	$26.20	$2.60	($5.34)	($1.48)	$147.58	$216.24
Cool Mix with Flow Spike Alternative	$25.75	$3.42	($11.61)	($1.48)	$147.63	$210.14
Cold Shock Alternative	$13.05	$2.63	($5.27)	($1.40)	$61.86	$97.04
Cold Shock with Flow Spike Alternative	$15.04	$3.11	($11.61)	($1.48)	$67.48	$108.19
No Bypass Alternative	$0.67	$0.16	($10.33)	($2.47)	$5.45	$8.75

Source: WAPA GTMax Model 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the Economic Value of Electrical Energy estimates out of 30 modeled traces.

None of the four cold water alternatives, nor the No Bypass Alternative would result in a decrease of reserve and emergency power available. Operations would follow LTEMP requirements for emergency situations. As outlined in the LTEMP FEIS, emergency reserves are typically only needed for a brief period of time, and any operational changes included in the action alternatives would be adjusted to meet the emergency exception criteria.

To summarize, based on the modeled generation and economic value due to electrical energy loss for each of the cool water alternatives, the cold water alternatives and the No Bypass Alternative, the Cool Mix Alternative and the Cool Mix with Flow Spike Alternative are likely to result in the most significant loss. Relative to the No Action Alternative, these two alternatives are modeled to have an average decrease of power generation over the four year period by up to 1.5 percent and an average decrease of economic value by up to 2.2 percent. The Cold Shock Alternatives result in the second-most modeled loss of roughly up to 0.7 percent for generation and 1.3 percent for economic value relative to the No Action Alternative. The No Bypass Alternative results in the least modeled loss with gains of up to 0.3 percent for generation and 0.08 percent for economic value relative to the

No Action Alternative. Overall, the effects described above may be most likely for power consumers in the surrounding counties and states. However, effects could be felt across the Western Power Grid because Glen Canyon Dam can supply power to this area. The effect's intensity would diminish farther from the generation source at the dam. This is because while Glen Canyon Dam is a major power supplier for the immediate surrounding counties and states, other power suppliers currently have and would continue to have increased influence in more distant portions of the Western Power Grid.

Cumulative Effects

Cumulative impacts on hydropower from the action alternatives would only occur during months when the flow options were implemented. All proposed cold water flow options would operate within the range of operations, as described in the LTEMP FEIS and under the assumptions of the existing cumulative effects analysis for hydropower conducted in the LTEMP FEIS, described in Section 4.17.3.12 of that document (DOI 2016a, p. 4.471).

The action alternatives would result in impacts on power generation at Glen Canyon Dam during the peak summer power months. Changes in operations at Glen Canyon Dam would reduce available generating capacity at Glen Canyon Dam under all four cold water flow options. This reduction in capacity would need to be replaced by purchases and generation from other sources. The financial impacts from the flow options would vary, depending on the reduction in the amount of power generated and the cost to purchase power from replacement sources. Power consumers would experience these impacts to varying degrees, depending on the location, with more severe impacts in the immediate areas around Glen Canyon Dam and less severe impacts farther away from the dam. Impacts on power generation and the need to purchase replacement power, the potential impacts on the Basin Fund and consumers, and the potential impacts on the transmission system would be greatest under the Cool Mix Alternative and the Cool Mix with Flow Spike Alternative. The Cold Shock with Flow Spike Alternative would have the third-most impacts. The Cold Shock alternatives would have the second-least impacts, and the No Bypass Alternative would have the least impacts.

If less hydropower generation occurs at Glen Canyon Dam, replacement power may be provided from natural gas powerplants, with a smaller portion supplied by coal-fired powerplants. Renewable generation such as wind, solar, or other environmentally friendly sources may also be used for replacement power. Nonrenewable replacement power sources would be associated with increased GHG emissions compared with hydropower generation. Actual replacement power sources may be included in future modeling by WAPA, and may be available for the final draft.

Results When Experiments are Running

Table 3-25 and **Table 3-26** summarize results only for the months when experiments are occurring. The ordering from these results mirrors the previous sections, but the average differences here show a greater magnitude because these effects are only for the particular months when experiments are occurring. The Cool Mix Alternative and the Cool Mix with Flow Spike Alternative would result in the most impacts on power generation, with an average monthly river mile 15 loss of approximately 22 GWh for months when experiments are occurring, and a river mile 61 loss of approximately 36 GWh. Cool Mix results in a higher loss because water would be consistently released through the river outlet works, with large amounts released during the flow spikes. The Cold Shock Alternative would have the third-most impact on modeled power generation, with an average monthly river mile 15 loss of approximately 1 GWh, because water would be released periodically during weekends. The Cold Shock with Flow Spike Alternative would have the second-least impact, with a river mile 15 gain of approximately 2 GWh and a river mile 61 loss of approximately 4 GWh. It would mirror the Cold Shock Alternative, but would include flow spikes, which would result in large releases of water through the river outlet works during those events. The No Bypass Alternative would have the least impact, with a river mile 15 gain of 25 GWh and a river mile 61 gain of 25 GWh.

Table 3-25
Potential Impacts to Generation during Months with Experiments, USGS

Alternative	Total Lost Production - river mile 15		Total Lost Production - river mile 61	
-	(GWh)	% Loss from No Action	(GWh)	% Loss from No Action
Cool Mix Alternative	21.98	8.80%	35.93	14.17%
Cool Mix with Flow Spike Alternative	19.26	7.70%	31.34	12.31%
Cold Shock Alternative	1.30	0.51%	9.18	3.57%
Cold Shock with Flow Spike Alternative	(1.73)	(0.68%)	3.76	1.45%
No By-Pass			(25.39)	(10.03%)

Source: USGS and Reclamation 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces for only the months when experiments are running.

Table 3-26
Potential Impacts to Generation during Months with Experiments, WAPA

Alternative	Total Lost Production - river mile 15		Total Lost Production - river mile 61	
-	(GWh)	% Loss from No Action	(GWh)	% Loss from No Action
Cool Mix Alternative	20.04	8.01%	34.27	13.49%
Cool Mix with Flow Spike Alternative	20.58	8.21%	34.53	13.54%
Cold Shock Alternative	2.28	0.90%	10.74	4.17%
Cold Shock with Flow Spike Alternative	2.43	0.96%	15.22	5.88%
No By-Pass	(18.99)	(7.49%)	(19.56)	(7.59%)

Source: WAPA GTMax Model 2024

Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces only for the months when experiments are running.

Results from WAPA's GTMax model show similar results from GCMRC, where the Cool Mix and Cool Mix with Flow Spike Alternatives result in the greatest loss, and the Cold Shock and the Cold Shock with Flow Spike Alternatives result in the second-greatest loss, and the No Bypass Alternative would result in the least loss.

Economic value due to electrical energy results only for the months when experiments are occurring mirrors the generation results above. The Cool Mix Alternative and the Cool Mix with Flow Spike Alternative would result in the most impacts on economic value of electrical energy, with an average monthly river mile 15 loss of approximately \$2–\$3.5 million for months when experiments are occurring, and an experiment month river mile 61 loss of approximately \$3.3–\$5 million. Cool Mix results in a higher loss because water would be consistently released through the river outlet works, with large amounts released during the flow spikes. The Cold Shock Alternative would have an average monthly river mile 15 loss of approximately \$0.6–\$1.9 million, and a river mile 61 loss of approximately \$1–\$2.7. The Cold Shock with Flow Spike Alternatives would have an average monthly river mile 15 loss of approximately \$0.4–\$2 million, and a river mile 61 loss of approximately \$0.6–\$3.2. The No Bypass Alternative would have the least impact with a river mile 15 gain of \$0.4 million, and a river mile 61 gain of \$0.5–\$1 million.

Table 3-27
Potential Impacts to Economic Value of Electrical Energy during Months with Experiments, USGS

Alternative	Total Lost Economic Value - river mile 15		Total Lost Economic Value - river mile 61	
-	($ million)	% Loss from No Action	($ million)	% Loss from No Action
Cool Mix Alternative	$2.32	14.09%	$3.29	19.31%
Cool Mix with Flow Spike Alternative	$2.08	12.63%	$2.94	17.15%
Cold Shock Alternative	$0.64	3.86%	$1.02	5.95%
Cold Shock with Flow Spike Alternative	$0.38	2.26%	$0.62	3.62%
No Bypass			($1.03)	(6.17%)

Source: USGS and Reclamation 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces only for the months when experiments are running.

Table 3-28
Potential Impacts to Economic Value of Electrical Energy during Months with Experiments, WAPA

Alternative	Total Lost Economic Value - river mile 15		Total Lost Economic Value - river mile 61	
-	($ million)	% Loss from No Action	($ million)	% Loss from No Action
Cool Mix Alternative	3.43	17.38%	5.13	23.58%
Cool Mix with Flow Spike Alternative	3.49	17.66%	5.06	23.12%
Cold Shock Alternative	1.85	9.08%	2.65	11.99%
Cold Shock with Flow Spike Alternative	1.98	9.72%	3.16	14.22%
No Bypass	(0.41)	(2.03%)	(0.49)	(2.21%)

Source: WAPA GTMax Model 2024
Model results for the operating period from January 2024 to September 2027. The figures presented are the average power generation estimates out of 30 modeled traces only for the months when experiments are running.

Rate Impacts

Rate impacts may be modeled by WAPA and may be available for the final draft.

Summary

Model results by USGS and WAPA produced the generation (MWh) and economic value due to electrical energy from energy generation at Glen Canyon Dam for each flow option. Based on average generation estimates over the 30 modeled traces, the Cool Mix Alternative and the Cool Mix with Flow Spike Alternative would result in the most impacts on power generation, with a total river mile 15 loss of approximately 130–145 GWh from 2024 to 2027. This loss is because water would be consistently released through the river outlet works, with large amounts released during the flow spikes. The Cold Shock Alternative and the Cold Shock with Flow Spike Alternative have the next highest amount of impact on power generation, with an average river mile 15 loss of approximately 65–70 GWh, because water would be released periodically during weekends. The No Bypass Alternative has the least impact on power generation, with an average river mile 15 gain of approximately 8.7 GWh because the bypass system would not be used, and instead, there would be changes in release volumes.

Economic value of electrical energy impacts would be directly correlated to impacts from power generation. Therefore, the Cool Mix Alternative and the Cool Mix with Flow Spike Alternative would have the most financial impacts, with an average river mile 15 estimated loss for economic value of electrical energy of around $12.5–$15.5 million. The Cold Shock and the Cold Shock with Flow Spike Alternative would have the next highest amount of economic value impacts, with an estimated river mile 15 loss for economic value of electrical energy of around $6–$9.2 million. The No Bypass Alternative would have the least amount of financial impact, with an estimated gain for economic value of electrical energy of around $0.97 million at river mile 15.

3.4 Geomorphology/Sediment

3.4.1 Affected Environment

Historically, the Colorado River conveyed high suspended sediment concentrations throughout most seasons with larger flood flows and lower base flows (USGS 2011). The placement of Glen Canyon Dam effectively cut off approximately 95 percent of the historical sediment supply from the upper watershed (Topping et al. 2000). Post-dam water releases have resulted in net erosion of sand from Marble and Grand Canyons. From 1964 to 2017, net erosion occurred for approximately 69 percent of all years in Marble Canyon and for approximately 52 percent of all years in Grand Canyon (Topping et al. 2021).

Maximum releases from the dam are substantially less than the historical annual peak flows, and the high-water zone has been lowered compared with the historical level. Pre-dam discharges below 9,000 cfs occurred frequently enough to allow for seasonal sand accumulation and storage downstream of river mile 16. Current dam operations do not allow for sustained discharges lower than 5,000 cfs at night and 8,000 cfs during the day (Topping et al. 2003). In conjunction with reduced sand supply compared with historical conditions, post-dam discharges have reduced the height of annual deposition, reduced the period of sand accumulation, increased the rate of sediment erosion, and contributed to the loss of beaches and sandbars (USGS 2011).

The Paria and Little Colorado Rivers, tributaries to the Colorado River, are the major sources of sediment replenishment downstream of the dam. These tributaries affect the mechanisms that control sandbars in Glen, Marble, and Grand Canyons. No major sediment source exists upstream of the Paria River, making sediment a nonrenewable resource in modern-day Glen Canyon (Grams et al. 2007).

Sediment

Sediment mass balance regulates the erosional and depositional processes in the Colorado River. The influx and efflux of sediment results in spatial and temporal variations in sandbars and channel-margin deposits throughout the Colorado River (Grams et al. 2013). Sediments are typically classified by particle size and include the following classes:

- Silt and clay (less than 0.06 millimeters)
- Sand (0.06 to 2.0 millimeters)
- Gravel and cobbles (2.0 to 200 millimeters)
- Boulders (greater than 200 millimeters)

In general, the term "fine sediment" refers to sediments that are sand-sized or smaller. This group makes up most of the transported sediment in the river and is carried in suspension by most dam releases. Finer sand contributes the most to sediment storage, deposition rates, and downstream sand export (Topping et al. 2021). The quantity of silt and clay transported depends mainly on the tributary supply. Sandbars contain some silt and clay, but their existence primarily depends on the transport of sand. Sand sediments in the Colorado River are delivered by tributary streams and ephemeral washes.[13] As described above, the Paria and Little Colorado Rivers are the dominant sources. In general, the lesser tributaries in the upper Marble Canyon upstream of river mile 30 together contribute roughly 10 percent of the sand annually supplied by the Paria River. Downstream from river mile 30, the lesser tributaries supply negligible amounts of sand (Griffiths and Topping 2017; Topping et al. 2021). The amount of sand stored within the riverbed each year depends on the tributary sand supply (which is highly variable), the frequency and duration of water released from the dam, and the amount of sand already deposited on the riverbed at the beginning of the year. Sand stored on the riverbed is the principal source for building sandbars during periods of high flow releases. Sediment transport is a function of, and increases with, the volume of water flowing in the river. It also depends on changes in the sediment size associated with tributary floods and dam operations.

The turbulence of flowing water can increase the amount of sediment in suspension and the amount that is available for transport. Sediment deposition occurs wherever there is more sediment influx than efflux (Grams et al. 2013). The greater the river's flow, the greater its velocity, turbulence, and sediment load. Finer sediment is carried in suspension by nearly all dam releases. Flows in the river are often large enough to carry sand grains in suspension or roll them along the riverbed. Higher flows and velocities are needed to move gravel and cobbles. The largest boulders remain in place for decades or more, awaiting a flood large enough to move them even short distances along the riverbed (DOI 2016a). The river stage defines the water level associated with a given discharge, which may be a result of both dam release and tributary inflow. Fluctuations in river stage are particularly important to cycles of deposition and erosion within sandbars. While fine sediments are readily transported by the Colorado River, the height of their deposition depends on river stage.

Seepage-induced erosion is also affected by fluctuations in river stage because groundwater levels within exposed sandbars rise and fall with increases and decreases in river stage. When the river

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[13] A wash that flows part of the time, usually after a rainstorm, during wet weather, or for only part of the year.

stage declines faster than groundwater can drain from the sandbar, the exposed bar face becomes saturated, forming rills[14] that move sand particles toward the river (Alvarez and Schmeeckle 2012).Sediment storage on the riverbed depends on the spatial variability of the riverbed (such as variations of boulders, cobbles, and bedrock), the depth to the riverbed, and the tributary sediment supply (Rubin et al. 2020). This sediment storage, in addition to storage within sandbars and along channel margins on the Colorado River, is the result of coupled flow, sediment transport, and storage within fan-eddy complexes[15] that result in deposition of sediments. Fan-eddy complexes are areas along the river where a tributary debris fan partially blocks the river flow (Schmidt and Rubin 1995).

Sediment storage does not mean there is no water or sediment movement. There is a mass balance between sediment deposition, erosion, and storage at a point of interest over a specified period. Thus, sediment storage is a dynamic condition that varies based on the specific spatial and temporal scales considered; it can be increasing (net deposition), decreasing (net erosion), or at equilibrium. Sand supplied by tributaries remains in storage for only a few months before most of it is transported downstream unless flows are below approximately 9,000 cfs (Topping et al. 2000; Rubin et al. 2002; USGS 2011b).

Since 1996, Reclamation has conducted HFE releases to manage limited sediment resources to maintain or increase sandbar size. HFEs are releases designed to improve sediment deposition, and these water releases from Glen Canyon Dam are much larger than the base flow that is typically released. HFE releases are the only existing mechanism for producing river stages high enough to contribute to significant sandbar building. Under LTEMP, Reclamation uses two 6-month sediment accounting periods (one during the fall and one during the spring). These are used to evaluate whether the sediment mass balance is optimal for sandbar building prior to HFE release implementation.[16] Sediment accounting periods are independent, meaning that accumulated sand from the prior accounting period is not used to trigger a potential HFE release during the following implementation window. HFE releases 34,000 cfs or greater are necessary for sandbar deposition (increased sandbar size); generally, sandbars erode between HFE releases (Hazel et al. 2022). After the most recent HFE release was completed in April 2023, reservoir balancing during July and August 2023 resulted in sustained high releases and net sediment export. This has effectively reduced the probability of triggering another HFE release between November 2023 and April 2024.

Geomorphic Features

The longitudinal profile of the Colorado River consists of long, flat pool reaches with intermixed short, steep rapids. The rapids are typically associated with debris-fan deposits formed by tributary debris flows,[17] such as fan-eddy complexes. Debris fans are sloping deposits of poorly sorted sediment ranging in size from clays and silts to larger boulders. Debris fans continue to be

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[14] Small grooves, furrows, or channels in soil made by water flowing down over its surface. A small stream.

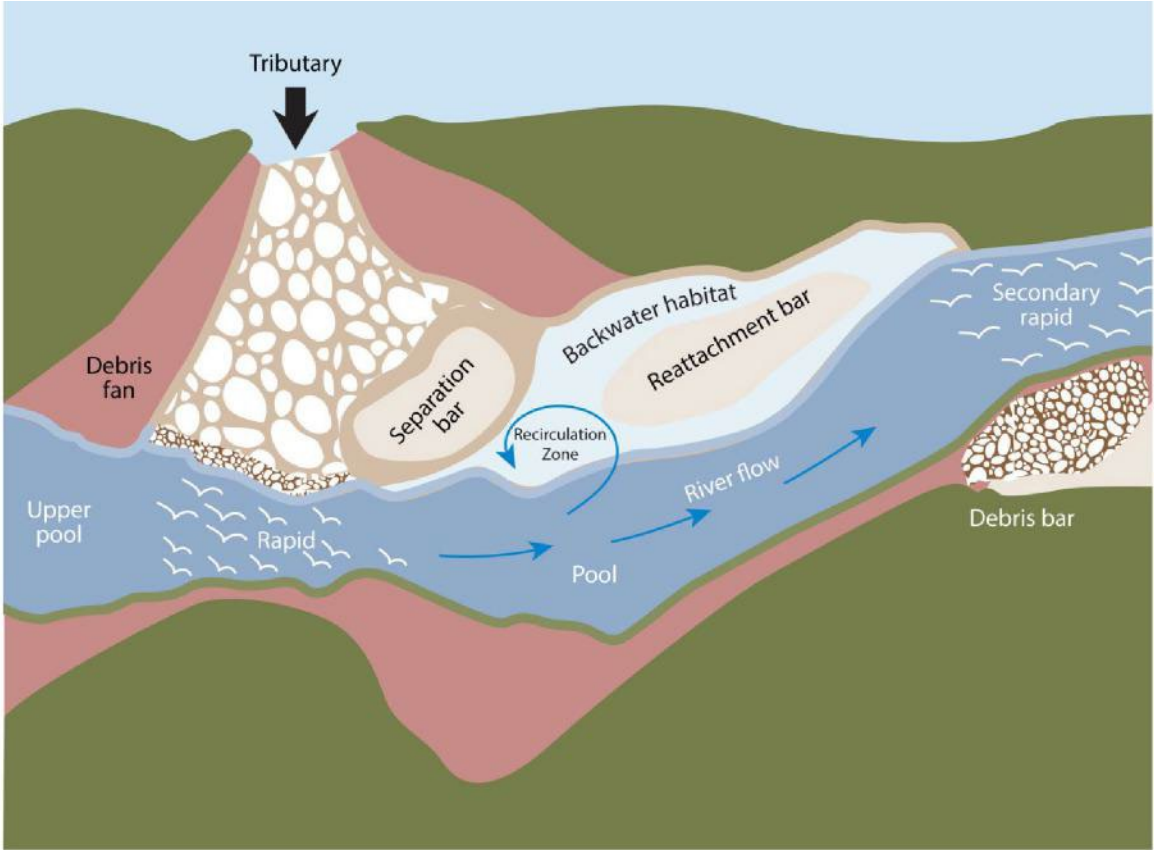
[15] The controlling geomorphic feature in the Colorado River for sediment deposition; debris fans partially block tributaries that cause the formation of rapids and eddies.

[16] Sediment accounting periods are periods over which sand inputs and exports are measured to evaluate whether conditions have been met to trigger an HFE release, which occurs during an HFE implementation window. Two HFE implementation windows occur (1) from October 1 to November 30, during the fall sediment accounting period; and (2) from March 2 to April 30 during the spring sediment accounting period.

[17] A large deposit of sediment into a tributary caused by slope failures on tributary canyons.

replenished and enlarged by debris flows triggered by slope failures into tributaries. The geologic conditions favorable for debris flows from side canyons vary greatly. Debris flows tend to be high-magnitude, short-duration events. Debris flows create and maintain the rapids, control the size and location of eddies, and serve as potential sources of sand to replenish Colorado River sandbars in Marble and Grand Canyons. The coarse sediments associated with debris-fan deposits can only be mobilized during elevated flows and do not constitute a significant contribution to sediment loads transported by the river. However, their dynamics are important with respect to their retention of fine sediments and the development of fan-eddy complexes (DOI 2016a). Debris fans extending into the Colorado River obstruct the channel, making it narrower and raising the bed elevation, which forms rapids through the point of constriction, and the downstream-directed current becomes separated from the riverbank (Webb and Griffiths 2001; see **Figure 3-16**). Downstream of the constriction, the channel is typically wider, the main current reattaches to the riverbank, and some of the water is redirected upstream. This change in flow direction forms a zone of low-velocity recirculating water (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 lower-velocity flows enhance the potential for sediment deposition (Schmidt and Rubin 1995).

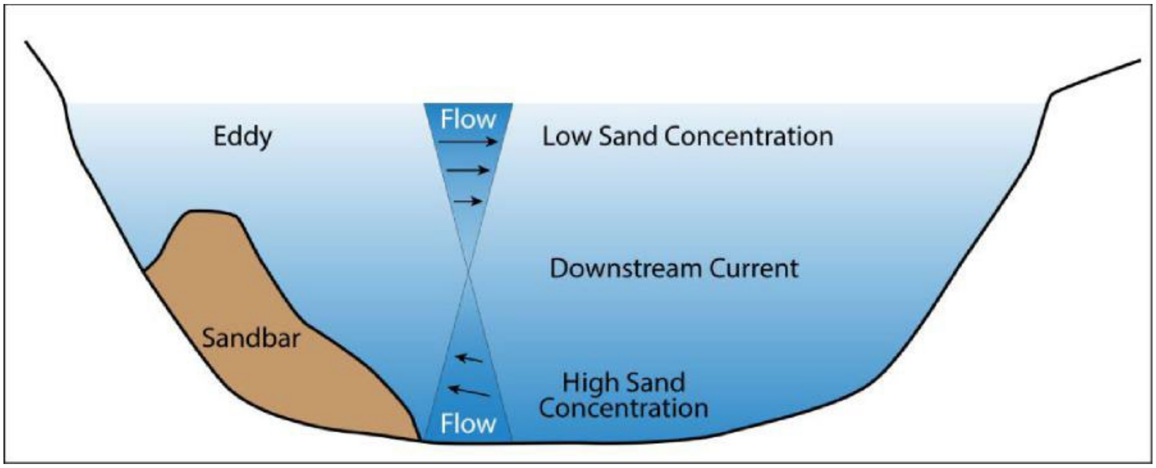
Figure 3-16
Diagram of the Fan-Eddy Complex on the Colorado River



Source: Webb and Griffiths 2001

The deep pools that form upstream of rapids (**Figure 3-16**) provide space for the temporary storage of substantial amounts of riverbed sediment (such as 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 controls the amount of sand and gravel that can be deposited in the pool. Aggraded debris fans allow the channel to store more sand in the associated pools and eddies. Separation bars form along the downstream face of a debris fan, and reattachment bars form outward from the downstream point where the recirculation zone meets the channel bank (Webb and Griffiths 2001). **Figure 3-17** presents a cross-sectional diagram demonstrating how these complexes can trap sediment and work to build sandbars. In this instance, water with a relatively high sand concentration (near the streambed) moves toward the eddy and builds a sandbar; water with a relatively low sand concentration (near the surface) moves from the eddy back to the main channel (Reclamation 1995).

Figure 3-17
Sediment Entrapment and Sandbar Building at a River Cross Section



Source: Reclamation 1995

Sand is deposited throughout Glen, Marble, and Grand Canyons in bars (or patches) on the riverbed, in eddies, and on terrace sandbars. Nearly all sandbars in the Grand Canyon are associated with fan-eddy complexes. In general, these complexes generate consistent sandbar features, which include separation bars and reattachment bars, based on their specific locations within the recirculation zone (USGS 2011). They continuously exchange sand with the river. Thus, the sandbars commonly found along the banks of the Colorado River are generally dynamic and unstable. HFE releases have been shown to increase the sandbar size, and sandbars erode between these events (Hazel et al. 2022). The magnitude of deposition varies by site, depending on geomorphic conditions and vegetative cover; some sandbars are stabilized by vegetation (Mueller et al. 2018; Hazel et al. 2022). Sandbars form a fundamental element of the river landscape and are important for vegetation, riparian habitat for fish and wildlife, cultural resources, and recreation (Reclamation 1995). For example, they form the substrate for limited riparian vegetation in this arid environment. Low-elevation sandbars create zones of low-velocity aquatic habitat (that is, backwaters) that may be utilized by juvenile native fishes. These low-elevation sandbars are also a source of sand for wind transport that may help protect archaeological resources. In addition, beaches provide camping areas for river and backcountry users.

3.4.2 Environmental Consequences

Methodology

Predictions for sand mass balance were generated using the Wright et al. (2010) sand routing model. Sandbar volume predictions were generated using the Mueller et al. (2018) sandbar model. Hourly dam release patterns were provided by WAPA. Monthly flow volumes and end-of-month Lake Powell elevations were provided by Reclamation (Reclamation 2022). Action alternatives were modeled based on the change to the sediment accounting period that is common to all action alternatives.

As described in the SMB EA (Reclamation 2023a), impacts on sediment transport are determined primarily by the rate at which water is released from the dam, as opposed to the location from where it is released. Therefore, the action alternatives analysis was split between those alternatives that incorporate flow spikes and those alternatives that do not, in addition to the Non-Bypass Alternative.

To model HFE regimes, sediment mass balance, and sandbar building patterns under the action alternatives, a set of 30 ensemble streamflow predictions, with monthly 4-year traces, was used to characterize the range of potential hydrologic conditions. These 30 traces are a subset of the 90 traces analyzed in the IG SEIS (Reclamation 2023c).

The smallmouth bass model was initially run to determine the months in which flow spikes would be expected to be triggered under the alternatives that include flow spikes. Two scenarios were considered in which different river miles, river mile 15 and river mile 61 (confluence with the Little Colorado River), were targeted.

The sediment model was initially run to determine when high flows would be triggered under different alternatives, what the magnitude and duration of a high flow would be, and what the magnitude of a flow spike could be (under alternatives that include flow spikes). The initial condition (bed thicknesses and bed grain-size distribution) for the sand routing model is based on a sand routing model run from September 1, 2002, to October 1, 2023, using sediment inputs and gage discharges downloaded from the Grand Canyon Monitoring and Research Center website in November (GCMRC 2023a). Each of the 30 hydrology traces were randomly assigned a trace of Paria River sediment inputs derived from the October 1996 to September 2023 record.

To generate final sediment modeling simulations, the sand routing model was run again with new hourly hydrographs generated by a hydropower optimization model and the same Paria River traces as in the previous round of modeling. Changes to the sediment mass balance were minimal, and HFE durations were not modified. In addition to discharge inputs, the output from this run of the sand routing model provided the concentration and suspended sand median grain-size inputs for the Mueller et al. 2018 sandbar model. The sandbar model was recalibrated to the 2015–2023 period, including data from October 2023. The model was initialized using the resulting October 1, 2023, volume and was run for each of the 30 traces.

Impact Analysis Area

The impact analysis area is the Colorado River at Glen Canyon Dam to Lake Mead, including sediment inputs from the Paria River and Little Colorado River tributaries. This analysis included targets of river mile 15 and river mile 61 (confluence with the Little Colorado River)

Assumptions and Regulatory Constraints

This analysis was performed under the following assumptions for all alternatives:

- Sand supplied from tributaries remains in storage for only a few months before most of it is transported downstream unless flows are below approximately 9,000 cfs (Topping et al. 2000, Rubin et al. 2002, Schmidt and Grams 2011a).
- Deposited sediment on the riverbed is dependent on spatial variability of the riverbed (such as variations of boulders, cobbles, and bedrock), the depth to the riverbed, and tributary sediment supply (Rubin et al. 2020).
- Erosion rates tend to be highest immediately after a flood (when bars have the most sediment available for erosion), then decrease with time (Grams et al. 2010). Steadier flows erode bars at a lower rate than fluctuating flows (Wright, Schmidt et al. 2008).
- High flows mobilize fine sand deposited by tributaries downstream of Glen Canyon Dam and rebuild sandbars in Marble and Grand Canyons (Schmidt and Grams 2011b.
- Total discharge maximum ramp rates of 4,000 cfs per hour up and 2,500 cfs per hour down are consistent with LTEMP.
- For analysis of impacts under the cold water alternatives, modeling assumed a minimum total discharge of 8,000 cfs during the day (7:00 a.m. to 7:00 p.m.), and a minimum total discharge of 5,000 cfs at night, consistent with LTEMP. Modeling under the Non-Bypass Alternative assumed a flow pattern consisting of a 4-hour flow with a discharge rate of 2,000 cfs (minimum powerplant capacity), followed by a 4-hour flow at a discharge rate of ~27,300 cfs (full powerplant capacity). This flow pattern was assumed to repeat weekly beginning on Sunday evenings. Triggered flows under the Non-Bypass Alternative targeted only river mile 61 (confluence with the Little Colorado River).
- No HFEs would be implemented below a Lake Powell elevation of 3,500 feet, as HFE magnitude would be below 37,000 cfs. Implementing an HFE below 3,500 feet could increase the risk of going below the power pool elevation of 3,490 feet, the depth below which the dam can no longer produce power. Hazel et al. (2022) concluded that discharges of 37,000 cfs or greater were required to result in significant deposition at separation and undifferentiated sandbar types (with a 34,000-cfs threshold for reattachment and upper-pool bar types). Under the 1-year sediment accounting period, if an HFE were triggered but not implemented due to this constraint, and there were no other HFEs in the accounting period, a positive sediment mass balance would be carried over into the next accounting period.
- The 1-year accounting period provides the flexibility to defer the consideration of a triggered fall HFE to the spring, given that the projected sediment mass balance would allow for a

spring HFE. Modeling assumes that under the 1-year accounting period, decision-makers would defer the consideration of an HFE from fall to spring depending on year-to-year circumstances and best-available information.

- For alternatives that do not include flow spikes, fall HFEs are assumed to be implemented on November 15, and spring HFEs are assumed to be implemented on April 15. However, if flow spikes occur in May or June and a spring HFE has been triggered, the HFE may be delayed from April until the first month of flow-spike implementation, if the duration for the later implementation date is within one tier of the earlier date.

Impact Indicators

For all alternatives evaluated, the primary indicators used in this analysis are: 1) the sediment mass balance; 2) the volume of sediment accumulated in sandbars and channel margin deposits; and 3) the probability, frequency, and duration of HFEs.

Issue 1: How would changes to flow and the sediment accounting period affect the probability of triggering HFEs?

To ensure statistically robust results, HFE probability was modeled using three different initializations of random Paria traces for the 30 hydrology traces, for a total of 90 unique hydrology-Paria traces.

No Action Alternative

Under the No Action Alternative, HFEs would continue to occur when triggered, as described in the LTEMP FEIS (DOI 2016a). HFEs are more likely to be triggered in the fall and would last an average of 97.5 hours, or approximately twice as long as fall HFEs that would occur under the action alternatives.

Alternatives with no Flow Spikes

Figure 3-18 through **Figure 3-20** summarize the likelihood of triggering an HFE under each alternative. Compared to the No Action Alternative, alternatives with no flow spikes would increase the likelihood of spring HFEs by approximately 26 percent. This type of alternative would result in shorter fall HFEs and longer spring HFEs.

Fall HFEs, if implemented, would last an average of approximately 56 hours, compared to 98 hours under the No Action Alternative. The average duration of spring HFEs, which are more likely to be triggered and implemented, would also be relatively long, lasting an average of 110 hours. Overall, the probability of longer HFEs would increase in both the spring and fall (**Figure 3-18** and **Figure 3-19**).

Modeling for this category of alternative accounted for the flexibility to defer the consideration of a triggered fall HFE to spring under the 1-year accounting period, provided that the projected sediment mass balance would allow for a spring HFE. As shown in **Figure 3-20**, the probability of triggering spring and fall HFEs of durations less than 100 hours under the alternatives with no flow spikes would be similar to the probabilities under the No Action Alternative. The probabilities of triggering HFEs greater than 100 hours would slightly decrease under the alternatives with no flow spikes, compared with the No Action Alternative.

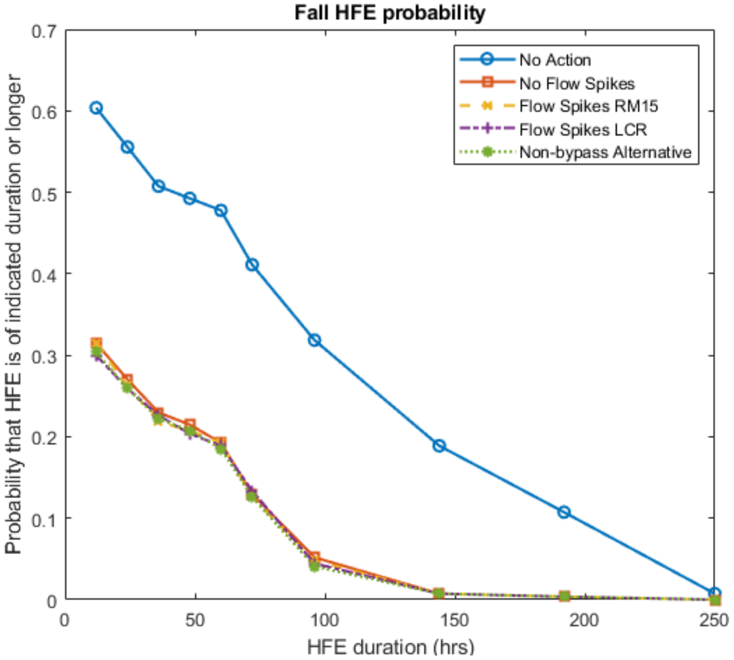
Alternatives with Flow Spikes

The alternatives with flow spikes are represented by the “FS RM 15” and “FS LCR” (LCR represents river mile 61) lines in **Figure 3-18** through **Figure 3-20**. The modeled HFE regimes under the flow spike alternatives are approximately identical for river mile 15 and river mile 61 (confluence with the Little Colorado River). The HFE regimes would generally be similar to those that would occur under the alternatives that do not include flow spikes. However, in some years, flow spikes would cause sand export in the lead-up to HFE implementation, which would reduce the resulting HFE duration.

Non-Bypass Alternative

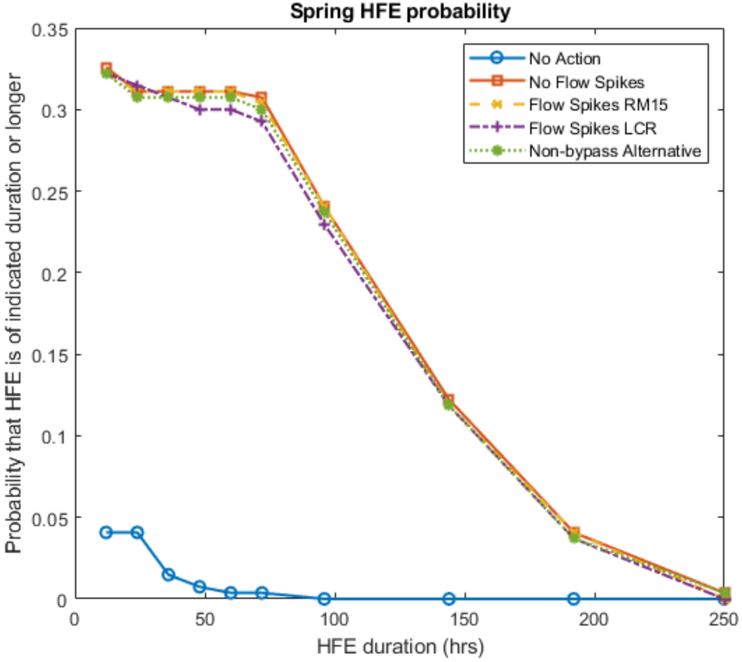
As shown in **Figure 3-18** through **Figure 3-20**, results of HFE modeling under the Non-Bypass Alternative are similar to those modeled under the cold water alternatives. The probability of spring HFEs under this alternative is generally slightly lower than under the cold water alternatives, except for spring HFEs lasting between 50 and 100 hours. Spring HFEs would last an average of 110 hours, which is comparable to the length of spring HFEs under the cold water alternatives.

Figure 3-18
Fall HFE Probability



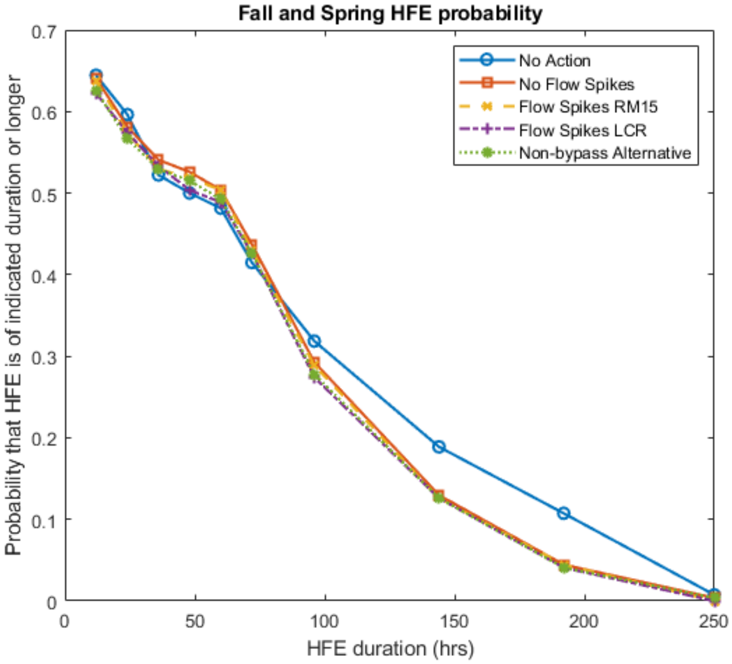
Probability of triggered fall HFEs based on 90 modeled hydrology-Paria traces.
Source: Salter and Grams (GCMRC 2024)

Figure 3-19
Spring HFE Probability



Probability of triggered spring HFEs based on 90 modeled hydrology-Paria traces.
Source: Salter and Grams 2024

Figure 3-20
Fall and Spring HFE Probability



Probability of HFEs being triggered in both fall and spring based on 90 modeled hydrology-Paria traces.
Source: Salter and Grams 2024

Issue 2: How would flow fluctuations and flow spikes affect sediment load transport, accumulation, and erosion?

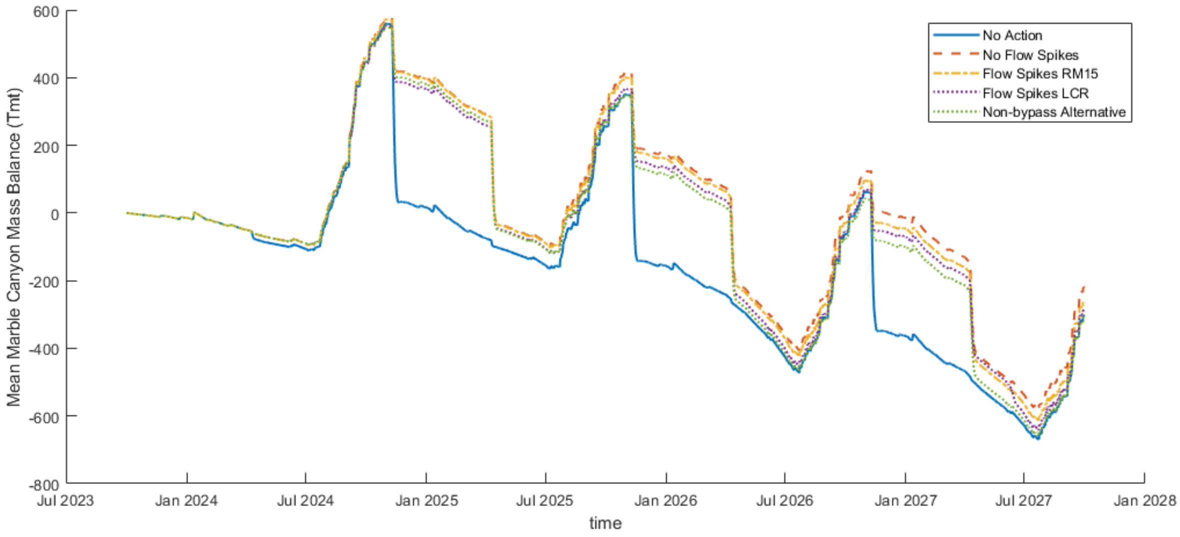
No Action Alternative

Under the No Action Alternative, operations of Glen Canyon Dam would not change. HFEs would continue to occur when triggered, as described in the LTEMP FEIS. When conducted, the HFEs would continue to contribute to sandbar building and sediment export in the Colorado River downstream of the dam. Sediment mass balance at Marble Canyon would continue to trend negative over the long-term and decrease sharply following HFEs. Sandbar building would continue to occur at its highest rate in the fall following fall HFEs, due to their much higher probability under the No Action Alternative. The exact impacts on sediment resources would continue to be highly dependent on water availability for HFEs, the operational releases, and sediment input from tributaries.

Alternatives with No Flow Spikes

Under the Cool Mix and Cold Shock Alternatives, HFEs would be triggered and implemented according to the 1-year sediment accounting period. Compared to the No Action Alternative, alternatives with no flow spikes would result in a slightly higher mass balance on average (**Figure 3-21**) because the average HFE duration would be slightly shorter under the 1-year sediment accounting period.

Figure 3-21
Comparison of Mean Marble Canyon Mass Balance Sand Routing Model Results for All Alternatives



Mean sand mass balance at Marble Canyon based on 30 traces.
Source: Salter and Grams 2024

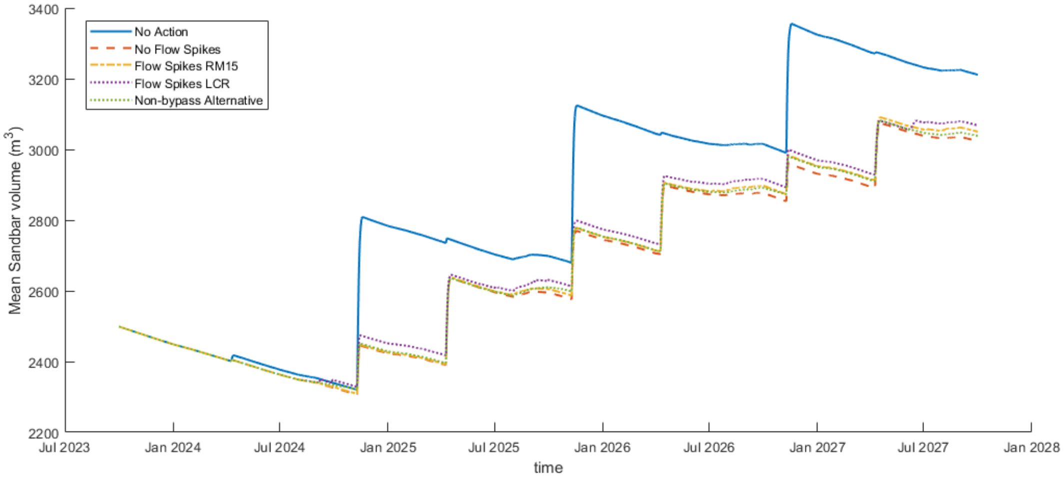
Sandbar volume would continue to increase, albeit in smaller, more frequent increases relative to the No Action Alternative (**Figure 3-22**) due to the shorter duration of spring HFEs. Secondary effects would include decreased HFE magnitude, in addition to coarser bed grain size which reduces suspended sand concentrations and, hence, sandbar deposition rate.

Alternatives with Flow Spikes

As shown in **Figure 3-21**, trends in mass balance under the flow spike alternatives are roughly similar to those trends under the alternatives without flow spikes, with the mean mass balance tending negative over the long-term. Flow spike alternatives would result in slightly lower mass balance relative to alternatives without flow spikes because, in general, elevated flows with low suspended sediment concentrations have greater erosive potential, while elevated flows with high suspended sediment concentrations generate a greater potential for deposition (USGS 2011, Topping et al. 2019). More erosion would result from flow spikes targeting river mile 61, compared to flow spikes targeting river mile 15 because flow spikes targeting river mile 61 would be triggered more frequently.

Sand deposition for sandbar formation can occur only when there is available sand in the system (Topping et al. 2021). Sandbar formation patterns would also roughly mirror those patterns modeled under the alternatives with no flow spikes. However, as shown in **Figure 3-22**, the modeling predicts that sandbar formation at river mile 61 under the flow spike alternatives would eventually surpass sandbar formation under the alternatives that do not include flow spikes.

Figure 3-22
Mean Sandbar Model Results for All Alternatives



Mean sandbar volume based on 30 traces.
Source: Salter and Grams 2024

If a flow spike occurred outside the sediment accounting period, it would increase sediment export, thereby decreasing the amount of available sand to perform an HFE. This would cause a reduction in sandbar size, because HFEs are the only mechanism for providing substantial deposition of high-elevation sandbars (Hazel et al. 2022).

Non-Bypass Alternative

Trends in mass balance and sandbar building under the Non-Bypass Alternative would be similar to those produced under the cold water alternatives, as shown in **Figure 3-21** and **Figure 3-22**. Compared to other action alternatives, the Non-Bypass Alternative would cause the greatest reductions in mass balance starting in Spring 2025. This alternative would generally produce the second-smallest sandbars, slightly surpassing volumes that would be generated under alternatives without flow spikes.

Similarities in sediment distribution patterns are consistent with the results produced by HFE modeling, which show that HFE regimes would be roughly similar across all action alternatives.

Cumulative Effects

The 1-year sediment accounting period would change the timing and duration of HFEs, while allowing for the option to defer the consideration of a triggered fall HFE to spring depending on sediment conditions. Flow spikes that occur outside of the sediment accounting period would increase the likelihood of HFE deferral due to increased sediment export.

Summary

The 1-year sediment accounting period would enable decision-makers to more easily implement HFEs in the spring, which would better approximate pre-dam conditions of high spring run-off flows. Alterations in the timing and duration of HFEs would affect patterns of sediment transport and sandbar growth. The 1-year sediment accounting period would result in longer spring HFEs and shorter fall HFEs, with a higher probability of longer spring HFEs under all action alternatives. In comparison, HFEs implemented under the No Action Alternative are much more likely to occur in the fall, with fall HFEs approximately eight times more likely to occur relative to spring HFEs.

Under the 1-year sediment accounting period, sand mass balance would undergo more gradual and frequent decreases following HFEs, and this trend would be mirrored in sandbar growth patterns. Under all action alternatives, this would result in smaller and slower-growing sandbars compared to the no action alternative. Alternatives without flow spikes and the Non-Bypass Alternative would result in the smallest sandbars, while flow spike alternatives would contribute to overall sandbar growth.

3.5 Aquatic Resources

3.5.1 Affected Environment

This section supplements the 2016 LTEMP FEIS (DOI 2016a) for aquatic resources with a summary of the affected environment as provided in the original 2016 document and supplemented, as necessary, to include changes that have occurred since 2016.

As described in the 2016 LTEMP FEIS, the Colorado River ecosystem supports numerous species of aquatic organisms, including the aquatic food base (i.e., invertebrates, algae, rooted plants, and organic matter that serve as the base of the food web for fish; **Section 3.5.1**), native fish (including endangered and other special status species; **Section 3.5.2**), and nonnative fish (including cold-water and warmwater species; subsection **Nonnative Fish**) (DOI 2016a). Changes to river flows can affect these aquatic organisms and their habitats that occur in channels, along shorelines, and in backwaters and tributary mouths. The affected environment includes the area potentially affected by implementation of the 2016 LTEMP FEIS. For aquatic resources, this area includes the Colorado River ecosystem from Glen Canyon Dam downstream to the Lake Mead inflow. The aquatic species described below are based on those covered in the 2016 LTEMP FEIS and any new species, species of increased concern, or species with changed status since 2016. Federally listed species are discussed in **Section 3.8**, Threatened and Endangered Species. The continued drought conditions in the southwestern US, declines in the level of Lake Powell, and warm epilimnetic water released from Glen Canyon Dam have likely influenced all aspects of the aquatic food web. These effects are still being determined, but the role of water temperature in shaping the aquatic resources and management options in the Colorado River and the consequences of warming water and the challenges of managing these conditions have increased in importance since the 2016 LTEMP FEIS. For some aquatic resources, language from the 2016 LTEMP FEIS is used herein to provide context to new data and information, and to provide the reader with the background for a voluminous and complex subject area.

Aquatic Food Base

The aquatic food base for fish in the Colorado River ecosystem includes invertebrates (animals without backbones), algae, rooted plants, and organic matter (Gloss et al. 2005). Although most of this food base is produced within the aquatic system, terrestrial inputs of organic matter (for example, leaf litter) and invertebrates also contribute. Instream production of both algae and invertebrates helps insectivorous birds and bats, reptiles, and waterfowl; indirect links include peregrine falcons, belted kingfishers, osprey, great blue herons, and bald eagles, which feed on fish or waterfowl that consume aquatic food base organisms (Bastow et al. 2002; Baxter et al. 2005; Sabo and Power 2002; Shannon et al. 2003b; Shannon et al. 2004; Stevens and Waring 1986a; Yard et al. 2004). See **Section 3.7** of this SEIS for a discussion of riparian and terrestrial wildlife. Flow patterns, temperature, and turbidity—all of which were and continue to be influenced by the presence and changing operations of Glen Canyon Dam—have a major influence on the food base of the Colorado River ecosystem within the Grand Canyon.

A description of the aquatic food base prior to and following the construction and operation of Glen Canyon Dam was provided in the 2016 LTEMP FEIS. This section supplements that information with findings following the FEIS. Included in the discussion are invasive aquatic species that have affected or may affect food base organisms of the Colorado River downstream of Glen Canyon Dam. The major groups of aquatic food base organisms include (1) periphyton (for example, algae, diatoms, and cyanobacteria that live attached to rocks and other surfaces) and rooted aquatic plants, (2) plankton (very small plants [phytoplankton] and animals [zooplankton] that occur in the water column), and (3) macroinvertebrates (i.e., invertebrates that are visible to the naked eye) and are generally attached to rocks and other surfaces.

Periphyton and Rooted Aquatic Plants

Physical factors associated with dam releases that have the greatest influence on tailwater algal communities include (1) daily and seasonal constancy of water temperatures, (2) modifications of nutrient regimes, (3) reduced sediment and increased water clarity, (4) formation of stable armored substrates, (5) fluctuations in water levels that produce daily drying and wetting cycles, and (6) reductions in seasonal flow variability and alterations in the timing or occurrence of extreme flows (Blinn et al. 1998). These conditions allowed ubiquitous *Cladophora glomerata* (a filamentous green algae) to become the dominant algal species below Glen Canyon Dam within 6 years of dam closure in 1963 (Czarnecki et al. 1976; Carothers and Minckley 1981; Blinn et al. 1989, 1998; Stanford and Ward 1991). This species remained dominant until 1995 (Blinn and Cole 1991; Blinn et al. 1995; Benenati et al. 1998), when changes in flow regimes stopped the repeated episodes of exposure and desiccation of the varial zone (that is, the portion of the river bottom and shoreline that is alternately flooded and dewatered during dam operations, often on a daily basis) and diluted nutrient concentrations associated with higher reservoir volumes caused the decrease in dominance of *Cladophora* (Benenati et al. 1998, 2000, 2001). Prior to June 1995, *Cladophora* composed 92 percent of the phytobenthic community, but it decreased to less than 50 percent after that time (Benenati et al. 2000). The aquatic flora is now dominated by miscellaneous algae, macrophytes, and bryophytes, including filamentous green algae (mainly *Ulothrix zonata* and *Spirogyra* spp.), the stonewort (*Chara contraria*), species of the aquatic moss *Fontinalis*, and the macrophyte *Potamogeton pectinatus*. *Cladophora* is still present, but in much reduced levels, probably due to changes in reservoir and river chemistry and discharge regimes starting in 1991, as authorized in the 1995 FEIS that limited daily range in dam releases to 8,000 cfs (Benenati et al. 2000; NPS 2005; Yard and Blinn 2001; Reclamation 1995).

More recent warmer releases starting in 2021, as a consequence of climate change and low Lake Powell elevations, have probably further changed the periphyton community of the Colorado River downstream of Glen Canyon Dam, but results of studies are not available for this SEIS.

Submerged macrophytes collected in the mainstream Colorado River included horned pondweed (*Zannichellia palustris*), Canadian waterweed (*Elodea canadensis*), Brazilian elodea (*Egeria densa*), pondweed (*Potamogeton* spp.), aquatic moss (*Fontinalis* spp.), and muskgrass (*Chara* spp. [green alga]) (Carothers and Minckley 1981; Valdez and Speas 2007). These species have persisted with dam operations since the 2016 LTEMP FEIS.

Plankton

Plankton occurring in the Colorado River downstream of Glen Canyon Dam includes both phytoplankton and zooplankton. The phytoplankton population downstream of the dam is diverse but sparse (with numbers never exceeding 3 million organisms per cubic meter [3,000 organisms per liter]) and decreases with distance downstream of Lees Ferry. A total of 122 species have been identified, with diatoms being dominant. In general, the phytoplankton of the Colorado River is considered relatively unproductive due to a combination of high flow rates, low temperatures, elevated turbidity (with increasing distance from the dam), and scouring action by rapids and suspended sediments, which limit reproduction and survival (Sommerfeld et al. 1976).

The factors that regulate zooplankton in the Colorado River below Glen Canyon Dam are the distribution and abundance of zooplankton in Lake Powell and operation of the dam (AZGFD

1996; Speas 2000). The low levels of Lake Powell may result in increases in composition and density of zooplankton downstream as waters are withdrawn from layers closer to the surface (Reclamation 1995). Cole and Kubly (1976) concluded that most zooplankton in the Colorado River originated from Lake Powell or tributaries (primarily Elves Chasm and Tapeats and Diamond Creeks). Mean zooplankton density in the 352 kilometers (approximately 219 miles) of river downstream of Glen Canyon Dam was 614 organisms per cubic meter (0.614 organisms per liter) (Benenati et al. 2001).

It has been reported that backwaters are localities where zooplankton populations can persist (Haury 1986) and that zooplankton densities in backwaters are significantly higher than those of the main channel (AZGFD 1996). Backwaters were thought to support more zooplankton because they are warmer and more stable, and they may retain nutrients that benefit both phytoplankton and zooplankton. Some production of zooplankton occurs in eddies, backwaters, and other low-velocity areas (AZGFD 1996; Stanford and Ward 1986; Blinn and Cole 1991). However, given that even under stable flows waters in backwaters are recycled 1.5 to 3.4 times per day, it seems unlikely that water-column resources such as zooplankton could ever become substantially higher in backwaters than in the mainstream river (Behn et al. 2010). These conditions have persisted with dam operations since the 2016 LTEMP FEIS.

Macroinvertebrates

Alterations in temperature and suspended sediment associated with the presence and operation of Glen Canyon Dam have resulted in a food base of low species diversity. Although aquatic productivity is relatively high in the Glen Canyon reach, because of high water clarity and photosynthesis, macroinvertebrate food base production in the Grand Canyon is extremely low, falling in the bottom 10 percent of production values for streams and rivers throughout the world (Cross et al. 2013).

The Colorado River in Glen and Grand Canyons supports very few mayflies (*Baetis* spp.), stone flies, or caddis flies (*Hydroptila arctica*, *Rhyacophila* spp., *Ceratophsyche oslari*, and others) because of a combination of stressors, including altered temperature regimes and a large varial zone (Stevens et al. 1997; Kennedy et al. 2016). Cold water released from Glen Canyon Dam can prevent aquatic insect eggs from hatching and may limit successful recruitment of these orders from warmer tributaries (Oberlin et al. 1999), while a large varial zone associated with hydropower production leads to desiccation-induced mortality of insect eggs laid along river edge habitats (Kennedy et al. 2016). The caddis fly *C. oslari* occurs throughout the Colorado River but at low abundance (Blinn and Ruiter 2009). Haden et al. (1999) believe that interspecific interactions between *Gammarus* and the net-building *C. oslari* may contribute to the caddis fly's limited presence in the Colorado River below Glen Canyon Dam. Since 1995, recent colonizers throughout the river (possibly as a result of reduced discharge variability from Glen Canyon Dam) include caddis flies, true flies (*Bibiocephala grandis* and *Wiedemannia* spp.), mayflies, beetles (*Microcylloepus* spp.), planarians, and water mites (Shannon et al. 2001). However, caddis flies and mayflies remain relatively sparse in the Colorado River, especially upstream of the Paria River.

Glen Canyon Dam operations have played an important role in the formation of the varial zone. Benthic communities subject to periodic stranding, desiccation, ultraviolet radiation, and winter freezing often have depleted species diversity, density, and/or biomass in the varial zone (Fisher and

LaVoy 1972; Hardwick et al. 1992; Blinn et al. 1995; Stevens et al. 1997). Kennedy et al. (2016) hypothesized that dam operations actually constrain the abundance and diversity of aquatic insects in this varial zone and in the Colorado River downstream of Glen Canyon Dam, thereby limiting the amount of invertebrate prey that is available to support native fish and nonnative trout populations.

Included in the preferred alternative of the 2016 LTEMP FEIS was a Macroinvertebrate Production Flow or “Bug Flow” experiment that proposed to stabilize flows and limit the varial zone. This experiment was implemented May–August in 2018, 2019, 2020, and 2022 to test the hypothesis proposed by Kennedy et al. (2016) that load-following flows from hydroelectric dams produce a population bottleneck for aquatic insects by short-circuiting recruitment processes. This phenomenon had been observed below Flaming Gorge Dam, a hydroelectric facility in the Upper Colorado River (Miller et al. 2020). Kennedy et al. (2016) proposed that Diptera egg survivorship was limited by fluctuating flows that desiccate egg masses and that the food base therefore can be enhanced by steadier flows. This argument may apply to selected chironomid and simuliid taxa, which comprise the bulk of the present fisheries food base in the tailwaters, but not to EPT (Ephemeroptera [mayflies], Plecoptera [stoneflies], and Trichoptera [caddisflies]) that require nonembedded habitats (Stevens et al. 2020).

Metcalfe et al. (2020) found that distributions of the two most widespread caddisfly species downstream of Glen Canyon Dam were both predicted by water temperatures. However, they also found that the abundance of one species decreased by as much as tenfold as diel flow stage change increased, despite the presence of female morphological adaptations for deepwater oviposition. These results show that net-spinning caddisflies have species-specific responses to environmental variation and suggest that environmental flows designed to reduce diel stage change and destabilize water temperatures may improve habitat quality for these ubiquitous and important aquatic insects. These studies determined that more stable flows may benefit aquatic macroinvertebrates downstream of Glen Canyon Dam, and also that the effect of fluctuating flows depends on longitudinal locations downstream of the dam where daily highs correspond with oviposition. However, the results are confounded by several variables, including temperature, location downstream, and macroinvertebrate species.

Yard et al. (2023) demonstrated important linkages between nutrients (soluble reactive phosphorus), invertebrates, and rainbow trout populations below Glen Canyon Dam. In this work, declines in phosphorus drove declines in invertebrates and ultimately led to large declines (of greater than 85 percent) in rainbow trout populations in the tailwater reach in 2012–2016. This study suggests that lowered reservoir elevations from ongoing drought could be limiting the transport of phosphorous to the tailwater and resulting in less food production. This work highlights the important linkages between nutrient inputs, invertebrate production, and fish populations in Glen Canyon. Phosphorous concentrations in the Colorado River downstream of Glen Canyon Dam are sometimes very low and at limiting levels (Ker et al. 2022). Lower water levels (and warmer temperatures) will generally mean less soluble reactive phosphorous and possible lower nutrient levels for macroinvertebrate production. This will translate to lower food production for fishes.

Nonnative and Invasive Species

Some nonnative invertebrate species were introduced after dam construction to supplement the aquatic food base of the Colorado River downstream of Glen Canyon Dam. Because of the low benthic food base noted in the late 1960s, AZGFD biologists introduced macroinvertebrates into the Glen Canyon reach, including crayfish, snails, damselflies, caddis flies, crane flies, midges, true bugs, beetles, and leeches (McKinney and Persons 1999a). These introductions were not monitored for a sufficient length of time to determine their success; however, most of these taxa did not persist in the river (Carothers and Minckley 1981; Blinn et al. 1992). *Gammarus lacustris* was also introduced into the Glen Canyon reach in 1968 to provide food for native and nonnative fish (Ayers et al. 1998), and *Gammarus* and midges have become important components of the aquatic food base.

Other nonnative, invasive species that have potentially detrimental effects on both the food base and fish communities have become established in the Colorado River below Glen Canyon Dam. The New Zealand mud snail was first detected in Glen Canyon in 1995. By 1997, densities on cobble/gravel substrates reached about 3,390 per square foot. The New Zealand mud snail has dispersed downstream through Grand Canyon and was documented in Lake Mead in 2009 (Sorensen 2010). The mud snail accounted for 20 to 100 percent of the macroinvertebrate biomass at six cobble bars studied in the Colorado River downstream of Glen Canyon Dam. The snails probably consume the majority of available epiphytic diatom assemblage. The New Zealand mud snail is a trophic dead-end and may adversely affect the food base in the Colorado River (Shannon et al. 2003b). Epiphytic diatom biomass estimates at Lees Ferry were an order of magnitude lower in 2002 than in 1992 (before New Zealand mud snails were present) (Benenati et al. 1998; Shannon et al. 2003b). However, the biomass of other dominant aquatic food base taxa has been variable and apparently not influenced by the presence of the snails (Cross et al. 2010). At high population levels (9,300 or more individuals per square foot), New Zealand mud snails can substantially modify lower trophic levels (Hall et al. 2006). Although the New Zealand mud snail occurs throughout the river from the Glen Canyon Dam to Lake Mead, its densities tend to be much higher in the upper reaches of the river (Cross et al. 2013). For example, in the Glen Canyon reach, densities of mud snails were an order of magnitude higher than downstream in the Grand Canyon, where sediment scouring and turbidity apparently limit the snails (Cross et al. 2013). Mud snails are free-living without an attachment device and are easily transported with flows.

The New Zealand mud snail has a good chance of being transported by either biological or physical vectors because of its small size and locally high population density (Haynes and Taylor 1984). Recreational fishing and fish stocking have been implicated in the spread and introduction of the New Zealand mud snail (Moffitt and James 2012). The New Zealand mud snail can also be carried by waterfowl from one system to another, by fish within a system (Haynes et al. 1985), and in caked mud on the boots and waders of anglers.

A reproducing population of the quagga mussel (*Dreissena bugensis*) has become established in Lake Powell since at least 2012 (NPS 2012b). Quagga mussels can alter food webs by filtering phytoplankton and suspended particulates (Benson et al. 2013). As of 2014, thousands of adult quagga mussels have been observed within the reservoir on canyon walls, Glen Canyon Dam, boats, and other underwater structures (Repanshek 2014), and these have continued to expand and increase in abundance. Quagga mussels established in Lake Powell may cause changes in dissolved nutrients, phytoplankton, and zooplankton within the reservoir, which would likely impact food web structure or trophic linkages below Glen Canyon Dam (Nalepa 2010).

The risk of quagga mussels becoming established within the Colorado River ecosystem was thought to be low, except in the Glen Canyon reach, where lower suspended sediment and higher nutrient levels (compared with downstream reaches) favor its establishment (Kennedy 2007). It is unlikely to establish at high densities within the river or its tributaries because of high suspended sediment, high ratios of suspended inorganic/organic material, and high-water velocities; all of these interfere with the mussel's ability to effectively filter food. High concentrations of sand may cause abrasion and physically damage its feeding structures (Kennedy 2007). Quagga mussels were identified in sampling locations between Glen Canyon Dam and Lees Ferry in November 2014. The mussels continue to be found in the river below the dam. Their distribution is patchy and highly influenced by fluctuating water levels and location-specific flow regimes. Adult mussels have also been found downstream in the Grand Canyon. Mussel larvae (veligers) pass through the Glen Canyon Dam and seek to attach to substrates in the river.

Quagga mussels have become established in Lake Powell and have been seen in the river below the dam as recently as 2022 and 2023. Their arrival in the river in 2014 happened sooner than expected. However, so far, there has not been a major infestation, and there is some thought by experts that the mussels will not become very well established in the river due to river currents and periodic sediment loads. Anglers are being advised to dry waders and boots before using them in any other body of water. Also, all private boaters are asked to drain all water from the boat and live wells as soon they exit the river.

A few nonnative, invasive invertebrates are fish parasites that use food base organisms as intermediate hosts. For example, the internal parasite *Myxobolus cerebralis*, which causes whirling disease in salmonids (trout species), uses the oligochaete worm *Tubifex tubifex* as an intermediate host (see the **Cold-water Nonnative Species** subsection for additional information on whirling disease). The parasitic trout nematode (*Truttaedacnitis truttae*) is present in rainbow trout in the Glen Canyon reach, but the ecological impact of this infestation is poorly understood. It may influence food consumption, impair growth, and reduce reproductive potential and survival of rainbow trout. The nematode may require an intermediate host such as a copepod or other zooplankton taxa (McKinney et al. 2001).

The Asian tapeworm (*Bothriocephalus acheilognathi*) was first introduced into the United States with imported grass carp (*Ctenopharyngodon idella*) and was discovered in the Little Colorado River by 1990 (Choudhury et al. 2004). It now parasitizes the humpback chub population from the Colorado and Little Colorado Rivers. The tapeworm could infect all native and nonnative fish species in the Little Colorado River where temperatures are more suitably warm (USGS 2004). Cyclopoid copepods are intermediate hosts for the tapeworm, although fish that prey upon small infected fish can acquire tapeworm infections as well. Thus, large humpback chub that normally consume little zooplankton can become infected by preying on smaller infected fish (USGS 2004). The Asian tapeworm requires at least 18°C (64°F) to complete its life cycle and may become an increasing threat to native fish as Lake Powell levels drop and dam release temperatures increase. Asian tapeworm monitoring occurs annually within the Little Colorado River, and additional monitoring is conducted on Asian fish tapeworms in humpback chub inhabiting the mainstream Colorado River as identified in the 2016 BiOp. When wild humpback chub were screened for infection prevalence in spring 2015 (21.4 percent, n = 140) and fall 2015 (6.6%, n = 258), the relative frequency of infection was highest in juveniles and subadult fish (200–300 mm) (Campbell et al. 2019). Elevated levels of infection near the major spawning grounds of humpback chub in the Little Colorado River promote parasitic infection, which may continue to persist without treatment or actions to control infections.

Increased body loads of the parasitic copepod known as anchor worm (*Lernaea cyprinacea*) and the Asian tapeworm cause poorer body condition in humpback chub from the Little Colorado River (Hoffnagle et al. 2006). For fish collected from 1996 to 1999, prevalence of the anchor worm was found to be 23.9 percent, and the mean intensity was 1.73 per fish in the Little Colorado River compared with 3.2 percent and 1.0 per fish in the Colorado River. The prevalence of Asian tapeworm was 51.0 percent and 252 per fish in the Little Colorado River, but only 15.8 percent and 12 per fish in the Colorado River, where temperatures were colder. Differences in parasite density and abundance between the Little Colorado River and Colorado River are caused by temperature differences. Temperatures in the Colorado River near the Little Colorado River do not reach those necessary for either parasite to complete its life cycle (at least 18°C [64°F]); thus, these parasites were probably contracted while the humpback chub was in the Little Colorado River (Hoffnagle et al. 2006). Anchor worms persist in the system and may increase in abundance or distribution with warmer river temperatures.

Food Web Dynamics

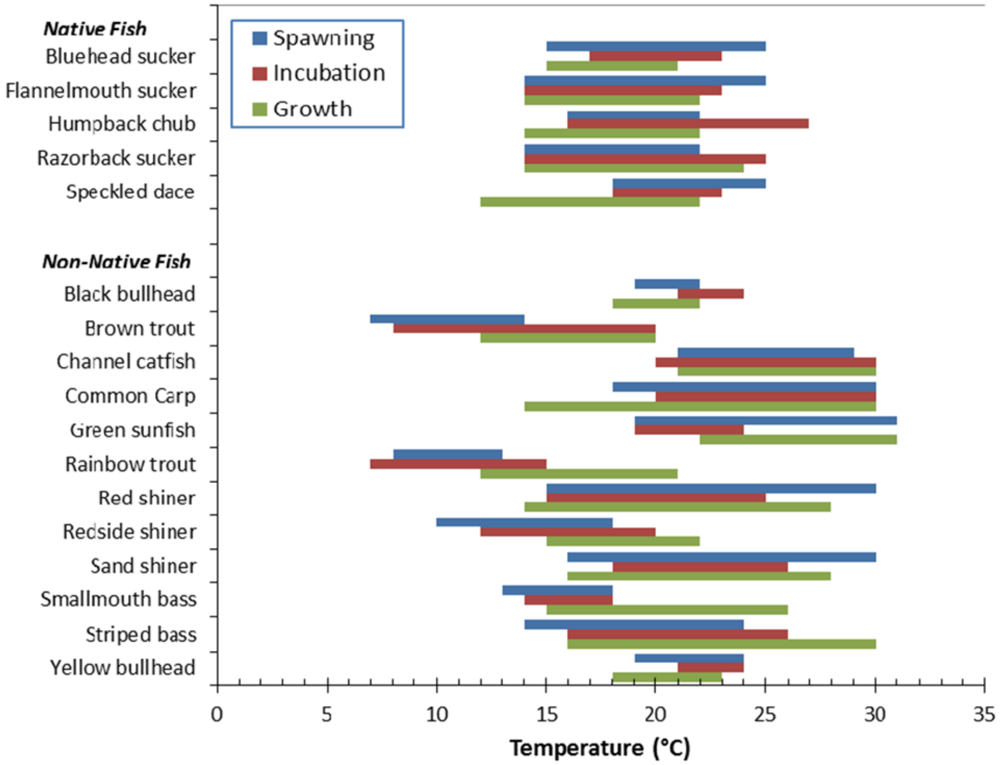
Primary production, specifically diatoms, forms the base of the aquatic food web in Glen Canyon. In contrast, a combination of primary production and terrestrial and tributary inputs of organic matter is the basis of the aquatic food web in Marble and Grand Canyons, but high-quality algal matter supports the food web to an extent that is disproportionate to its availability. Midges and blackflies principally fuel the production of native and nonnative fish, 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). Prior to the low fluctuating flows that started in 1995, the primary foods of humpback chub in the Colorado River through Grand Canyon were simuliids, *Gammarus*, chironomids, and terrestrial invertebrates (Valdez and Ryel 1995). Fluctuating flows from power plant releases were hypothesized to desiccate egg masses in varial shoreline zones (Cross et al. 2013; Kennedy et al. 2016). Experiments to regulate dam releases on weekends and provide more stable flows (“bug flows”) were implemented in 2018–2020 to encourage macroinvertebrate oviposition in varial habitats. It was determined that a 400 percent increase in caddisflies occurred during two of the three years, but it was uncertain if these increases were because of low sediment (Deemer et al. 2021).The food web of the Colorado River within Glen Canyon is rather simple. Complexity increases with distance from the dam (Cross et al. 2013). The New Zealand mud snail and nonnative rainbow trout dominate the food web in the Glen Canyon reach. 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., greater than 20 percent of invertebrate production consumed by fish). Epiphytic diatoms, *Gammarus*, midges, and blackflies provide the primary food base for rainbow trout (Cross et al. 2013).

Below large tributaries with substantial sediment input, 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 mainstream and tend to consume all of the available invertebrate production in downstream reaches (Cross et al. 2013).

Native Fish

Of 11 species of native fish that historically been found within the analysis area, five species have persisted (Valdez and Carothers 1998, **Table 3-29**). These include the humpback chub, razorback sucker, bluehead sucker, flannelmouth sucker, and speckled dace present within the mainstream Colorado River and its tributaries. Humpback chub and razorback sucker are addressed in **Section 3.8**, Threatened and Endangered Species. In addition, two other native fish species, the flannelmouth sucker and bluehead sucker, are included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006). These species are considered warmwater fishes, and temperature requirements of these and other species in the analysis area are shown in **Figure 3-23**. This figure illustrates the large temperature overlap between native fishes and nonnative species that helps to explain why these species can coexist in a system like the Colorado River downstream of Glen Canyon Dam.

Figure 3-23
Temperature Ranges for Spawning, Egg Incubation, and Growth by Native and Nonnative Fish of the Colorado River System below Glen Canyon Dam



Source: Valdez and Speas 2007

Of the remaining three species—the Zuni bluehead sucker (*Catostomus discobolus yarrowi*), Little Colorado sucker (*Catostomus latipinnis* sp. 3), and Little Colorado spinedace (*Lepidomeda vittata*)—are endemic to the upper reaches of the Little Colorado River. The remaining three species—the bonytail (*Gila elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow (*Ptychocheilus lucius*)—have been extirpated from the mainstream between Glen Canyon Dam and Hoover Dam. The extirpated species and those found only in the upper reaches of the Little Colorado River are considered outside the affected area considered in this SEIS. Currently, five species of native fish are known to exist in the Colorado River between Glen Canyon Dam and Lake Mead (**Table 3-29**); these are discussed in detail in the following sections.

Table 3-29
Native Fish of the Colorado River in the Project Area

Species	Listing Status[a]	Presence in Project Area[b]
Humpback chub (*Gila cypha*)	ESA-T, CH; AZ-SGCN	30-Mile Spring to Pearce Ferry; Little Colorado River; translocated to Shinumo, Havasu, Bright Angel Creeks
Razorback sucker (*Xyrauchen texanus*)	ESA-E, CH; AZ-SGCN	Lava Falls Rapid to Pearce Ferry, few upstream of Lava Falls
Bluehead sucker (*Catostomus discobolus*)	NL, CSp; AZ-SGCN	Paria River to Pearce Ferry, including tributaries
Flannelmouth sucker (*Catostomus latipinnis*)	NL CSp; AZ-SGCN	Glen Canyon Dam to Pearce Ferry, including tributaries
Speckled dace (*Rhinichthys osculus*)	NL CSp	Glen Canyon Dam to Pearce Ferry, including tributaries

Sources: 56 *Federal Register* 54957; AZGFD 2001a, 2001b, 2002a, 2002b, 2003; Andersen 2009; Bezzerides and Bestgen 2002; Coggins and Walters 2009; Francis et al. 2015; Makinster et al. 2010; Ptacek et al. 2005; Rees et al. 2005; Rinne and Magana 2002; Service 2002; Ward and Persons 2006; Woodbury et al. 1959; Gloss and Coggins 2005; GCMRC 2014; Albrecht et al. 2014; Valdez and Carothers 1998

[a] ESA = Endangered Species Act; E = endangered, T = threatened; CH = federally designated critical habitat in project area; AZ-SGCN = Arizona species of greatest conservation need; NL = not listed; CSp = included in the Rangewide Conservation Plan and Agreement (AZGFD 2006)

[b] Habitat and life history information is presented in species-specific discussions in this section.

Special Status Fish Species

Bluehead Sucker

The bluehead sucker is a medium-sized river sucker (Catostomidae). Adults may reach 300 to 450 millimeters in total length in large rivers but may be smaller in tributaries; they may live from 6 to 8 years to as many as 20 years (Sigler and Sigler 1987; Bezzerides and Bestgen 2002; AZGFD 2003). This species has been reported to be as large as 500 millimeters total length in the mainstream Colorado River in Grand Canyon, with tributary fish being smaller (Valdez and Ryel 1995; AZGFD 2003). A related subspecies, the Zuni bluehead sucker, occurs in the headwaters of the Little Colorado River along with bluehead sucker that is the same subspecies as in the mainstream Colorado River (AZGFD 2002a).

Distribution and Abundance. Bluehead sucker populations are declining throughout the species' historic range, and the species has been identified as an Arizona species of greatest conservation need

(AZGFD 2012). The bluehead sucker is included in the Arizona statewide conservation agreement for six native fish species (AZGFD 2006). In the Colorado River Basin, this species is found in the Colorado River and its tributaries from Lake Mead upstream into Arizona, Colorado, New Mexico, Utah, and Wyoming. This species is also found in the Snake River (Idaho and Wyoming), the Bear River (Idaho and Utah), and Weber River (Utah and Wyoming) drainages (Bezzerides and Bestgen 2002; AZGFD 2003).

Within the Grand Canyon, the bluehead sucker is found in the Colorado River mainstream and its tributaries, including the Little Colorado River, Clear Creek, Bright Angel Creek, Kanab Creek, and Havasu Creek (Rinne and Magana 2002; AZGFD 2003; Ptacek et al. 2005; NPS 2013c). Prior to 2014, it was also found in Shinumo Creek but was largely displaced from that system by large debris flows (Healy et al. 2014). Annual fish monitoring conducted between 2000 and 2009 in the Colorado River between Glen Canyon Dam and the inflow to Lake Mead shows the bluehead sucker to be present in all reaches of the river (Makinster et al. 2010). This species is rare in the upper sections of GCNP, because of cold dam releases, and increases in number near the Little Colorado River inflow and downstream with warmer water temperatures (Bunch et al. 2012a; Bunch et al. 2012b). Bluehead suckers are found more often in GCNP with warmer dam releases.

Abundance estimates using monitoring data and Age-Structured Mark-Recapture models show the abundance of age-1 (juvenile) bluehead suckers in the Grand Canyon declined from 1990 to 1995, increased from 1995 to 2003, and then declined through 2009 (Walters et al. 2012). Similar estimates for age-4 (adult) fish show abundance began increasing from the late 1990s until 2005 or 2006, after which abundance also declined. The estimated abundance of age-1 bluehead sucker has ranged from 1,000 or less to as many as 60,000 fish between 2000 and 2009 (Walters et al. 2012). Estimated abundance of age-4+ adults during this same period ranged from about 5,000 to as many as 75,000 fish. Although the bluehead sucker was likely extirpated from Shinumo Creek following fires and debris flows in 2014 (Healy et al. 2014), relatively high numbers of individuals remain in the Lower Colorado River between Lava Falls Rapid (river mile 179) and Lake Mead (Bunch et al. 2012a; Bunch et al. 2012b). Sampling of the larval fish community in the western Grand Canyon between Lava Falls and Pearce Ferry collected bluehead sucker larvae throughout the analysis area (Albrecht et al. 2014). In this analysis area, the bluehead sucker was the most abundant species in the larval fish community, composing almost 40 percent of the total catch.

Long-term fish monitoring by AZGFD (Rogowski et al. 2018) show bluehead sucker in the Colorado River from Lees Ferry to Pearce Ferry increasing in catch-per-unit-effort from 2000 to 2010, followed by a general decline with some variability, and then increasing to former high levels in 2016 and 2017. Relative abundance of bluehead sucker shows some decline with high variability to 2023 (Rogowski et al. 2023).

Habitat. The bluehead sucker typically inhabits large streams and may also be found in smaller streams and creeks (Sigler and Sigler 1987; AZGFD 2003). Riverine habitats may range from cold (12°C [54°F]), clear streams to warm (28°C [82°F]), very turbid rivers. Large adults live in deep water (6 to 10 feet), while juveniles use shallower, lower velocity habitats (Bezzerides and Bestgen 2002). In clear streams, the bluehead sucker stays in deep pools and eddies during the day. It moves to shallower habitats (for example, riffles or tributary mouths) to feed at night, while in turbid waters they may use shallow areas throughout the day (Beyers et al. 2001; AZGFD 2003). In the Grand Canyon, larval and young bluehead suckers inhabit backwater areas and other nearshore, low-velocity habitats such as eddies, embayments, and isolated pools (Childs et al. 1998; AZGFD 2003; Albrecht et al. 2014).

Life History. The bluehead sucker is an omnivorous benthic forager with a modified lower jaw used as a scraping radula. It feeds by scraping algae, invertebrates, and other organic and inorganic material off rocks and other hard surfaces (Ptacek et al. 2005). Larvae drift to backwaters and other areas of low current, where they feed on diatoms, zooplankton, and dipteran larvae.

In the Lower Colorado River, this species spawns in spring and summer after water temperatures exceed 15.5°C (60°F). Valdez and Ryel (1995) reported large concentrations of bluehead sucker and flannelmouth sucker in tributary mouths through Grand Canyon in spring as presumed spawning runs. Spawning in Grand Canyon tributaries occurs mid-March through June in water depths ranging from a few inches to more than 3 feet and at temperatures of 15.5 to 20°C (60 to 68°F) over gravel-sand and gravel-cobble substrates (AZGFD 2003; NPS 2013e). In Kanab Creek, spawning has been reported to occur at temperatures of 18.2–24.6°C (64.8–76.3°F) (Maddux and Kepner 1988). Smaller tributaries may provide nursery grounds for populations of large adjacent rivers (Rinne and Magana 2002).

Factors Affecting Distribution and Abundance in the Grand Canyon. As with the humpback chub, decreases in distribution and abundance of the bluehead sucker throughout its range, as well as in portions of the Colorado River and its tributaries below Glen Canyon Dam, have been attributed to two main factors: (1) habitat degradation through loss, modification, and/or fragmentation and (2) interactions with nonnative species (Gloss and Coggins 2005; Ptacek et al. 2005). Disturbance related to fire and flooding may also influence bluehead sucker distribution in tributaries (Healy et al. 2014). The construction and operation of Glen Canyon Dam has altered downstream temperature and flow regimes. Cold tailwaters below dams are below temperatures needed for spawning and recruitment (Rinne and Magana 2002; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was a sudden increase in mainstream water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012).

The introduction of nonnative fish has increased competition with and predation on bluehead sucker (AZGFD 2003; Ptacek et al. 2005). Large nonnative predators such as channel catfish and trout, midsized fish like sunfish, and even smaller nonnative minnows may all prey on one or more life stages of the bluehead sucker (Rinne and Magana 2002; Ptacek et al. 2005; Yard et al. 2011).

Flannelmouth Sucker

The flannelmouth sucker is a medium to large river sucker (Catostomidae). It has a maximum total length greater than 600 millimeters and a maximum weight of about 1,400 grams (AZGFD 2001b; Rees et al. 2005). It is a long-lived species, living as long as 30 years (AZGFD 2001b). The flannelmouth sucker is included in a statewide conservation agreement (AZGFD 2006).

Distribution and Abundance. Historically, the flannelmouth sucker ranged throughout the Colorado River Basin, in moderate to large rivers in Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming (Bezzerides and Bestgen 2002; Rees et al. 2005). Within the Grand Canyon, this species may be found in the mainstream Colorado River and its tributaries, including the Little Colorado and Paria Rivers and Shinumo, Bright Angel, Kanab, and Havasu Creeks (Douglas and Marsh 1998; Weiss 1993; AZGFD 2001b; Bezzerides and Bestgen 2002). In contrast to bluehead sucker, flannelmouth sucker are only found below the barrier falls in Shinumo and Havasu Creeks. Annual monitoring conducted between 2000 and 2009 found the flannelmouth sucker to be present in all reaches of the river between Lees Ferry and the inflow to Lake Mead (Makinster et al. 2010). Abundance, across all reaches and measured as catch-per-unit-effort, has been increasing since 2000, especially since about 2004 (Makinster et al. 2010). However, abundance had been decreasing within individual reaches between river mile 0 and river mile 179 since about 2005 but increasing downstream of river mile 179. Surveys of the small-bodied and larval fish communities in the western Grand Canyon (Lava Falls to Pearce Ferry) found flannelmouth sucker to be present throughout the reach, accounting for over 38 percent of the total larval catch in this area (Albrecht et al. 2014). With warmer releases from Glen Canyon Dam, starting in 2015, flannelmouth sucker have expanded upstream of the Paria River and are now found more commonly in the Lees Ferry reach.

Abundance estimates using monitoring data and Age-Structured Mark-Recapture models show an increase in the abundance of age-1 (juvenile) and age-4 (adult) flannelmouth suckers in the Grand Canyon between 2000 and 2008 (Walters et al. 2012). Abundance of age-1 flannelmouth sucker increased from about 2,500 in 2000 to about 10,000 in 2008, while abundance of age 4+ adults increased from about 10,000 to about 25,000 for this same period (Walters et al. 2012). Other abundance estimates based on electrofishing catch-per-unit-effort for this same time period showed an increase in abundance from less than 1,000 in 2000 to about 12,000 in 2009, while the estimated abundance of age-4+ adults increased from about 2,500 in 2001 to about 31,000 in 2009 (Walters et al. 2012).

Long-term fish monitoring by AZGFD (Rogowski et al. 2018) shows flannelmouth sucker in the Colorado River from Lees Ferry to Pearce Ferry increased slowly in catch-per-unit-effort from 2000 to 2011, followed by a general decline to 2014 and an increase to 2017. Relative abundance of adult flannelmouth sucker remained high to 2023 (Rogowski et al. 2023).

Habitat. This species prefers large to moderately large rivers. Adults may prefer deep water when not feeding (Rinne and Minckley 1991), while larvae and young are often associated with shallow, slow-moving nearshore areas such as backwaters and shoreline areas of slow runs or pools (AZGFD 2001b; Rees et al. 2005). Although it is a riverine species, in the Upper Colorado River Basin the flannelmouth sucker has been collected from Flaming Gorge and Fontenelle Reservoirs. In the Colorado River in the Grand Canyon, subadults are found in eddies and runs over sand bottoms. In the Little Colorado River, adult and juvenile flannelmouth suckers use low-velocity, nearshore habitats with large amounts of cover during the daylight, and their use of faster, more exposed midchannel habitats increases at night (Gorman 1994). Juveniles and adults may be considered habitat generalists and can be found using pool, run, and eddy habitats. Surveys of larval flannelmouth sucker in the western Grand Canyon (Lava Falls to Pearce Ferry) found the highest abundance of larvae in embayments, isolated pools, backwaters, and other low-velocity habitats (Albrecht et al. 2014).

Life History. The flannelmouth sucker is an omnivorous benthic feeder, foraging on invertebrates, algae, plant seeds, and organic and inorganic debris (Bezzerides and Bestgen 2002; Rees et al. 2005; Seegert et al. 2014). Larvae feed primarily on aquatic invertebrates, crustaceans, and organic debris (Childs et al. 1998). As they become juveniles and adults, their diet shifts and becomes primarily composed of benthic matter including organic debris, algae, and aquatic invertebrates (Rees et al. 2005; Seegert et al. 2014).

This species has been reported to prefer water temperatures ranging from 10 to 27°C (50 to 81°F) and is most common at about 26°C (79°F) (Sublette et al. 1990). Water temperatures reported during spawning activity range from 6 to 18.5°C (43 to 65°F) but are usually above 14°C (57.2°F) (Bezzerides and Bestgen 2002). In the Lower Colorado River Basin, flannelmouth sucker spawning typically occurs in March and April (Bezzerides and Bestgen 2002). Water temperature has been suggested as a primary cue for spawning in other parts of this species range, but it does not appear to provide a spawning cue in the Grand Canyon where relatively synchronized spawning has been reported among sucker stocks from creeks with different temperature and flow regimes (Weiss 1993; Weiss et al. 1998). In the Paria River, the timing of spawning has been correlated with the receding limb of the hydrograph (Weiss 1993).

In the Grand Canyon, flannelmouth suckers apparently spawn at only a limited number of tributaries, and fish may move considerable distances to reach spawning sites (Douglas and Marsh 1998; Weiss et al. 1998; Douglas and Douglas 2000). Tributary spawning in the Grand Canyon may be timed to take advantage of warm, ponded conditions at tributary mouths that occur during high flows in the mainstream Colorado River (Bezzerides and Bestgen 2002). Valdez and Ryel (1995) reported large concentrations of bluehead sucker and flannelmouth sucker in tributary mouths through Grand Canyon in spring as presumed spawning runs.

Body condition of flannelmouth sucker is variable throughout the Grand Canyon, but is greatest at intermediate distances from Glen Canyon Dam, possibly because of the increased number of warmwater tributaries in this reach (Paukert and Rogers 2004). Mean condition peaks during the pre-spawn and spawning periods and is lowest in summer and fall (McKinney et al. 1999b; Paukert and Rogers 2004). Sucker condition in September was positively correlated with Glen Canyon discharge during summer (June–August), possibly due to an increased euphotic zone and greater macroinvertebrate abundance observed during higher water flows (Paukert and Rogers 2004).

Factors Affecting Distribution and Abundance in the Grand Canyon. Flannelmouth sucker populations have declined throughout the species' historic range; in the Lower Colorado River, this decline has been attributed primarily to flow manipulation and water development projects (Rees et al. 2005). However, since 2005, flannelmouth sucker numbers have been increasing and now represent one of the most abundant species in the Grand Canyon (Fonken et al. 2023). Cold-water releases from Glen Canyon Dam have altered the thermal regime of the main channel of the Colorado River, which for larvae may result in slow growth, delayed transition to the juvenile stage, and possibly higher mortality (Rees et al. 2005).

In the cold tailwaters below Glen Canyon Dam, water temperatures (8 to 12°C [46 to 54°F]) are at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers; even though water temperatures do warm downstream, the cold summer water temperatures have been suggested as a major factor limiting survival of YOY, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam was low in the 1990s and then increased after 2000; the largest recruitment estimates were for 2003 and 2004, when there was a sudden increase in mainstream water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). Paukert and Rogers (2004) reported post-spawn condition of flannelmouth sucker below Glen Canyon Dam to be variable, but were typically greatest in the vicinity of warmwater tributaries such as the Paria River, the Little Colorado River, and Bright Angel Creek.

The flannelmouth sucker in the Grand Canyon may also be experiencing competition with and predation by nonnative species that are in the system (Rees et al. 2005). Potential competitors include species such as the channel catfish and the common carp. Potential predators include rainbow and brown trout, channel catfish, and red shiner. Rainbow and brown trout diet sampling found enough juvenile flannelmouth suckers in trout stomachs to account for as much as 50 percent of the estimated annual mortality rates of juveniles (Yard et al. 2011; Walters et al. 2012). The ability of flannelmouth sucker to escape trout predation is also inhibited by colder water temperatures (Ward and Bonar 2003).

Speckled Dace

The speckled dace is native to the western United States and is one of eight species in the genus *Rhinichthys*. It is a small fish, typically less than 76 millimeters in length, and has a relatively short lifespan of about 3 years (Sigler and Sigler 1987).

Distribution and Abundance. This species is native to all major western drainages from the Columbia and Colorado Rivers south to Mexico (AZGFD 2002b). Within the Grand Canyon, this species occurs within the mainstream Colorado River and its tributaries, including the Little Colorado River (Robinson et al. 1995; Ward and Persons 2006; Makinster et al. 2010). Long-term fish monitoring of the Colorado River below Glen Canyon Dam since 2000 shows the speckled dace to be the third most common fish species (and most common native species) in the river between Glen Canyon Dam and the Lake Mead inflow, and it was captured most commonly in the western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010).

Long-term fish monitoring by AZGFD (Rogowski et al. 2018) show speckled dace in the Colorado River from Lees Ferry to Pearce Ferry increased slowly in catch-per-unit-effort from 2000 to 2011, followed by a decline to 2013 and an increase to 2017. Relative abundance of speckled dace shows a decline to 2023. The greatest decline was in the western Grand Canyon coincident with dramatic increases in humpback chub abundance, suggesting competition or possibly predation by humpback chub (Rogowski et al. 2023).

Habitat. The speckled dace may be found in a variety of habitats, ranging from cold, fast-flowing mountain streams to warm, intermittent desert streams and springs. Where found, it occurs in rocky runs, riffles, and pools of headwater streams, creeks, and small to medium rivers, typically in waters with depths less than 1.6 feet (AZGFD 2002b); it rarely occurs in lakes (Page and Burr 1991). Valdez and Ryel (1995) reported the largest numbers of specked dace in gravel/cobble fans at arroyos and side canyons of the Colorado River through Marble and Grand Canyons.

Life History. The speckled dace is an omnivorous bottom feeder, feeding primarily on insect larvae and other invertebrates, as well as algae and fish eggs (Seegert et al. 2014). Its young are mid-water plankton feeders (Sigler and Sigler 1987). This dace spawns twice, once in spring and again in late summer (AZGFD 2002b). Spawning occurs over gravel in areas prepared by the male.

Factors Affecting Distribution and Abundance in the Grand Canyon. The speckled dace is a widespread and abundant species in western North America (AZGFD 2002b). Although this species is the most widely distributed and abundant native fish species in the Grand Canyon ecosystem, its abundance and distribution could be affected by many of the same factors that affect the abundance and distribution of the other native fish in the ecosystem, namely altered temperature, flow, and sediment regimes and predation by nonnative fish (AZGFD 2002b; Gloss and Coggins 2005).

Nonnative Fish

As many as 25 species of nonnative fish have been reported with some regularity from Lakes Powell and Mead and the Colorado River and its tributaries between these reservoirs (Valdez and Speas 2007; Coggins et al. 2011; Reclamation 2011c; **Table 3-30**). Most of these introduced species are native to other basins in North America but not to the Colorado River System, and a few are species from outside North America. These fish occur in the Grand Canyon as a result of intentional and unintentional introductions, especially into Lakes Powell and Mead. A number of species were stocked as game fish and others as forage fish for the stocked game fish (Valdez and Ryel 1995). Among these nonnative species, three are largely restricted to Lake Powell and/or Lake Mead and are found in the Colorado River and its tributaries below Glen Canyon Dam only occasionally; these species are black crappie, bluegill, and gizzard shad (**Table 3-30**). Another four species—northern pike, threadfin shad, rock bass, and yellow perch—are largely restricted to the upper Little Colorado River watershed (Ward and Persons 2006; Valdez and Speas 2007). The remaining 18 species have been reported from the mainstream Colorado River and/or its tributaries between Glen Canyon Dam and the inflow to Lake Mead. New introductions of nonnative fish species continue to be documented throughout the Colorado River Basin, and new introductions are likely to occur (Martinez et al. 2014).

Table 3-30
Nonnative Fish Found in the Colorado River through Glen and Grand Canyons

Species	Native Origin	Presence in Project Area
Cold-water Species		
Rainbow trout (*Oncorhynchus mykiss*)	North America	Colorado River from Glen Canyon Dam to Havasu Creek; abundant from Glen Canyon Dam to Lees Ferry; abundance decreases through Marble Canyon to the confluence of the Little Colorado River, although substantial numbers may still be present in some locations in some years; locally abundant at the Little Colorado River confluence and some locations through Grand Canyon in some years
Brown trout (*Salmo trutta*)	Europe	Colorado River from Glen Canyon Dam to Kanab Creek; locally abundant near confluence with Bright Angel Creek, the Little Colorado River, and some other tributaries
Coolwater Species		
Walleye (*Sander vitreum*)	North America	Lake Powell; Colorado River from Lava Falls to Lake Mead; generally rare throughout Glen Canyon (but consistently observed during electrofishing surveys), Marble Canyon, and the Grand Canyon
Yellow perch (*Perca flavescens*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed
Northern pike (*Esox lucius*)	North America	Lake Powell; Lake Mead; upper Little Colorado River
Warmwater Species		
Black bullhead (*Ictalurus melas*)	North America	Lake Powell, Lake Mead; Colorado River at the Little Colorado River; Colorado River downstream of Diamond Creek; generally absent from Glen Canyon, rare in Marble Canyon, and locally common in some areas of the Grand Canyon
Yellow bullhead (*Ameiurus natalis*)	North America	Colorado River downstream of the Little Colorado River to Lake Mead; Little Colorado River abundance presumed similar to that of black bullhead
Channel catfish (*Ictalurus punctatus*)	North America	Lake Powell, Lake Mead, Colorado River from Marble Canyon to Lake Mead; generally absent from Glen Canyon, rare in Marble Canyon, and numerous in the Grand Canyon
Green sunfish (*Lepomis cyanellus*)	North America	Lake Powell; Lake Mead; Kanab Creek; discovered in abundance in a slough located just downstream of Glen Canyon Dam in 2015 (eradication efforts conducted); found in Glen, Marble, and Grand Canyons
Bluegill (*Lepomis macrochirus*)	North America	Lake Powell; Lake Mead; rare in the Grand Canyon; abundance presumed similar to that identified for green sunfish

Species	Native Origin	Presence in Project Area
Largemouth bass (*Micropterus salmoides*)	North America	Lake Powell; Kanab Creek; Lake Mead to Maxson Canyon; generally absent from Glen Canyon and Marble Canyon; rare in the Grand Canyon
Smallmouth bass (*Micropterus dolomieui*)	North America	Lake Powell; Colorado River at the Little Colorado River, below Glen Canyon Dam; found in small numbers from Glen Canyon through the Grand Canyon
Rock bass (*Ambloplites rupestris*)	North America	Lake Powell; Lake Mead; upper Little Colorado River watershed
Black crappie (*Pomoxis nigromaculatus*)	North America	Lake Powell; Lake Mead; generally absent from Glen Canyon, Marble Canyon, and Grand Canyon
Fathead minnow (*Pimephales promelas*)	North America	Colorado River from the Paria River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon
Golden shiner (*Notemigonus crysoleucus*)	North America	Colorado River from Glen Canyon to Separation Canyon; Kanab Creek; generally rare throughout Glen Canyon, Marble Canyon, and the Grand Canyon
Redside shiner (*Richardsonius balteatus*)	North America	Lake Powell; Colorado River at the Little Colorado River; generally rare throughout Glen Canyon, Marble Canyon, and Grand Canyon
Red shiner (*Cyprinella lutrensis*)	North America	Colorado River at the Little Colorado River; Colorado River from Bridge Canyon to Lake Mead
Common carp (*Cyprinus carpio*)	Eurasia	Lake Powell, Lake Mead, Colorado River from Glen Canyon Dam to Lake Mead; found in the Little Colorado River
Goldfish (*Carassius auratus*)	Eurasia	Lake Powell; Lake Mead; upper Little Colorado River watershed
Plains killifish (*Fundulus zebrinus*)	North America	Little Colorado River; Colorado River from Little Colorado River confluence to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon
Mosquitofish (*Gambusia affinis*)	North America	Lake Powell; Colorado River from Separation Canyon to Lake Mead; generally absent from Glen Canyon and Marble Canyon; locally common in some areas of the Grand Canyon
Striped bass (*Morone saxatilis*)	North America	Lake Powell; Colorado River from Havasu Creek to Lake Mead
Gizzard shad (*Dorosoma cepedianum*)	North America	Lake Powell; generally absent from Glen Canyon, Marble Canyon, and the Grand Canyon
Threadfin shad (*Dorosoma petenense*)	North America	Lake Powell; Lake Mead; Colorado River from Glen Canyon to Separation Canyon; Upper Little Colorado River watershed; generally rare in Glen Canyon, Marble Canyon, and the Grand Canyon

Sources: Holden and Stalnaker (1975); Valdez and Ryel (1995); Gloss and Coggins (2005); Valdez and Speas (2007); Coggins et al. (2011); Reclamation (2011e)

Common nonnative fish species in Lake Powell include striped bass, smallmouth bass, largemouth bass, walleye, bluegill, green sunfish, common carp, and channel catfish. Species that occur in the reservoir and are also associated with tributaries and inflow areas downstream of Glen Canyon Dam, include fathead minnow, mosquitofish, red shiner, and plains killifish (NPS 1996; Reclamation 2007). Largemouth bass and black crappie populations were stocked initially and, following successful establishment, were the principal target species in the sport fisheries for many years. Both species have declined in years due to a lack of habitat structure for young fish. Filling and fluctuation of the reservoir resulted in changing habitat that eliminated most of the vegetation favored by many species (Reclamation 2007a). Smallmouth bass and striped bass were introduced following these changes in habitat structure and are now the dominant predators in the reservoir (Reclamation 2007a). Threadfin shad were introduced to provide an additional forage base and quickly became the predominant prey species (NPS 1996). Gizzard shad were accidentally introduced into Morgan Reservoir in the San Juan River drainage in 1996 and subsequently proliferated in Lake Powell (Mueller and Brooks 2004; Vatland and Budy 2007).

Reductions in Lake Powell’s levels have lowered the epilimnetic (top) and mesolimnetic (middle) layers in proximity to the dam penstocks where fish can become entrained. Some of these fish survive passage through the generators and end up downstream of Glen Canyon Dam. Two species that are believed to have become entrained in the penstocks and passed downstream into the Colorado River are substantial predators of native fish, including the humpback chub. These nonnative fish species include the smallmouth bass and the green sunfish. Smallmouth bass and green sunfish live in the warmer levels of the lake’s waters, closer to the surface. As warmer water reaches the dam’s water intakes, the nonnative, predatory fish have a greater chance of passing through the dam alive. This increases the threats to the native fish in the Grand Canyon and Glen Canyon’s downstream rainbow trout fishery.

Juvenile smallmouth bass were found in the Colorado River in a slough habitat about 3 miles below Glen Canyon Dam on June 30, 2022, and during July and August in 2023, underscoring the urgency of this emergent issue. In September 2022 and August 2023, the NPS began to deploy the EPA-approved fish piscicide rotenone to kill these invasive, predatory fish.

The Comprehensive Fisheries Management Plan (NPS 2013a) and Expanded Non-Native Aquatic Species Management Plan (NPS 2019) for GCNRA and GCNP describe management actions and tools that can be taken in the Colorado River below Glen Canyon Dam to improve the recreational rainbow trout fishery in GCNRA while protecting native fish in the Grand Canyon. These plans were developed in close cooperation with AZGFD and other partners. They identify smallmouth bass, walleye, flathead catfish, and brown trout as “Very High threat level” and rainbow trout and green sunfish as “High threat level.” Threat levels were assigned based on their current abundance and distribution and following reviews of published literature on their potential for adverse impact. These threats are assessed annually, and actions to address each of these threats are being developed. Healy et al. (2022) demonstrate how management actions such as a fall HFE can have unanticipated consequences, including triggering migration, colonization, and rapid population growth by brown trout, to the Colorado River below Glen Canyon Dam. Brown trout are established in Bright Angel Creek and have expanded their distribution upstream to the tailwaters of Glen Canyon Dam likely aided by fall HFEs and flow management (Healy et al. 2022). Increased flows during fall HFEs likely initiated migration of adult brown trout to upstream spawning grounds, thus resulting in expansion of the population (Runge et al. 2018).

In addition, the annual distribution of nonnative fish in the lower portions of the Grand Canyon is influenced by the elevation of Lake Mead at the interface of the Colorado River inflow. A lower lake elevation starting in early 2000 allowed the Colorado River to carve a new channel and form a large rapid about mile downstream of Lees Ferry. This rapid has sufficient drop and velocity to be at least a partial barrier to most fish species (Hansen 2021) and has reduced the access by nonnative fish species moving upstream in the Lower Colorado River from Lake Mead. This rapid could reduce the numbers of predaceous species in the lower Grand Canyon, like smallmouth bass, striped bass, walleye, and channel catfish, which might otherwise move into the Colorado River.

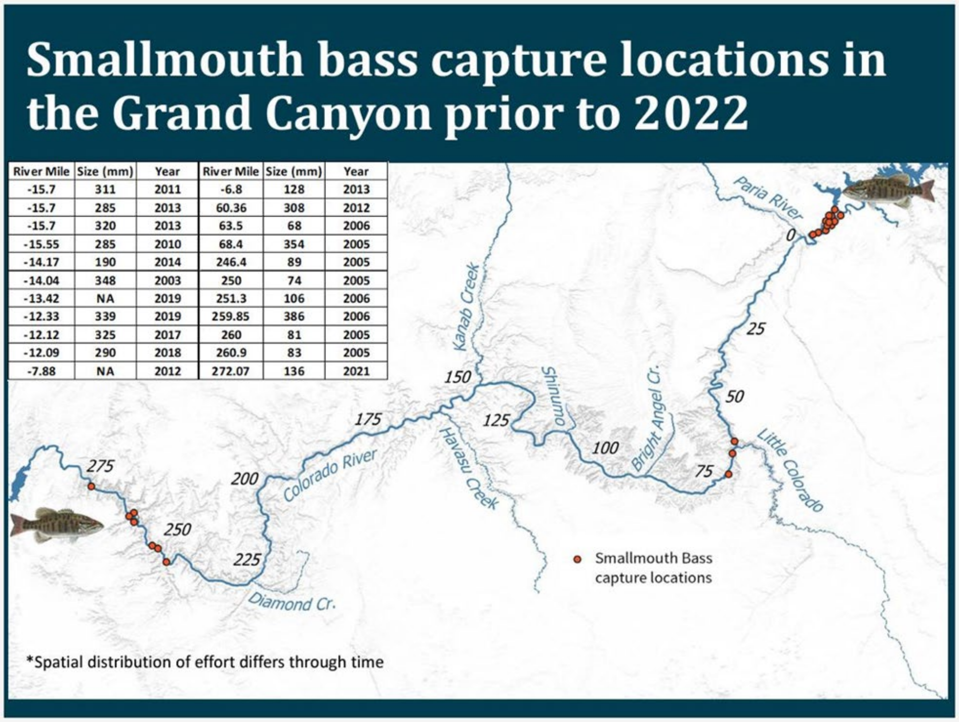
More detailed information on cold-water and warmwater nonnative fish species is provided in the next two sections.

Smallmouth Bass

The smallmouth bass is an invasive and large-bodied piscivorous fish that is a substantial threat to native fish populations throughout the Upper Colorado River Basin (Breton et al. 2015). Based on results of a bioenergetics model, Johnson et al. (2008) ranked smallmouth bass as the most problematic invasive species in the Upper Basin because of their high abundance, habitat use that overlaps with most native fish, and ability to consume a wide variety of life stages of native fish (Bestgen et al. 2008). Expanded populations of piscivores such as smallmouth bass are a major impediment to conservation actions aimed at recovery efforts for the four endangered fish in the Upper Colorado River Basin (Service 2002a, 2002b, 2002c, 2002d, 2018, 2020). Smallmouth bass also pose a threat to other desirable species in the Grand Canyon, including rainbow trout and brown trout that are considered sportfish.

Distribution and Abundance. The smallmouth bass is native to interior eastern North America west of the Appalachian Mountains, but it has been widely introduced throughout the United States. The smallmouth bass was stocked into Lake Powell in 1982 and has been observed in the Colorado River downstream of Glen Canyon Dam since early 2000, although the source of these fish is not known. Prior to 2022, there are records of 22 individuals being caught between Glen Canyon Dam and Pearce Ferry (**Figure 3-24**). Capture locations show three concentrations of fish, including at the Lees Ferry reach below the dam, near the confluence of the Little Colorado River, and in the newly exposed channel at the inflow to Lake Mead.

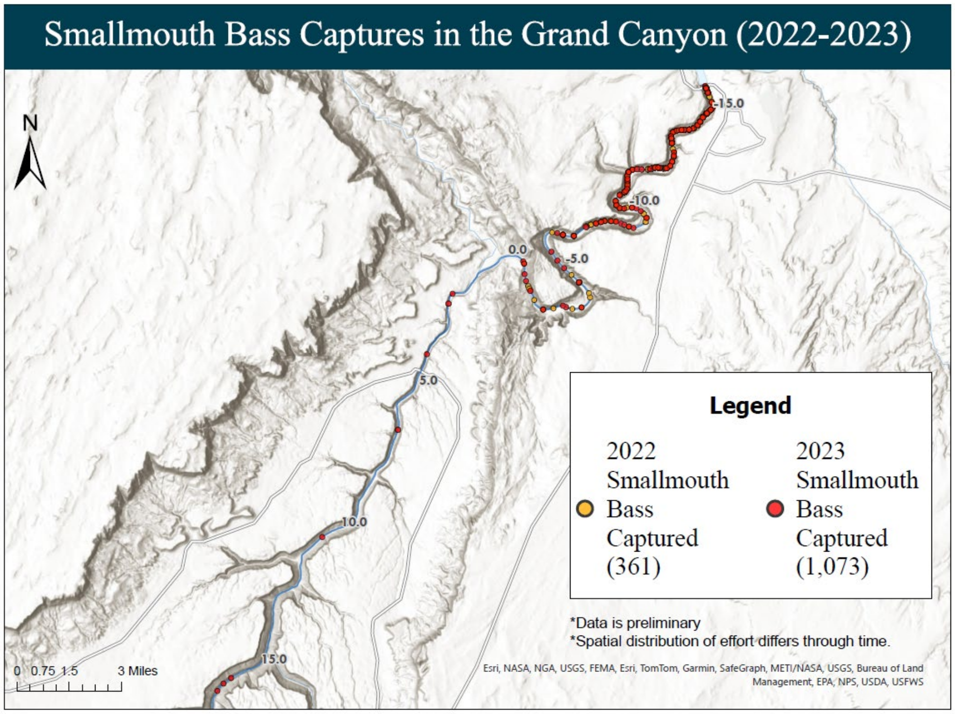
Figure 3-24
Smallmouth Bass Capture Locations in the Grand Canyon prior to 2022 and 2022-2023



River Mile	Size (mm)	Year	River Mile	Size (mm)	Year
-15.7	311	2011	-6.8	128	2013
-15.7	285	2013	60.36	308	2012
-15.7	320	2013	63.5	68	2006
-15.55	285	2010	68.4	354	2005
-14.17	190	2014	246.4	89	2005
-14.04	348	2003	250	74	2005
-13.42	NA	2019	251.3	106	2006
-12.33	339	2019	259.85	386	2006
-12.12	325	2017	260	81	2005
-12.09	290	2018	260.9	83	2005
-7.88	NA	2012	272.07	136	2021

*Spatial distribution of effort differs through time

Source: GCMRC 2014



*Data is preliminary
*Spatial distribution of effort differs through time.

Source: Reclamation GIS 2024

The likely origin of these fish is passage through the dam, moving down the Little Colorado River from upstream reservoirs, and moving upstream from Lake Mead, respectively; some bass have also possibly moved or been transported downstream from the Lees Ferry reach. Greater numbers of smallmouth bass have been captured in the Lees Ferry reach in 2022 and 2023 that have either passed from Lake Powell through the penstocks or have been recently spawned in the area. Most of the smallmouth bass in the Lees Ferry reach have been caught in and near the -12-mile slough (located 12 miles upstream of Lees Ferry), a small side channel of the Colorado River. Prior to 2022, the bass were mostly large subadults and adults, suggesting that these fish survived passing from Lake Powell through the penstocks. Starting in 2022, many of the bass are smaller, indicating that these fish have been produced locally, probably in and around the -12-mile slough.

Specific data on these fish have been collected but are not available or citable at this time. A preliminary integrated smallmouth bass model has been developed that predicts propagule pressure (entrainment or passage of smallmouth bass through Glen Canyon Dam) and downriver population growth (lambda) based on Lake Powell elevation and temperature, lake inflow volumes, and outflows (see **Appendix A**). These predictions, which are for river mile 15 and the Little Colorado River confluence, can be used to inform possible impacts of alternatives on smallmouth bass. The smallmouth bass model does not link at this time to other population models, such as the humpback chub integrated model.

Habitat and Life History. Within its native range the smallmouth bass seems most abundant in pools of streams that consist of a substantial proportion of riffle habitat, clean, rocky, hard bottoms, and gradients of 0.5 to about 5.0 meters per kilometer. In large rivers and lakes, smallmouth bass tend to congregate over hard, stony bottoms, where currents are present. Currently, smallmouth bass occur in the mainstream Colorado River, in the Verde River system, and throughout the Salt River Basin below about 2,200 meters in elevation (AZGFD 2005).

Temperature is one of the most important factors limiting distribution of smallmouth bass (Bestgen 2018). Faster growth rates of adults are generally associated with higher summer temperatures. Faster growth rates occur in southern reservoirs, resulting in a shorter life span than in northern regions. In summer, smallmouth bass inhabit warmer shoreline areas of large lakes in the north and deeper, cooler waters in the south. Growth does not begin until water temperatures reach 10–14°C (50–57°F). Field data indicate that adults prefer temperatures of about 21–27°C (70–81°F) in summer. Smallmouth bass have been reported “sunning” themselves in pools with water temperatures of about 26.7°C (80°F) in summer (Edwards et al. 1983). When temperatures drop to 15–20°C (59–68°F), adults seek deep, dark areas. At about 10°C (50°F), bass become inactive and seek shelter. At 6–7°C (43–45°F), most smallmouth bass are beneath the rock substrate, with few remaining on top. The lower lethal temperature is near freezing. Bass will congregate around warm springs in winter when available.

Smallmouth bass spawn in spring, usually mid-April to July, depending on geographical location and water temperature. Large fluctuations in water level can affect reproductive success of smallmouth bass (Pflieger 1975; Montgomery et al. 1980). Ideal spawning conditions include one or more substantial rises in water level a week or two prior to bass nesting (Pflieger 1975) and relatively stable water levels while nesting is in progress (Watson 1955; Pflieger 1975). Rising water may flush nest areas with cold water, causing nest desertion and halting embryo development (Watt 1959; Montgomery et al. 1980). Falling water levels may drive guarding males off, limit water circulation around eggs, and increase predation, resulting in lower reproductive success (Neves 1975; Montgomery et al. 1980).

Fry seem to be especially vulnerable to flood conditions and fluctuating water levels (Larimore 1975). A rapid drop in water level may trap them in areas where they will become desiccated (Montgomery et al. 1980). A stream rise of only a few inches, and consequent increase in water velocity, may displace advanced fry newly risen from the nest (Webster 1954). Most fry remain in shallow water (Doan 1940; Forney 1972), although some may be found at depths of 4.6–6.1 meters (approximately 15–20 feet) (Stone et al. 1954; Forney 1972). Fry 20–25 millimeters (0.79–1 inch) in length cannot maintain themselves in current velocities faster than 200 millimeters per second (Larimore and Duever 1968). An increase in turbulence during floods creates conditions with which smallmouth fry appear unable to cope (Webster 1954). Fry also cannot tolerate and are displaced at high turbidities (2,000 Jackson Turbidity Units) combined with an increase in water velocity, but they will not be displaced at moderate turbidities (250 Jackson Turbidity Units) (Larimore 1975). Low water temperatures during flood conditions will reduce fry swimming ability (Larimore and Duever 1968).

Bestgen and Hill (2016b) studied patterns of smallmouth bass reproduction in partially regulated and unregulated reaches of the Green River and the unregulated Yampa River of the Upper Colorado River Basin. Patterns of reproduction in the Yampa River were in contrast with regulated or partially regulated Green River reaches, where smallmouth bass reproduction occurred later, and sometimes well after water temperatures reached the threshold 15.5°C (60°F). In the regulated reach of the Green River, successful hatching did not occur until relatively low and stable baseflow levels were reached, noting that high streamflow in 2011 delayed hatching. They postulated that stable baseflows were required for smallmouth bass so spawning habitat was available and suitable for successful reproduction; spawning at higher flows may have been attempted but could not be determined.

Mature females may contain 2,000–15,000 golden yellow eggs. Males may spawn with several females on a single nest. On average each nest contains about 2,500 eggs, but nests may contain as many as 10,000 eggs (Pflieger 1975). Eggs hatch in about 10 days at water temperatures of 12.8°C (55°F), but can hatch in 2 to 3 days if temperatures are approximately 23.9°C (75°F). Males guard the nest from the time eggs are laid until fry begin to disperse, a period of up to a month (Pflieger 1975).

Proposal to Manage Smallmouth Bass in the Grand Canyon. The existence of established smallmouth bass populations in Lake Powell combined with the passing of epilimnetic water from the lake through Glen Canyon Dam to the Colorado River below creates a conduit for repeated introduction of smallmouth bass below Glen Canyon Dam. This complicates efforts to minimize the risk of smallmouth bass establishment and expansion in the Colorado River below Glen Canyon Dam. While directed removal efforts can take place in areas where smallmouth bass have been identified, because introductions of smallmouth bass from Lake Powell could continue unless deterrents are developed, five flow options from Glen Canyon Dam are currently being evaluated as directed by the Secretary of the Interior's designee as part of the SMB EA (Reclamation 2023). These five alternatives all involve releasing water from Glen Canyon Dam to disrupt smallmouth bass spawning—through changes in water velocity to alter smallmouth bass nesting behavior and increase mortality rate of fry and larvae, through decreases in water temperature to prevent or delay the onset of spawning, or through a combination of modified flow and temperature—to try and prevent smallmouth bass from reproducing and establishing downstream of Glen Canyon Dam. A proposed target water temperature for these actions is mainstream water temperature of 15.5°C (60°F), near the confluence of the Little Colorado River (river mile 61), the temperature when smallmouth bass spawning behavior begins for introduced populations in the Upper Colorado River Basin (Bestgen and Hill 2016b).

Cold-water Nonnative Species

Brown and rainbow trout make up the cold-water nonnative fish community of the Colorado River between Glen Canyon Dam and the inflow to Lake Mead. The rainbow trout is common in the Glen Canyon reach and in the mainstream Colorado River between the confluence with the Paria River and the confluence with the Little Colorado River (Makinster et al. 2010; Reclamation 2011c). Rainbow trout are also found in Bright Angel Creek, Shinumo Creek, Nankoweap Creek, Tapeats Creek, Kanab Creek, and Havasu Creek (Reclamation 2011c). Brown trout are found primarily in and near Bright Angel Creek, which supports a small spawning population (Reclamation 2011c), but they are also found throughout the upper reaches of the river corridor, including in Glen Canyon. Since 2017, brown trout have been captured relatively infrequently in the Grand Canyon with only 19 individuals captured between river miles 17.9 and 277.5 during sampling in 2022 (Fonken et al. 2023).

Rainbow Trout

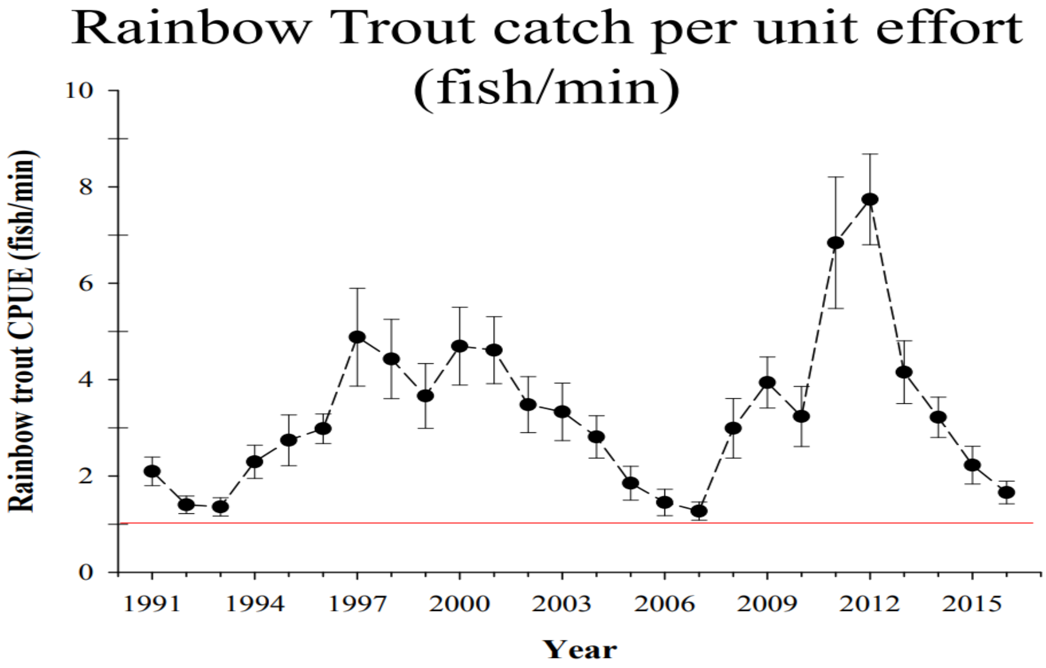
The rainbow trout is very common in the reach of the mainstream Colorado from Glen Canyon Dam to the Paria River, and this population serves as the principal basis for the trout fishery. This species is also found in relatively high abundance in Marble Canyon between the Paria River and the confluence of the Colorado River with the Little Colorado River (Makinster et al. 2010; Reclamation 2011c). Downstream of the Little Colorado River confluence, smaller numbers of rainbow trout are found in localized aggregations associated with some tributaries, such as Nankoweap Creek and Tapeats Creek.

Rainbow trout were initially introduced in the Grand Canyon region through stocking of tributaries, such as Bright Angel Creek, during the 1920s. Additional introductions of rainbow trout were made downstream of Glen Canyon Dam in 1964 following completion of dam construction. Prior to 1991, the population was maintained through annual stocking, and stocking continued through 1998 (Makinster et al. 2011). Since that time, the Glen Canyon rainbow trout fishery has been maintained through natural reproduction of rainbow trout rather than through stocking, and, with the exception of localized spawning in some downstream tributaries, most of the rainbow trout production in the Colorado River downstream of Glen Canyon Dam occurs within the Glen Canyon reach.

Standardized annual monitoring of the population of rainbow trout in the 15-mile reach of the Colorado River between Glen Canyon Dam and Lees Ferry began in 1991. Based on catches of rainbow trout during annual monitoring surveys, the abundance of rainbow trout in Glen Canyon generally increased over the period from 1991 to 1997, remained at high levels until approximately

2001, and then declined to low levels by 2007 (**Figure 3-25**). From 2008 through 2010, the relative abundance of rainbow trout in the Glen Canyon reach again increased to near historic high levels. Relative abundance reached all-time high levels in water years 2011 and 2012, followed by a decline in water year 2013 consistent with previous high abundance estimates (AZGFD data as reported in GCMRC 2014; **Figure 3-25**). The decline continued to the lowest level in 2016 (Rogowski et al. 2023). This decline in rainbow trout in the Lees Ferry reach may be related to declines in nutrient levels from lower reservoir elevations (Yard et al. 2023).

Figure 3-25
Mean (±2 Standard Error) Electrofishing Catch Rates of Rainbow Trout in the Glen Canyon Reach, 1991–2016



Source: Rogowski et al. 2023

Rainbow trout recruitment and population size within the Glen Canyon reach appear to be largely driven by dam operations (AZGFD 1996; McKinney et al. 1999a; McKinney et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman et al. 2011; Korman et al. 2012). McKinney et al. (1999a) attributed the increase in abundance from 1991 to 1997 to increased minimum flows and reduced fluctuations in daily discharges resulting from the implementation of interim flows between 1991 and 1996 and adoption of the current modified low fluctuating flow regime in 1996. The decline in abundance from 2001 to 2007 has been attributed to the combined influence of increased trout metabolic demands 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 mud snail, which serves as a poor food source (Cross 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.

Long-term monitoring of the rainbow trout population in Lees Ferry (**Figure 3-25**; Rogowski et al. 2023) shows the highest catch rate in 2011 and 2012, likely as a consequence of warmer releases from Glen Canyon Dam and an input of nutrients from a changed reservoir elevation of Lake Powell. This was after a fall steady flow experiment and equalization flows in 2011 that boosted food base production in the Lees Ferry reach and contributed to greater growth and an increase in abundance of rainbow trout. The population declined tenfold by 2016 due to a combination of lower recruitment and reduced survival of larger trout, which were likely driven by changes in nutrients and invertebrate prey availability (Yard et al. 2023). Survival rates for trout 8.8 inches or longer in 2014, 2015, and 2016 were, respectively, 11 percent, 21 percent, and 22 percent lower than average survival rates between 2012 and 2013. Abundance would have been threefold to fivefold higher had survival rates for larger trout remained at the elevated levels estimated for 2012 and 2013.

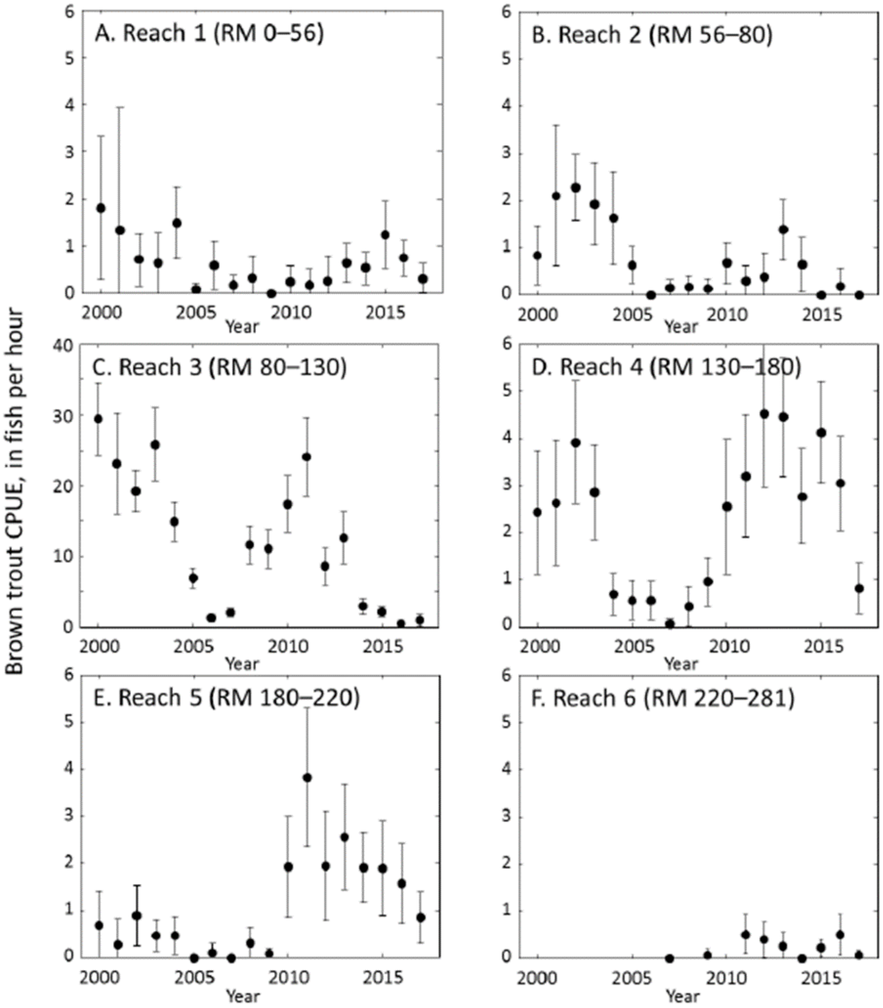
Rainbow trout growth declined between 2012 and 2014 due to reduced prey availability, which led to very poor fish condition by fall of 2014 (approximately 0.9–0.95, fish condition). Poor condition in turn resulted in low survival rates of larger fish during the fall of 2014 and winter of 2015, which contributed to the population collapse. In Glen Canyon, large recruitment events driven by high flows can lead to increases in the population that cannot be sustained due to limitations in prey supply. In the absence of the ability to regulate prey supply, flows that reduce the probability of large recruitment events can be used to avoid boom-and-bust population cycles (Korman et al. 2017).

Brown Trout

As with rainbow trout, brown trout are not native to the Colorado River and were stocked in the Grand Canyon in the first half of the 1900s. Brown trout are no longer stocked in the Colorado River downstream of Glen Canyon Dam and are now found primarily in Glen Canyon below the dam as NPS removals have substantially decreased brown trout numbers around Bright Angel Creek (Healy et al. 2020).

Overall, the abundance (based on electrofishing surveys) of brown trout in the Colorado River between Lees Ferry and Pearce Ferry at the Lake Mead inflow declined from 2000 to 2006; abundance may have increased somewhat between 2007 and 2009 (**Figure 3-26**; Makinster et al. 2010), but increases were observed concurrently with more frequent HFE releases during fall (Runge et al. 2018; Yackulic et al. 2020; Healy et al. 2023). Because spawning by brown trout in the Grand Canyon occurs primarily in tributaries (for example, Bright Angel Creek), recruitment rates may be less affected by conditions in the mainstream than recruitment rates of rainbow trout. However, increases in brown trout recruitment were observed in 2014–2015 in the Lees Ferry reach of the Colorado River in Glen Canyon (Stewart 2016), and adult brown trout immigration to Lees Ferry is likely influenced by management actions both in tributaries and the mainstream (Healey et al. 2023). Brown trout were observed to be spawning near the 4-mile bar in Glen Canyon during the fall of 2014, and an increase in age-1 brown trout, likely as a result of spawning and recruitment in 2014, was observed in 2015 (Korman et al. 2015). Spawning of brown trout was also observed during October and November of 2015 near the 4-mile bar in Glen Canyon (Korman et al. 2015).

Figure 3-26
Mean Catch-per-unit Effort of Brown Trout between Lees Ferry and Pearce Ferry (2000-2017)



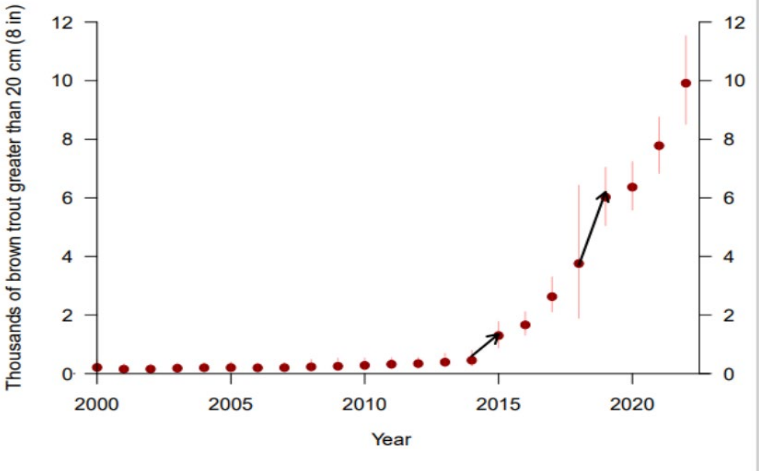
Sources: Data from AZGFD; figure from Runge et al. 2018
Notes: Captured during electrofishing surveys on the Colorado River between Lees Ferry and Pearce Ferry for reaches 1–6 (plots A–F), 2000–2017. Reach locations are provided in river miles downstream of Lees Ferry (river mile 0). Most surveys occurred during the spring (April–June). The closed circles show the mean value; error bars represent 95 percent confidence intervals; note change in y-axis scales. Reach 6 (F) was sampled in 2004–2006 and in 2010, but data were not included because of high turbidity, and no sampling occurred in 2008 for Reach 6.

Although the number of brown trout is small relative to rainbow trout, Yard et al. (2011) found that, on an individual basis, the brown trout is a more active predator on native fish in the Colorado River than rainbow trout (see subsection **Rainbow Trout**). Yard et al. (2011) also found a significant positive correlation between temperature and the levels of piscivory by brown trout. Other studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout in different ways. For example, while the incidence of predation attempts increased, the success of predation of rainbow trout on YOY humpback chub decreased as temperatures increased from 10°C to 20°C (50°F to 68°F) (Ward 2011). In contrast, the success of predation by brown trout did not change significantly over the same temperature range (Ward 2011).

The brown trout population at Lees Ferry historically consisted of a small number of large fish supported by low levels of immigration from downstream reaches. Over the period 2014–2016, the number of nonnative brown trout captured during routine monitoring in the Lees Ferry reach, downstream of Glen Canyon Dam, began increasing. This pattern persisted into 2019 (Healy et al. 2023). Management agencies and stakeholders questioned whether this increase in brown trout represents a threat to the humpback chub, to the rainbow trout sport fishery, or to other resources of concern. This population of brown trout is showing signs of sustained successful reproduction and is on the cusp of recruiting locally hatched fish into the spawning class, based on analysis with a new integrated population model (Runge et al. 2018). The proximate causes of this change in status are a large pulse of immigration in the fall of 2014 and higher reproductive rates in 2015–2017. The ultimate causes of this change are not clear. The pulse of immigrants from downstream reaches in fall 2014 may have been induced by three sequential HFE releases from the dam in the Novembers of 2012–2014, but they may also have been the result of a unique set of circumstances unrelated to dam operations. The increase in reproduction may have been the result of any number of changes, including an Allee effect, warmer water temperatures, a decrease in competition from rainbow trout, or fall high-flow releases.

Correlations over space and time among predictor variables do not allow for a clear inference about the cause of the changes. Brown trout incidence of predation was higher (8 to 70 percent) than the rainbow trout IP (0.5 to 3.3 percent); however, rainbow trout were 50 times more abundant than brown trout in the study area (Yard et al. 2011) Brown trout are also able to thrive in warmer river water than rainbow trout and are better adapted to hunting other fish in the murky river water of the Colorado River when the Paria River and side canyons are flowing.

Figure 3-27
Abundance of Adult Brown Trout in the Lees Ferry Reach, 2000–2022



Source: Rogowski 2023

The numbers of brown trout in Lees Ferry increased from 2014 to 2016, primarily in adult size classes (Runge et al. 2018). Healy et al. (2022) document how the use of a weir to block access to tributary spawning areas combined with fall HFEs from Glen Canyon likely lead to increases in brown trout immigration to the Glen Canyon Dam tailwaters. Runge et al. (2018) also evaluated the impact of brown trout expansion on humpback chub downstream and proposed and evaluated management options. The abundance of brown trout in the Lees Ferry reach has increased dramatically from 2015 to 2022, and this uptick will potentially affect rainbow trout as predators in the Lees Ferry reach, humpback chub and other native species downstream (depending on movement patterns of brown trout), and the aquatic food base.

There are interventions that may be effective in moderating the growth of the brown trout population in the Lees Ferry reach. Across causal hypotheses, it is predicted that removal strategies (for example, a concerted electrofishing effort or an incentivized take program targeted at large brown trout) could reduce brown trout abundance by approximately 50 percent relative to status quo management. Reductions in the frequency or a change in the seasonal timing of high-flow releases from Glen Canyon Dam could be even more effective, but only under the causal hypotheses that involve effects of such releases on immigration or reproduction. Brown trout management flows (i.e., dam releases designed to strand young fish at a vulnerable stage) may be able to reduce brown trout abundance to some degree but are not forecast to be the most effective strategy under any causal hypothesis (Runge et al. 2018).

Runge et al. (2018) considered six alternatives to managing the brown trout population, including the status quo, two strategies aimed at removing adult brown trout, and three strategies designed to discourage immigration or reproduction through flow operations. These six alternatives were not meant to be comprehensive. There was a much larger set of possible interventions, including large infrastructure options like building a temperature control device on the dam, but the focus was on practical approaches whose implementation seemed to be possible in the near term (say, the next 5 years). One strategy was to reward anglers that catch and keep brown trout as an incentive to remove the fish from the river. The incentivized harvest began November 11, 2020. For the next 3 to 4 years, eligible anglers will be offered a reward of at least $25 for each brown trout over 6 inches in length removed from the Colorado River between Glen Canyon Dam and the mouth of the Paria River. This reward may vary with the seasons or be adjusted annually but will typically be in the range of $25–$33. The current reward is $33 per brown trout and $15 for each PIT-tagged brown trout. In May of 2022, there was a total payout of $16,529 to 34 anglers with one angler receiving $9,876. A total of 163 brown trout were removed in May with 30 PIT tags returned. The incentivized harvest program shows a decline in the numbers of brown trout in the Lee's Ferry reach indicating the effectiveness of this program (GCMRC 2024).

Surveys of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead, as well as experimental fish removal studies, indicate the presence of 17 nonnative warmwater fish species (Trammell and Valdez 2003; Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011; Albrecht et al. 2014; Rogowski et al. 2017; **Table 3-30**). Among the species collected, the common carp, fathead minnow, and red shiner are generally the most common warmwater species in the mainstream tributaries (Ackerman et al. 2006; Makinster et al. 2010; Coggins et al. 2011). Smaller -bodied warmwater nonnative species, such as fathead minnow, red shiner, plains killifish, and bullhead, are found primarily in tributaries, especially in the Little Colorado River. Other species collected from this reach include green sunfish, smallmouth bass, striped bass, redside shiner, golden shiner, and walleye (Service 2008). During July 2015, a large (compared to previous green sunfish captures), reproducing population of green sunfish was discovered in a slough at river mile -12, approximately 3 miles downstream of Glen Canyon Dam. Neither the source nor the mechanism of introduction for some of these species (such as green sunfish and smallmouth bass) into the Glen Canyon reach is known with certainty; however, the nearest source for a number of these species is Lake Powell and their most likely entrance into this reach is entrainment through the dam. These species are also reproducing in and around the -12 river mile slough.

Over the 23 years of AZGFD monitoring, relative abundance of most nonnative fish species has decreased, and abundance of most native species has increased. In 2022, similar fish distribution patterns to recent years were observed (e.g., 2016–present), with nonnative rainbow trout composing most (89.4 percent) of the electrofishing catch in Marble Canyon, and native fish composing most of the catch (98.7 percent) downstream of the Little Colorado River confluence (USGS 2023b).

Interactions with Native Species

Nonnative fish in the Colorado River are considered to adversely affect native fish in the system through predation and/or competition, and by serving as hosts for parasites (Minckley 1991; Coggins et al. 2002, 2011; Gloss and Coggins 2005; Olden and Poff 2005).

Table 3-31
Nonnative Warmwater Fish Species Reported from the Little Colorado River Watershed

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

Species	Below Chute Falls	Above Chute Falls
Black crappie	-	X
Yellow perch	-	X

Sources: Ward and Persons 2006; Stone et al. 2007

[a] X = present; – = absent

[b] Fish reported from below and above Chute Falls within the 21-mile perennially flowing portion of the Little Colorado River corridor

Predation and Competition

Piscivory by rainbow and brown trout has been suggested as a large source of mortality for native fish in the Colorado River and its tributaries below Glen Canyon Dam (Blinn et al. 1993; Marsh and Douglas 1997; Yard et al. 2011; Whiting et al. 2014). Near the confluence of the Little Colorado River, Yard et al. (2011) found that 90 percent of the vertebrate prey consumed by rainbow and brown trout were fish and estimated that rainbow and brown trout consumed over 30,000 fish in the vicinity of the Little Colorado River during a 1-year study period. The incidence of piscivory (proportion of individuals feeding on fish) by species was 70 percent for brown trout and only up to 3.3 percent for rainbow trout. However, rainbow trout were approximately 50 times more abundant during the study period, and it was estimated that they accounted for more than half of the total number of fish consumed in the analysis area (Yard et al. 2011). Overall, trout ate 85 percent more native fish than nonnative fish, even though native fish composed less than 30 percent of the small fish available as prey in the analysis area. Of ingested fish that were identifiable, 56 percent was composed of native fish, while another 28.8 percent was composed of unidentified suckers (presumably native flannelmouth and bluehead suckers). Of the identified native fish consumed by the trout, about 27 percent were humpback chub, 15 percent were speckled dace, 11 percent were flannelmouth sucker, and 3 percent were bluehead sucker (Yard et al. 2011). Because the majority of humpback chub consumed by trout during the study were YOY and subadults (less than 3 years old), predation on such fish could affect recruitment to the humpback chub population in the Grand Canyon (Coggins and Walters 2009; Yard et al. 2011). Because of differences in the levels of piscivory exhibited by brown and rainbow trout, current decisions to implement removal actions at the Little Colorado River to benefit humpback chub are triggered by levels of both brown trout and rainbow trout present in the reach, as well as consideration of the status (estimated size) of the humpback chub population.

In the Grand Canyon, brown trout, rainbow trout, channel catfish, and black bullhead are considered the primary predators of humpback chub, while common carp are a major humpback chub egg predator in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; Service 2008). Fathead minnow, red shiner, and plains killifish may be important predators and competitors of young humpback chub, especially in the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1997; Service 2008). Marsh and Douglas (1997) examined predation of native fish by nonnative fish in the Little Colorado River and found rainbow and brown trout, channel catfish, and black and yellow bullhead to be predators of native fish. In stomachs from these species that contained food, native fish composed about 14 percent of the ingested materials, and ingested species included humpback chub, speckled dace, and bluehead and flannelmouth suckers. Whiting et al. (2014) evaluated the diets of rainbow and brown trout from Bright Angel Creek and found that native fish (primarily speckled dace) composed approximately 4 percent of the diet for larger rainbow trout and 19 percent of the diet for larger brown trout.

While trout predation on humpback chub has been demonstrated, it is uncertain whether or not trout piscivory has had (or has) a population-level effect on the humpback chub (Yard et al. 2011). Although survival and recruitment of humpback chub have increased following trout removal in 2003 and 2006, it is not known if this increase is due to trout removal or other environmental factors (including warming water temperature), and further experimentation would be needed to tease apart other system-level dynamics that could have contributed to the adult humpback chub population increases observed since 2000. For example, the temperature of water released from Glen Canyon Dam increased during the trout removal study period to temperatures that may have improved humpback chub growth and survival (Coggins et al. 2011) and that caused negative impacts on trout populations. Ongoing studies have indicated that water temperature may influence the susceptibility of native fish to predation from brown and rainbow trout (for example, Ward 2011; Ward and Morton-Starner 2015).

Research on the food web dynamics of the Grand Canyon provides further evidence that competition between native fish and nonnative fish is likely occurring. Invertebrates, primarily blackflies and midges, are important food items for both humpback chub and nonnative fish, particularly rainbow trout. Throughout Marble and Grand Canyons, invertebrate production is low, and fish consume most of this production. Cross et al. (2013) hypothesized that an influx of rainbow trout from upstream, coupled with this limited resource base, may lead to strong competition among fish in the Grand Canyon and that dam operations that alter fish populations, such as HFE releases, may exacerbate this effect.

Parasites and Diseases

The potential for expansions and infestations of nonnative parasites may also be influenced by water temperatures. Rahel and Olden (2008) suggested that climate change could facilitate expansion of nonnative parasites. This may be an important threat to humpback chub. Optimal Asian tapeworm development occurs at 25–30°C (77–86°F) (Granath and Esch 1983), and optimal anchor worm temperatures are 23–30°C (73–86°F) (Bulow et al. 1979). Cold water temperatures in the mainstream Colorado River in Marble and Grand Canyons have likely prevented these parasites from completing their life cycles and limited their distribution. Warmer climate trends or operational alternatives could result in warmer overall water temperatures, thereby increasing the prevalence of these parasites, which can weaken humpback chub and increase mortality rates. Declines in the elevation of Lake Powell have resulted in warmer releases from Glen Canyon Dam, and these warmer temperatures will likely provide more suitable conditions for the proliferation of a number of fish parasites that could negatively affect native fish species (see **Figure 3-34**).

Nonnative Fish Control Activities and Effects of Flow Conditions

A number of management activities have been designed and implemented to test their efficacy for controlling and reducing the abundance and distribution of nonnative fish in the Colorado River and its tributaries below Glen Canyon Dam. These control activities included (1) flow releases from Glen Canyon Dam designed to reduce trout recruitment, and (2) mechanical removal of trout and warmwater nonnative fish in the vicinity of the Colorado River–Little Colorado River confluence

(Reclamation 2011c). A series of HFE releases was conducted in 1996, 2004, 2008, 2012, 2013, 2014, 2016, 2018, and 2023 to benefit sandbar resources, improve camping beaches, and potentially improve the quality of shoreline habitats for native fish in GCNP (Melis et al. 2010, 2012). Dodrill et al. (2015) reported that although experimental floods increased the prevalence and extent of backwaters, the effects were modest and would be expected to dissipate quickly. There was a large increase in rainbow trout early life stage survival rates and in the abundance of rainbow trout following the 2008 spring HFE release; whether such increases would be supported by future spring HFE releases is unclear, and the effects of fall HFE releases on rainbow trout are less clear; however, preliminary analyses of recent studies indicate that the abundance of age-0 rainbow trout did not increase as a result of fall HFE releases that occurred in 2012, 2013, and 2014 (VanderKooi 2015; Gimbel 2015). The potential effects of HFE releases on trout are described below, as are the possible effects of equalization flows on trout.

Nonnative Fish Suppression Flows

Flows designed to reduce trout recruitment in Lees Ferry were tested in 2003–2005. These flows, conducted from January through March, were intended to dewater and expose rainbow trout redds (i.e., trout nests where eggs are deposited) in the Glen Canyon reach to lethal air temperatures for part of the day, thereby reducing the survival of trout eggs in the exposed redds (Korman et al. 2005; Korman et al. 2011; Korman and Melis 2011). The flow regimes tested during this period consisted of increasing the extent of daily flow variation during winter and early spring from the normal range of 10,000–18,000 cfs in January and 7,000–13,000 cfs in February–March to a range of 5,000–20,000 cfs in January–March; these operations also resulted in longer periods of dewatering for redds at lower elevations than would occur under normal operations. The fluctuating flows were determined to have resulted in increasing the incubation mortality rate from 5–11 percent under normal flow conditions to 23–49 percent under fluctuating flows (Korman et al. 2005; Korman et al. 2011; Korman and Melis 2011). However, no measurable reduction in age-0 abundance was observed, presumably due to increased survival of those rainbow trout that survived.

These results suggest that the increased level of incubation mortality (from the flow fluctuation) did not exceed compensatory survival responses (Korman et al. 2011). Because of these results, it has been suggested that a more limited fluctuating flow regime may be effective, targeting juvenile trout after the majority of density-dependent responses to egg incubation and hatching success have been realized, but before age-0 trout leave habitats that are potentially more sensitive to flow fluctuations (Korman et al. 2011; Korman and Melis 2011). Testing flow regimes under which flow variation is increased during late spring and summer months when small age-0 trout are utilizing potentially flow-sensitive, low-angle habitat has been suggested (Korman et al. 2005; Korman and Melis 2011).

Nonnative Fish Removal

The removal of predatory, nonnative fish has been conducted in various locations in the Upper and Lower Basins of the Colorado River since the mid-1990s with varying degrees of success (Mueller 2005). Since 2003, the Upper Colorado River Endangered Fish Recovery Program has mechanically removed (primarily with boat electrofishing) smallmouth bass from various regions of the Upper Colorado River Basin to reduce predation and competition on humpback chub, Colorado pikeminnow, razorback sucker, and bonytail. The numbers of smallmouth bass removed are in the millions and the program has spent a total of over $11.6 million. Annual expenditures for removal range from about $200,000 to nearly $1.1 million or about 5 to 27 percent of the program budget. This removal program has reduced the numbers of smallmouth bass in some areas and for short time periods, but the numbers rebound when suitable low-flow conditions prevail with warm temperatures. Recent (2021 and 2022) experimental releases from Flaming Gorge Dam have been used to disrupt smallmouth bass spawning in the Green River (Bestgen et al., USGS 2023b). Preliminary results from the 2021 experiment indicate spawning was interrupted; however, it is unclear whether smallmouth bass recruitment overall declined, which would be needed for flow modifications to be effective at reducing smallmouth bass populations (Bestgen et al.).

Removal of nonnative fish in the Colorado River near the Little Colorado River confluence was conducted from 2003 to 2006, and in 2009 (Korman et al. 2005; Makinster et al. 2009; Coggins et al. 2011). Fish removal activities in 2003–2006 captured more than 36,000 fish, of which 23,266 were nonnative species (including 19,020 rainbow trout) (Korman et al. 2005; Coggins et al. 2011). The removal of trout was estimated to have reduced rainbow trout abundance in this reach from about 6,500 in January 2003 to about 620 in February 2006. Immigration and recruitment account for the difference between the number of trout removed and the abundance estimates. During the 2003–2006 removal activities, large increases in the abundance of fathead minnow and black bullhead were reported beginning in September 2005, suggesting increases in immigration, survival, or both. The observed increase may have been due to increased emigration from the Little Colorado River where these species spawn, or because the combination of reduced rainbow trout numbers and increasing water temperatures may have caused these species to be more abundant and susceptible to capture (Coggins et al. 2011).

Coincident with the 2003–2006 removal activities, the humpback chub population stabilized and increased, suggesting that the nonnative fish removal (especially the removal of rainbow trout) may have allowed higher survival and recruitment by humpback chub (Coggins and Walters 2009; Coggins et al. 2011). However, the relationship between trout removal and survival of humpback chub is not clear because there was a systemwide decrease in rainbow trout abundance and drought-induced increases in river water temperatures during the time of the removal activities that could also have led to increased survival and recruitment of juvenile native fish (Coggins et al. 2011). As indicated in Figure 3-30, stabilization and increases in the adult humpback chub population may have begun as early as 2002, prior to the nonnative fish removal actions. Because changes in the adult humpback chub population rely, in part, on survival and recruitment of juvenile humpback chub, increases in survival rates may have occurred for several years prior to the fish removal activities. Further, even though the abundance of trout appeared to return to pre-removal levels by 2009, the estimated adult abundance of humpback chub continued to increase.

Nonnative fish removal was also conducted in 2009, the results of which indicated that rainbow trout abundance in the vicinity of the Little Colorado River had rebounded from the declines observed in 2006–2007 (Coggins et al. 2011; Reclamation 2011e). The number of rainbow trout in the vicinity of the Little Colorado River prior to the 2009 removal activities was estimated to be similar to the high densities estimated in 2002 (prior to the 2003 fish removal activities) (Wright and Kennedy 2011).

Nonnative fish removal is also being conducted in Shinumo and Bright Angel Creeks to restore and enhance the native fish communities and to reduce predation and competition on threatened humpback chub from nonnative fish. These removals are being conducted to implement conservation measures identified in the 2008 Biological Opinion, the 2009 Supplement, the 2011 Biological Opinion on the operation of Glen Canyon Dam, and the 2016 LTEMP FEIS (Service 2008, 2009; Reclamation 2011e, DOI 2016a). Nonnative fish (primarily rainbow trout) are being removed from Shinumo Creek to minimize predation on newly translocated humpback chub and to reduce competition. From 2009 through 2014, 5,569 rainbow trout were removed from Shinumo Creek using netting, angling, and electrofishing. Brown trout do not occur in Shinumo Creek above a waterfall barrier near the mouth, but a fe“ brown trou” were removed below the waterfall. Rainbow trout densities were reduced between summer 2011 and winter 2012 but rebounded with a strong cohort in June 2012 (likely a compensatory response). Abundance of bluehead sucker increased in the lower reaches downstream of translocation areas and speckled dace increased throughout Shinumo Creek as rainbow trout densities were reduced. A sequence of headwater fires and floods occurred in the summer of 2014 that almost eliminated all nonnative and native fish from Shinumo Creek (Healy et al. 2023). The NPS plans to remove the remaining nonnative trout and monitor the native fish. Nonnative fish, primarily rainbow trout, occur in small numbers in Havasu Creek and are also removed when encountered (Healy et al. 2014).

From 2010 to 2012, trout reduction efforts in Bright Angel Creek included the installation and operation of a fish weir trap and backpack electrofishing in the lower portion of the creek, including the confluence of Bright Angel Creek to Phantom Creek. From 2012 to 2015, removals were expanded to encompass the entire length of Bright Angel Creek (approximately 16 kilometers [about 10 miles]) and Roaring Springs (approximately 3 kilometers [about 2 miles]). The operation of the weir was also extended from October through February to capture greater temporal variability in the trout spawning migration. From 2010 to December 2014, about 28,000 brown trout and 4,800 rainbow trout were removed from Bright Angel Creek from both the weir and by electrofishing. Data on early 2015 removals and native fish response are still being analyzed, but trout abundance appears to have been reduced and native fish distribution has expanded upstream. These data are preliminary and may change slightly with further analysis (Healy et al. 2014; Nelson et al. 2012, 2015). As determined through consultation with Traditionally Associated Tribes and others, and consistent with the Memorandum of Agreement (MOA) between the NPS and the Arizona State Historic Preservation Office, trout removed from the creeks were preserved and distributed for beneficial use through human consumption, or for use by the Tribes for other purposes.

In July of 2015, AZGFD biologists discovered an unusually large, reproducing population of green sunfish in a backwater slough connected to the mainstream Colorado River approximately 3 miles downstream of Glen Canyon Dam. Although the downstream end of the slough is connected to the main channel under the typical range of releases from Glen Canyon Dam, the upstream end of the slough is isolated from the main channel except during high flows. Green sunfish are known to be prolific, with a single female capable of producing up to 10,000 eggs. Green sunfish are considered likely predators of small-bodied native fish and native fish eggs. Biologists with the AZGFD, NPS, USGS, Service, and Reclamation have determined that green sunfish pose a threat to native fish, including the humpback chub. Two removal efforts using electrofishing, seine netting, and trapping were conducted in August of 2015 but failed to deplete the population despite removing more than

3,000 fish. Biologists from the NPS and AZGFD constructed and installed a large block net at the downstream end of the main slough to minimize the escapement of green sunfish. After analyzing alternative methods for control, the agencies authorized a short-term targeted treatment of the slough with the fish toxin rotenone.

In 2017, the slough was treated with liquid ammonia to kill the green sunfish that were present, following techniques developed by Ward et al. (2013) in controlled ponds. The treatment was partly effective at killing fish but was considered impractical because of technical considerations and the short-term effect of the treatment. In 2018, a project was proposed by Reclamation (Greimann et al. 2018) with the goal of cooling water temperatures in the Upper Slough so that invasive green sunfish and other warmwater fish do not find warmwater conditions that allow them to propagate in this off-channel slough area. The proposed design showed that connecting the slough to the mainstream Colorado River would reduce temperatures in the slough sufficiently to not meet the thermal requirements of green sunfish for spawning. Despite these efforts, green sunfish are regularly captured by fish monitoring efforts in the mainstream river.

High-Flow Experiments

HFE releases build on two decades of extensive scientific research, experimentation, and analysis of the Colorado River downstream of Glen Canyon Dam. Spring HFE releases increase productivity of the aquatic food base, whereas fall HFE releases do not appear to affect the long-term composition of the aquatic food base and may scour the food base prior to the winter nongrowing season. HFE releases do not appear to directly affect humpback chub or the rainbow trout fishery, but there may be indirect effects tied to food base and trout production. Fall HFE releases may be connected to the recent increase in brown trout at Lees Ferry and consequent increased predation on rainbow trout and on downstream native fish populations (Yackulic et al. 2014; Healey et al. 2023).

HFE are generally conducted in April (spring) or November (fall), when most fish species are not actively spawning in the mainstream Colorado River between Glen Canyon Dam and Pearce Ferry. Although humpback chub spawn in the Little Colorado River in March to May, their young do not descend into the mainstream until late June or July with monsoonal storms (Yackulic et al. 2014). Similarly, other native species such as flannelmouth sucker and bluehead sucker spawn either in tributaries in April or May, or in the mainstream in June or July, during a time when HFEs are not being conducted and when high flows and water velocities are unlikely to affect large numbers of young fish.

Figure 3-25A 72-hour HFE release was conducted in April 2023 that consisted of an approximately 40,000 cfs release designed to resuspend and store sand that had accumulated in Marble Canyon from July 1, 2022, through October 2022 and remained in Marble Canyon during the low winter 2022/2023 releases. Preliminary findings included determining that sand concentrations were higher in mid-Marble Canyon during the April 2023 HFE release than during any of the 2004–2018 HFE releases but that the sand grain size was slightly coarser than during most of these earlier HFE releases (Grams 2023). This result is consistent with Topping and others (JGR 2021); there was substantial sand accumulation in upper Marble Canyon before this HFE release but a generally longer interval between the Paria River sand inputs and the HFE release. Sand concentrations were higher in central Grand Canyon (at National Canyon) than during most of the 1996 and 2008–2018

HFE releases. Roughly 200,000–400,000 metric tons of sand had been eroded from Marble Canyon since July 1, 2023, owing to high summer "balancing" releases and the decision to not conduct a fall 2023 HFE release for a lack of sufficient sediment.

Equalization Flows

There is also a potential for the abundance of YOY rainbow trout to be affected by the high, steady, and sustained flows that result from equalization flows as required by the 1968 Colorado River Basin Project Act. A substantial increase in numbers of age-0 trout was observed in 2011 following a period of sustained high flows required for equalization (Korman et al. 2011). It has been hypothesized that the high, steady flows associated with equalization operations could benefit age-0 rainbow trout by inundating additional habitat for spawning, incubation of eggs, and production of food resources, and that these factors resulted in the observed increase in the numbers of age-0 trout. Implementation of equalization flows is separate and distinct from LTEMP and would not be affected by LTEMP.

3.5.2 Environmental Consequences

Methodology

Previous research and monitoring conducted within the Colorado River and its tributaries were evaluated and analyzed to inform the results of this analysis. The environmental consequences for fisheries and aquatics within the project area are based on relationships of how flow alterations would impact the food base; fish habitat; native species, including special status species; and nonnative species that are potential predators of native species within the Colorado River. This analysis used qualitative relationships between changes in flow and habitat, food base abundance and distribution, specific species' distribution based on habitat requirements, and impacts from interactions of native with nonnative aquatic species.

Results of hydrologic models were used to evaluate effects of flows on aquatic resources; these included the CRSS model and the GTMax. Preliminary quantitative models integrating information on smallmouth bass population dynamics, potential entrainment rates, water temperature, and other variables to assess invasion risk and potential management options for smallmouth bass were also used for this SEIS.

Impact Analysis Area

The affected environment includes the area potentially affected by the implementation of the 2016 LTEMP FEIS. For aquatic resources, this area includes the Colorado River ecosystem from Glen Canyon Dam downstream to the Lake Mead inflow. More specifically, the scope primarily encompasses the Colorado River ecosystem, which includes the Colorado River mainstream corridor, the affected tributary mouths, and interacting resources in the associated riparian zones, located primarily from the forebay of Glen Canyon Dam to Pearce Ferry. The aquatic species described above are based on those covered in the 2016 LTEMP FEIS and any new species, species of increased concern, or species with changed status since 2016.

Assumptions

- Flow alterations would not impact tributary streams except fish access and habitat at the mouths.
- Lake Mead and Lake Powell would not be influenced because annual flows will remain the same.
- The biological analyses depend on the available reports and publications, data inputs, modeling assumptions, and validity of the models.
- The LTEMP FEIS was used to provide background and for the analysis of effects of flow on aquatic resources.
- The SMB EA was used to provide background and for analysis of effects of flow on aquatic resources.
- The Bureau of Land Management (BLM) Sensitive Species Lists Arizona statewide conservation agreement for six native fish species was used to identify special status fish species.
- The Lower Colorado River Multi-Species Conservation Program's Habitat Conservation Plan was used for areas downstream of Separation Canyon.

Impact Indicators

Impacts were evaluated for aquatics species that use the Colorado River; these species were included in the affected environment section. The indicators included:

- Changes in distribution and abundance of food base items, including primary and secondary producers such as algae and macroinvertebrates
- Changes in the river channel area affected by flows, including the main channel and shallow-water habitats
- Changes in the distribution and abundance of native and nonnative fish species
- Changes in fish habitats, including talus shorelines and backwaters

Issue 1: How would flow alterations at Glen Canyon Dam affect the aquatic food base, native fish species, and nonnative fish species?

The following alternatives summarize impacts on the aquatic food base, native fish, and nonnative fish. These alternatives are being considered through 2027 if certain conditions are met and it is anticipated that other mitigation factors will be present by 2027. There is substantial uncertainty in how the alternatives may impact the aquatic food base, native fish, and nonnative fish populations in the Colorado River ecosystem below Glen Canyon Dam. Predictive models can be useful for making comparisons of different alternatives under a specific set of assumptions. Modeling efforts to assess the complex interactions between physical factors, including reservoir levels, river warming, and river discharge; biological factors, including native and nonnative fish populations (and the interactions between them); and aquatic food base responses were helpful in assessing impacts. These modeling efforts should be recognized as descriptions of how the Colorado River ecosystem downstream of Glen Canyon Dam may respond to these different alternatives using the best available information. The evaluations of the flow alternatives below are based on the best available information for the Upper and Lower Basins of the Colorado River and, where applicable, information from other river basins.

No Action Alternative

The changing climate and aridity has resulted in Lake Powell's low elevation and warmer releases from Glen Canyon Dam (Reclamation 2022). Under the No Action Alternative, these conditions would likely continue. This alternative also would continue to allow nonnative, invasive fish species passage through the dam likely with increased abundances and ranges of these species in the Colorado River downstream of Glen Canyon Dam. Increased abundances of these species could increase interactions between competitive and predatory, invasive species and native species (Coggins et al. 2011). The lower lake elevation means that the penstocks will continue to withdraw warmer water from the epilimnion and mesolimnion, where fish populations occur, rather than from the deeper, colder, fishless water of the hypolimnion.[18]

With the No Action Alternative, no additional flow-based actions would be implemented under LTEMP to disrupt the spawning of smallmouth bass downstream of Glen Canyon Dam. The smallmouth bass population could continue to grow and expand in the Lees Ferry reach and potentially farther downstream. A preliminary model from Eppehimer and Yackulic (see **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 (Little Colorado River confluence) under each of the six alternatives (see **Appendix A**). Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024–2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024 but is predicted to be > 1 for 17 percent of the traces evaluated by 2027. For river mile 61, the model predicted λ is > 1 for 3 percent of the traces in 2024 but is predicted to be > 1 for 17 percent of the traces evaluated by 2027. No uncertainty in model inputs, functional relationships, or outputs are described.

Native fish interactions with invasive, piscivorous fish like smallmouth bass would likely increase as the nonnative fish range expands. This could result in increased predation and competition and possibly decreased abundance of native fish species. Smallmouth bass are a major concern in the Upper Basin and are considered a contributing factor to the low abundance of native fish. If under the No Action Alternative smallmouth bass and other invasive fish (for example, green sunfish, walleye, and striped bass) become established in the Lower Colorado River despite other management actions to prevent further distribution (for example, mechanical removal), the No Action Alternative could detrimentally affect native species. This is largely because of continued regional drought conditions and the potential for continued decline in Lake Powell's elevation, and the consequential potential increase in nonnative fish entrainment, passage, and warmwater releases

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[18] In summer, Lake Powell has three thermally stratified layers: the epilimnion (top), mesolimnion or thermocline (middle), and hypolimnion (bottom). The epilimnion is warm and oxygenated. The mesolimnion is characterized by a rapid change in temperature with the depth, and it is sufficiently oxygenated to support fish. The hypolimnion is devoid of oxygen and is the coldest.

conducive to spawning and improved survival by these nonnative fish species (Summit Technologies Inc. 2022).

The No Action Alternative would likely result in warmer dam releases compared to alternatives, and this could increase growth rates of rainbow trout in the Lees Ferry reach but could also increase the abundance and numbers of brown trout that are known predators and competitors of rainbow trout and native fish (Runge et al. 2018). The potential for increased abundances of invasive fish species in the Lees Ferry reach, like smallmouth bass and green sunfish, would also increase the chances for these species to expand farther downstream, possibly as far as Pearce Ferry in the Lake Mead inflow, and into population centers of humpback chub and razorback sucker. Warmer water temperatures would likely increase the growth rates of native fish species (flannelmouth sucker, bluehead sucker, and speckled dace); however, they would also increase the chances of parasites and diseases in these species, as well as competition and predation by the invasive species. Warmer releases could also provide more suitable thermal continuity in the mainstream between tributaries and enable warmwater invasive fish species (for example, channel catfish, carp, black bullhead, fathead minnow, and red shiner) to expand their range and numbers.

Native Fish

Flannelmouth sucker, bluehead sucker, and speckled dace in their juvenile and adult life stages are tolerant to a high range of river flows. The direct effect of spring or fall HFE releases on these life stages is expected to be minimal. Spring HFE releases could displace recently hatched larvae and post-larvae and subject these life stages to stress, starvation, and predation; however, the effect is not expected to be at a population level. Fall HFE releases could negatively affect flannelmouth sucker and bluehead sucker indirectly by altering the availability of their food base. Speckled dace generally occupy sheltered shorelines or cobble and gravel bars at mouths of tributaries or side canyons, where changes in the flow stage causes them to shift to available habitats (Valdez and Ryel 1995). Benthic periphyton and drifting macroinvertebrates become displaced with HFE releases as the high velocities scour the riverbed. In the fall, there is less solar radiation and less photosynthesis at the river level, and recovery of the primary and secondary producers is slower than in the spring. Although HFE releases will scour the food base, the food base recovers more quickly in spring than in fall, and these fish species are capable of weeks with little or no food.

Nonnative Fish

HFE releases can have both a negative and positive effect on nonnative fish. The high velocities of HFE releases could displace nonnative fish, such as green sunfish and smallmouth bass, into population centers of humpback chub, where they prey on and compete with the native fish. This displacement could also reduce survival of nonnative fish through habitat deficiency, predation, starvation from reduce food supply, or decreased water clarity from sediment inputs, especially below tributaries, which can impede sight-feeders.

HFE releases will back up water into tributary mouths that will create a large ponding effect; this could allow nonnative fish to more readily access these tributaries and interact with native fish species. In the Little Colorado River, the 1996 HFE release backed up the river water for nearly 1 mile upstream and inundated areas occupied by native fish, possibly leading to higher levels of competition and predation (Webb et al. 1999). In Havasu Creek, the 1996 HFE release inundated small waterfalls that are otherwise upstream fish barriers and allowed mainstream fish to access the stream that is otherwise inaccessible under normal powerplant operations.

The majority of rainbow trout in this alternative's affected area are found in the 15-mile Lees Ferry reach immediately downstream of Glen Canyon Dam. HFE releases can have a substantial effect on rainbow trout in Lees Ferry, as the high velocities can displace fish, especially the younger and smaller fish, downstream to reaches where the water clarity, food supply, and habitat are not as suitable; young fish generally occupy low-angle shoreline habitats that can be inundated or desiccated with changes in flow stage (Korman et al. 2011).

Spring HFE releases in April can have a greater effect on rainbow trout than fall HFE releases; this is because most spawning takes place January–March when the high-water velocities can scour and displace the incubating eggs and fry, resulting in low survival. High flows could displace young rainbow trout from shoreline habitats and increase downstream displacement (Avery et al. 2015; Korman and Campana 2009) that could lead to increased interactions with other rainbow trout and humpback chub (Avery et al. 2015). HFE releases can also displace brown trout and other predators and competitors of rainbow trout. Spring and fall HFE releases could negatively affect rainbow trout by altering the availability of their food base. Unlike the native fish, rainbow trout require a more constant and regular supply of food. The food base is expected to recover more quickly from a spring HFE release than a fall HFE release.

Aquatic Food Base

Under the No Action Alternative, flow regimes would remain like the conditions modeled in the LTEMP FEIS (DOI 2016a). Low reservoir volumes above the dam would continue to provide low-nutrient waters to areas below the dam, which would result in lower primary and secondary production. This could be offset by the decreased sediment load. Increased light availability would continue to cause high productivity directly below the dam and through the Lees Ferry reach. Productivity would remain variable farther downstream (Deemer et al. 2022). Under current conditions, phytoplankton populations would remain diverse but less abundant, and the abundance and diversity of macroinvertebrates would continue to provide a limited food supply for native and desired nonnative fish populations, such as rainbow trout (DOI 2016a; Kennedy et al. 2013).

Macroinvertebrate production flows (bug flows) were conducted in 2018, 2019, 2020, and 2022 to improve the productivity and diversity of the aquatic food base and to learn more about the response of the food base to fluctuating power-production flows. These experiments demonstrated that fluctuating power-production releases affect certain macroinvertebrates that rely on relatively stable flows to maintain wetted shallow shorelines for final emergence of adult life stages. Under the No Action Alternative, HFE releases would also continue to be conducted with available sediment supplies, in either spring or fall. Under the No Action Alternative, HFE releases would continue under favorable conditions of hydrology and sediment. All HFE releases scour the food base in the Lees Ferry reach, but there is a more rapid recovery following a spring HFE release when higher solar radiation provides a more continuous and relatively greater level of photosynthetic production than after a fall HFE release.

Cool Mix Alternative

The Cool Mix Alternative is a mix of water released simultaneously through the penstocks and the river outlet works to maintain a daily average water temperature of about 15.5°C (60°F) from below Glen Canyon Dam to the Little Colorado River (river mile 61). Cool temperatures of less than 15.5°C (60°F) year-round are expected to lead to minimal to no initiation of spawning in smallmouth bass and possibly other species, such as green sunfish, as well as poor growth and survival of early life stages. These species generally require higher temperatures to successfully spawn and incubate their eggs, and survival and growth of early life stages would lead to little to no recruitment if these temperatures could be maintained year-round. In spring, summer, and fall, water temperatures warm longitudinally downstream of Glen Canyon Dam. Temperatures downstream of the Little Colorado River (river mile 61) have reached 15.5°C (60°F) in recent years, but only occurred rarely before 2022. A preliminary model from Eppehimer and Yackulic (see **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 under each of the six alternatives. Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024-2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024-2027. For river mile 61, the model predicted λ is > 1 for none of the traces in 2024-2027. No uncertainty in model inputs, functional relationships, or outputs are described.

Native Fish

Cooler temperatures are also not expected to negatively affect the following species and their food base: flannelmouth sucker, bluehead sucker, or speckled dace or their food base. Native fish species below Glen Canyon Dam routinely encounter temperatures colder than the target temperatures for all flow options (Yackulic et al. 2014). While this alternative would aim to reduce water temperatures, native fish naturally experience water temperatures colder than those expected from this flow option. Cooler temperatures would slow the growth of these species but also increase their survival if abundance and predation rates of nonnative species decline under cooler water conditions. Cooler temperatures may also benefit these species by limiting the maturation and reproductive capabilities of parasites such as the Asian tapeworm (*Bothriocephalus acheilognathi*) and the anchor worm (*Lernaea cyprinacea*), which require 18°C (64.4°F) or higher to mature and reproduce.

Nonnative Fish

Cool temperatures could negatively affect nonnative, warmwater fish, such as smallmouth bass, green sunfish, fathead minnows, red shiners, channel catfish, and common carp. This is the point of the cool-mix release option. Cool temperatures could, in turn, benefit the native fish by potentially reducing competition and predation from nonnative species. For example, the cooler temperatures are intended to delay or disrupt maturation and spawning by smallmouth bass, based on observations in the Upper Colorado River (Bestgen and Hill 2016b). Smallmouth bass typically spawn from May through July in the Upper Basin shortly after the first day when temperatures increase above 15.5°C (60°F) (Bestgen and Hill 2016b). Cool temperatures of less than 15.5°C (60°F) year-round are expected to lead to minimal to no initiation of spawning in smallmouth bass and possibly other species, such as green sunfish, as well as poor growth and survival of early life stages. These species generally require higher temperatures to successfully spawn and incubate their eggs, and survival and growth of early life stages is poor at these temperatures. Timing the releases of the Cool Mix Alternative to maximize the impact on smallmouth bass spawning in a way that integrates with the natural downstream warming of the Colorado River to river reaches occupied by a higher abundance of native species, such as the confluence with the Little Colorado River (river mile 61), requires detailed assessment. An important unknown is whether nearshore thermal environments may persist that would offer warmer refuge for nonnative species.

It may only be possible to maintain temperatures below 15.5°C (60°F) from below the dam through river mile 45 in Marble Canyon when reservoir elevations low monthly volumes are low; however, it may also be possible to release enough cold water to overcome a lower volume of warmer water going through the penstocks (USGS 2022) and increase the distance of effect to river mile 61 at the mouth of the Little Colorado River. However, since smallmouth bass have been detected mainly in the Glen Canyon reach, implementation of this alternative could still be effective at reducing the likelihood of successful spawning of smallmouth bass where most fish have been found as of the end of 2023. The effect of cool water releases will be ameliorated downstream of Glen Canyon Dam and may not affect the smallmouth bass. Eppehimer and Yackulic (see **Appendix A**) predict that the river can be cooled with releases downstream to river mile 15 or 30.

Cooler temperatures would create a more favorable thermal environment for rainbow trout. This species has persisted with these lower temperatures since the dam began releasing cold, hypolimnetic waters in the 1970s. Cooler temperatures may reduce upstream movement of brown trout into the Lees Ferry reach, which would reduce competition and predation on rainbow trout (Runge et al. 2018). Cooler temperatures are not expected to negatively affect rainbow trout’s food base.

Aquatic Food Base

The cooler temperatures are not expected to negatively affect the aquatic food base .

Cool Mix with Flow Spike Alternative

The Cool Mix with Flow Spike Alternative would release a mix of water through the penstocks and river outlet works to maintain a daily average water temperature below 15.5°C (60°F) from below Glen Canyon Dam to the Little Colorado River (river mile 61), with the goal of disrupting smallmouth bass spawning (same as the Cool Mix Alternative). For modeling purposes, river mile 15 and river mile 61 were analyzed to cover the area where smallmouth bass may be found. Additionally, up to three 8-hour flow spikes (up to 45,000 cfs) would be added between June and mid-July, if sufficient water is available. The cold release would likely disrupt spawning in margin habitats that may be warmer than the mainstream river by cooling these margins. Also, the higher velocity of the flow spikes could scour and displace eggs and fry from nests and likely displace the females during egg construction and deposition, as well as the males that later guard the fertilized eggs and newly hatched fry. The concept of flow spikes is being tested to disrupt spawning of smallmouth bass in the Green River downstream of Flaming Gorge Dam (Bestgen 2018). Available data to date suggests these flow spikes interrupt smallmouth bass spawning, but it is unclear if smallmouth recruitment is lowered. A preliminary model from Eppehimer and Yackulic (see **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 under each of the six alternatives. Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024-2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024-2027. For river mile 61, the model predicted λ is > 1 for none of the traces in 2024-2027. No uncertainty in model inputs, functional relationships, or outputs are described.

In spring, summer, and fall, water temperatures warm longitudinally downstream of Glen Canyon Dam, and temperatures downstream of the Little Colorado River (river mile 61) are expected to warm above 15.5°C (60°F). Also, the high wave of flow spikes is expected to dampen with the distance downstream of Glen Canyon Dam, such that the effect of these stage changes may not be as great downstream of the Little Colorado River where most native fish populations occur.

Native Fish

Cooler temperatures are also not expected to negatively affect the flannelmouth sucker, bluehead sucker, or speckled dace or their food base over the long term. While this alternative would aim to reduce water temperatures, native fish naturally experience water temperatures colder than those expected from this alternative and have increased over the last two decades under a similar thermal regime. Flow spikes are not expected to affect the juveniles and adults of flannelmouth sucker and bluehead sucker; however, they could displace larvae and early juveniles from backwaters and shoreline habitats, leading to reduced survival. This effect is not expected to be at the population level.

Flow spikes would inundate cobble and gravel deposits at the mouths of tributaries and side canyons where speckled dace are common, but this species is able to temporarily relocate along talus shorelines (Valdez and Ryel 1995; Webb et al. 1999). Cooler temperatures would slow the growth of these species but also increase their survival (Yackulic et al., 2014). Cooler temperatures may also benefit these species by limiting the maturation and reproductive capabilities of parasites such as the Asian tapeworm and the anchor worm which require 18°C (64.4°F) or higher to mature and reproduce (Hoffnagle et al. 2006).

Nonnative Fish

Cool temperatures of less than 15.5°C (60°F) year-round are expected to lead to minimal to no initiation of spawning in smallmouth bass and possibly other species, such as green sunfish, as well as poor growth and survival of early life stages. These species generally require higher temperatures to successfully spawn and incubate their eggs, and survival and growth of early life stages is poor at these temperatures. These cool temperatures could also negatively affect other nonnative, warmwater fish, such as fathead minnows, red shiners, channel catfish, and common carp. This could, in turn, benefit the native fish by potentially reducing competition and predation from nonnative species. The combination of cool temperatures and flow spikes would likely have a greater negative effect on smallmouth bass than cool temperatures alone. Cool temperatures may not reach all habitats or be moderated by warmed shorelines, but spike flows would likely generate high velocities that would affect smallmouth bass nest areas at various depths, depending on the nests' location. These higher velocities would likely scour some nests and displace eggs, fry, and juvenile fish and disrupt spawning behaviors of adult fish. Also, increased water depths over nest areas would likely make these areas unsuitable for spawning and cause the adults to abandon the nests.

Cooler temperatures are expected to create a more favorable thermal environment for rainbow trout, especially in the Lees Ferry reach. This species has persisted and thrived with these lower temperatures since after Glen Canyon Dam was completed and hypolimnial flows began. Cooler temperatures may reduce upstream movement of brown trout into the Lees Ferry reach, which would reduce the competition and predation on rainbow trout (Runge et al. 2018). Cooler temperatures are not expected to negatively affect rainbow trout's food base. Spike flows in May–July could displace juvenile rainbow trout and lead to lower recruitment. These spike flows would not likely affect spawning by rainbow trout; this is because most spawning in the Lees Ferry reach takes place during January–March. Downstream displacement of rainbow trout could lead to increases in interactions with other fish species (Avery et al. 2015).

Aquatic Food Base

The cooler temperatures are not expected to negatively affect the aquatic food base, as this temperature range is not colder than dam release of the last five decades. Short-term spike flows would scour the benthos, but the food base reduction would be temporary and would recover quickly; this is because solar radiation and photosynthesis are high during May–July.

Cold Shock Alternative

The Cold Shock Alternative would release water for at least 48 hours through the river outlet works, releasing the minimum amount of water required to create a cold shock all the way down to river mile 61 (confluence with the Little Colorado River) to disrupt smallmouth bass spawning and rearing. A cold shock is achieved through a sudden drop in temperature, with a target temperature of 13°C (55.4°F) or below. This option would begin as soon as daily water temperatures near river mile 61 reach 15.5°C (60°F); after this, weekly use of the river outlet works, anticipated to occur during weekends, would be initiated and would last for up to 12 weeks. A preliminary model from Eppehimer and Yackulic (see **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 under each of the six alternatives. Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024-2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024 but is predicted to be > 1 for 3 percent of the traces evaluated by 2027. For river mile 61, the model predicted λ is > 1 for 0 percent of the traces in 2024 but is predicted to be > 1 for 10 percent of the traces evaluated by 2027. No uncertainty in model inputs, functional relationships, or outputs are described.

Native Fish

This alternative would reduce water temperatures, but not to levels that are colder than what native fish likely experienced in a pre-Glen Canyon Dam environment. Adult and large juvenile flannelmouth and bluehead suckers would likely experience slower growth (Hansen et al. 2023). A cold-shock effect could also result in direct mortality of post-larvae and juveniles.

Nonnative Fish

The Cold Shock Alternative would likely have a negative effect on nonnative, warmwater fish, such as smallmouth bass, green sunfish, channel catfish, common carp, fathead minnows, and red shiners. These species evolved in warmwater environments and are more susceptible to sudden decreases in water temperature than cold-water species; they also have lower growth and survival in cold water. Reduced populations of warmwater nonnative fish would benefit the native, warmwater fish by reducing competition and predation. The cold shock is expected to disrupt nesting and spawning by smallmouth bass. The cold shock would result in direct mortality of eggs and fry, and it could cause abandonment of nest sites by nesting females and males that subsequently guard the eggs and larvae.

Adult and juvenile rainbow trout are less susceptible to cold shocks than warmwater species. However, recently hatched fry and early juveniles would likely be negatively affected by the sudden decrease in temperature, especially in the Lees Ferry reach, if these cold-shock releases happen between January and June. A sudden cold release could weaken the young fish and displace them from their habitats, resulting in predation, starvation, or eventual death due to a lack of suitable habitat. Downstream displacement of rainbow trout could lead to increases in interactions with other rainbow trout and humpback chub (Avery et al. 2015).

Aquatic Food Base

Cold-shock releases would likely negatively affect the aquatic food base, as certain multivoltine species would not be able to complete their life cycles as they otherwise do in warmer temperatures. This could affect the availability of some macroinvertebrates species that constitute the food base. It could also negatively affect univoltine species that have become acclimated to warmer water, especially in the Lees Ferry reach. Depending on the magnitude of these releases, the combination of cold temperatures and higher velocities could displace the benthos and reduce the food base; this reduction would persist if these releases were to continue weekly on weekends for 12 weeks.

Cold Shock with Flow Spike Alternative

The Cold Shock with Flow Spike Alternative would release water for at least 48 hours through the river outlet works for the minimum amount of time required to create a cold shock all the way down to the Little Colorado River (river mile 61) to disrupt smallmouth bass spawning; this would be the same as the Cold Shock Alternative. In addition, up to three 8-hour flow spikes would be added between June and mid-July, if sufficient water is available. The flow spike would likely disrupt bass spawning in margin habitats that may be warmer than the mainstream river. As much water as possible (up to 45,000 cfs, depending on water availability) would be released through the penstocks and river outlet works during flow spikes. This option would begin as soon as daily water temperatures near the Little Colorado River warm to 15.5°C (60°F). This option would provide weekly 48-hour cold-shock releases for up to 12 weeks and at least one 8-hour spike flow. A preliminary model from Eppehimer and Yackulic (see **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 under each of the six alternatives. Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024-2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024 but is predicted to be > 1 for 3 percent of the traces evaluated by 2027. For river mile 61, the model predicted λ is > 1 for none of the traces in 2024 but is predicted to be > 1 for 10 percent of the traces evaluated by 2027. No uncertainty in model inputs, functional relationships, or outputs are described.

Native Fish

While this alternative would aim to reduce water temperatures, native fish naturally experience water temperatures colder than those expected from each flow option. Adult and older juvenile flannelmouth suckers and bluehead suckers would not likely be negatively affected by the Cold Shock with Flow Spike Alternative, although colder water and higher water velocity would be expected to result in slower growth rates (Hansen et al. 2023). Weekly use of cold-shock events could reduce growth and survival of young flannelmouth suckers and bluehead suckers. A cold-shock effect combined with flow spikes could also result in direct mortality of post-larvae and juveniles.

Nonnative Fish

The Cold Shock with Flow Spike Alternative would likely have a larger impact on nonnative, warmwater fish, such as smallmouth bass, green sunfish, channel catfish, common carp, fathead minnows, and red shiners, than native species. These species evolved in warmwater environments and have lower growth and survival in cold water. However, these species also have very large native population ranges, which demonstrate their ability to adapt and persist across a wide range of climates. Reduced populations of warmwater nonnative fish would possibly benefit the native warmwater fish by reducing competition and predation.

The Cold Shock with Flow Spike Alternative is designed to disrupt smallmouth bass spawning by keeping temperatures below suitable spawning conditions and by increasing the depths and velocities at nest locations. This option is based on experimental work in the Upper Basin (Bestgen 2018). In theory, this option would disrupt maturation and spawning by smallmouth bass and also disrupt water and habitat conditions in nest areas. The higher velocity and deeper water could likely displace females in the act of spawning, as well as males guarding eggs and fry. The higher velocity could also displace eggs and fry; combined with cold temperatures, the higher velocity might kill most of the embryos.

Adult and juvenile rainbow trout are more resistant to cold shocks than warmwater species. These cold releases are not expected to substantially affect the population in the Lees Ferry reach. However, recently hatched fry and early juveniles would likely be negatively affected by the sudden decrease in temperature, especially in the Lees Ferry reach. A sudden cold release could weaken the young fish and displace them from their habitats, resulting in predation, starvation, or eventual death due to lack of suitable habitat. Flow spikes in spring could displace juvenile rainbow trout from low-angle shoreline habitats and expose them to predation or starvation (Korman et al. 2011). Downstream displacement of rainbow trout could lead to increases in interactions with other rainbow trout and humpback chub (Avery et al. 2015). It is unclear how a cold shock would affect rainbow trout, but reduced feeding behavior and metabolic and growth rates may be anticipated (Yackulic et al. 2014; Van Haverbeke et al. 2017), as indicated by the 15.5˚C–18˚C (60˚F–64.4˚F) optimal growth range for rainbow trout (Mishra et al. 2021).

Additionally, spike flows could create spawning and rearing habitat for rainbow trout on high-elevation cobble and gravel bars (USGS 2011), if spawning were to occur between June and mid-July. The survival of trout eggs and fry in these high-elevation habitats would depend on the duration of the elevated flow; flows of short duration would likely strand the eggs and fry (Korman and Melis 2011).

Aquatic Food Base

Cold-shock releases would likely negatively affect the aquatic food base. This is because certain multivoltine species would not be able to complete their life cycles as they otherwise do in warmer temperatures. This could affect the availability of some macroinvertebrates species that constitute the food base. It could also negatively affect univoltine species that have become acclimated to warmer water, especially in the Lees Ferry reach. The periodic flow spikes could also scour the benthos and lead to a short-term decrease in food base until photosynthetic activity could restore the primary and secondary production. Depending on the magnitude of these releases, the combination of cold temperatures and higher velocities could displace the benthos and reduce the food base; this reduction could persist if these releases were to continue weekly on weekends for 12 weeks.

Non-Bypass Alternative

The Non-Bypass Alternative consists of weekly flow spikes using a combined action of lowering and then increasing the river stage within the range of the powerplant's capacity; this alternative would use only the penstocks and would not involve the river outlet works. This alternative is proposed as an experiment that would use low releases to cause male smallmouth bass to abandon nests in shallower nearshore habitats, such as backwaters and sloughs, and higher-velocity releases to displace eggs and fry, or cause abandonment by male smallmouth bass, from nests in deeper water nearer the main channel. It would also disrupt and potentially cause stranding and other impacts to eggs and fry of smallmouth bass. A preliminary model from Eppehimer and Yackulic (See **Appendix A**) was developed to assess the potential for smallmouth bass population growth rate at river mile 15 and river mile 61 under each of the six alternatives. Based on assumed functional relationships between smallmouth bass population dynamics, available habitat, predicted temperature responses, and rate of entrainment, the model predicts smallmouth bass intrinsic rate of population growth (λ) at river mile 15 and river mile 61 for each year 2024-2027. For river mile 15, predicted λ is > 1 for none of the traces in 2024 but is predicted to be > 1 for 17 percent of the traces evaluated by 2027. For river mile 61 (confluence with the Little Colorado River), the model predicted λ is > 1 for 3 percent of the traces in 2024 but is predicted to be > 1 for 17 percent of the traces evaluated by 2027. No uncertainty in model inputs, functional relationships, or outputs are described.

For timing, low releases would occur late Sunday night (9:00 p.m. to 1:00 a.m.) and high releases would occur early Monday morning (7:00 a.m. to 11:00 a.m.). For duration, low releases would be long enough (4 hours) to dewater active, low-angle spawning habitats but short enough to allow for a subsequent high flow to collapse the low-flow trough at some desired point downstream (as part of the longitudinal kinematic wave). High releases would be long enough (4 hours) to increase the velocity in active spawning habitat and collapse the low-flow trough at some desired point downstream. For magnitude, releases would be low enough to dewater active, low-angle spawning habitat (2,000 cfs) and high enough to increase the velocity in active spawning habitat (powerplant capacity of up to 30,000 cfs); a stage change would provide a 1.6- to 3.3-foot change below, and a 3.3- to 6.6-fee change above the minimum for normal operations.

For frequency, releases would be weekly to keep bass from successfully renesting. The weekly spikes would be triggered when temperatures reach 15.5°C (60°F) in areas where bass are observed spawning (that is, 12-mile slough). By keeping the durations of the low flow and the high flow short (that is, 4 hours), the trough created by the low flow is collapsed by the wave created by the high flow such that the minimum flow at the Little Colorado River never falls below 5,000 cfs (the minimum flow specified in the ROD) and the high flow attenuates in such a way that the maximum flow at the Little Colorado River stays below 25,000 cfs (the maximum nonexperimental flow specified in the ROD).

Native Fish

High flows within the powerplant's capacity are experienced by flannelmouth sucker, bluehead sucker, and speckled dace. Young life stages would likely remain along sheltered talus shorelines. Although some young fish may become displaced from shorelines or backwaters and exposed to predation and starvation, the effect of these high flows on these species is expected to be minimal. Weekend flows of 2,000 cfs, if they occurred April–June, could negatively affect young and juvenile flannelmouth suckers and bluehead suckers that could be displaced from desiccated shoreline habitats and backwaters. Older juveniles and adults are not expected to be negatively affected by short-term low flows followed by high flows. Speckled dace have been observed to move and adjust locations along shoreline habitats with flow stages (Valdez and Ryel 1995; Webb et al. 1999). The native Colorado River Basin fish evolved in a highly variable flow environment, and assessments of how juvenile humpback chub use different habitats or their survival rates did not vary during a transition from fluctuating to steady flows below the Little Colorado River (Gerig et al.2014).

Nonnative Fish

High flows within the powerplant's capacity are not expected to negatively affect adult nonnative fish; however, some young could be displaced from their habitats, as these fish experience this flow range under current operations. Weekend flows of 2,000 cfs could negatively affect nonnative, warmwater fish, such as smallmouth bass, green sunfish, channel catfish, common carp, fathead minnows, and red shiners. These low flows would desiccate shallow shoreline habitats and backwaters that are preferred (but not required) habitats of these species and displace them to the mainstream, leading to increased predation and starvation. For smallmouth bass, rising water would flush solar-warmed shoreline nest areas with water at the temperature of main river, potentially causing nest desertion and halting embryo development if the main river temperatures are significantly lower. Rising flows could also displace juvenile and adult smallmouth bass from preferred habitats and possibly lead to starvation and predation. Subsequent falling water levels could drive spawning females and guarding males from nests, exposing the eggs and fry to predation and to less water circulation and aeration of the eggs.

High flows within the powerplant's capacity are experienced by rainbow trout. No effect is expected on adults. Changes in the flow stage are expected to displace young and juvenile trout and expose these fish to starvation and predation, or possibly displace them downstream to population centers of native fish where they can prey on and compete with those fish. Downstream displacement of rainbow trout could lead to increases in interactions with other rainbow trout and humpback chub (Avery et al. 2015). Weekend flows of 2,000 cfs could negatively affect eggs and fry through desiccation, if they occurred January–March. These flows could displace juveniles and lead to reduced survival from predation or starvation. Adult rainbow trout would not be as negatively affected, as the larger fish are able to shift habitat during dramatic flow changes.

Aquatic Food Base

High flows within the powerplant's capacity are not expected to negatively affect the food base in the Lees Ferry reach or farther downstream. However, weekend flows of 2,000 cfs would desiccate much of the river bottom, especially the shallow shelves where most primary and secondary production occur. These low flows are scheduled to last only 4 hours and would be conducted at night when there would be less drying of the algae that support much of the benthos. This shortened period of drying, especially at night, would likely allow for recovery of the benthic community (Blinn et al. 1999).

Cumulative Effects

Overall, cumulative effects of these flow alternatives on native and federally listed fish would likely be temporary and beneficial overall. This is because the flow options are meant to disrupt smallmouth bass spawning and recruitment.

Cumulative impacts on adult rainbow trout would likely be negligible because rainbow trout can adjust to changes in flow and temperature. In addition, cold spikes may create a temporary thermal environment that is preferred by rainbow trout. However, impacts on young rainbow trout in the Lees Ferry reach from options that include cold shocks or flow spikes, or both, would likely be negative; this is because the young rainbow trout would be displaced from low-angle shoreline habitats by changing flow volumes and temperatures (Korman and Campana 2009). This could result in increased interactions with native fish in downstream locations.

The cumulative impacts on the aquatic food base from the flow options would likely be temporary and likely would not have major impacts on the productivity, abundance, or diversity of aquatic organisms. These impacts would result from changes to the water quality (derived from fluctuations in the water temperature and nutrient concentrations, in particular) and the fluctuation of water depth downstream of the dam. All flow options (except the Non-Bypass Alternative) would operate within the spatial and temporal bounds and under the assumptions of the existing analysis conducted in the LTEMP FEIS (DOI 2016a). Therefore, cumulative impacts on organisms of the aquatic food base would not differ substantively from those included in the LTEMP FEIS. The effects of a low flow of 2,000 cfs on the food base have not been evaluated; however, because the low flow would be short term (4 hours) and at night, the effect is not expected to be long term.

Summary

Five alternatives, as well as taking no action, are evaluated. The primary goal of the five alternatives is to disrupt spawning by invasive smallmouth bass through the use of high- or low-flow releases from Glen Canyon Dam and changes in water temperatures. These alternatives are based on information provided by various working groups and the scientific literature in both the Upper and

Lower Colorado River Basins. For the Colorado River ecosystem below Glen Canyon Dam, efforts are ongoing to develop predictive models that integrate information from the native and introduced range of smallmouth bass into a framework that allows for the evaluation of these different alternatives as a predictive model. The results of one version of this model, which predict smallmouth bass population responses to each alternative, were included in this evaluation, and the document from USGS (see **Appendix A**). The provided modeling efforts do not integrate predicted smallmouth bass and native fish population dynamics under each of the alternatives, the model only predicts smallmouth bass population responses. The Eppehimer and Yackulic (see **Appendix A**) report predicts that smallmouth bass population growth (lambda) at river mile 15 and at the Little Colorado River confluence would be below 1.0 for only the cool mix and cool mix with spike flows. This means that these two alternatives, if implemented under the right conditions and model assumptions are accurate, could prevent population growth of the smallmouth bass in these two areas. Other modeling efforts are not available to be included in this evaluation. The evaluations of the five alternatives here are based on the information that is available, including the SMB EA and the Smallmouth Bass Ad Hoc Group report (2023). This report encapsulated the combined efforts and contributions of all AMWG members, including federal agencies engaged in plan implementation. The document titled "Invasive Fish Species Below Glen Canyon Dam: A Strategic Plan to Prevent, Detect and Respond" received approval from the AMWG.

Four of the flow alternatives presented use both penstock releases as well as the river outlet works to generate either high flows or spikes and cooler releases or cold shocks. Only the Non-Bypass Alternative uses the penstocks and not the river outlet works. The five alternatives each have the potential to disrupt smallmouth bass spawning by either desiccating or inundating nesting areas, creating unsuitable water temperatures, or both. Potentially, the most effective alternatives for disrupting smallmouth bass spawning are the Cool Mix with Flow Spike and the Cold Shock with Flow Spike Alternatives, as these alternatives theoretically would disrupt both the physical habitat of smallmouth bass nesting as well as the suitable and necessary temperature regimes. This is supported by the preliminary modeling work by Eppehimer and Yackulic (see **Appendix A**), and the explicit assumptions made in that model. A detailed evaluation of model uncertainties, such as how available habitat changes under different alternatives, the influence of turbidity, prey resources, and the entrainment rate of smallmouth bass would help to characterize uncertainty of the model predictions. From the Upper Basin, the preliminary analyses of the 2018 flow experiment below Flaming Gorge to disrupt smallmouth bass spawning documents that spawning was disrupted, but it is unclear from the available data whether recruitment of smallmouth bass was interrupted (Bestgen et al. 2022 FY report). Previous flow experiments below GCD to interrupt rainbow trout spawning caused mortality of rainbow trout eggs and fry, but recruitment did not decline because of compensatory survival of the remaining young rainbow trout (Korman et al. 2011). Generally, the five alternatives are not expected to have a negative population-wide effect on native fish, as these species have adapted to a large range of flows and temperatures in the Colorado River. However, all alternatives assume that establishment of smallmouth bass will have impacts on native fish populations, which is consistent with the recommendations of the Smallmouth Bass Ad Hoc Group report (2023). These alternatives are not expected to have long-term negative effects on rainbow trout in the Lees Ferry reach.

3.6 Terrestrial Resources and Wetlands

3.6.1 Affected Environment

Riparian Vegetation

This section supplements the 2016 LTEMP FEIS (DOI 2016a) for vegetation with a summary of the affected environment, as provided in the original 2016 document and supplemented, as necessary, to include changes that have occurred since 2016.

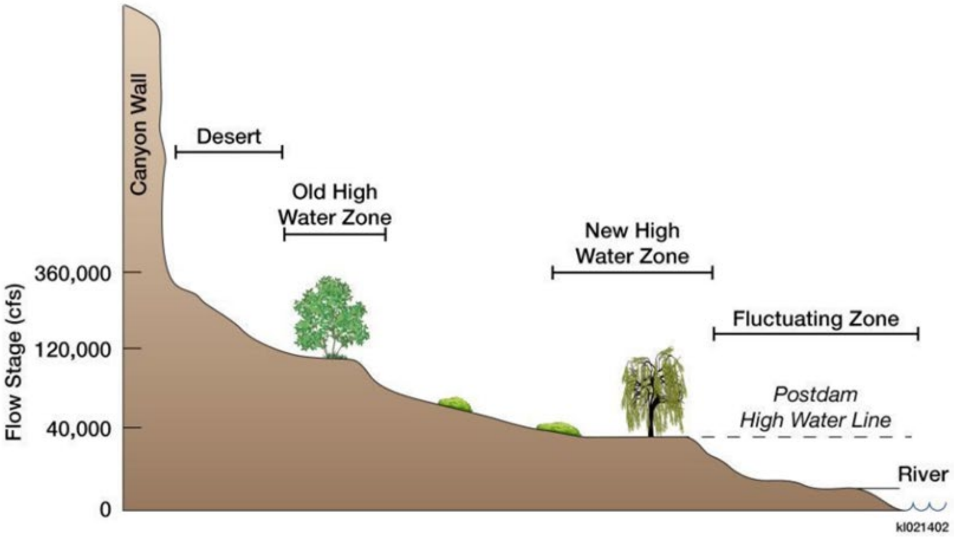
As described in the 2016 LTEMP FEIS, vegetation along the Colorado River corridor from Glen Canyon Dam to Lake Mead is affected by the peak magnitudes, daily fluctuations, and seasonal pattern of river flows, and most evidence indicates that riparian vegetation composition, structure, distribution, and function are closely tied to ongoing Glen Canyon Dam operations (DOI 2016a). Since the operation of Glen Canyon Dam began, there have been dramatic changes in the distribution and composition of riparian vegetation communities (Sankey et al. 2015; Turner and Karpiscak 1980; Webb et al. 2011). There has been a net increase in riparian vegetation cover and density as a result of altered flow regimes, including increases in both native and nonnative species (Durning et al. 2021; Sankey et al. 2015; Stevens et al. 1995).

Existing vegetation communities are described in detail in the LTEMP FEIS (DOI 2016a). For the purpose of this SEIS, the definition of the riparian zone is consistent with the definition provided in the 2016 LTEMP FEIS. Riparian vegetation includes all plant species found within the fluctuating zone, new high-water zone (NHWZ), and old high-water zone (OHWZ) of the mainstream Colorado River downstream of Glen Canyon Dam, as first described by Carothers and Brown (1991) and shown in **Figure 3-28**.

Historical and Remnant Riparian Communities

Prior to Glen Canyon Dam's construction, the riparian community was shaped by seasonal flow patterns, sediment transport, turbidity, and nutrient pulses (Johnson 1991). Large-stature woody tree species were largely absent from the system; however, individual specimens of Fremont cottonwood (*Populus fremontii*) and willows (*Salix* spp.) were identified and recorded prior to the dam's construction (Department 2016a). Other historical woody species in this reach of the Colorado River included mesquite (*Prosopis glandulosa*), New Mexico olive (*Forestiera pubescens*), Apache plume (*Fallugia paradoxa*), and netleaf hackberry (*Celtis reticulata*) (Department 2016a; Ralston et al. 2005). Nonnative tamarisk (*Tamarix ramosissima*) was introduced to the Colorado River Basin in the 1800s and documented before the dam (Ralston 2005). These species mainly occupied areas of the OHWZ and relied primarily on surface water flows and periodic flooding events to saturate the soil (DOI 2016a). The OHWZ provides important habitat for nesting birds, reptiles, amphibians, mammals, and insects (Carothers and Brown 1991; Reclamation and NPS 2016). Although there has been an increasing trend in riparian vegetation aerial cover and density since the dam's operation began, desirable plant species, such as cottonwoods and willows, remain extremely rare (Durning et al. 2017; Palmquist et al. 2018).

Figure 3-28
Riparian Vegetation Zones along the Colorado River below Glen Canyon Dam



Source: adapted from Carothers and Brown 1991; Reclamation 1996; DOI 2016a

Existing Riparian Communities

Since operation of Glen Canyon Dam began in 1963, the riparian environment has become more stable, with increased and more consistently available groundwater and few destructive floods; this is due to regulated flow releases and cessation of seasonal flooding events (Johnson 1991). Geomorphological and physical changes caused by low water volumes have led to a downslope migration of riparian vegetation, resulting in the designation of a NHWZ (DOI 2016a). The NHWZ is dominated by grasses and fast-growing shrub species such as arrowweed (*Pluchea sericea*), seepwillow (*Baccharis salicifolia* and *B. emoryi*), desert broom (*Baccharis sarothroides*), honey mesquite (*Prosopis glandulosa*), and nonnative tamarisk (Reclamation and NPS 2016; Johnson 1991).

The fluctuating zone (also referred to as the varial zone) is the lowest riparian zone adjacent to the river's wetted edge. The fluctuating zone is subjected to frequent changes in water flow and vegetation is composed of a mix of mainly grasses and flood-tolerant shrubs with a few forbs, sedges, and rushes that can withstand periodic scouring events and inundation (Reclamation and NPS 2016; Durning et al. 2021; Palmquist et al. 2018). Prior to the dam's construction, fluvial marsh and wetland habitats were primarily associated with perennial tributaries and springs (Webb et al. 2002). However, decreased seasonal variability of flow levels and increased base flows have led to the expansion of perennial species in the fluctuating zone and NHWZ (Sankey et al. 2005).

The distribution and diversity of both native and nonnative plant species have increased since the dam's operations began (DOI 2016a). For example, recruitment of some species, such as mesquite and hackberry, is rarely observed in the OHWZ; however, these species are now recruiting in the NHWZ (DOI 2016a). Arrowweed, a dominant native woody species, is found in both the OHWZ and NHWZ (DOI 2016a). Other native species, such as Goodding's willow (*Salix gooddingii*) and Fremont cottonwood, have experienced a decline in population due, at least in part, to the reduction in flood flows on upper riparian terraces and foraging by beavers on cottonwood seedlings (Reclamation and NPS 2016; Mortenson et al. 2008; Stevens et al. 2001). Tamarisk, however, has become widespread throughout all riparian zones below the dam. Also, there has been a general increase in vegetation since dam operations began (Bedford et al. 2018; Mortenson et al. 2008). Increased riparian vegetation, regardless of its native status, provides valuable habitat for many wildlife, avian, amphibious, and invertebrate populations (DOI 2016a).

During development of the 2016 LTEMP FEIS, the effects of dam operations on riparian vegetation health along the river corridor were evaluated, and modeling results suggested long-term declines, particularly in native plant communities. With operational flows limited to less than 45,000 cfs, the overall extent and health of the riparian areas in GCNP have and would continue to be altered, and nonnative vegetation and monoculture species would likely increase. Therefore, a 20-year experimental riparian-restoration project was developed by the NPS and other agencies, as designated in the environmental commitments of the 2016 LTEMP ROD. There are four specific vegetation issues influenced by dam operations that emerged in the 2016 LTEMP FEIS that the restoration projects specifically seek to address: (1) encroachment of vegetation on sandbars, (2) decrease in native plant species, (3) erosion of archaeological resources, and (4) narrowing and loss of plants in the OHWZ (DOI 2016a). Implementation of HFE releases under LTEMP have influenced riparian vegetation in this reach. In 2012 an HFE protocol was developed to improve sediment conservation downstream of the Paria River. This protocol was adopted under LTEMP and has influenced riparian vegetation in this reach. Since 2012, six HFE releases have been conducted, the most recent being in April 2023.

In August 2021, the NPS, in coordination with GCMRC, developed a Long-Term Experimental and Management Plan Riparian Vegetation Project Plan (NPS and GCMRC 2021) that provides guidance for non-flow experimental vegetation treatments to accomplish the following objectives: (1) control nonnative plant species affected by dam operations, including tamarisk and other highly invasive species; (2) develop native plant materials for replanting through partnerships and the use of regional greenhouses; (3) replant native plant species to priority sites along the river corridor, including native species of interest to Tribes; (4) remove vegetation encroaching on campsites; and (5) manage vegetation to assist with cultural site protection.

Special Status Plant Species

Several special status species found within the Colorado River corridor are outside the zone of the dam's operational effects (DOI 2016a); therefore, they were dismissed from further consideration[19].

3.6.2 Environmental Consequences

Methodology

Analysis in this section is informed by hydrologic and vegetation models showing the effects of dam releases on the hydrology and riparian vegetation. As discussed in the 2016 LTEMP FEIS, the primary effects on riparian vegetation below Glen Canyon Dam will be a direct function of the

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[19] Zoom call between Emily Palmquist, USGS, and Stephen Zipper and Katelyn Cary, SWCA Environmental Consultants, on December 1, 2022.

changes in flow regimes under each alternative. The vegetation model (Butterfield and Palmquist 2023) has several limitations that should be noted when considering the modeling results. The model was designed as a conceptual model, as opposed to a predictive model; therefore, the results are used in this analysis carefully and in combination with the literature because the model is a simplification with limitations in the ability to assess on-the-ground changes. However, it is the best available tool for the impact analysis, when used in conjunction with field studies and literature. The environmental consequences for riparian vegetation are presented as a discussion of how each alternative may affect the proportion of native cover, total species' richness, and total vegetation cover relevant to the plant community composition.

Impact Analysis Area

The analysis area is consistent with the 2016 LTEMP FEIS and includes the Colorado River mainstream corridor and interacting resources in associated riparian zones located primarily from the forebay of Glen Canyon Dam to Pearce Ferry above Lake Mead. Modeling data were subdivided for the analysis into three regions: Marble Canyon, eastern Grand Canyon, and western Grand Canyon. These regions are floristically distinct and experience different climate conditions; thus, it was determined appropriate to provide separate assessments for each region.

Assumptions

- Upland habitat would not be impacted by flow alterations.
- Lake Mead and Lake Powell would not be influenced because annual flows will remain the same.
- The biological analyses depend on the data inputs, modeling assumptions, and validity of the models.
- The vegetation modeling (Butterfield and Palmquist 2023) assumptions include the following:
    - Nine alternative scenarios were compared against the No Action Alternative scenario, such that results indicate changes in suitable habitat relative to the No Action Alternative.
    - Thirty hourly traces provided by the GCMRC for each scenario were used in the analysis.
    - Riparian plant community data from 44 Northern Arizona University sandbar sites collected in 2014 through 2019, coupled with the digital elevation models of those sandbars provided by the GCMRC, were used to train the models. The elevation of each plant community monitoring plot above the river stage was calculated at 15-minute intervals during the year prior to data collection. These elevations were used as estimates of the depth to groundwater and inundation experienced by the plants in those plots. Three hydrological variables were extracted from the distribution of elevations above river stage: the 95th percentile, 5th percentile, and minimum elevation. These hydrological variables reflect the trough of daily fluctuations during the lowest streamflow month of the year, the peak of daily fluctuations during the highest streamflow month of the year, and the peak of the HFE release.

- Analyses were also subdivided into groups of traces with similar lake elevations: 0–10 percent; 10–25 percent; 25–50 percent; and 50–100 percent. The driest 10th percentile traces are represented in the discussion of impacts below.
- The three hydrological variables (native cover, total species' richness, and total vegetation cover), along with the minimum temperature, mean annual precipitation, and insolation, were used as predictor variables to train the habitat suitability models for each of 47 common riparian plant species using maximum entropy (Maxent) algorithms.
- This modeling approach can address changes to shifts in the highest flows and lowest flows (that is, no HFE releases versus having HFE releases), but it does not account for flow frequency or timing. Thus, changes in plant species' habitat suitability due to alterations in the frequency, timing, or duration of HFE releases are not reflected by these analyses.

Impact Indicators

Changes in riparian vegetation composition, structure, and distribution.

Issue 1: How would flow alterations at Glen Canyon Dam affect riparian vegetation?

No Action Alternative

Under the No Action Alternative, no changes would be made to Glen Canyon Dam's operations. The flow regime and sediment transport conditions would remain consistent with the management actions described in the LTEMP FEIS (DOI 2016a). Riparian vegetation communities would continue along current trajectories. As water volumes in the Colorado River continue to decrease in response to regional drought conditions, it is likely that species' recruitment would continue to occur in the lower riparian zones, unless sediment availability and habitat become limiting factors. Upper riparian zones may transition to desert ecosystems.

Cool Mix Alternative

The Cool Mix Alternative is a mix of water released simultaneously through the penstocks and the river outlet works to maintain a daily average water temperature of about 15.5°C (60°F) from below Glen Canyon Dam to the Little Colorado River to disrupt smallmouth bass spawning. Under this alternative, HFE releases would also be implemented. The Cool Mix Alternative would have consistent releases that result in flow patterns similar to the patterns under current management. Therefore, overall, this alternative is expected to have similar impacts on riparian vegetation as the No Action Alternative described above. In Marble Canyon, this alternative would result in a negligible increase in the proportion of native versus nonnative vegetation cover, a negligible decrease in species' richness, and a small increase in total vegetation cover, compared with the No Action Alternative. In eastern Grand Canyon, this alternative would result in a negligible decrease in the proportion of native versus nonnative vegetation cover, a negligible increase in species' richness, and a small increase in total vegetation cover, compared with the No Action Alternative. In western Grand Canyon, this alternative would result in a negligible decrease in the proportion of native versus nonnative vegetation cover, a small increase in species' richness, and a small increase in total vegetation cover, compared with the No Action Alternative.

Cool Mix with Flow Spike Alternative

The Cool Mix with Flow Spike Alternative includes consistent releases from the river outlet works to maintain a daily average water temperature of about 15.5°C (60°F) with flow spikes that would consist of 8-hour periods of elevated flows between May and July to reduce water temperatures and disrupt smallmouth bass spawning. Because these flow spikes would be of a similar magnitude as HFE releases previously conducted in the program (up to 45,000 cfs), spikes would have similar impacts on riparian vegetation as HFE releases.

In Marble Canyon, this alternative would result in no change in the proportion of native versus nonnative vegetation cover, a negligible decrease in species' richness, and no change to a negligible increase in total vegetation cover (depending on the flow spike scenario), compared with the No Action Alternative. In eastern Grand Canyon, this alternative would result in a negligible decrease in the proportion of native versus nonnative vegetation, no change in species' richness, and a negligible to small increase in total vegetation cover (depending on the flow spike scenario), compared with the No Action Alternative. In western Grand Canyon, this alternative would result in a negligible decrease in the proportion of native versus nonnative vegetation cover, a negligible decrease or negligible increase in species' richness (depending on the flow spike scenario), and a negligible to small increase in total vegetation cover (depending on the flow spike scenario), compared with the No Action Alternative.

Cold Shock Alternative

The Cold Shock Alternative would release water for at least 48 hours through the river outlet works, releasing the minimum amount of water required to create a cold shock all the way down to the Little Colorado River to disrupt smallmouth bass populations. The Cold Shock Alternative would also include implementation of HFE releases of similar magnitude to flow spikes in the Cool Mix with Flow Spike Alternative. Therefore, the impacts on riparian vegetation from the Cold Shock Alternative are similar to those described for the Cool Mix with Flow Spike Alternative.

Cold Shock with Flow Spike Alternative

The Cold Shock with Flow Spike Alternative would release water for at least 48 hours through the river outlet works for the minimum amount of time required to create a cold shock all the way down to the Little Colorado River to disrupt smallmouth bass spawning. In addition, up to three 8-hour flow spikes would be added between June and mid-July. The flow spikes would be similar in magnitude to HFE releases; thus, the Cold Shock with Flow Spike Alternative would have flow patterns like the Cool Mix with Flow Spike Alternative. Impacts on riparian vegetation would be the same as those listed above for the Cool Mix with Flow Spike Alternative.

Non-Bypass Alternative

The Non-Bypass Alternative would result in higher daily fluctuations in flows with weekly drops in flow to a minimum of 2,000 cfs followed by a steep increase in flow to a maximum of ~27,300 cfs. These changes would last for approximately 8 hours at the dam. Compared with the other flow alternatives, the Non-Bypass Alternative would have daily flow fluctuations that may reduce shoreline stability.

In Marble Canyon, this alternative would result in a small increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative. In eastern Grand Canyon, this alternative would result in a small increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative. In western Grand Canyon, the effects of this alternative would be most pronounced and would result in a moderate increase in the proportion of native versus nonnative species cover, a small increase in species' richness, and a small decrease in total vegetation cover, compared with the No Action Alternative.

Cumulative Effects

The effects of the LTEMP SEIS alternatives on riparian vegetation are negligible to small and are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the Basin at large. Therefore, no cumulative effects on vegetation are anticipated.

Summary

Overall, the impacts of any of the alternatives on riparian vegetation are expected to be negligible to small, with nearly all changes expected to be below a 1 percent change. This is due to the minor changes in monthly and HFE volumes, with the caveat that changing the timing of HFE releases may have impacts on riparian plant communities that are not captured by the vegetation modeling approach described above.

3.7 Wildlife

3.7.1 Affected Environment

To supplement the 2016 LTEMP FEIS (DOI 2016a), this section summarizes the affected environment for wildlife, including, as necessary, changes that have occurred since 2016.

The affected environment for wildlife includes the area that may be influenced by implementation of the alternative flow options at Glen Canyon Dam as discussed in the SMB EA (Reclamation 2023a), specifically the Colorado River ecosystem from Glen Canyon Dam downstream to Pearce Ferry boat ramp. Because the proposed action would maintain upper and lower bounds of water releases consistent with the original LTEMP FEIS (Department 2016a), it is assumed that wildlife species that primarily use upland habitat would not be affected by daily fluctuation in flows. Thus, this section covers both non-listed wildlife (except for fish, which are discussed in **Section 3.4**) and special status species that primarily utilize riparian habitat zones. This section also covers special status species listed by the State of Arizona as species of greatest conservation need. Federally listed species are discussed in **Section 3.8**, Threatened and Endangered Species.

As described in the 2016 LTEMP FEIS, the Colorado River ecosystem supports numerous invertebrates, amphibians, reptiles, birds, and mammals (DOI 2016a). Changes to water volume, flows, and sediment transport can affect vegetation and thus habitat for riparian wildlife and waterbirds. The wildlife species described below are those most likely to be found in the Colorado

River ecosystem downstream of Glen Canyon Dam in the riparian zone as described in the 2016 LTEMP FEIS (DOI 2016a).

Invertebrates

Thousands of invertebrate species are known to occur in the riparian corridor of the Grand Canyon (DOI 2016a), predominately terrestrial and aquatic flies, herbivorous insects (especially cicadas, leafhoppers, and aphids), spiders and scorpions, beetles, and many different species of wasps, bees, and ants. These invertebrates fill a variety of ecological roles and serve as pollinators, regulate populations of other invertebrates, and provide food resources for many terrestrial and aquatic wildlife species. A detailed discussion of the affected environment for invertebrates can be found in Section 3.7.1 of the 2016 LTEMP FEIS (DOI 2016a).

Changes that have occurred since the 2016 LTEMP FEIS analysis and may have resulted in changes to invertebrates or invertebrate habitat include the following:

- *Changes to riparian vegetation health along the river corridor resulting from ongoing dam operations.* Riparian vegetation composition, structure, distribution, and function along the Colorado River corridor downstream of Glen Canyon Dam is closely tied to Glen Canyon Dam operations (DOI 2016a). As described in the 2016 LTEMP FEIS, effects of dam operations include the potential for long-term declines in native plant communities along the river and increases in nonnative vegetation and monoculture species (DOI 2016a).
- *Changes in riparian vegetation resulting from HFE releases and other experimental vegetation treatments.* Riparian vegetation communities can be affected through scouring and erosion during high flows (Reclamation 2023a). HFE releases and other vegetation experiments conducted since the 2016 LTEMP FEIS may have influenced riparian vegetation along this reach of the river, directly influencing riparian invertebrate habitat (Reclamation 2023a).
- *Changes in the occurrence and distribution of invasive invertebrates.* The NPS has identified several species of invasive invertebrates in the area, including the New Zealand mud snail (*Potamopyrgus antipodarum*) and quagga mussels (*Dreissena bugensis*), which have been detected downstream of Glen Canyon Dam (Reclamation 2023a) and are further discussed in **Section 3.5**.

Invertebrate abundance and species' richness largely depend on the supporting vegetation. Thus, changes in vegetation in the riparian zone resulting from ongoing operations of the dam, drought conditions, HFE releases, and other vegetation experiments may have directly influenced invertebrate abundance and biodiversity. Similarly, changes in the abundance and distribution of invasive vegetation and invasive invertebrate species may have occurred, affecting native species and larger riparian ecosystems.

Changes to special status invertebrates that have occurred since the 2016 LTEMP FEIS analysis are discussed in subsection **Special Status Invertebrates**.

Amphibians and Reptiles

The Colorado River ecosystem provides habitat for numerous reptile and amphibian species, including three amphibian and 24 reptile species documented in the riparian zone of the river corridor (DOI 2016a). As described in the 2016 LTEMP FEIS, the highest densities and diversity of amphibians and reptiles tend to occur in riparian areas nearer the river's edge due to the presence of water, abundant vegetation, and invertebrate food (DOI 2016a). The common amphibian species along the river corridor are the canyon treefrog (*Hyla arenicolor*), red-spotted toad (*Bufo punctatus*), and Woodhouse's toad (*Anaxyrus woodhousii*). The most common lizard species along the river corridor are the side-blotched lizard (*Uta stansburiana*), western whiptail (*Aspidoscelis tigris*), desert spiny lizard (*Sceloporus magister*), and tree lizard (*Urosaurus ornatus*). The more common snake species in riparian areas downstream of Glen Canyon Dam include the Grand Canyon pink rattlesnake (*Crotalus viridis abyssus*), speckled rattlesnake (*Crotalus mitchellii*), black-tailed rattlesnake (*Crotalus molossus*), common king snake (*Lampropeltis getula*), and gopher snake (*Pituophis catenifer*).

Amphibians tend to use backwaters or shallow waters of aquatic and riparian habitats, while lizards and snakes tend to use a mix of riparian and shoreline habitat. While tortoises are present in the greater Colorado River area, they primarily utilize adjacent upland habitat (for example, Mojave desert scrub, creosote bush flats in basins and mountain bajadas, and Joshua tree forests), and are therefore not discussed further. A more detailed discussion of the affected environments for amphibians and reptiles can be found in Section 3.7.2 of the 2016 LTEMP FEIS (DOI 2016a). Special status amphibian and reptile species are discussed below.

Changes that have occurred since the 2016 LTEMP FEIS analysis may have resulted in changes to vegetation as described in **Section 3.6**. (DOI 2016a). Amphibian species depend on riparian areas to forage, seek refuge from predators, and regulate their temperature. Reptiles are also dependent on the riparian areas along the Colorado River. Lizards are primarily insectivorous, and the shoreline and riparian areas are ideal foraging areas. Changes to the vegetation abundance and diversity could affect lizard species.

Birds

As described in the 2016 LTEMP FEIS, upward of 300 bird species have been documented in the greater Grand Canyon region, several of which are considered obligate riparian species. Common riparian birds include Lucy's warbler *(Oreothlypis luciae*), Bell's vireo (*Vireo bellii*), common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-breasted chat (*Icteria virens*), and black-chinned hummingbird (*Archilochus alexandri*) (DOI 2016a). Riparian habitats along the river provide breeding habitat, migratory stopover sites, and wintering areas for birds throughout the year (DOI 2016a). Birds that nest in the riparian zone are directly and indirectly affected by river flows, which influence vegetation distribution and composition, the abundance of invertebrates that serve as food sources, and the availability of nest sites. Terrestrial and waterbird (for example, ducks, geese, herons, sandpipers, and killdeer) species, especially winter waterfowl, also inhabit the river corridor (DOI 2016a). Common waterfowl species include American coot (*Fulica americana*), American widgeon (*Anas americana*), bufflehead (*Bucephala albeola*), common goldeneye (*B. clangula*), common merganser (*Mergus merganser*), gadwall (*A. strepera*), green-winged teal (*A. crecca*), lesser scaup (*Aythya affinis*), mallard (*A. platyrhynchos*), ring-necked duck (*Aythya collaris*), and Canada goose (*Branta canadensis*). As discussed in the 2016 LTEMP FEIS, increased riparian habitat and productivity resulting from Glen Canyon Dam operations have benefited several bird species (DOI 2016a). A more detailed discussion of the affected environments for birds can be found in Section 3.7.3 of the

2016 LTEMP FEIS (DOI 2016a). Special status bird species are discussed in subsection **Special Status Species** (DOI 2016a).

Changes that have occurred since the 2016 LTEMP FEIS analysis may have resulted in changes to vegetation as described in **Section 3.6**. Of the 30 riparian bird species that inhabit the river corridor, at least 76 percent eat insects or feed insects to their young (DOI 2016a). Changes to vegetation in riparian areas (for example, tamarisk levels) can influence the availability of invertebrate prey and nest sites.

Mammals

The habitat along the river also supports numerous mammals, including those that use aquatic habitat and riparian zones. The only aquatic mammals in the area are beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter (*Lontra canadensis*). Beavers occur throughout the river corridor from Glen Canyon Dam to the Grand Wash Cliffs, where riparian vegetation is well established (DOI 2016a). Their populations have increased since construction of the dam owing to increased riparian vegetation. Muskrats and river otters are rarely documented along the river corridor, in part because the river otter is classified as extirpated from the Grand Canyon (DOI 2016a). Rodents are the most abundant small mammals within the riparian zone, including the cactus mouse (*Peromyscus eremicus*), rock pocket mouse (*Chaetodipus intermedius*), deer mouse (*Peromyscus maniculatus*), and rock squirrel (*Spermophilus variegatus*) (DOI 2016a). Bats are documented downstream of Glen Canyon Dam occupying rock crevices, caves, and upland trees and feeding on insects along the Colorado River and its tributaries.

Changes that have occurred since the 2016 LTEMP FEIS analysis and may have resulted in changes to vegetation and thus the affected environment for mammals are like those described for invertebrates in subsection **Invertebrates**. (DOI 2016a).

Special Status Species

Consistent with the 2016 LTEMP FEIS (DOI 2016a), special status species are defined as those that may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are either State of Arizona species of greatest conservation need (AZ-SGCN) or bald or golden eagles protected by the Bald and Golden Eagle Protection Act of 1940 (BGEPA) (**Table 3-32**). Those species that are designated as Arizona species of greatest conservation need and are also federally listed are discussed in **Section 3.8**, Threatened and Endangered Species.

Special status species found in the area include the northern leopard frog (*Lithobates pipiens*), American peregrine falcon (*Falco peregrinus*), bald eagle (*Haliaeetus leucocephalus*), golden eagle (*Aquila chrysaetos*), osprey (*Pandion haliaetus*), and spotted bat (*Euderma maculatum*) (**Table 3-32**). The northern leopard frog has not been observed since 2004. The species is presumed extirpated in Glen and Grand Canyons downstream of Lees Ferry (DOI 2016a). The American peregrine falcon is a migratory bird that nests in upland habitat in the summer and feeds on prey commonly found in the river corridor including fish, songbirds, and bats (DOI 2016a). Multiple peregrines were observed hunting at Yaki and Lipan Points during 2008 migration studies (HawkWatch 2009). Downstream of Glen Canyon Dam, bald eagles have been observed wintering in areas with ample fish populations.

Table 3-32
Species Listed on the Arizona Species of Greatest Conservation Need List in 2012 and in 2022

Common Name	Scientific Name	Status in 2012	Status in 2022
Invertebrates			
Niobrara (Kanab) ambersnail*	*Oxyloma haydeni kanabensis*	ESA-E; AZ-SGCN Tier 1	AZ-SGCN Tier 1
Amphibians and Reptiles			
Northern leopard frog	*Lithobates pipiens*	AZ-SGCN Tier 1	AZ-SGCN Tier 1
Birds			
American peregrine falcon	*Falco peregrinus*	AZ-SGCN Tier 1	AZ-SGCN Tier 1
Bald eagle	*Haliaeetus leucocephalus*	AZ-SGCN Tier 1; BGEPA	AZ-SGCN Tier 1
Golden eagle	*Aquila chrysaetos*	AZ-SGCN Tier 2; BGEPA	AZ-SGCN Tier 2
Ridgway's rail (Yuma)*	*Rallus obsoletus yumanensis*	ESA-E; AZ-SGCN Tier 1	AZ-SGCN Tier 1
California condor*	*Gymnogyps californianus*	ESA-XN; AZ-SGCN Tier 1	AZ-SGCN Tier 1
Western yellow-billed cuckoo*	*Coccyzus americanus*	ESA-T; AZ-SGCN Tier 1	AZ-SGCN Tier 1
Southwestern willow flycatcher*	*Empidonax traillii extimus*	ESA-E; AZ-SGCN Tier 1	AZ-SGCN Tier 1
Mammals			
Spotted bat†	*Euderma maculatum*	AZ-SGCN Tier 1	AZ-SGCN Tier 2
Pale Townsend's big-eared bat†	*Corynorhinus townsendii pallescens*	AZ-SGCN Tier 3	AZ-SGCN Tier 1

Source: Reclamation and NPS 2016; AZGFD 2022

Notes: AZ-SGCN; (BGEPA).

*Indicates a species that are federally listed as threatened or endangered (discussed in **Section 3.8**).

† Indicates a change in status between 2012 and 2022.

Osprey were not included in the 2022 AZ-SGCN and are therefore not included in the table.

Golden eagles prefer to nest along cliffs and mesas and generally feed on small mammals such as rabbits and ground squirrels but also prey on large insects, birds, reptiles, and carrion. Observations of bald and golden eagles have been declining (DOI 2016a). Large numbers of ospreys use the Colorado River corridor during fall migration, usually August–September, and feed almost exclusively on fish, although they will also prey on snakes, frogs, shorebirds, and waterfowl (DOI 2016a). Spotted bats are the only special status mammals in the area and are rarely encountered in Arizona, but they may occur in areas where cliffs and water sources are available. Dominant prey items are moths but also include June beetles and sometimes grasshoppers that are taken while on the ground (DOI 2016a).

Table 3-16 includes those species that may occur along the river corridor as listed in the 2016 LTEMP FEIS (DOI 2016a). Changes to special status species that have occurred since the 2016 LTEMP FEIS analysis are outlined in **Table 3-32** and include the following:

- The addition of the pale Townsend's big-eared bat to the Arizona SGCN tier 1
- A change from Arizona SGCN tier 1 to tier 2 for the spotted bat

3.7.2 Environmental Consequences

Methodology

Wildlife-specific models were not available for use in this analysis due, in part, to limited data availability. The analysis in this section is informed by hydrologic and vegetation models showing the effects of dam releases on the hydrology and riparian vegetation (**Sections 3.2**, Hydrology, and **3.6**, Terrestrial Resources and Wetlands). As discussed in the 2016 LTEMP FEIS, the primary effects on wildlife and special status species below the Glen Canyon Dam will be a direct function of the changes in distribution and abundance of wildlife habitat and aquatic species that result under each alternative. The environmental consequences for wildlife and special status species are presented as a qualitative discussion of how each alternative may affect vegetation, riparian habitat, and the aquatic food sources on which wildlife and special status species depend.

Impact Analysis Area

The analysis area is consistent with that used in the 2016 LTEMP FEIS. It includes the Colorado River mainstream corridor and interacting resources in associated riparian zones located primarily from the forebay of Glen Canyon Dam to Pearce Ferry above Lake Mead.

Assumptions

Two assumptions were made for the wildlife analysis:

- The proposed flow alternatives would not impact upland habitat.
- The analyses of impacts on wildlife and special status species depend on the data inputs, modeling assumptions, and validity of the models.

Impact Indicators

Impacts were evaluated for species that primarily use riparian and wetland habitat zones in the following species groups: invertebrates, amphibians and reptiles, birds, mammals (collectively, general wildlife), and species status species. For each group, impacts of each alternative were evaluated based on the following indicators:

- Change in riparian and open water habitat
- Change in aquatic habitat and food base
- Direct effects of HFE releases and other flow and non-flow actions

Issue 1: How would flow alterations at Glen Canyon Dam affect general wildlife?

No Action Alternative

Under the No Action Alternative, no changes would be made to Glen Canyon Dam operations. Vegetation and habitat conditions would remain consistent with the management actions described in the LTEMP FEIS (Reclamation 2016). As described in the LTEMP FEIS, under current management, water volumes in the Colorado River will continue to decrease in response to regional drought conditions. Frequent extended high flows would result in an overall decrease in native plant communities and decrease in wetland habitat. Upper riparian zones would likely transition to desert ecosystems (Reclamation 2016). This alternative would also continue to allow nonnative, invasive fish species passage through the dam, likely resulting in increased abundances and ranges of these species downstream of Glen Canyon Dam. Under the No Action Alternative there would be no change to the current trajectories for wildlife species that use riparian habitats, including invertebrates, amphibians and reptiles, birds, and mammals, beyond those predicted to result from current management and drought conditions along the Colorado River.

Cool Mix Alternative

The Cool Mix Alternative is a mix of water released simultaneously through the penstocks and the river outlet works to maintain a daily average water temperature of about 15.5°C (60°F) from below Glen Canyon Dam to the Little Colorado River to disrupt smallmouth bass spawning. Under this alternative, HFE releases would also be implemented. The Cool Mix Alternative would have consistent releases that result in flow patterns similar to the patterns under current management (SMB EA). Therefore, this option is expected to have similar impacts on invertebrates, amphibians, reptiles, and mammals that use riparian habitats as the No Action Alternative described above.

Cool Mix with Flow Spike Alternative

The Cool Mix with Flow Spike Alternative includes consistent releases from the river outlet works to maintain a daily average water temperature of about 15.5°C (60°F) with flow spikes that would consist of 8-hour periods of elevated flows between May and July to reduce water temperatures and disrupt smallmouth bass spawning. Because these flow spikes would be of a similar magnitude as the HFE releases previously conducted in the program (up to 45,000 cfs), spikes would have similar impacts as HFE releases. A summary of impacts on invertebrates, amphibians and reptiles, and mammals from HFE releases and flow spikes are as follows:

Invertebrates

Increased flows associated with HFE releases and flow spikes may result in temporary displacement of aquatic insects that use shoreline habitat for feeding and reproduction. These impacts would be temporary because invertebrate species can move in response to fluctuations in flow and would recolonize after HFEs have ended. Higher flows are not expected to change the amount of overall vegetation. HFE releases and flow spikes may enhance germination for certain riparian plant species and prevent establishment of other species, changing composition in ways that could have beneficial impacts on invertebrate biodiversity and abundance (Reclamation 2023b).

Amphibians and Reptiles

Impacts of the Cool Mix with Flow Spike Alternative on amphibians and reptiles would be the same as those listed for invertebrates (that is, temporary displacement and negligible changes in riparian vegetation composition).

Birds

Impacts of the Cool Mix with Flow Spike Alternative on birds would include those described for invertebrates. In addition to temporary impacts from fluctuations in flows, HFE releases and flow spikes may have additional impacts on nesting bird species. HFE releases and flow spikes implemented during the breeding season could impact shoreline nesting birds through higher water elevations washing away nests along the shoreline.

Mammals

Beaver, mice and other small rodents are the most abundant mammals in riparian zones. Impacts of the Cool Mix with Flow Spike Alternative on riparian mammals include the potential for displacement of individuals in the flood zone during HFE releases; however, no long-term population-level effects are expected. HFE releases could provide critical water resources to obligate riparian mammals at higher elevations if the HFEs occur during the hottest months.

In addition to the impacts of higher flows on invertebrates, amphibians, reptiles, birds, and mammals described above, this alternative also would have periods of steady flows that are consistent or higher than the minimum daily flow (8,000 cfs) under LTEMP FEIS. Higher discharge rates during these consistent flow periods could provide additional benefits to obligate wetland species that favor wet environments.

Cold Shock Alternative

The Cold Shock Alternative would release water for at least 48 hours through the river outlet works, releasing the minimum amount of water required to create a cold shock all the way down to the Little Colorado River to disrupt smallmouth bass populations. The Cold Shock Alternative would also include implementation of HFE releases of similar magnitude to flow spikes under the Cool Mix with Flow Spike Alternative. Therefore, the impacts on wildlife from the Cold Shock Alternative would be like those described for the Cool Mix with Flow Spike Alternative.

Cold Shock with Flow Spike Alternative

The Cold Shock with Flow Spike Alternative would release water for at least 48 hours through the river outlet works for the minimum amount of time required to create a cold shock all the way down to the Little Colorado River to disrupt smallmouth bass spawning. In addition, up to three 8-hour flow spikes would be added between June and mid-July. The flow spikes would be similar in magnitude to HFE releases; thus, the Cold Shock with Flow Spike Alternative would have flow patterns like those under the Cool Mix with Flow Spike Alternative. The impacts on invertebrates, amphibians, reptiles, birds, and mammals would be the same as those listed above for the Cool Mix with Flow Spike Alternative.

Non-Bypass Alternative

The Non-Bypass Alternative would result in higher daily fluctuations in flows with weekly drops in flow to a minimum of 2,000 cfs followed by a steep increase in flow to a maximum of ~27,300 cfs. These changes would last for approximately 8 hours at the dam. Compared with other flow alternatives, the Non-Bypass Alternative would have daily flow fluctuations that may reduce shoreline stability. This instability could lead to a decrease in the abundance of aquatic invertebrates and greater disruption to wildlife habitat, as compared with the other action alternatives. During low-flow periods, foraging habitat for certain waterfowl may decrease. These impacts would be temporary and followed by higher flows that would increase foraging habitat. More mobile species, such as waterfowl, would likely adjust by foraging in Lake Powell, Lake Mead, or farther downriver, whereas amphibians, reptiles, and insects may be less able to adapt to the less stable shoreline environment, resulting in decreased biodiversity or abundance.

Cumulative Effects

The effects of the LTEMP SEIS alternatives on wildlife are relatively small and are not expected to contribute substantially to cumulative impacts along the Colorado River corridor or within the Colorado Basin at large. Therefore, no cumulative effects on wildlife are anticipated.

Issue 2: How would flow alterations at Glen Canyon Dam affect special status species?

Special status species are defined as those that may occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead and that are either AZ-SGCN or bald or golden eagles protected by the BGEPA. Environmental consequences for those species that are also federally listed are discussed in **Section 3.8**, Threatened and Endangered Species.

The impacts on species status species are similar under each alternative. Thus, this section summarizes impacts on special status species groups (invertebrates, amphibians and reptiles, birds, and mammals) under all alternatives.

All Alternatives

Special Status Invertebrates

There are no special status invertebrates in the analysis area.

Special Status Amphibians and Reptiles

Under the No Action Alternative, current conditions for special status amphibians and reptiles would be unchanged. As compared with the No Action Alternative, all other alternatives that alter releases have the potential to impact amphibians and reptile species dependent on wetland habitats, including the northern leopard frog, which is the only special status species amphibian in the project area. Impacts would be similar to those described under the general wildlife section. Alternatives with higher daily fluctuations (in particular the Non-Bypass Alternative) would have the potential to lower insect production, potentially resulting in relatively greater impacts on the northern leopard frog.

Special Status Birds

None of the alternatives are anticipated to impact the American peregrine falcon, bald eagle, golden eagle, or birds protected under the Migratory Bird Treaty Act (16 United States Code 703 – 712). These species would not be as sensitive to fluctuations in flows; this is because they are not riparian-obligate species, and they can forage in a variety of habitats. Nesting sites for these species are in upland zones that would not be impacted by any of the alternatives.

Special Status Mammals

None of the alternatives are anticipated to have population-level impacts on the spotted bat or pale Townend's bat. Under alternatives that decrease the shoreline stability, which potentially would decrease the abundance of insects, bat species may experience a shift in foraging habitat.

Cumulative Effects

The effects of the LTEMP SEIS alternatives on special status species are relatively small and are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the Basin at large. Therefore, no cumulative effects on wildlife are anticipated.

Summary

Summary of Impacts of General Wildlife

Riparian wildlife populations depend on suitable habitat, food, and water resources. While changes in water temperature would not impact riparian wildlife, changes in releases from Glen Canyon Dam have the potential to directly and indirectly impact riparian habitat and wildlife species. Alternatives with more fluctuations, and less consistent monthly release volumes, would have a greater impact on species that use nearshore habitats or feed on insects. Impacts from daily, weekly, and monthly water release changes would likely be temporary. For instance, under all alternatives, HFE releases could displace invertebrates, amphibians, reptiles, birds, and mammals who use shoreline habitat for foraging, nesting, and breeding. These species can move in response to fluctuations in flow and would return after HFE releases or flow spikes end. In some cases, HFE releases or flow spikes may have more permanent impacts on certain species (for example, destruction of a nest during an HFE). However, higher-flow events also have the potential to provide critical water resources to obligate riparian species at higher elevations during the hottest months.

Periods of low flows under the Non-Bypass Alternative could impact the availability of foraging habitat for certain waterfowl, who would likely adjust by foraging in Lake Powell, Lake Mead, or farther downriver. Steady releases that would occur under the Cool Mix with Flow Spikes, Cold Shock, and Cold Shock with Flow Spikes Alternatives could also provide additional benefits to obligate wetland species that favor wet environments. None of the alternatives are expected to significantly alter the amount of riparian and wetland habitat (Butterfield and Palmquist 2023). Although some temporary impacts may occur under all alternatives, none of the alternatives are expected to have long-term population-level effects on wildlife.

Summary of Impacts on Special Status Wildlife

All alternatives that result in fluctuations in flows may have negligeable to minor impacts on the northern leopard frog, which depends on wetland and riparian habitat. All other special status species identified within the project area do not depend on riparian or shoreline habitats. Therefore, there would be no impacts on special status wildlife species.

3.8 Threatened and Endangered Species

3.8.1 Affected Environment

Two species of native fish that are listed under the ESA (16 United States Code 1531, as amended), the humpback chub and the razorback sucker, occur in the potentially affected portions of the Colorado River and its tributaries between Glen Canyon Dam and the inflow to Lake Mead. These two species are also designated as Arizona species of greatest conservation need. The bonytail, also listed under the ESA, has been extirpated from the Grand Canyon for over five decades, but it has recently been stocked in Lake Powell (Pennock and Gido 2021). Some fish have apparently been passing through the penstocks at Glen Canyon Dam and have been captured in the Colorado River in the Lees Ferry reach. The number of bonytail in the analysis area is too small to consider in this SEIS.

Humpback Chub

The humpback chub is a large, long-lived species endemic to the Colorado River system. This member of the minnow family attains a total length of about 450 millimeters (17.7 inches) and weight of about 1,000 grams (2.2 pounds), and it may live as long as 40 years (Hendrickson 1994; Valdez and Ryel 1995; Andersen 2009). The humpback chub was federally listed as endangered in 1967 and was grandfathered into protection with passage of the ESA in 1973. It was reclassified from endangered to threatened with a 4(d) rule on October 18, 2021 (Service 2021).

In downlisting the humpback chub, the Service evaluated the stressors associated with the five listing factors and detailed in the species status assessment (Service 2018b). These include river flows (Factor A) and predatory, nonnative fish (Factor C) in the Upper Basin populations. They also include river flows (Factor A), water temperature (Factor A), food supply (Factor A), and predatory, nonnative fish (Factor C) in the Lower Basin population (Service 2021). Minimization of each of these factors was important in downlisting the species. Critical habitat includes the Colorado River from Nautaloid Canyon (river mile 35) to Granite Park (river mile 209), and the lower 8 miles of the Little Colorado River (Service 1994).

Distribution and Abundance

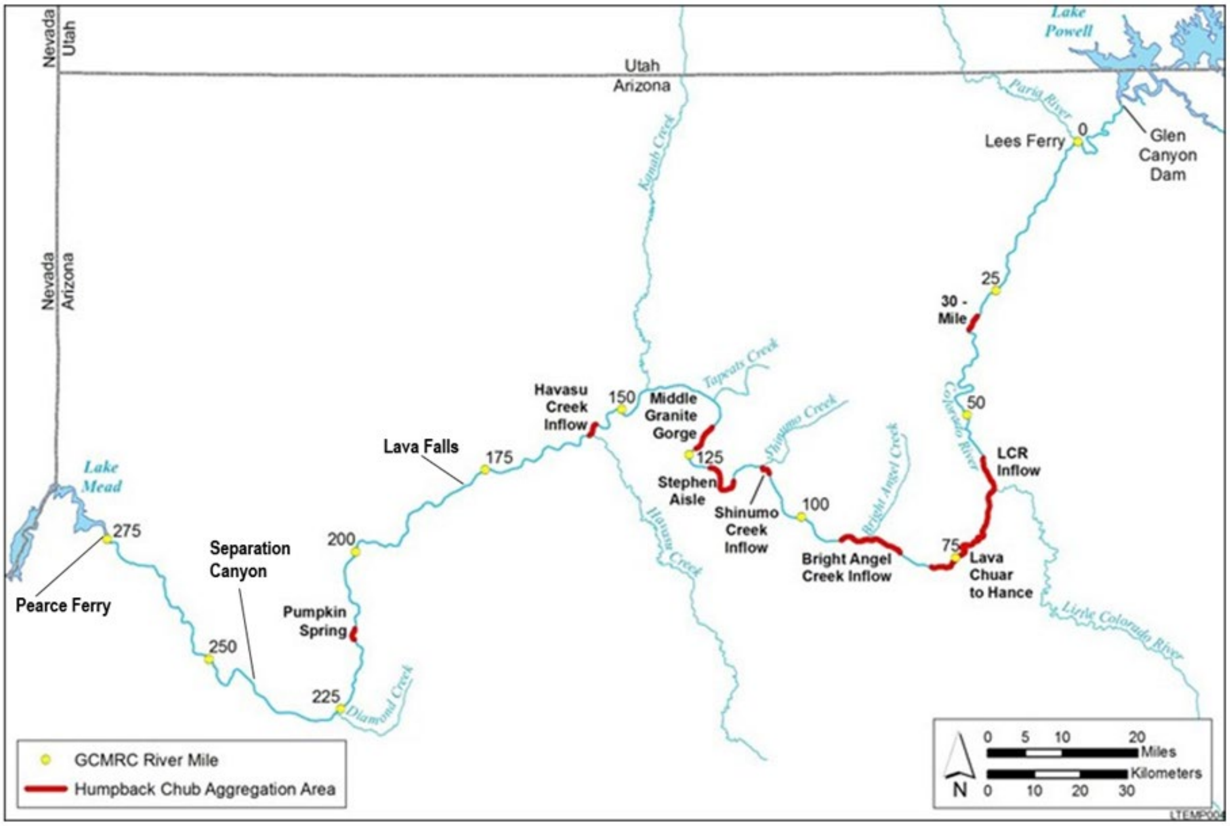
Historically, this species occurred in whitewater regions of the Colorado River and some larger tributaries from below Hoover Dam upstream into Arizona, Utah, Colorado, and Wyoming. Currently, the humpback chub is restricted to six population centers, five in the Upper Colorado River Basin and one in the Lower Basin (Service 2018a). The Upper Basin populations occur in (1) the Colorado River in Cataract Canyon, Utah; (2) the Colorado River in Black Rocks, Colorado; (3) the Colorado River in Westwater Canyon, Utah; (4) the Green River in Desolation and Gray Canyons, Utah; and (5) the Green and Yampa Rivers in Dinosaur National Monument, Colorado. The last population is considered extirpated, and an effort began in 2021 to reintroduce the species and reestablish a new population in the Green and Yampa Rivers within Dinosaur National Monument (Valdez et al. 2021). The only population in the Lower Basin occurs in the Colorado

River from about 30-Mile Spring downstream to the Lake Mead inflow (Rogowski et al. 2018), and in the Little Colorado River, with translocations to several tributaries (Service 2018a).

The Colorado River population in the Grand Canyon is the largest of the five remaining population centers of the humpback chub. Within the Grand Canyon, this species was most abundant in the vicinity of the confluence of the Colorado River and Little Colorado River prior to 2017 (Paukert et al. 2006), but it has expanded into western Grand Canyon, where the largest population of humpback chub is now found, as described below. In addition, eight other areas (aggregations) where humpback chub were regularly collected have been identified; these aggregation areas are located at 30-Mile, Lava Chuar-Hance, Bright Angel Creek inflow, Shinumo Creek inflow, Stephen Aisle, Middle Granite Gorge, Havasu Creek inflow, and Pumpkin Spring (**Figure 3-29**; Valdez and Ryel 1995). Since 2009, translocations of humpback chub have been made by the Service to introduce juvenile fish upstream of Chute Falls in the Little Colorado River, and by the NPS to introduce juvenile fish into Shinumo and Havasu Creeks, with the goal of establishing additional spawning populations within the Grand Canyon (NPS 2012b, 2013g; Healy et al. 2019). A large debris flow in August 2014 scoured the Shinumo Creek channel and displaced or killed most of the fish that were translocated into that creek (Nelson et al. 2014). Survey data collected in 2013, 2014, and 2015 suggest that translocated humpback chub have successfully spawned in Havasu Creek (NPS 2013g).

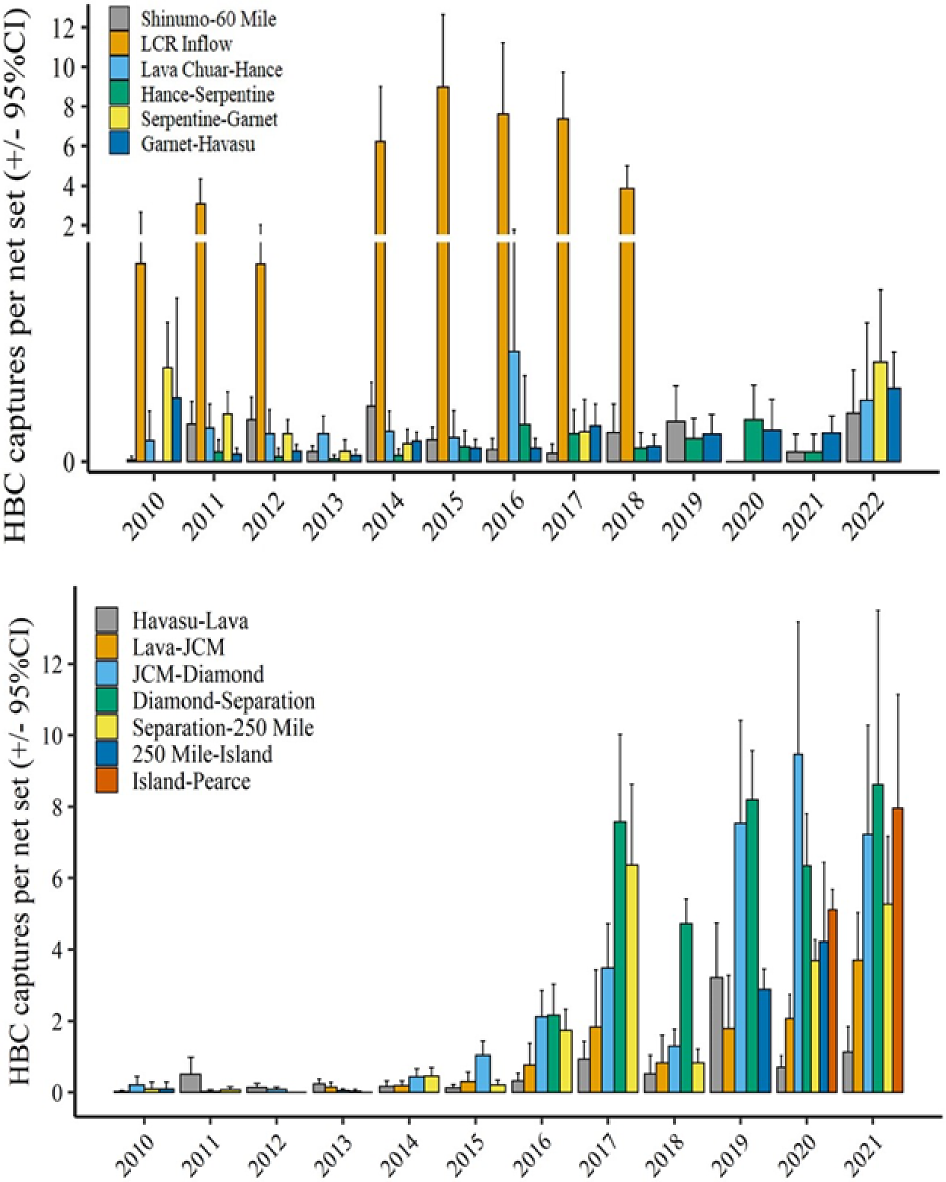
In about 2015, catch rates of humpback chub captured downstream of Havasu Rapids began to increase and then tripled starting in 2017 (**Figure 3-30**; Van Haverbeke et al. 2017; Dzul et al. 2023). Mark-recapture estimates of adults in the Colorado River in western Grand Canyon (Havasu Rapids to Pearce Ferry) showed an increase in numbers of about 20,000 in 2018 to about 66,000 in 2022 with high survival (**Figure 3-30**; Dzul et al. 2023; Van Haverbeke et al. 2023). Since about 2017, western Grand Canyon has been populated by humpback chub representing all size classes, with the highest densities of adults consistently between Lava Falls and Separation Canyon (river miles 180–240) (Dzul et al. 2023). It is unclear whether the humpback chub downstream of Havasu Rapids constitute a new population or an expansion of the aggregations found upstream, but the fish in this area now compose the largest group of humpback chub in the Colorado River system. These numbers of adults compare to about 10,000–15,000 adults in the Little Colorado River/Colorado River aggregation (Yackulic et al. 2022; GCDAMP 2023a).

Figure 3-29
Humpback Chub Aggregation Areas along the Colorado River between Glen Canyon Dam and Lake Mead, and the Area of Western Grand Canyon with the Expanded Population of Humpback Chub



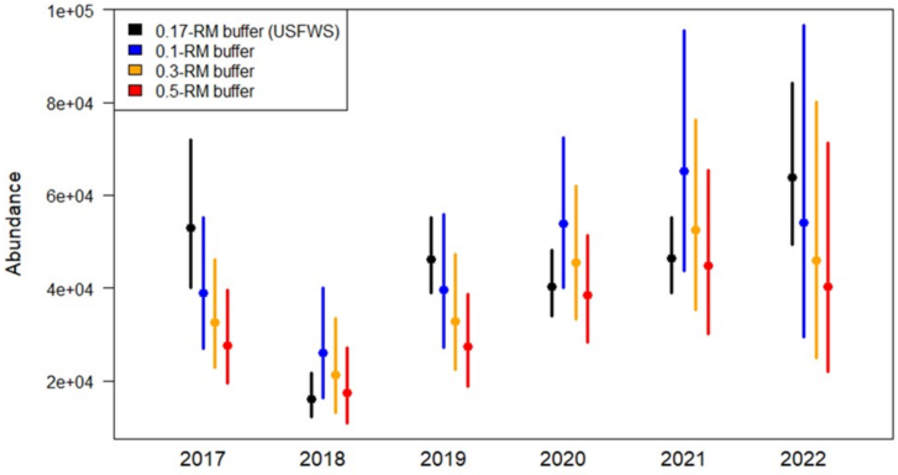
Sources: Valdez and Ryel 1995; VanderKooi 2011; NPS 2013b

Figure 3-30
Annual Catch-per-unit Efforts of Humpback Chub at Sample Sites above (top) and below (bottom) Havasu Rapids, 2010–2022



Source: Dzul et al. 2023

Figure 3-31
Abundance Estimates of Humpback Chub in Western Grand Canyon (Havasu Rapids to Pearce Ferry), 2017–2022



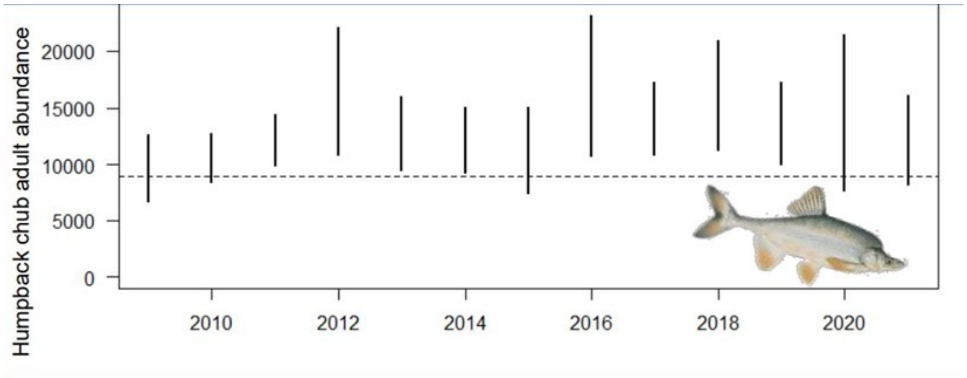
Source: Dzul et al. 2023

Habitat

Throughout the humpback chub's current range, adults are found in turbulent, high-gradient, canyon-bound reaches of large rivers and in deep pools separated by turbulent rapids (Service 2018a). Within the Grand Canyon, the humpback chub is found in the Colorado River in the vicinity of the Little Colorado River (river miles 30–110; **Figure 3-29**), in western Grand Canyon (Van Haverbeke et al. 2017; Dzul et al. 2023), and various aggregations. Adults are associated with large eddy complexes (Valdez and Hoffnagle 1999) and warm tributaries or springs (Valdez and Ryel 1995). Converse et al. (1998) found that densities of subadult humpback chub in the mainstream 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. Korman et al. (2004) found that juvenile humpback chub responded to changing flows by shifting locations to maintain similar habitat conditions. One recent mark-recapture study reported that approximately 87 percent of recaptured fish were collected in the same mainstream river reach or tributary where they were originally tagged, with 99 percent 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 miles throughout the Grand Canyon.

The main spawning area for the humpback chub within the Grand Canyon has been the Little Colorado River, which provides warm temperatures suitable for spawning and shallow, low-velocity pools for larvae (Gorman 1994). Many of the larval fish remain in the Little Colorado River for one or more years, and growth rates and survival are relatively high compared with estimates for the colder waters of the mainstream Colorado River (Dzul et al. 2014; Yackulic et al. 2014). Spring abundance estimates for age-1 humpback chub within the Little Colorado River from 2009 to 2012 ranged from approximately 1,000 to more than 9,000 individuals (Dzul et al. 2023), and numbers of adults ranged from about 10,000 to 15,000 (**Figure 3-32**). Within the Little Colorado River, young humpback chub prefer shallow, low-velocity, nearshore pools and backwaters; they move to deeper and faster areas with increasing size and age (AZGFD 2001a). In the mainstream Colorado River, YOY fish may be found in backwater and other nearshore, slow-velocity areas that serve as nursery habitats (Valdez and Ryel 1995; Robinson et al. 1998; AZGFD 2001a; Stone and Gorman 2006).

Figure 3-32
Abundance of Adult Humpback Chub that Spawn in the Little Colorado River, 2009–2021



Source: Yackulic 2022; GCDAMP 2023a

Juvenile humpback chub (under 3 years old) were collected in all types of nearshore habitats by the Humpback Chub Near-Shore Ecology Study, with the highest numbers collected from talus slopes (Dodrill et al. 2015). Since about 2017, large numbers of young humpback chub have been found in the mainstream Colorado River, especially downstream of Havasu Rapid (Dzul et al. 2023), indicating that mainstream spawning is occurring and may be widespread with increased water temperatures from low elevations of Lake Powell.

These nearshore habitats may be beneficial to the humpback chub (and other native fish) because they provide shallow, productive, warm refugia for juvenile and adult fish (Reclamation 1995; Hoffnagle 1996). Temperature differences between main channel and nearshore habitats can be pronounced in backwaters and other low-velocity areas. The extent of warming is variable and depends on the timing of the daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation (Korman et al. 2006). For example, summertime water temperatures in backwaters have been reported to be as high as 25°C (77°F), while main channel temperatures have been near 10°C (50°F) (Maddux et al. 1987) and have warmed in recent decades.

The amount of warming that occurs in backwaters is affected by daily fluctuations, which drain and fill backwater habitats with cold main channel waters (Valdez 1991; Angradi et al. 1992; AZGFD 1996; Behn et al. 2010). During the low, steady, summer flow experiment conducted in 2000 of about 8,000 cfs, temperatures in one backwater were as much as 13°C (23°F) warmer than in the adjacent main channel during some portions of the day; temperature differences were much less at night (Vernieu and Anderson 2013). Backwater temperatures in summer have been reported to be as much as 2 to 4°C (3.6 to 7.2°F) warmer under steady flows than under fluctuating flows (Hoffnagle

1996; Trammell et al. 2002; Korman et al. 2006; Anderson and Wright 2007). In general, the levels of warming observed in nearshore areas and backwaters during the low summer steady flows in 2000 persisted only for short periods of time and were smaller than seasonal changes in water temperatures (Vernieu and Anderson 2013). Consequently, temperature effects of steady flows on native fish were probably small.

While juvenile humpback chub have been reported to show positive selection for backwater habitats, the spatial extent of such habitats in the Colorado River is small compared with other nearshore habitats, such as talus slopes (Dodrill et al. 2015). Dodrill et al. (2015) reported that the total abundance of juvenile humpback chub was much higher in talus than in backwater habitats, and that when relative densities were extrapolated using estimates of backwater prevalence after a HFE release, the majority of juvenile humpback chub were still found outside of backwaters. This suggests that the role of HFE releases designed to maintain backwater habitats in influencing native fish population trends in the Colorado River may be limited.

Life History

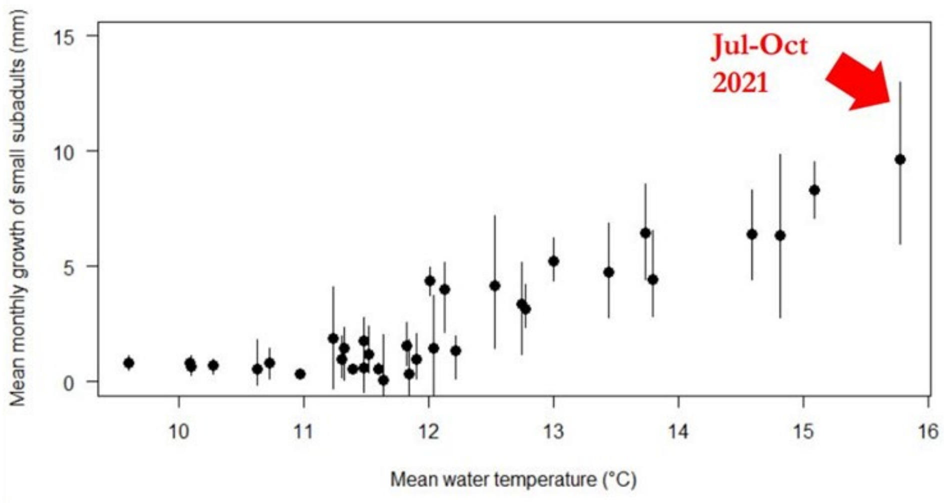
The humpback chub is primarily an insectivore, with larvae, juveniles, and adults all feeding on a variety of aquatic insect larvae and adults, including dipterans (primarily chironomids and simuliids), Thysanoptera (thrips), Hymenoptera (ants, wasps, and bees), and amphipods (such as *Gammarus lacustris*) (Kaeding and Zimmerman 1983; Valdez and Ryel 1995; AZGFD 2001a; Cross et al. 2013). Feeding by all life stages may occur throughout the water column as well as at the water surface and on the river bottom.

The Grand Canyon humpback chub population has changed dramatically in the last 10–15 years. Humpback chub were mostly unable to reproduce in the mainstream Colorado River because of cold water temperatures, with the exception of local reproduction at the 30-Mile Spring (Valdez and Masslich 1999; Andersen et al. 2010). Nearly all reproduction was thought to occur in the lower 8 miles of the Little Colorado River (AZGFD 2001a; Van Haverbeke et al. 2017). Declining reservoir elevations began in about 2002 (Vernieu et al. 2005; Dibble et al. 2021). Warmer water in the mainstream Colorado River allowed for juvenile humpback chub survival and growth in the eastern part of Grand Canyon in the mainstream Colorado River near the Little Colorado River (Limburg et al. 2013; Yackulic et al. 2014; Finch et al. 2016) and likely increases in the Little Colorado River population. In western Grand Canyon, warmer water conditions have likely led to recruitment in the mainstream (Van Haverbeke et al. 2017), which supports what is now the largest population of humpback chub in the entire Colorado River. Additional work is underway to understand the demographics of this population (Dzul et al. 2023).

The life history model for humpback chub is mostly known from the Little Colorado River population. Here, adult humpback chub move into the Little Colorado River from the Colorado River to spawn from March to May (Kaeding and Zimmerman 1983; Gorman and Stone 1999; Valdez and Ryel 1995; Service 2008). This species requires a minimum temperature of 15.5°C (60°F) to reproduce, but mainstream water temperatures typically have ranged from 7 to 12°C (45 to 54°F) because of water releases from Glen Canyon Dam (Andersen 2009). Temperatures now exceed these levels in the eastern Grand Canyon and are much higher in the Lower Colorado River and western Grand Canyon (Dzul et al. 2023). For example, drought-induced warming and the lower levels of Lake Powell have resulted in mainstream water temperatures since 2003 consistently exceeding 12°C (54°F) in the summer and fall months. Although some increases in spawning may have played a role in the estimated increase in the humpback chub population in the system since that time, it is likely that the increased temperatures resulted in higher survival of juveniles in the mainstream (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014) coupled with the rapid and large expansion of humpback chub in western Grand Canyon.

Increasing water temperatures have been shown in the laboratory to increase humpback chub hatching success, larval survival, and larval and juvenile growth; improve swimming ability; and reduce predation vulnerability (Hamman 1982; Ward 2011; Ward and Morton-Starner 2015). It is postulated that, with warmer water, the growth and survival of juveniles in the mainstream will be greater and result in increased mainstream recruitment, contributing to the overall adult population (Yackulic et al. 2014; Van Haverbeke et al. 2017; Dzul et al. 2023). There was rapid growth of small subadults in the mainstream Colorado River in the vicinity of the Little Colorado River during 2021, which coincided with the warmest water temperatures observed in decades during July–October 2021 (**Figure 3-33**).

Figure 3-33
Mean Monthly Growth of Small Subadult Humpback Chub in the Mainstream Colorado River in the Vicinity of the Little Colorado River



Source: Yackulic 2022 [Fisheries review: Annual Reporting FY2021 (usbr.gov)]

Increased water temperatures may also affect predation of YOY humpback chub by rainbow and brown trout (*Salmo trutta*) (Ward 2011; Ward and Morton-Starner 2015; Yard et al. 2011) and allow for the establishment of warmwater nonnative species, which can also prey on humpback chub. Ward and Morton-Starner (2015) conducted laboratory studies that indicated predation success of rainbow trout on YOY humpback chub decreased from approximately 95 percent to 79 percent as water temperature increased from 10°C to 20°C (50°F to 68°F); predation success by brown trout was about 98 percent and did not change significantly over the same temperature range. Yard et al. (2011) examined the effects of temperature on trout piscivory in the Colorado River and reported no relationship between water temperature and the incidence of piscivory by rainbow trout, but a significant positive correlation was found between water temperature and the incidence of piscivory for the brown trout.

Factors Affecting Distribution and Abundance in the Grand Canyon

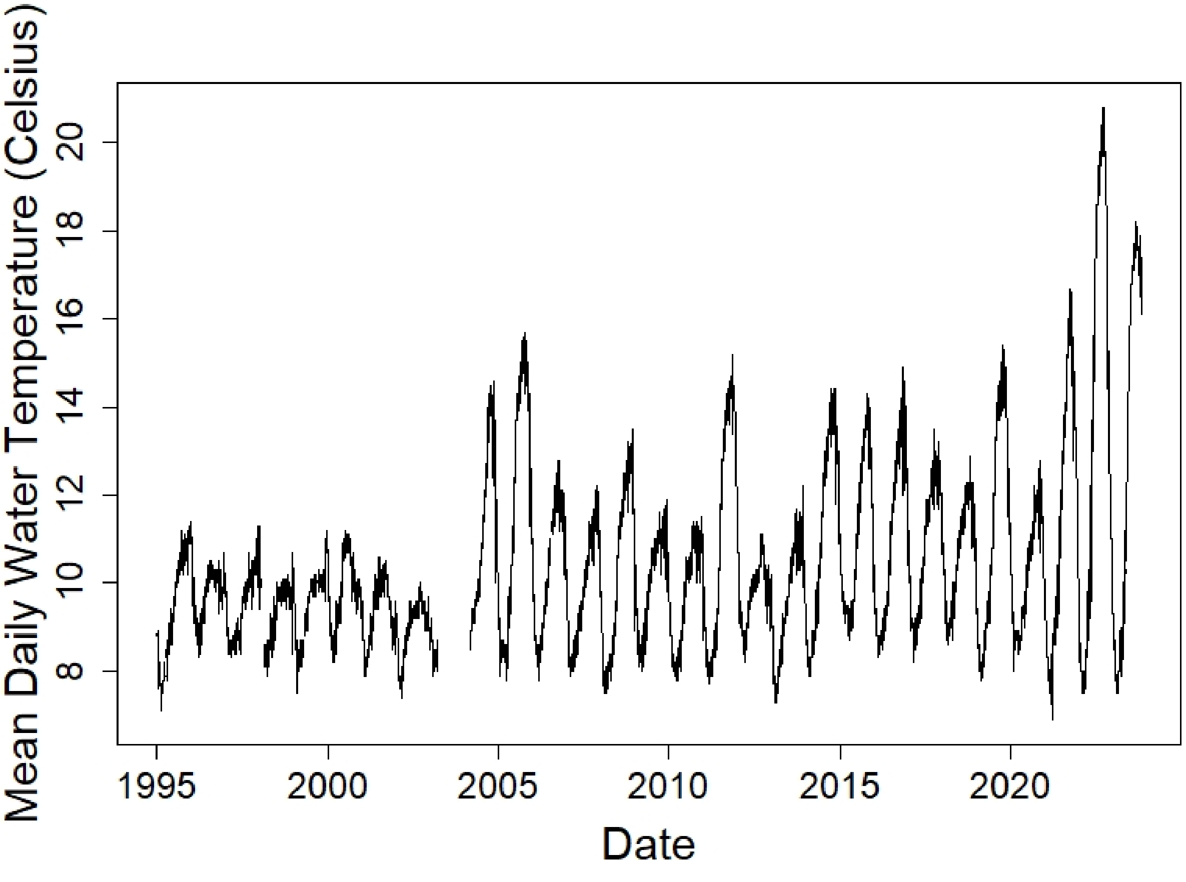
Factors that affect distribution and abundance of humpback chub in the Grand Canyon include habitat alterations associated with dams and reservoirs and the introduction of nonnative fish that act as competitors and/or predators (see Interactions with Native Species) (AZGFD 2001a; Andersen 2009; Yard et al. 2011; Kennedy et al. 2013). The abundance and distribution of nonnative fish are discussed in the Cold-water Nonnative Species section. In addition, the Colorado River now includes nonnative fish parasites, such as the Asian tapeworm and anchor worm, which may infect some humpback chub and affect survival (Clarkson et al. 1997; Hoffnagle et al. 2006; Andersen 2009). While cold-water releases from Glen Canyon Dam have limited reproduction and recruitment of humpback chub (and other native fish) in the mainstream Colorado River, warmer mainstream temperatures over the last two decades have been sufficiently high to allow for growth, survival, and recruitment of humpback chub, contributing to the improving status of this species in the Grand Canyon (Reclamation 2011e; Yackulic et al. 2014). As of the fall 2023, the increasing abundance of humpback chub in western Grand Canyon is currently an area of important research (Van Haverbeke et al. 2017; Gilbert et al. 2022; Dzul et al. 2023).

Population estimates indicate that the number of adult humpback chub that spawn in the Little Colorado River have ranged from about 10,000 to 15,000 (**Figure 3-32**). A number of factors have been suggested as being responsible for the observed increases, including experimental water releases, trout removal, declines in trout abundance due to low DO levels during 2006, and drought-induced warming (Andersen 2009; Coggins and Walters 2009). Some experimental releases, such as the November HFE in 2004, may have adversely affected rainbow trout and improved humpback chub habitat along the main channel (Korman et al. 2010). However, the March 2008 HFE release may have improved rainbow trout spawning habitat quality and age-0 survival rates in the Glen Canyon reach (Korman et al. 2011). Following this release, the abundance of rainbow trout (using catch-per-unit effort as a surrogate for abundance) in this reach was reported to be about 300 percent greater in 2009 than in 2007 (about 3.9 fish per minute versus 1.3 fish per minute) (Makinster et al. 2011), and a similar increase in rainbow trout abundance between 2007 and 2009 was observed at the Little Colorado River confluence (river miles 56–69) (Kennedy and Ralston 2011).

Predation by rainbow and brown trout at the Little Colorado River confluence has been identified as an additional mortality source affecting humpback chub survival, reproduction, and recruitment (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). Predation by channel catfish and black bullhead are also thought to threaten humpback chub in the Grand Canyon, particularly if warmer water conditions occur (NPS 2013e). Because of their size, adult humpback chub are less likely to be preyed on by trout; however, emergent fry, YOY, and juvenile humpback chub are susceptible to predation in the mainstream Colorado River in the vicinity of the Little Colorado River (Yard et al. 2011).

As previously discussed, the cold water temperatures in the main channel are below the temperature needed for spawning, egg incubation, and growth of the humpback chub (as well as for most native fish). Survival of humpback chub young in the mainstream was thought to be low because of cold mainstream water temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), which may limit hatching success, reduce larval survival and larval and juvenile growth (Coggins and Pine 2010), reduce swimming ability, and increase predation vulnerability (Ward and Bonar 2003; Ward 2011). Water temperatures in the mainstream Colorado River have generally been elevated over the last decade (**Figure 3-34**). These temperatures are not optimal for humpback chub spawning and growth. However, juveniles can now successfully grow to adulthood in the Colorado River mainstream, and mainstream recruitment is likely contributing to the overall adult population that now appears to be stable or increasing (Yackulic et al. 2014; **Figure 3-31**).

Figure 3-34
Water Temperatures of the Colorado River at Lees Ferry as Measured at USGS Gage #09380000, 1995 to Present



Source: USGS 2023
Note: Warmest temperatures of less than 20°C (68°F) in 2022 were in late September and early October.

Water temperatures below Glen Canyon Dam began increasing in 2003 as a result of drought conditions that lowered the level of Lake Powell and resulted in the release of warmer water from the dam (Andersen 2009; Andersen et al. 2010); temperatures have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels and somewhat due to relatively high inflow in 2008, 2009, 2011, and 2023. In 2005, the maximum mainstream water temperature exceeded 15°C (59°F) at Lees Ferry and approached 18°C (64°F) in the vicinity of the Little Colorado River (river mile 61), the warmest temperature at those locations since the reservoir was filled in 1980 (**Figure 3-34**). Maximum water temperature in the mainstream at Lees Ferry reached about 14°C (57°F) in 2008 (USGS 2014b), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. In 2011, maximum mainstream water temperatures at Lees Ferry and the Little Colorado River confluence (river mile 61) reached about 15°C (59°F) and 15.5°C (60°F), respectively (**Figure 3-34**), and in recent years, including 2022, water temperatures at Lees Ferry and the Little Colorado River confluence reached 20°C (68°F) (GCMRC 2023b). This warmer water likely benefited the humpback chub and other native fish, but it may also have benefited nonnative warmwater species (such as channel catfish and striped bass) that are more common over a wider spatial range (Andersen 2009; Coggins and Walters 2009; Kennedy and Ralston 2011; Smallmouth Bass Ad Hoc Group 2023).

Razorback Sucker

The razorback sucker is a large river sucker (Catostomidae) endemic to the Colorado River system. It is a large fish that may live up to 40 years, with adults reaching a total length of up to 1,000 millimeters (39 inches) and weights of 5–6 kilograms (11–13 pounds), but they are more typically found within the 400–700 millimeter (16–28 inch) total length range and weigh less than 3 kilograms (7 pounds) (Service 2018b). The razorback sucker was listed as endangered in 1991 (56 *Federal Register* 54957). Critical habitat was designated in 1994 and includes the Colorado River and its 100-year floodplain from the confluence of the Paria River downstream to Hoover Dam (a distance of about 500 miles), including Lake Mead to full pool elevation (59 *Federal Register* 13374).

Distribution and Abundance

The razorback sucker is endemic to large rivers of the Colorado River system from Wyoming to Mexico. The species currently is found in the Green River, Upper Colorado River, and San Juan River subbasins of the Upper Basin, and in the Lower Colorado River in Lake Powell (Francis et al. 2015), in Lake Mead and Lake Mohave, between Lake Havasu and Davis Dam, and in tributaries of the Gila River subbasin (Service 2018b). The largest remaining wild-spawned population was in Lake Mohave (Marsh et al. 2003); however, the wild fish have died from old age and the population is being supported by the rearing of wild-spawned larvae in hatcheries and the release of those fish to the reservoir. Within the Grand Canyon, this species historically occurred in the Colorado River from Lake Mead into Maxson Canyon (river mile 252.5), with several documented captures at the Little Colorado River inflow in 1989 and 1990, and at the Paria River mouth in 1963 and 1978 (NPS 2013e).

Until recently, the last razorback sucker collected from the Grand Canyon (river mile 39.3) was caught in 1993, and the species was considered extirpated from the Grand Canyon. However, razorback suckers and flannelmouth-razorback sucker hybrids have recently been captured from the Little Colorado River (Douglas and Marsh 1998) and from the western Grand Canyon (Bunch et al. 2012a; Bunch et al. 2012b; Rogowski and Wolters 2014; Rogowski et al. 2015). Four fish that were sonic-tagged in Lake Mead in 2010 and 2011 were detected in the spring and summer of 2012 in GCNP up to Quartermaster Canyon (river mile 260) (Kegerries and Albrecht 2012, as cited in NPS

2013e). An additional untagged adult razorback sucker was captured in GCNP near Spencer Creek (river mile 246) in October 2012 (Bunch et al. 2012b), and another adult was collected in late 2013 (GCMRC 2014) at the same location. Recent sampling of channel margin habitats has also documented razorback sucker larvae as far upstream as river mile 179 (just upstream of Lava Falls), indicating that spawning is occurring in the mainstream river in the western Grand Canyon (Albrecht et al. 2014).

Razorback sucker studies were conducted in the Lake Mead inflow in 2010 and in the lower Grand Canyon since 2014. Larval fish sampling verified razorback sucker spawning and larval production in the Colorado River within GCNP for the first 6 years of the project (2014–2019) (Rogers et al. 2023). In 2019, eight larval razorback suckers were captured during April and May and distributed from river mile 127.3 to river mile 279.0. A razorback sucker captured in May 2019 at river mile 127.3 was the farthest upstream that razorback sucker larvae had been captured within the expanded study area (2016–2019; river mile 88.6–279.0). This finding extended the distribution of age-0 razorback sucker 17.5 river miles farther upstream than the previously identified most-upstream capture of razorback sucker in 2018 (one captured, river mile 144.8). This information indicates that the razorback sucker may be slowly expanding upstream from Lake Mead into the Colorado River through Grand Canyon, but the majority of the fish captured are in western Grand Canyon.

Habitat

The razorback sucker uses a variety of habitats, ranging from mainstream channels to slow backwaters of medium and large streams and rivers (AZGFD 2002c; Service 2018b). In rivers, habitat requirements of adults in spring include deep runs, eddies, backwaters, and flooded off-channel areas; in summer, runs and pools, often in shallow water associated with submerged sandbars; and in winter, low-velocity runs, pools, and eddies. In reservoirs, adults prefer areas with water depths of 1 meter (3.3 feet) or more over sand, mud, or gravel substrates. Young require nursery areas with quiet, warm, shallow water such as tributary mouths, backwaters, and inundated floodplains along rivers, and coves or shorelines in reservoirs. Captures of larval razorback sucker in the western Grand Canyon found the highest density of larvae in isolated pools, which comprised less than 2 percent of all habitat sampled (Albrecht et al. 2014; Rogers et al. 2023). Similar results were found in 2015, when the highest catch of larval razorback sucker was found in isolated pools, followed by backwaters, which comprised 2.1 percent and 9.1 percent of habitats sampled, respectively (Kegerries et al. 2015).

Life History

Both adults and immature fish are omnivorous, feeding on algae, zooplankton, and aquatic insect larvae. In Lake Mohave, their diet has been reported to be dominated by zooplankton, diatoms, filamentous algae, and detritus (Marsh 1987). Razorback suckers exhibit relatively fast growth the first 5 to 7 years of life, after which growth slows and possibly stops (AZGFD 2002c). Both sexes are sexually mature by age 4. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and at water temperatures typically greater than 14°C (57°F) (Service 2002a, 2018b). In reservoirs, spawning occurs over rocky shoals and shorelines. Temperatures for spawning, egg incubation, and growth of this species range from 14 to 25°C (57 to 77°F).

Hatching success is temperature-dependent, with complete mortality occurring at temperatures less than 10°C (50°F); optimum temperatures for adults are around 22–25°C (72–77°F) (AZGFD 2002c). Based on back-calculation from the dates of larval collection, Kegerries et al. (2015) estimated that the onset of spawning in the western Grand Canyon was in mid-February when average daily water temperatures were between 10 and 12°C (50 and 54°F). Spawning appeared to peak toward the end of March when water temperatures were in the range of 12–14°C (54–57°F), although the entire spawning period was estimated to range from mid-February to July (Kegerries et al. 2015).

Historically, this species exhibited upstream migrations in spring for spawning, although current populations include groups that are sedentary and others that move extensively (Minckley et al. 1991). Adults in the Green River subbasin have been reported to move as much as 62 miles to specific areas to spawn (Tyus and Karp 1990). In Lake Mohave, individuals have been reported to move 12 to 19 miles between spring spawning and summer use areas (Mueller et al. 2000). Kegerries et al. (2015) reported that sonic-tagged razorback sucker either stayed near spawning areas or moved up to 361 kilometers (224 miles) within the western Grand Canyon, the Colorado River inflow to Lake Mead, and throughout Lake Mead.

Factors Affecting Distribution and Abundance in the Grand Canyon

The decline of the razorback sucker throughout its range has been attributed primarily to habitat loss due to dam construction, the loss of spawning and nursery habitats as a result of diking and dam operations, and alteration of flow hydrology (AZGFD 2002c; Service 2018b). For example, the 80 percent reduction in the historical distribution of this species has been attributed to the construction of Hoover, Parker, Davis, and Glen Canyon Dams on the Colorado River and Flaming Gorge Dam on the Green River (Valdez et al. 2012). In addition, competition with and predation by nonnative fish have also been identified as important factors in the decline of this species (Minckley et al. 1991; Service 2002a). In the Grand Canyon, the decline of native fish, including razorback sucker, has been attributed to multiple factors, including modifications to river temperatures and discharge patterns due to Glen Canyon Dam and the subsequent establishment of nonnative fish populations. This has led to more than two decades of experimental actions to understand the factors that influence the occurrence, abundance, and distribution of native fish in Grand Canyon (Gloss and Coggins 2005; Coggins et al. 2015; Service 2018b).

As described above, efforts to better understand the use of the western Grand Canyon by razorback sucker have revealed that the species is more widespread there than previously thought; it occupies and spawns in the river from at least Lava Falls through the entirety of Lake Mead, and it maintains a reproducing population in the project area (Albrecht et al. 2014; Kegerries et al. 2015). Currently, there is little information on the habitat use and life history needs for the species in the Grand Canyon and Lake Mead. Additional research and monitoring are needed to better understand the management implications for the recovery of razorback sucker in this reach of its range (Albrecht et al. 2014; Service 2018b).

Southwestern Willow Flycatcher

The southwestern willow flycatcher (*Empidonax traillii extimus*) was listed as endangered in 1995 *(Federal Register* 60:10694). Critical habitat was designated in 2013 *(Federal Register* 78:344), but no critical habitat was designated between Glen Canyon Dam and Lake Mead. The southwestern willow flycatcher is designated as a Tier 1 species of greatest conservation need in Arizona.

Southwestern willow flycatchers are neotropical migrants that typically breed in dense, riparian habitats near saturated soils or surface water. They arrive on their breeding grounds in the southwestern US in May through mid-June and depart in late July through early September. Southwestern willow flycatchers rarely breed in linear habitats that are more than 10 meters (33 feet) wide, though they will use these habitats during migration (Sogge et al. 2010). Southwestern willow flycatchers use native riparian vegetation (for example, willows [*Salix* spp.]) as well as tamarisk (*Tamarix* spp.) and are generalist insectivores.

Disjunct breeding locations in the Grand Canyon have been documented below Lees Ferry in Marble Canyon and in lower Grand Canyon below Diamond Creek (river miles 225.5–277) (Braden and McKernan 2006; McLeod et al. 2008; Sogge et al. 1997). No southwestern willow flycatcher nests or nesting behavior have been identified in the inner gorge (river miles 77.9–116.5). Habitat quality declined between the 1980s and the mid-2010s, and detections of breeding southwestern willow flycatchers declined accordingly. No breeding southwestern willow flycatchers were detected between Lees Ferry and Diamond Creek in 2004 through 2015. During that period, breeding or territorial southwestern willow flycatchers were detected downstream of Diamond Creek at Burnt Springs (2007) and river mile 275 (2004, 2006, and 2010) (reviewed in Reclamation and NPS 2016).

Surveys were completed in 2019 and 2021 from river mile 0 through river mile 280. No willow flycatchers were detected during surveys in 2019. In 2021, four willow flycatchers were detected in May between Lees Ferry and Diamond Creek, but no willow flycatchers were detected during subsequent surveys. The detected birds were likely spring migrants and were not confirmed to be southwestern willow flycatchers (Terwilliger and Holm 2021). Surveys were completed in 2023 between Diamond Creek (river mile 225) and Pearce Ferry (river mile 280). Suspected southwestern willow flycatchers were detected at Burnt Springs (two individuals) and at river mile 275 (two individuals); however, the birds did not produce diagnostic vocalizations, and their identity was not confirmed (Terwilliger and Whyte 2023).

Most patches of riparian vegetation in the Grand Canyon lack a consistent, dependable source of water for maintaining moist/saturated soil conditions and/or slow-moving or standing surface water (Stroud-Settles et al. 2013). As a result, most habitat in the Grand Canyon that might be used by southwestern willow flycatchers is of marginal quality, and these patches are likely to continue to decline without an increase in surface water. Furthermore, the tamarisk leaf beetle has transformed and will continue to transform the patches of dense tamarisk into unpredictable, diminished patches (Stroud-Settles et al. 2013; Terwilliger and Holm 2021). Riparian vegetation in the only two sites (river mile 259.5 [Burnt Springs] and river mile 275) where breeding southwestern willow flycatchers have been detected over the past 20 years is maintained by water in tributary canyons or from springs and is not dependent on flow in the mainstream of the Colorado River. The Colorado River corridor continues to provide habitat for migrating willow flycatchers.

Western Yellow-Billed Cuckoo

The western yellow-billed cuckoo (*Coccyzus americanus*) distinct population segment was listed as threatened in 2014 *(Federal Register* 79:59992). Critical habitat was designated in 2021 *(Federal Register* 86:20798), but no critical habitat was designated between Glen Canyon Dam and Lake Mead. The western yellow-billed cuckoo is designated as a Tier 1 species of greatest conservation need in Arizona.

Western yellow-billed cuckoos are neotropical migrants that typically breed in blocks of riparian woodland that are 50 acres or larger in size (Halterman et al. 2016; *Federal Register* 78:61622). Occupied lowland riparian habitat generally consists of mature, multilayered cottonwood and willow forest, although other riparian trees species such as mesquite and tamarisk may be present. Nest locations typically have high canopy closure (McNeil et al. 2013). Western yellow-billed cuckoos are late spring migrants. Some individuals can arrive in mid- to late May, but most do not arrive until mid-June. Nesting generally peaks during July and early August and can continue into September. Fall migration begins in August, and most birds have left by mid-September (McNeil et al. 2013). Large prey items such as cicadas, katydids, grasshoppers, and caterpillars form the bulk of the cuckoo's diet (*Federal Register* 78:61622), and arrival on the breeding grounds may be timed to coincide with abundant prey.

The Grand Canyon upstream of Separation Canyon does not support the large blocks of mature riparian forests used by western yellow-billed cuckoos as breeding habitat. Western yellow-billed cuckoos were regularly detected between Spencer Creek (river mile 246) and Pearce Ferry in the late 1990s and into the early 2000s when high water levels in Lake Mead supported cottonwood-willow vegetation (McKernan and Braden 2002). Declining water levels in Lake Mead in the early 2000s left riparian vegetation along the mainstream between Separation Canyon and Pearce Ferry on high, dry riverbanks, where the vegetation subsequently died (McLeod et al. 2008). After the early 2000s, the only stands of mature, riparian habitat in the analysis area were in side canyons, such as Burnt Springs, and at the spring-fed river mile 275 site and were not dependent on flow in the mainstream of the Colorado River. An incidental detection of a western yellow-billed cuckoo was recorded at Burnt Springs during southwestern willow flycatcher surveys in 2021 (Terwilliger and Holm 2021). Riparian vegetation along the mainstream provides habitat that could be used by migrating western yellow-billed cuckoos.

3.8.2 Environmental Consequences

Methodology

Previous research and monitoring conducted within the Colorado River and its tributaries were evaluated and analyzed to inform the results of this analysis. The environmental consequences for fisheries threatened and endangered fish within the project area are based on relationships of how flow alterations would impact the food base; fish habitat; native species, including special status species; and nonnative species that are potential predators of native species within the Colorado River. This analysis used qualitative relationships between changes in flow and habitat, food base abundance and distribution, specific species' distribution based on habitat requirements, and impacts from interactions of native species with nonnative aquatic species.

Results of hydrologic models were used to evaluate the effects of flows on aquatic resources; these models included the CRSS model and the GTMax. Preliminary quantitative models for smallmouth bass that are ongoing by USGS scientists were also used as part of the evaluation (see **Appendix A**).

The analysis in this section for threatened and endangered birds is informed by hydrologic and vegetation models showing the effects of dam releases on the hydrology and riparian vegetation, and the resulting impacts on vegetation. As discussed in the 2016 LTEMP FEIS, the primary effects on riparian vegetation below the Glen Canyon Dam will be a direct function of the changes in flow regimes under each alternative. The vegetation model has several limitations that should be noted when considering the modeling results. The model was designed as a conceptual, as opposed to a predictive, model; therefore, the results are used in this analysis carefully and in combination with the literature because the model is a simplification with limitations in the ability to assess on-the-ground changes. However, it is the best available tool for impact analysis, when used in conjunction with field studies and literature. Therefore, the environmental consequences for riparian vegetation are presented as a qualitative discussion of how each alternative may affect riparian vegetation cover.

Impact Analysis Area

The analysis area is consistent with that used in the 2016 LTEMP FEIS. It includes the Colorado River mainstream corridor, affected tributary mouths, and interacting resources in associated riparian zones located primarily from the forebay of Glen Canyon Dam to Pearce Ferry above Lake Mead.

This area includes the Colorado River ecosystem from Glen Canyon Dam downstream to the Lake Mead inflow. More specifically, the scope primarily encompasses the Colorado River ecosystem, which includes the Colorado River mainstream corridor and interacting resources in associated riparian zones located primarily from the forebay of Glen Canyon Dam to Pearce Ferry.

Assumptions

- Flow alterations would not impact tributary streams except fish access and habitat at the mouths.
- Lake Mead and Lake Powell would not be influenced because annual flows will remain the same.
- The results of biological analyses and the ecological modeling that are available depend on the data inputs, modeling assumptions, and validity of the models.
- The LTEMP FEIS and the SMB EA were used to provide background and for the analysis of flows’ effects on aquatic resources.
- The BLM Sensitive Species Lists Arizona statewide conservation agreement for six native fish species was used to identify special status fish species.
- Lower Colorado River Multi-Species Conservation Program’s Habitat Conservation Plan was used for areas downstream of Separation Canyon.

Impact Indicators

- Changes in distribution and abundance of food base items, including primary and secondary producers such as algae and macroinvertebrates
- Changes in river channel area affected by flows, including the main channel and shallow-water habitats
- Changes in distribution and abundance of native and nonnative fish species and hypothesized interactions between these groups of fish
- Changes in fish habitats, including talus shorelines and backwaters
- Changes in woody riparian vegetation or marsh vegetation

Issue 1: How would flow alterations at Glen Canyon Dam impact threatened and endangered bird species using habitats along the Colorado River?

Southwestern Willow Flycatcher

Riparian habitat that supports breeding southwestern willow flycatchers in Grand Canyon exists only in areas where vegetation is maintained by tributaries or springs and is not influenced by flows in the mainstream Colorado River. Migratory willow flycatchers could use riparian vegetation along the mainstream Colorado River.

Section 3.6, Terrestrial Resources and Wetlands describes anticipated changes in the characteristics of riparian vegetation communities. However, no alternative is expected to result in important structural changes in riparian habitat or vegetation productivity that could affect migrating southwestern willow flycatchers.

As discussed in **Section 3.7**, Wildlife, invertebrates with only terrestrial life stages are not expected to be affected differentially by the alternatives. Those invertebrates with both aquatic and terrestrial life stages are expected to benefit from the alternatives with more stable flows. These changes in food production are expected to result in negligible impacts on the southwestern willow flycatcher.

Western Yellow-billed Cuckoo

Riparian habitat that could support breeding western yellow-billed cuckoos in Grand Canyon occurs only in areas where vegetation is maintained by tributaries or springs and is not influenced by flows in the mainstream Colorado River. Migratory or transient western yellow-billed cuckoos could use riparian vegetation along the mainstream Colorado River. No impacts on western yellow-billed cuckoos were anticipated from any alternatives analyzed in the LTEMP FEIS, and no impacts are anticipated from any alternatives analyzed herein.

California Condor

Along the Colorado River in Glen and Grand Canyons, California condors use cliffs for nesting and roosting and beaches for bathing, resting, preening, and feeding. No impacts on California condors were anticipated from any alternatives analyzed in the LTEMP FEIS, and no impacts are anticipated from any alternatives analyzed herein.

Issue 2: How would flow alterations at Glen Canyon Dam impact threatened and endangered fish species in the Colorado River?

Humpback Chub and Razorback Sucker

No Action Alternative

Under the No Action Alternative, the humpback chub and razorback sucker may be subjected to increasing levels of predation and competition from nonnative fish, especially smallmouth bass and possibly green sunfish and other invasive, aquatic species. Although population levels of humpback chub are likely the highest since construction of Glen Canyon Dam, invasions of nonnative species, especially smallmouth bass, could lead to the decline of some population centers of native fish species, such as near the mouth of the Little Colorado River. Smallmouth bass populations could theoretically expand throughout the Colorado River ecosystem below Glen Canyon Dam (potentially as far downstream as below Havasu Rapid and the Lake Mead inflow), where they could negatively affect the expanded population of humpback chub and interfere with movement of razorback sucker into the Colorado River from Lake Mead.

Cool Mix Alternative

The humpback chub and razorback sucker are not likely to be negatively affected by this lower-temperature regime because these fish existed in the Colorado River downstream of Glen Canyon Dam when dam release temperatures were generally below 15°C (59°F) prior to 2022. Although humpback chub is found upstream of the Little Colorado River (as an aggregation at 30-Mile Spring and near the confluence of the Little Colorado River at river mile 61), the majority of the population is now found downstream in western Grand Canyon between Havasu Rapid (river mile 157) and Pearce Ferry (river mile 280) (Rogowski et al. 2018; **Figure 3-31**). The razorback sucker is found primarily in the Lake Mead inflow with a few individuals moving upstream into the Colorado River.

Under the Cool Mix Alternative, the presumed distributions of these species would remain about the same and are expected to persist under this alternative. Cooler water temperatures would likely slow the growth of humpback chub and razorback sucker; however, these could lead to improvements in survival if the predation risk by nonnative species declines. The temperatures proposed under this alternative would be consistent with the conditions present when the analysis for the LTEMP FEIS (DOI 2016a) was conducted. In other words, impacts on the humpback chub would not likely be different from those analyzed in the LTEMP FEIS. Cooler temperatures may also benefit humpback chub and razorback sucker by limiting the reproductive capabilities of parasites, such as Asian tapeworm and anchor worm, which require 18°C (64.4°F) or higher to mature and reproduce (Hoffnagle et al. 2006).

Cool Mix with Flow Spike Alternative

The humpback chub and razorback sucker would not likely be negatively affected by the proposed lower-temperature regime or by the flow spikes. This is because these fish existed in the Colorado River downstream of Glen Canyon Dam when dam release temperatures were generally below 15°C (59°F) prior to 2022. These species have also persisted through nine HFE releases since 1996 (Webb et al. 1999; Melis 2011). Cooler water temperatures are expected to slow the body growth of these species; however, they could also increase the species' survival (depending on interactions with nonnative species) and decrease their susceptibility to parasites. The temperatures proposed under this alternative would be consistent with the conditions present when the analysis for the LTEMP FEIS (DOI 2016a) was conducted. Impacts on the humpback chub and razorback sucker from the temperature would not likely be different from those analyzed in the LTEMP FEIS.

The proposed timing of the flow spikes between June and mid-July occurs during a time of year when flow spikes have not been conducted below Glen Canyon Dam. Although flow spikes and HFE releases are conceptually similar, HFE releases have been conducted in April and November. Flow spikes from June to mid-July could displace newly hatched larvae and early juvenile humpback chub from shoreline habitats and subject them to starvation and predation. However, this effect is expected to dissipate with distance downstream of Glen Canyon Dam and especially downstream of the Little Colorado River where the majority of humpback chub and razorback sucker occur; it also is not expected to be a population-level effect.

Flow spikes between June and mid-July would occur before the highest seasonal water temperature warming below Glen Canyon Dam; these could create different thermal conditions in the Colorado River ecosystem below Glen Canyon Dam than what has been observed during previous HFE releases. Large juvenile and adult humpback chub are able to adjust their position along talus shorelines with changes in flow stage (Converse et al. 1998; Webb et al. 1999; Korman et al. 2004; Dodrill et al. 2015; Finch et al. 2015). They are not expected to be greatly affected by these spike flows. The number of razorback sucker upstream of the Little Colorado River is small, and this alternative is not expected to substantially affect this species.

Cooler temperatures are not expected to negatively affect the food base of humpback chub and razorback sucker, but short-term spike flows could scour the benthos. This would temporarily reduce the food base; however, the food base is expected to recover quickly because solar radiation and photosynthesis are high during May–July. Cooler temperatures may benefit these species by limiting the reproductive capabilities of parasites, such as the Asian tapeworm and the anchor worm, which require 18°C (64.4°F) or higher to mature and reproduce.

This alternative would be most likely to lower water temperatures below 15.5°C (60°F) from Glen Canyon Dam to river mile 45 in Marble Canyon, depending on the temperature and volume of water through the penstocks (USGS 2022), and increase the distance of effect to river mile 61 at the confluence with the Little Colorado River. Because smallmouth bass have most recently been documented in the region of river immediately below Glen Canyon Dam, this alternative would have the greatest effect on river temperature and stage in the area where smallmouth bass have been found; however, both the temperature and flow spike effects would be reduced near the first large aggregation of humpback chub near the Little Colorado River inflow.

Cold Shock Alternative

A sudden surge of cold water would not likely negatively affect large juvenile and adult humpback chub or razorback sucker. However, low water temperatures could impair larvae and small juvenile humpback chub's swimming ability and increase the predation risk (Ward and Morton-Starner 2015). The risk of this effect depends on the extent and timing of the cold shock. For example, the cold shock would most likely have its largest effect near Glen Canyon Dam where smallmouth bass have been spawning. However, the impact of the cold shock in areas of the Colorado River where native fish are found in higher abundance, including the Little Colorado River inflow, would be likely be less than near Glen Canyon Dam; this is because the water would warm with distance.

Cold Shock with Flow Spike Alternative

A sudden surge of cold water would not likely negatively affect large juvenile and adult humpback chub or razorback sucker, but it could cold shock and displace young and early juvenile fish from secure talus shoreline habitats or backwaters (Clarkson and Childs 2000). It could also expose them to predation by cold-water predators like rainbow trout and brown trout. This effect would likely be greater if flow spikes are released during May–July when humpback chub are generally younger and smaller and are not able to maintain their position within different habitat types at higher water velocity. This risk would be reduced if flow spikes occur after July when juvenile humpback chub would have had a longer opportunity to reach older ages, larger body sizes, and better swimming ability.

This displacement effect is likely proportional to the size of the flow spike. As the flow spike effect on the river stage dissipates with distance downstream, so does the risk of displacement. Weekly use of cold-shock events could reduce growth and survival of young humpback chub and razorback sucker, but the effect is not expected to be a population-level effect. Periodic flow spikes are not expected to negatively affect large juvenile and adult humpback chub or razorback sucker. However, high-water velocity could displace young and early juveniles, especially if they are cold shocked, and expose them to starvation and predation.

There are few reports of razorback suckers in the affected reach of the Colorado River (from Glen Canyon Dam to the confluence with the Little Colorado River at river mile 61). Water temperatures and flow volumes from the proposed flow option would affect downstream reaches occupied by adult razorback suckers moving into the lower Grand Canyon from Lake Mead. The effects, however, would be dissipated with distance downstream, especially below the Little Colorado River. Also, the few larvae and juvenile razorback suckers produced in the lower Grand Canyon could be affected as flow changes inundate or desiccate backwaters used by juveniles. However, the effects are expected to be minor because flow characteristics would moderate with distance from the dam.

Non-Bypass Alternative

High flows of up to 30,000 cfs are not expected to negatively affect large juvenile and adult humpback chub or razorback sucker. This level of river discharge within the powerplant’s capacity are experienced by these species during normal operations and some HFE events. Although some young fish may become displaced and exposed to increased predation risk, the effect of these high flows on humpback chub and razorback sucker is expected to be minimal. Low-flow events, including discharge levels of 2,000 cfs, have rarely been seen in the Colorado River downstream of Glen Canyon Dam in recent decades. In 1990–1991, “research flows” were released as low as 1,000 cfs on weekends from Labor Day to Easter, but an in-depth evaluation was not done on resource responses to these low-flow events.

Studies of humpback chub by Valdez and Ryel (1995) indicated that much of the shoreline talus habitat and the backwaters used by juveniles were dewatered during extreme low-flow events, forcing the fish to move to mainstream habitats where they were possibly at greater risk of predation. Adult humpback chub and razorback suckers most likely moved to more suitable habitats during extreme low flows and were not affected by these short-term events.

High and low flows under this alternative are proposed to occur such that as the high-flow wave travels downstream, it catches and then collapses the low-flow trough by the time it reaches the Little Colorado River. Doing this would prevent the minimum flow near the Little Colorado River from decreasing below 5,000 cfs. Similarly, with distance from Glen Canyon Dam, the duration of any low-flow trough would also be reduced. However, the phenomenon of a collapsed trough is not likely to occur at the location of the upstream-most population of the humpback chub at river mile 30. However, the fish of this population have exhibited an ability to withstand large variations in flow.

Cumulative Effects

The cumulative effects of these flow alternatives on threatened and endangered fish would likely be temporary and beneficial overall. This is because the flow options are meant to disrupt smallmouth bass spawning and recruitment. At present, smallmouth bass are detected near Glen Canyon Dam, which is spatially separated from the first large aggregation of humpback chub near the Little Colorado River confluence (river mile 61). This spatial separation between smallmouth bass near Glen Canyon Dam and the humpback chub aggregation near the Little Colorado River likely reduces the potential impacts of the proposed flow alternatives on native fish; this is because of the attenuation of either a flow or temperature treatment between Glen Canyon Dam and the Little Colorado River confluence. At present, small numbers of smallmouth bass are reported near the Little Colorado River and in western Grand Canyon near Diamond Creek.

However, if smallmouth bass populations expand to include the Colorado River near the Little Colorado River confluence, then the potential effectiveness of the proposed flow scenarios may be reduced. If one or more of these alternatives were to effectively control the expansion in range and abundance of smallmouth bass, the cumulative effect on the threatened and endangered fish would be beneficial by reducing the levels of predation and competition.

The humpback chub in the Colorado River downstream of Glen Canyon Dam is now at its highest population level since monitoring began following construction of Glen Canyon Dam (for the recent abundance trend in western Grand Canyon, see **Figure 3-31**). The recent invasion of smallmouth bass below Glen Canyon Dam above Lees Ferry is a new threat that could negatively affect the humpback chub and the razorback sucker, if the bass are displaced or move downstream. Implementation of one or more of the five proposed alternatives could negatively affect the smallmouth bass and benefit the threatened and endangered species by reducing the risk of predation by nonnative fish on native species and reducing the competition between nonnative and native fish species. The cumulative effects of any of the five alternatives are not likely to negatively affect the aquatic resources of the Colorado River downstream to Lake Mead.

Summary

Altogether, five action alternatives and the No Action Alternative were evaluated (see the summary table). The primary goal of the five alternatives is to disrupt spawning by invasive smallmouth bass through the use of high- or low-flow releases from Glen Canyon Dam and by lowering the water temperature through the use of the river outlet works. The five action alternatives are based on a series of conceptual models that have been developed by various working groups with information from the scientific literature and ongoing work in the Upper Colorado River Basin, where efforts to reduce smallmouth bass populations through mechanical removal and flow operations have been ongoing since 2003.

For the Colorado River ecosystem below Glen Canyon Dam, efforts are ongoing to develop predictive models that integrate information from elsewhere into a framework that allows for the evaluation of these different alternatives as a predictive model. These modeling efforts for the Colorado River ecosystem below Glen Canyon Dam are not completed; thus, they are not included in this evaluation. The evaluations of the five alternatives here are informed by the information that is publicly available in the references described.

Four of the flow alternatives presented use both penstock releases and the river outlet works to generate either high flows or spikes and cooler releases or cold shocks. Only one alternative (the Non-Bypass Alternative) uses the penstocks and not the river outlet works. Each of the five alternatives has the potential to disrupt smallmouth bass spawning by either desiccating or inundating nesting areas, and/or creating unsuitable water temperatures. The alternatives with the most potential effect for disrupting smallmouth bass spawning are the Cool Mix with Flow Spike and the Cold Shock with Flow Spike Alternatives; this is because these alternatives disrupt both the physical habitat of smallmouth bass nesting and the suitable and necessary temperature regimes. Furthermore, the cool-mix alternatives and to a lesser extent the cold-shock alternatives could benefit the rainbow trout fishery by maintaining a colder system that is advantageous to the species and by reducing warmwater predators that also negatively affect this species within the temperature ranges where they coexist.

Generally, the five alternatives are not expected to have a negative population-wide effect on native fish, as these species have adapted to a large range of flows and temperatures in the Colorado River. However, all alternatives do assume that smallmouth bass populations will have impacts on native fish populations. These alternatives are not expected to have long-term, negative effects on the rainbow trout in the Lees Ferry reach.

3.9 Air Quality

3.9.1 Affected Environment

Air quality is primarily affected by air emission sources, both natural (e.g., wildfires and windblown dust) and human-made (e.g., emission from stationary sources like fossil fuel–fired powerplants, industrial facilities, and space heating, as well as on-road and off-road mobile sources such as vehicles).

Changes in operations at Glen Canyon Dam can create either more or less hydroelectricity at certain times of the day to meet regional electricity demand. If less electricity is unavailable at Glen Canyon Dam, demand must be met by other means, which may include powerplants fueled by fossil fuels (including coal, oil, and gas turbine plants) and nuclear, other hydroelectric, wind, and solar energy sources, or by demand-side management. Changes in the operation of Glen Canyon Dam, therefore, may indirectly affect air quality by potentially changing the degree to which electricity demand is met within the region, with either non-emission hydropower, wind, or solar powerplants, or emission-producing powerplants, such as fossil fuel–fired powerplants that can directly affect air quality and related resources. These changes can also affect GHG emissions that can influence climate change. Information on GHGs and climate change is discussed in **Section 3.17**, Climate Change.

Local Air Quality

The Clean Air Act (CAA), as amended (42 USC 7401), established Prevention of Significant Deterioration (PSD) provisions for use in protecting the nation's air quality and visibility. The PSD provisions apply to new or modified major stationary sources and are designed to keep an attainment area in continued compliance with the National Ambient Air Quality Standards (NAAQS). Major stationary sources are industrial-type facilities and include powerplants and manufacturing facilities that emit more than 100 tons per year of a regulated pollutant. No major stationary sources are proposed for construction or modification by the proposed alternatives; therefore, the statutory provisions specific to PSD are not applicable. However, there are criteria pollutants for which thresholds for increases in pollution concentrations have been established. These include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulate matter (PM), which are often analyzed.

The PSD standards are most stringent in Class I areas and are progressively less stringent in the Class II and Class III areas (**Table 3-33**). The GCNRA and LMNRA are designated as Class II areas, while GCNP is the nearest designated Class I area. Coconino and Mohave Counties in Arizona were chosen as the local air quality analysis area because they contain both the Glen Canyon Dam facility and the GCNP Class 1 area.

Table 3-34 presents criteria pollutant and volatile organic compound (VOC) emission totals in 2020 for Coconino and Mohave Counties in Arizona (EPA 2023a), which encompass the GCNP Class 1 area. The data represent 13 source categories (e.g., fuel combustion by power generation and industry, highway vehicles, off-highway vehicles, and miscellaneous sources). Miscellaneous sources, including prescribed/structural fires, wildfires, fugitive dust, and agricultural production, account for a predominant portion of the two-county totals of PM with an aerodynamic diameter less than or equal to 2.5 micrometers ($PM_{2.5}$), particulate matter with an aerodynamic diameter less than or equal to 10 micrometers (PM_{10}), and SO_2. Highway vehicles are primary contributors to total carbon monoxide (CO), VOC, and nitrogen oxides (NOx) emissions.

Data on emissions from Tribal lands in Coconino and Mohave Counties are hard to find because the emissions data are presented in total emissions for Tribal lands that straddle many counties and even many states. Since the publication of the 2016 Glen Canyon Dam Long-Term Experimental and Management Plan FEIS, Navajo Generating Station, which was a major source of air pollutants in the area, ceased emissions on November 18, 2019.

Table 3-33
CAA PSD Designations

Designation	Definition
Class I Area	Class I area visibility is protected more stringently than under the NAAQS; these areas 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 NAAQS would be considered insignificant.

Table 3-34
Criteria Pollutant and VOC Emissions (tons) in Counties Encompassing GCNP

County	CO	NOx	VOCs	$PM_{2.5}$	PM_{10}	SO_2
Coconino, AZ	102,498	11,499	105,687	7,440	14,398	643
Mohave, AZ	48,202	8,996	37,360	1,988	6,229	109
Total	150,700	20,495	143,047	9,428	20,627	752

Source: EPA 2023a

Notes: CO = carbon monoxide; NOx = nitrogen oxides; $PM_{2.5}$ = particulate matter with an aerodynamic diameter of less than or equal to 2.5 microns; PM_{10} = particulate matter with an aerodynamic diameter of less than or equal to 10 microns; SO_2 = sulfur dioxide; and VOC = volatile organic compound

Regional Air Quality

Changes in operations at Glen Canyon Dam can affect regional air quality if these changes result in corresponding increases or decreases in power generation at other facilities in the Western Interconnection grid. The regional air quality analysis area encompasses an 11-state area that includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. Under the CAA, the EPA has established the NAAQS for six criteria pollutants considered harmful to public health and the environment (40 CFR 50): SO_2, NO_2, CO, ozone, $PM_{2.5}$, PM_{10}, and lead (Pb) (EPA 2015). Each state in this 11-state area can have its own State Ambient Air Quality Standards for criteria pollutants. If a state has no standard corresponding to one of the NAAQS or a standard less stringent than NAAQS, the NAAQS apply. In addition, any state can establish standards for pollutants other than criteria pollutants. Several states have adopted standards for additional pollutants: visibility-reducing particles, sulfates, hydrogen sulfide (H_2S), and vinyl chloride for California; fluorides for Idaho; H_2S, settled PM, and fluoride in forage for Montana; H_2S for Nevada; total suspended particulates, H_2S, and total reduced sulfur for New Mexico; particle fallout for Oregon; radionuclides and fluorides for Washington; and H_2S, suspended sulfates, fluorides, and odors for Wyoming.

Parts of the 11-state area have not yet attained the NAAQS for SO_2, 8-hour ozone, $PM_{2.5}$, PM_{10}, and Pb. Currently, there are no nonattainment areas for NO_2 and CO in the United States and, thus, in the 11-state area. Each state has one or more nonattainment areas. Arizona has nonattainment areas for all five of the above air pollutants. California has nonattainment areas for four air pollutants. Utah has nonattainment areas for three air pollutants. Two states (Montana and New Mexico) have nonattainment areas for two air pollutants, while six states (Colorado, Idaho, Nevada, Oregon, Washington, and Wyoming) have nonattainment areas for one air pollutant (EPA 2023b).

There are regional air pollution problems such as ozone, acid deposition, and visibility degradation in some areas in the western United States. Ozone issues are most prevalent around urban centers, except for elevated wintertime ozone at higher elevations near oil and gas fields in Utah, Wyoming, and Colorado, where atmospheric conditions can prevent pollutants dispersing, and snow cover reflects sunlight needed for ozone formation back to the atmosphere. Impacts of acid deposition have been observed in the Desert Southwest, where excess nitrogen deposition facilitates invasion of nonnative grass species that compete with native plant species and increase fire risk as a result of increased biomass fuel loading. Acid deposition may also affect high-elevation lakes where excess nitrogen deposition can alter aquatic species composition. Visibility impairment is a widespread and pervasive problem throughout the country and in many national parks and wilderness areas where the CAA specifically requires visibility protection.

Visibility degradation is caused by cumulative emissions of air pollutants from a myriad of sources scattered over a wide geographical area. In general, the primary cause of visibility degradation is the scattering and absorption of light by fine particles, with a secondary contribution provided by gases. In general, visibility conditions in the western United States are substantially better than those in the eastern United States because of the higher pollutant loads and humidity levels in the East (EPA 2006). The typical visual range (defined as the farthest distance at which a large black object can be seen and recognized against the background sky) in most of the western United States is about 60 to 90 miles, while that in most of the eastern United States is about 15 to 30 miles. Most visibility degradation is associated with combustion-related sources, while fugitive dust sources contribute to some extent. In particular, smaller particles such as $PM_{2.5}$ scatter light more efficiently; these particles include ammonium sulfate, ammonium nitrate, particulate organic matter, light-absorbing carbon (or soot), mineral fine soil, and sea salt. Ammonium sulfate and ammonium nitrate are formed by chemical reactions in the atmosphere that include emissions of SO_2 and NOx, respectively. Particulate organic matter (POM) can be emitted directly from vegetation or can form in the atmosphere from a variety of gaseous organic compounds. The Interagency Monitoring of Protected Visual Environments program is a network of monitoring sites for visibility located in Class 1 areas (IMPROVE Program 2023). The Hance Camp at GCNP (monitoring site number: GRCA2) is the longest running site in the GCNP. The data from the monitor show that on the most impaired days ammonium sulfate is the largest contributor to visibility impairment, on the haziest days POM was the largest contributor to visibility impairment, and on the clearest days ammonium sulfate is the largest contributor to visibility impairment (Federal Land Manager Environmental Database 2023).

Visibility was singled out for particular emphasis in the CAA Amendments of 1977. Visibility in a Class I area is protected under two sections of the CAA Amendments. Section 165 provides for the PSD program for new sources. Section 169(A), for older sources, describes requirements for both reasonably attributable single sources and regional haze, which address multiple sources. Federal land managers have a responsibility to protect visibility in Class I areas. There are 156 mandatory federal Class I areas in the United States. In 1999, the EPA issued the final Regional Haze Rule (64 FR 35714, July 1, 1999), which sets a national visibility goal for preventing future and remedying existing impairment to visibility in Class I areas. The rule is designed to reduce visibility impairment from existing sources and limit visibility impairment from new sources. States with Class I areas or states affecting visibility in Class I areas must revise their state implementation plans, prepare emission-reduction strategies to reduce regional haze, and establish glide paths for each Class I area. States are required to periodically review whether they are making reasonable progress toward meeting the goal of achieving natural conditions by 2064. Wildfires and windblown dust storms can significantly degrade visibility at Class I areas in the 11-state area. Emissions of SO_2 and NOx from fossil fuel combustion are the major human-made causes of visibility impairment; these emissions have been substantially reduced in the past few decades in response to state and federal requirements (Air Resource Specialists, Inc. 2013; EPA 2023c).

Regional Air Emissions

Table 3-35 presents statewide criteria pollutants and VOC emissions for the 11-state area within the Western Interconnection in 2020 (EPA 2023a). As discussed above, emission data are sorted into 13 source categories. Emissions from wildfires were removed from the data presented in the summary below because they can vary widely from year to year and in years with large occurrences can exceed emissions of some pollutants from all other sources. California had the highest emissions of VOCs and all the criteria pollutants except $PM_{2.5}$, PM_{10}, and SO_2; Oregon had the highest emissions of $PM_{2.5}$ and PM_{10}, and New Mexico had the highest emissions of SO_2.

Table 3-35
Criteria Pollutant, VOC and GHG Emissions for 2020, over the 11-State Regional Affected Area

State	2020 Annual Emissions (tons)*						2020 Annual Emissions (metric tons)*	2020 Annual Emissions (metric tons)*
	CO	NOx	VOCs	$PM_{2.5}$	PM_{10}	SO_2	20-year CO2e	100-year CO2e
Arizona	697,606	107,896	547,837	27,499	115,711	717	40,414,236	40,229,110
California	2,116,621	379,782	2,146,321	132,917	439,718	9,475	178,257,920	177,709,461
Colorado	670,917	105,876	532,376	52,623	247,085	617	28,553,063	28,392,067
Idaho	352,579	57,336	386,668	60,685	362,242	879	12,805,704	12,644,640
Montana	393,235	72,053	444,785	77,664	411,568	1,662	10,526,410	10,303,246
Nevada	333,093	66,942	247,390	20,346	106,118	566	16,370,120	16,294,329
New Mexico	428,660	144,439	629,044	27,659	110,383	78,291	17,930,604	17,843,361
Oregon	1,259,833	103,392	767,764	137,060	594,496	5,115	29,610,840	28,183,686
Utah	350,140	71,870	345,887	23,531	129,388	1,004	18,294,832	18,181,531
Washington	890,479	139,753	576,991	58,983	131,771	2,199	35,100,815	34,834,000
Wyoming	162,234	49,917	226,108	43,418	337,728	269	8,103,502	8,058,545
11-State Total	**7,655,398**	**1,299,257**	**6,851,172**	**662,385**	**2,986,208**	**100,794**	**395,968,045**	**392,673,977**

Source: EPA 2023a; IPCC 2023

*Emissions from wildfires were removed from the emissions data because the unpredictable differences in wildfire from year to year can skew results.

Table 3-35 also shows total statewide gross GHG emissions on a consumption basis in terms of carbon dioxide equivalent[20] (CO_2e). Emissions from wildfires were removed from the data. California had the highest GHG emissions in the 11-state area, followed by Arizona and Washington.

3.9.2 Environmental Consequences

Methodology

Glen Canyon Dam hydropower generation does not generate air emissions. However, dam operations can affect emissions within the power grid. Operations can also impact emissions and ambient air quality over the 11-state Western Interconnection region, which includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets generation from other generating facilities (i.e., coal-fired, natural gas-fired,) that do generate air emissions in the Western Interconnection. Differences among alternatives in the amount of generation could affect regional air emissions, if lost generation is offset by generation from units fueled by coal, natural gas, oil, or other sources that generate air emissions.

Air quality issues within the analysis area are discussed above. Coal, natural gas, and oil units emit SO_2 and NOx, which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an important role in visibility degradation by contributing to haze. Among human-caused sources, sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor contributor.

Effects on visibility are analyzed through a comparison of regional SO_2 and NOx emissions under the various alternatives. Fossil fuel units also emit other criteria pollutants that can harm human health and the environment; potential effects are analyzed through a comparison of highest emission case levels of criteria pollutants emissions (CO, NOx, Pb, $PM_{2.5}$, PM_{10}, and SO_2) under the various alternatives.

To compute total air emissions under the alternatives, emissions were summed from all generating facilities in the United States portion of the Western Electricity Coordinating Council (WECC) region which approximately matches the 11-state analysis area. Pollutant emission factors (in pounds per megawatt-hour [lb/MWh]) for the WECC region for the year 2021, available in the Emissions and Generation Resource Integrated Database (eGRID) (EPA 2023d) were used to compute emissions. Composite emission factors that are representative of power generation from all types of generation currently in operation over the Western Interconnection were employed. Composite emission factors are estimated to be 0.22 lb/MWh for SO_2 and 0.537 lb/MWh for NOx.

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[20] The carbon dioxide equivalent is a measure used to compare the emissions from various GHGs on the basis of their global warming potential (GWP), which is defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period. Because the persistence in the atmosphere of some GHGs differs from CO_2, the GWP factors are typically given for 20- and 100-year time scales. For example, the 20-year GWP factor is 82.8 for methane (CH_4) and 273 for nitrous oxide (N_2O), and the 100-year GWP factor is 29.8 for CH_4 and 273 for N_2O. Accordingly, CO2e emissions are estimated by multiplying the mass of each gas by the GWP (IPCC 2023).

Exact emissions of replacement power are difficult to estimate. Two low-cost sources, wind and solar generation, typically produce at their maximum generation level based on the solar or wind conditions at the given moment. Generation sources that are able to quickly adjust output to meet high demand or to replace short-term generation reductions elsewhere on the grid—sometimes called "peaker" plants—are typically fueled by gas or oil, although battery energy storage systems can meet the same need, and are growing in popularity. Higher-cost sources such as coal, natural gas, and oil-fueled power generation facilities often do not run at full capacity if lower-cost generation sources (that is, hydropower and other renewables) are able to meet most grid demand. However, if there are reductions in longer-term baseload generation of the type provided by hydropower facilities like the Glen Canyon Dam as a result of the proposed alternatives, coal or natural gas–generated power could be the lowest cost source with available generation capacity for baseload power replacement.

New renewable generation facilities coming online, such as the 3,500 MW SunZia Wind facility, will increase the amount of renewable energy on the grid, potentially reducing overall grid emissions in the Western Interconnection Region, which would in turn reduce emissions from and reduce generation at the Glen Canyon Dam facility. Additionally, over time, older and higher-emitting facilities are replaced by new zero- or lower-emission sources, and emissions-reduction equipment on existing facilities is upgraded, resulting in reduced emissions. Although it is likely that grid emissions would decrease over the timeline of this plan, it is difficult to estimate the amount of that decrease. Because of these unknowns, the analysis of air quality employed two scenarios: one using the existing average emissions of all generation in the WECC region as an approximate expected emissions scenario, and one using the average emissions of coal power generation, the highest emission source, as a highest emission "worst-case" air quality impacts scenario.

Pollutant emission factors (in lb/MWh) specific to coal power generation for the WECC region were also obtained from eGRID for use in modeling a highest emissions scenario. Coal generation emission factors are estimated to be 1.13 lb/MWh for SO_2 and 1.71 lb/MWh for NOx. For other criteria pollutants facility level data for power generation facilities in the 11-state Western Interconnection region was obtained from the 2020 National Emissions Inventory (EPA 2023b) and matched to generation facilities with coal listed as the primary fuel type from eGRID (EPA 2023d) to determine an emission factor per MWh from coal generation. Coal generation emission factors for criteria pollutants using this method were estimated to be 0.676 lb/MWh for CO, 0.130 lb/MWh for $PM_{2.5}$, 0.189 lb/MWh for PM_{10}, 0.032 lb/MWh for VOCs, and 0.00004 lb/MWh for Pb. Because some of the generating units in the National Emissions Inventory dataset listing coal as a primary fuel also burn a secondary fuel, the SO_2 and NOx emissions factors derived using this method were slightly different from the eGRID results, the eGRID emissions factors were used for calculating SO_2 and NOx emissions.

Potential impacts on regional ambient air quality associated with dam operations are compared in terms of air emissions among alternatives relative to air emissions for the No Action Alternative.

Impact Analysis Area

Emissions are considered on an 11-state area regional basis; replacement power generation facilities may be anywhere in the region.

Assumptions

It is assumed that:

- The reservoir level would not change significantly under any proposed alternative.
- Power replacement would be 1:1 (i.e., 1 MWh of generation lost from the Glen Canyon Dam would be replaced by 1 MWh from another facility).
- Information to determine the facilities at which replacement generation would occur is not available. All replacement generation would occur in the WECC region.
- The average air emissions per MWh from power generation on the regional grid will not change substantially during the temporal extent of the project.
- Generating facilities would not offer capacity that would result in violation of the conditions of their state or federal air permits.

Impact Indicators

- Change in the expected amount of power produced in MWh and emissions of EPA Criteria Air Pollutants (tons or pounds per year) produced to generate an equivalent amount of replacement power from other generation types.

Issue 1: How would reductions in hydropower generation from Glen Canyon Dam due to proposed flow alterations impact air quality because of the replacement of power using generation sources with greater air emissions?

No Action Alternative

Under the No Action Alternative, the existing level of generation from the Glen Canyon Dam facility would continue; no change in emissions of criteria pollutants would occur due to changes at the facility.

Impacts Common to All Action Alternatives

Each of the cold-water alternatives (the action alternatives except the Non-Bypass Alternative) consider both implementing the proposed management actions at the level needed to meet cooling targets at river mile 15, which would allow Reclamation to target smallmouth bass in the more heavily populated areas, and implementing the proposed management actions at the level needed to meet cooling targets at river mile 61 (the confluence with the Little Colorado River), which would allow Reclamation to target smallmouth bass that have traveled farther downstream.

Although differences are expected in air quality and associated impacts among the various alternatives, potential air quality impacts are anticipated to be negligible.

Emissions of SO_2 and NOx are of interest due to their contribution to visibility impairment. The modeled differences among alternatives are presented in **Table 3-36** below, which shows the emissions levels of SO_2 and NOx under each of the alternatives assuming the reduction in generation from the Glen Canyon Dam facility was replaced by power with the average level of emissions across the WECC regional grid. In 2020, there was a total of 1,299,257 tons of NOx emissions and 100,794 tons of SO_2 emissions within the 11-state analysis area (EPA 2023a).

Table 3-36
Grid Average Emissions Scenario Summary Table for 5-year Total Emissions

Criteria Pollutant	No Action	Cool Mix (river mile 61)	Cool Mix (river mile 15)	Cool Mix with Flow Spike (river mile 61)	Cool Mix with Flow Spike (river mile 15)	Cold Shock (river mile 61)	Cold Shock (river mile 15)	Cold Shock with Flow Spike (river mile 61)	Cold Shock with Flow Spike (river mile 15)	Non-Bypass
NOx (Tons)	0.000	61.707	38.963	55.045	37.562	27.617	18.808	22.312	17.466	-11.209
SO_2 (Tons)	0.000	25.280	15.963	22.551	15.388	11.314	7.706	9.141	7.156	-4.592

Source: EPA 2023a

All criteria pollutants are of interest due to their potential contribution to air quality impairment. The modeled differences among alternatives are presented in **Table 3-37** below, which shows the emissions levels of each of the alternatives under a highest emissions scenario, which assumes the reduction in generation from the Glen Canyon Dam facility would be replaced entirely by power with the average emissions of the coal generations facilities on the WECC regional grid. Although it is not expected that the reduction in generation from the Glen Canyon Dam facility would be replaced entirely by power from coal generation facilities, this scenario is analyzed to provide a maximum value for possible emissions under the proposed action alternatives.

Table 3-37
Highest Emissions Scenario Summary Table for 5-year Total Emissions

Criteria Pollutant	No Action	Cool Mix (river mile 61)	Cool Mix (river mile 15)	Cool Mix with Flow Spike (river mile 61)	Cool Mix with Flow Spike (river mile 15)	Cold Shock (river mile 61)	Cold Shock (river mile 15)	Cold Shock with Flow Spike (river mile 61)	Cold Shock with Flow Spike (river mile 15)	Non-Bypass
CO (tons)	0.000	77.720	49.074	69.329	47.309	34.784	23.689	28.102	21.999	-14.118
NOx (tons)	0.000	196.497	124.073	175.283	119.610	87.944	59.893	71.051	55.619	-35.694
Pb (tons)	0.000	0.004	0.003	0.004	0.003	0.002	0.001	0.002	0.001	-0.001
$PM_{2.5}$ (tons)	0.000	14.892	9.403	13.285	9.065	6.665	4.539	5.385	4.215	-2.705
PM_{10} (tons)	0.000	21.746	13.731	19.398	13.237	9.733	6.628	7.863	6.155	-3.950
SO_2 (tons)	0.000	129.849	81.990	115.830	79.041	58.115	39.578	46.952	36.754	-23.587
VOCs (tons)	0.000	3.689	2.329	3.290	2.245	1.651	1.124	1.334	1.044	-0.670

Source: EPA 2023a, 2023d

Cool Mix Alternative

River Mile 61

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 61.707 tons for NOx and 25.280 tons for SO_2 under the grid average emissions scenario, and would be 196.497 tons for NOx and 129.849 tons for SO_2 under the highest emissions scenario.

As shown in the tables above, this alternative would result in the greatest increase in emissions over the No Action Alternative. Total emissions under the highest emissions scenario this alternative were compared with the total criteria pollutant emissions in the 11-state regional affected area shown in **Table 3-35**, to examine the potential contribution of the project to regional emissions under the highest potential emissions case. The percentage contribution of the calculated emissions during the highest emissions year of the highest emissions scenario under this alternative compared with the total 11-state regional area emissions for each of the criteria pollutants is shown in **Table 3-38** below.

Table 3-38
Percentage of 11-State Regional Affected Area Emissions Expected under Highest Emissions Scenario Highest Emissions Year for Cool Mix at Little Colorado River Alternative

CO	NOx	VOCs	Pb	$PM_{2.5}$	PM_{10}	SO_2
0.000%	0.006%	0.000%	0.022%	0.001%	0.000%	0.052%

Source EPA 2023a, 2023d
Note: % = percent

River Mile 15

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 38.963 tons for NOx and 15.963 tons for SO_2 under the grid average emissions scenario, and 124.073 tons for NOx and 81.990 tons for SO_2 under the highest emissions scenario.

Cool Mix with Flow Spike Alternative

River Mile 61

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 55.045 tons for NOx and 22.551 tons for SO_2 under the grid average emissions scenario, and 175.283 tons for NOx and 115.830 tons for SO_2 under the highest emissions scenario.

River Mile 15

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 37.562 tons for NOx and 15.388 tons for SO_2 under the grid average emissions scenario, and 119.610 tons for NOx and 79.041 tons for SO_2 under the highest emissions scenario.

Cold Shock Alternative

River Mile 61

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 27.617 tons for NOx and 11.314 tons for SO_2 under the grid average emissions scenario, and 87.944 tons for NOx and 58.115 tons for SO_2 under the highest emissions scenario.

River Mile 15

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 18.808 tons for NOx and 7.706 tons for SO_2 under the grid average emissions scenario, and 59.893 tons for NOx and 39.578 tons for SO_2 under the highest emissions scenario.

Cold Shock with Flow Spike Alternative

River Mile 61

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 22.312 tons for NOx and 9.141 tons for SO_2 under the grid average emissions scenario, and 71.051 tons for NOx and 46.952 tons for SO_2 under the highest emissions scenario.

River Mile 15

Under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be 17.466 tons for NOx and 7.156 tons for SO_2 under the grid average emissions scenario, and 55.619 tons for NOx and 36.754 tons for SO_2 under the highest emissions scenario.

Non-Bypass Alternative

Under the Non-Bypass Alternative, the implementation of high-flow events routed through the generation facility would result in a slight increase in power generation compared with the No Action Alternative. As a result, under this alternative, total LTEMP-related average air emissions over the 5-year project timeline would be reduced by 11.209 tons of NOx and 4.592 tons of SO_2 under the grid average emissions scenario. Under the highest emissions scenario, total LTEMP-related average air emissions over the 5-year project timeline would be reduced by 35.694 tons of NOx and 23.587 tons of SO_2.

Cumulative Effects

The potential impacts from future projects such as the slough restoration or thermal curtain at the Glen Canyon Dam would not have any substantial cumulative effects on air quality. There could be minor impacts on local air quality during any potential construction.

Summary

Although differences are expected in potential ambient air quality and associated impacts among the various alternatives, potential air quality impacts are anticipated to be negligible. The Cool Mix at Little Colorado River Alternative would result in the greatest increase in air emissions of NOx, SO_2, and other criteria air pollutants compared with the No Action Alternative. The increase in emissions under any of the Action Alternatives is not expected to result in any significant deterioration of air quality; any violation or significant increase in level of existing violation of any NAAQS or State

Ambient Air Quality Standards; or any increase in the levels of visibility impairment at any Class I or Class II areas including GCNP, GCNRA, and LMNRA.

3.10 Visual Resources

3.10.1 Affected Environment

Visual resources are the physical features that make up the visible landscape, including land, water, vegetation, topography, and human-made features such as buildings, roads, utilities, and structures. They also include the response of viewers to those features. To supplement the 2016 LTEMP FEIS (DOI 2016a), this section provides a summary of the affected environment from the original 2016 document, modified as necessary to include changes that have occurred since 2016.

As described in the 2016 LTEMP FEIS, visual resources are important for visitors to GCNP and GCNRA as well as to American Indian communities who use these lands for subsistence or ceremonial uses. The Grand Canyon Protection Act of 1992 specifically calls for the conservation of visual resources in addition to visual resources being an important component of federal management of these areas. Also, in regard to American Indian communities the 2016 LTEMP FEIS states, "The Canyons have a significant place in the traditional cosmology of the indigenous communities of the Southwest. American Indian communities may visually experience the Canyons quite differently than recreational users who experience the Canyons not only during recreational activities but also while gathering natural resources or performing religious ceremonies" (DOI 2016a: 3-192).

The 2016 LTEMP FEIS identified the following visual resource issues that may be affected by the No Action and action alternatives:

- Exposure of lake deltas in Lake Mead and Lake Powell
- Changes in vegetation and sandbar size

Since the proposed flow alterations at Glen Canyon Dam would not change yearly release amounts, resulting in no changes to water levels in Lake Mead or Lake Powell, the inventory of visual resources focuses on the portion of the Colorado River between Glen Canyon Dam and the inlet of Lake Mead. Specifically, how flow alterations at Glen Canyon Dam would affect landscape character along the Colorado River.

The landscape character along the Colorado River within GCNP and GCNRA, as well as within the Hualapai and Navajo Indian Reservations, is defined by sweeping vistas of red rock towers, buttes, and mesas typical of the Colorado Plateau's physiographic province (Fenneman 1931). Recreational activities along this portion of the Colorado River include boating, kayaking, swimming, and fishing, in addition to viewing this varied, high-quality landscape from both locations along the river and from scenic overlooks above the river. The LTEMP FEIS further states, "Stewart et al. (2000) found that the more valued aspects of a river rafting trip include simply being in a natural setting, having the opportunity to stop in scenic places, and being able to view flora, fauna, and geology… For many Tribes, trails that enter the Canyons are sacred and the scenic setting along these trails plays an important part in the travel and ceremonial experience" (DOI 2016a: 3-193).

Vegetation along the river comprises riparian species such as native willows, nonnative and invasive tamarisk (salt cedar), and isolated areas of cottonwoods, as well as cattails, bulrushes, and reeds in return-current channels (backwaters), channel margins, and mouths of tributary streams from Glen Canyon Dam downstream to Lake Mead. Vegetation farther upslope along rock terraces includes saltbush, arrowweed, rabbitbrush, and other arid-adapted plant species. Previously planned and implemented HFE releases from Glen Canyon Dam, which help recreate natural floods common before the construction of the dam, have allowed for the transportation and deposition of sand, resulting in the formation of sandbars along the river. In some areas, these HFE releases can decrease the extent of bank armoring and strip vegetation along the existing sandbars, including tamarisk, allowing the landscape to appear more similar to its natural character. The LTEMP FEIS further states, "Vegetation increases the visual interest of many places by adding variety in color and texture and is also a visual cue for Tribes in determining the health of the ecosystem. For example, sandbars and marshes along the river may contain stands of native vegetation which are important for many Tribal communities" (DOI 2016a: 3-193).

The construction of Glen Canyon Dam has altered the landscape character along the Colorado River as "Prior to construction of Glen Canyon Dam, the banks of the Colorado River consisted primarily of open sandy beaches and bare talus slopes with native riparian vegetation established above the elevation of annual scouring flows within the Grand Canyon" (DOI 2016a: 3-197). Additionally, "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 of 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" (DOI 2016a: 3-198).

Specific details regarding visual resources and common recreational activities in GCNRA and GCNP are discussed in the LTEMP FEIS (DOI 2016a: 3-193 through 3-198). This includes an overview of the management of visual resources in the 1979 GCNRA General Management Plan (NPS 1979) and 1995 GCNP General Management Plan (NPS 1995).

3.10.2 Environmental Consequences

Methodology

Compared with the LTEMP FEIS, this SEIS focuses on proposed hourly, daily, or monthly flow alterations at Glen Canyon Dam, as there would be no adjustments to the yearly release amounts. Based on this narrower focus, the assessment of visual impacts did not consider changes to water levels in Lake Mead or Lake Powell, as these changes would be minor over the long term. These shorter-term flow alterations have the potential to affect the existing landscape character along the Colorado River, including potential changes to vegetation, such as bank armoring, and the formation of sandbars. As part of these proposed flow alterations, a 1-year sediment accounting window approach to conducting HFE releases from Glen Canyon Dam has been proposed under all but the No Action Alternative.

To assess potential changes to landscape character along the Colorado River, this analysis focuses on a qualitative assessment of effects associated with these changes in flow from Glen Canyon Dam as well as the modified approach to identifying when to conduct HFE releases. This analysis also considers and references analyses contained in **Section 3.4**, Geomorphology/Sediment, **Section 3.8**, Threatened and Endangered Species, and **Section 3.14**, Recreation, which assess the effects of the flow alterations under different alternatives on the prevalence of riparian vegetation and the formation of sandbars.

Impact Analysis Area

The visual resource impact analysis area was defined as the area from the canyon's rim to rim associated with the Colorado River between Glen Canyon Dam and the inlet of Lake Mead. The LTEMP FEIS did not specifically identify an analysis area for visual resources. The tall canyon walls along this stretch of the Colorado River would visually constrain the effects from this SEIS, limiting the visual resource impact analysis area to this canyon landscape.

Assumptions

- Vegetation at a certain distance from the river would not be impacted by proposed flow alterations.
- Lake Mead and Lake Powell would not be influenced, as yearly flows will remain the same.
- The 1-year sediment accounting window approach to conducting HFE releases from Glen Canyon Dam would not result in additional HFE releases.

Impact Indicators

The assessment of potential impacts associated with proposed flow alterations at Glen Canyon Dam on landscape character along the Colorado River was developed focusing on a qualitative assessment considering modeling associated with **Section 3.4**, Geomorphology/Sediment, **Section 3.8**, Threatened and Endangered Species, and **Section 3.14**, Recreation.

Issue 1: How would flow alterations at Glen Canyon Dam affect landscape character along the Colorado River?

No Action Alternative

Under the No Action Alternative, there will be no changes to daily, weekly, monthly, or yearly flows from Glen Canyon Dam; therefore, existing trends of bank armoring associated with dense riparian vegetation (including tamarisk) will continue under the No Action Alternative. The current LTEMP rules for HFE releases, which focus these events in the fall with limited occurrences in the spring, will remain in effect. Timing most of the HFE releases outside the spring germination window, in combination with the overall trend of decreasing water volumes in the Colorado River over the long term, will continue to result in a narrowing lower riparian zone. In response to regional drought conditions and aridification, the upper riparian zones may transition to desert ecosystems, further modifying the area's landscape character. For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species. When conducted, the HFE releases would continue to contribute to sandbar building and sediment export in the Colorado River. For additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Cool Mix Alternative

Impacts on landscape character under the Cool Mix Alternative would be similar to those under the No Action Alternative, as most short-term and all long-term flows would remain the same, with changes in water temperature along the Colorado River having minimal effects on riparian vegetation and sandbar building. For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species, and for additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, increased flow events during flow spikes would be similar to HFE releases and could result in increases in sandbar building, decreases in bank armoring, and more favorable spring germination conditions for riparian vegetation types, allowing the area's landscape to appear more natural in character than under the No Action Alternative. The change in water temperature along the Colorado River would have minimal effect on riparian vegetation and sandbar building, with the flow spikes having the primary beneficial effect on landscape character. The addition of the HFE option under this alternative would further facilitate higher flows, potentially increasing the benefit to sandbar building and decreasing the extent of potential bank armoring. For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species. For additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Cold Shock Alternative

Impacts on landscape character under the Cold Shock Alternative would be similar to those under the No Action Alternative, as most short-term and all long-term flows would remain the same, with changes in water temperature along the Colorado River having minimal effects on riparian vegetation and sandbar building. During cold shock flows, periods of elevated steady flows in the Colorado River may benefit riparian species, allowing for higher germination rates with the potential for landscape character to appear more natural than under the No Action Alternative and Cool Mix Alternative. For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species. For additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Cold Shock with Flow Spike Alternative

Under the Cold Shock with Flow Spike Alternative, increased flow events during flow spikes would be similar to HFE releases and could result in increases in sandbar building, decreases in bank armoring, and more favorable spring germination conditions for riparian vegetation types, allowing the landscape to appear more natural in character than under the No Action Alternative. The change in water temperature along the Colorado River would have minimal effect on riparian vegetation and sandbar building, with the flow spikes having the primary beneficial effect on landscape character. During cold shock flows, periods of elevated steady flows in the Colorado River may benefit riparian species, allowing for higher germination rates with the potential for landscape character to appear more natural than under the No Action Alternative and Cool Mix Alternative. The addition of the HFE option under this alternative would further facilitate higher flows, potentially increasing the benefit to sandbar building and decreasing the extent of bank armoring. For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species. For additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Non-Bypass Alternative

Under the Non-Bypass Alternative, the high-volume flows proposed would help build sandbars and strip vegetation along the river, reducing the extent of bank armoring. During low-volume flows, less water would be available to native riparian vegetation species, which may result in decreased vegetation along the river's sandbars. These effects on water levels within the Colorado River would be most intense near Glen Canyon Dam, with the influence of high- and low-volume flows on river water levels decreasing farther downriver. In general, the Non-Bypass Alternative could allow the area's landscape character to appear more natural than under the No Action Alternative, with the river system becoming more dynamic, similar to its condition prior to the construction of the Glen Canyon Dam. The addition of the HFE option under this alternative would further facilitate higher flows, potentially increasing the benefit to sandbar building and decreasing the extent of bank armoring.

For additional analysis related to riparian vegetation, refer to **Section 3.8**, Threatened and Endangered Species. For additional analysis related to sandbar building, refer to **Section 3.4**, Geomorphology/Sediment, and **Section 3.14**, Recreation.

Cumulative Effects

Under all flow options, the range of potential discharge volumes would remain within the existing range of flows outlined in the LTEMP FEIS. Since all proposed flow options would operate within the spatial and temporal bounds and under the assumptions of the existing analysis conducted in the LTEMP FEIS, and since there are no specific reasonably foreseeable future actions to be analyzed, there would be no additive cumulative impacts on landscape character along the Colorado River beyond those included in the LTEMP FEIS.

Summary

Existing trends of increasing bank armoring and a narrowing lower riparian zone will continue to affect the area's landscape character under the No Action Alternative, with beneficial effects on sandbar building and sediment export occurring when HFE releases are conducted. Under the Cool Mix Alternative, impacts on landscape character would be similar to those under the No Action Alternative. Where increased flow regimes have been proposed under the Cool Mix with Flow Spikes, Cold Shock, Cold Shock with Flow Spikes, and Non-Bypass Alternatives, landscape character has the potential to be improved over the short term through increases in sandbar building, decreases in bank armoring, and more favorable spring germination conditions for some riparian vegetation types during high-volume flows. The proposed flow regimes would likely have few long-term beneficial impacts on landscape character, as—while some plant species could experience temporary, positive impacts from high-flow disturbance events and access to higher water tables during summer months—steady flow conditions are necessary for germination success rates. The addition of the HFE option under all action alternatives would further facilitate higher flows, potentially increasing the benefit to sandbar building and decreasing the extent of bank armoring.

3.11 Water Quality

3.11.1 Affected Environment

Inflows from the Upper Colorado River Basin dictate the system's water quality. Water quality includes, but is not limited to, chemical properties, nutrient levels, temperature, and bacteria.

Lake Powell Water Quality

Lake Powell is stratified into vertical layers with different thermal, chemical, and biological processes. For this SEIS, the focus is mainly on the vertical stratification near Glen Canyon Dam, which acts as the release point for water into the Colorado River (Reclamation and NPS 2016).

Temperature

Lake Powell is thermally stratified—that is, arranged into layers with distinct temperatures and chemical characteristics—during the spring, summer, and early fall. Generally, Lake Powell's epilimnion, or uppermost layer from the reservoir surface to a depth of about 60 feet, depending on the season and location, ranges from 25˚C to 30˚C (77˚F to 86˚F) in the summer and may drop to 6˚C to 10˚C (42.8˚F to 50˚F) in the winter. Lake Powell's hypolimnion, or deeper layer beginning from a depth of about 180 feet below the surface of the reservoir, ranges from 6˚C to 9˚C (42.8˚F to 48.2˚F) (DOI 2016a). In the winter, the thermal stratification breaks down, and Lake Powell experiences turnover where the different layers mix to create relatively homogenous conditions throughout the water column (DOI 2016a). Full turnover does not occur every year, but partial turnover does.

The penstocks are 15 feet in diameter with a centerline elevation of 3,470 feet. Up until recently, the penstock intakes have aligned with the top of the cooler hypolimnion layer with temperatures around 10˚C to 12.2˚C (50˚F to 54˚F). The river outlet works are located at an elevation of 3,374 feet and typically fall within the lower hypolimnion layer with temperatures around 6.1˚C to 8.9˚C (43˚F to 48˚F). Due to the lower lake elevation, the warm epilimnion layer is currently found closer to the penstocks, which means that water released through the penstocks is warmer than historical values (GCDAMP 2023). Ongoing drought and aridification have led to continued and increased warming throughout the reservoir, particularly during the spring, summer, and early fall months.

Salinity and Conductivity

Historically, salinity has been a concern for the Colorado River Basin (USGS 2021). Salinity causes economic and environmental damage in agricultural, municipal, and industrial industries.

Salinity and conductivity are stratified with temperatures. The lower, cooler waters tend to have higher salinity and conductivity values (Boehrer and Schultze 2008). Releases from lower elevations in Lake Powell through the river outlet works are cooler and more saline compared with releases from higher elevations through the Glen Canyon Dam penstocks (DOI 2016a).

Dissolved Oxygen

DO can vary within the reservoir due to variations in inflows, inflow water temperatures, seasonal reservoir circulation, and biological processes. In years of high inflows and when the reservoir elevations are low, flows cut through deltaic sediments, resuspending organic matter and nutrients that contribute to both chemical and biological oxygen demand as the inflow water passes down through the reservoir water column. The resulting plumes of low-oxygen water drive water column concentrations lower. When deltaic sediments and organic matter are not resuspended, oxygen demand is decreased, and DO concentrations remain higher Generally, Lake Powell DO concentrations are at their highest in the spring to early summer when inflows are well oxygenated and wind-induced mixing is high.

Low DO concentrations move through the reservoir and closer to the dam during the summer into the fall because of organic matter decomposition and chemical reactions that consume oxygen. DO gradually increases in the winter because of the higher oxygen-carrying capacity of cold water and the natural mixing processes that occur during turnover. Releases using the river outlet tubes are made from depths beneath the powerplant intakes. The release waters tend to have lower temperatures, higher salinity, and lower oxygen levels than the water discharged from the dam during normal operations.

Other chemical and biological processes within Lake Powell can vary, depending on inflow, precipitation, and other environmental conditions (DOI 2016).

Colorado River Water Quality

Apart from DO, the water quality of the Colorado River below the dam is highly defined by the water quality of Lake Powell, particularly at the elevations of the penstocks and river outlet works. Typically, the water discharged from the dam is characterized as cold, clear, below saturation in DO, and low in nutrients. However, due to the recent drought conditions and aridification, the discharged water is released from higher in the water column. Once the discharged water has been released, the chemical and physical properties are affected by ambient meteorological conditions, primary production and respiration from the aquatic environment, aeration from rapids, and inputs from other tributary sources and overland flow (DOI 2016a). The processes affecting the water quality of releases are complex and explained in detail below.

There are minimal inflows from the dam to Lees Ferry, resulting in minor changes in water quality through this stretch. At Lees Ferry, the Paria River joins the Colorado River, which influences water quality in the Colorado River. Typically, these inflows contain warmer, nutrient-rich water that mixes with the Colorado River. During flood events, these inflows can bring large amounts of sediment and organic material. Several other minor tributaries can have different physiochemical properties; however, their mean flows are low enough that their contribution to water quality is minor (DOI 2016a).

When HFE releases have been conducted, a large, temporary change in water quality below Glen Canyon Dam has been observed. The excess discharge is typically derived from the river outlet works, meaning the water is cooler and more saline. The increased discharge from a river outlet work creates aeration at the outlet and increased DO. There can be minor increases in turbidity with the excess flows and additional scouring of the riverbed and banks below the dam; however, the stretch of the river below the dam has already experienced significant scouring since the construction of the dam (USGS 2018). See **Section 3.4**, Geomorphology/Sediment, for additional information on sediment resources.

Temperature

Following the completion of Glen Canyon Dam, the Glen Canyon Dam tailwaters temperatures stabilized and ranged from 7.2˚C to 12.2˚C (45˚F to 54˚F) annually. Since the early 2000s, drought conditions, aridification, and lower water levels in Lake Powell have led to a general warming of water temperatures in the Colorado River below the dam (Reclamation and NPS 2016).

Temperatures in the Colorado River in the Grand Canyon are highly variable over space and time and are primarily controlled by the discharge and temperature released from Glen Canyon Dam and solar radiation dynamics along the river corridor (Mihalevich et al. 2020). As water moves farther away from Glen Canyon Dam (e.g., below river mile 88), the influence of release discharge and temperature on water temperature becomes less, and local meteorological conditions become more important in determining the heat budget. During summer periods, increases in water temperatures downstream of Glen Canyon Dam are attributed to solar radiation and air temperatures (Dibble et al. 2021). The water in the Colorado River generally warms 1˚C (1.8˚F) for every 30 miles traveled downstream during warmer months of the year under specific discharge and meteorological conditions. Some variation in lateral warming also occurs, with warmer temperatures along the shoreline and cooler water in the deep, fast-moving areas (DOI 2016a). Warming is greatest from June through August (DOI 2016a).

Salinity and Conductivity

The construction of Glen Canyon Dam has significantly altered the downstream transport of total dissolved solids (TDS) since river impoundment. Lake Powell retains about 10 percent of TDS loaded to the system via calcite precipitation (Deemer et al. 2020). Salinity below the dam typically ranges from 300 to 600 milligrams per liter for TDS. Slight seasonal variation has been found in salinity and conductivity levels below the dam. However, releases from lower elevations in Lake Powell contain cooler and more saline water (Reclamation and NPS 2016).

Dissolved Oxygen

Current DO levels in Lake Powell and the Glen Canyon Dam tailwaters are lower compared with historical levels owing to a combination of low reservoir elevations and high inflows in recent years. Resuspended sediments at the inflow areas cause low DO plumes because that suspended sediment creates high biological and chemical oxygen demand (i.e., bacteria and other biota consuming oxygen, and chemical reactions consuming oxygen). This problem is exacerbated whenever large sediment inputs occur, especially when sediment erodes from the reservoir banks in the springtime, and during low lake elevations, when more bed-cutting and bank erosion occurs. Under low lake elevations, the residency time in Lake Powell is shorter for the low DO plumes, and the low DO water appears at Glen Canyon Dam sooner than it would under higher starting lake elevations. The DO concentrations in Lake Powell do not typically correlate with DO concentrations in the Colorado River because the low DO condition resolves downstream of Lee Ferry as the water is reaerated through whitewater action (Hall et al. 2012). The Colorado River DO increases approximately 1 milligram per liter between Glen Canyon Dam and Lees Ferry. This approximation can vary between negligible reoxygenation and approximately 3 milligrams per liter increases during very low oxygen releases during daylight hours (GCMRC 2023a).

DO levels below the dam vary throughout the year; levels as low as 2.2 milligrams per liter have been observed in the summer and fall. Levels have risen as high as 9 to 10 milligrams per liter in the spring. Lower values have been observed in the forebay (GCMRC 2023a). This seasonal variation is due to changes in DO at the penstock level of Lake Powell during the year. In recent years, periods of low DO (that is, less than 5 milligrams per liter) have become more common due to the age of the reservoir and the greater volume of deltaic sediment available to be remobilized.

As the reservoir water level decreases, warmer, well-oxygenated waters exist closer to the penstocks, and the resulting discharged waters may eventually lead to higher DO in the downstream reach. Notably, when water is discharged through the river outlet works, such as during HFE releases, it becomes well-aerated and contains greater DO concentrations (Reclamation and NPS 2016).

3.11.2 Environmental Consequences

Methodology

This section describes the methods used to determine the potential effects on water quality associated with the alternatives.

Temperature and Conductivity

Temperature exerts a major influence on biological and chemical processes. For example, the temperature of dam releases affects the aquatic ecosystems and fish population dynamics in downstream river segments. Further, the salinity of waters both within Lake Powell and dam releases are of interest to the Colorado River Basin Salinity Control Program.

Hydrologic traces generated by CRMMS provide a range of inflow, outflow, and reservoir elevations that could uniquely influence water quality conditions within Lake Powell. To anticipate the potential water quality impacts associated with different hydrologies and management practices within Lake Powell and in downstream receiving waters, the CE-QUAL-W2 Lake Powell water quality model was applied to predict outflow temperature and TDS. Salinity is the measure of the amount of dissolved salt in water, where TDS measures all dissolved solids in a water sample, and it is a similar constituent, as it estimates the level of salt within a water sample. TDS was used in the CE-QUAL-W2 model as a proxy for salinity. While CE-QUAL-W2 does have a DO module (Cole and Wells, 2021) recent modeling results suggest the need for its recalibration to improve performance under low water levels and with the aging of the reservoir.

To understand the drivers of water quality change in Lake Powell, a 2D hydrodynamic model has been developed using CE-QUAL-W2 (Williams 2007). CE-QUAL-W2 uses hydrological and weather information to calculate the individual heat and constituent fluxes that contribute to reservoir mixing and stratification. To do this accurately, high-quality weather and hydrological information are needed. Additionally, high-quality bathymetric data are needed to build the model grid. Lake Powell modeling for this SEIS uses updated bathymetric information (Jones and Root 2020) to simulate temperature and TDS within the reservoir.

All traces from all operational alternatives were evaluated in CE-QUAL-W2, resulting in 300 model runs. The simulation period for all models was between September 11, 2023, and October 1, 2027. Models were initialized on September 11, 2023, because it is the date of the most recently processed lake-wide water quality profiles at the time of this evaluation.

Dissolved Oxygen

A long-term record of DO profiles from the reservoir forebay (site name LPCR0024; Deemer et al. 2023) were used to model and predict DO concentration within a 10-meter (33-foot) envelope of the penstock depth for the 180 hydrological traces generated as part of the SEIS. While the Lake Powell CE-QUAL-W2 does have a DO module (Williams 2007), recent observations suggest the need for its recalibration to improve performance under low water levels and with the aging of the reservoir.

A total of 132 water quality profiles from the months of August, September, and October (1967 to 2022) were used to calculate yearly mean late-summer/early fall DO concentrations in six 10-meter (33-foot) layers of the Lake Powell water column that represent the heights from which water could be drawn through the penstocks under the various SEIS hydrological traces (20 feet to less than 53 feet, 53 feet to less than 85 feet, 85 feet to less than 118 feet, 118 feet to less than 151 feet, 151 feet to less than 184 feet, and 184 feet to less than 217 feet).

Impact Analysis Area

The impact analysis area is Glen Canyon Dam and the Colorado River down to the inlet of Lake Mead.

Assumptions

- Change in water temperature would be expected across the analysis area.
- The action alternatives would lead to an alteration of flows.
- A minor shift in water chemistry would occur due to water being drawn from a different layer in Lake Powell.
- Temperature and flow ranges would remain within existing and historical management, leading to minor impacts from previous assessments.

Salinity and Temperature Assumptions

Testing of the new Lake Powell water quality model was carried out over a 12-year simulation period. This relatively long duration was used to evaluate the influence of modeling assumptions, such as the use of constant bathymetry and the omission of ephemeral tributary sources. This is important when modeling future climate change or hydrologic conditions, or both. For this simulation, a combination of measured and modeled input data were used following the methods described by Mihalevich (2022). Reclamation’s hourly release data from Glen Canyon Dam penstocks and river outlet works were utilized. Sub-hourly water quality data measured below Glen Canyon Dam near Page, Arizona (gage #09379901), were used to evaluate model predictions.

The results of the long-term model test show good agreement between observed and predicted release temperatures from Glen Canyon Dam with a root mean squared error of 0.79°C (33.62°F). The distribution of temperature residuals (not shown, calculated as model minus observed) is normal and centered around zero, indicating that the predictions are free of long-term systematic bias. Predictions of specific conductance from Glen Canyon Dam also agree with the measured patterns and magnitudes below the dam, resulting in a root mean squared error of 36.71 microsiemens per centimeter. The distribution of specific conductance residuals was normal and skewed slightly positive (the mean error was 16.65 microsiemens per centimeter), suggesting that model predictions tend to be higher than observations. This is consistent with the salinity retention that can occur in Lake Powell because of calcite precipitation, but that is not modeled within CE-QUAL-W2 (Deemer et al. 2020).

Dissolved Oxygen Assumptions

Linear models were built to predict these water-layer-specific DO concentrations as a function of minimum reservoir elevation in that year, the volume of the spring inflow (calculated as the inflow from April to July), and the years since the reservoir was filled. This model was based on the best model for predicting whole-metalimnion mean DO in the late summer and fall (Deemer 2023). No LTEMP hydrologic trace resulted in minimum spring reservoir elevations less than 3,490 feet, so the only river outlet works releases predicted were those associated with high-flow events, flow spikes, cool mix treatments, or cold shock treatments. For the days when any amount of river outlet works spill was used, a daily average DO concentration of 8 mg/L was assigned.

A weighted average DO concentration (August to November) was calculated by assigning modeled penstock DO concentrations for days without river outlet works releases and 8-mg/L DO for days with river outlet works releases. Additionally, 8 mg/L DO concentrations were estimated, regardless of the river outlet works spill rate based on the aeration that has been observed when water is spilled through the river outlet works (Hueftle and Stevens 2001; Vernieu 2010).

River outlet works releases of 425 cubic meters per second during the 2008 HFE release resulted in supersaturated DO concentrations (12.6 mg/L; Vernieu 2010) below the dam; therefore, 8-mg/L DO was considered a conservative estimate for partial river outlet works spills. Future work to constrain the relationship between the bypass spill rate and reaeration would help more accurately model outflow DO concentrations resulting from a bypass spill. This modeling exercise did not attempt to characterize monsoon-driven, low DO events. Lake Powell can also develop low-oxygen zones due to inputs from monsoon storms, as was observed in 2021.

Impact Indicators

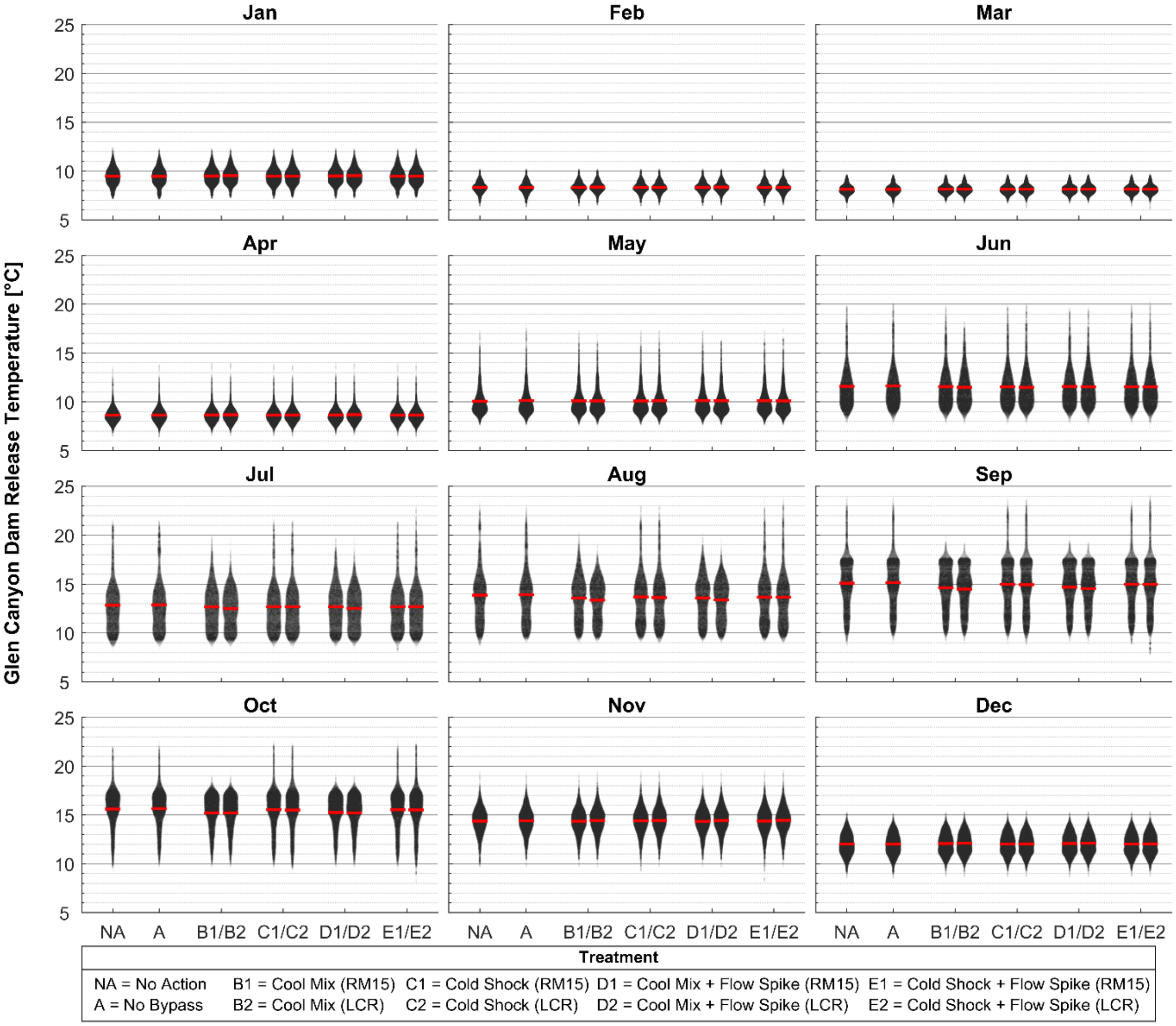
- Temperature
- Salinity
- DO

Issue 1: How would flow alterations impact temperature?

No Action Alternative

Under the No Action Alternative, Glen Canyon Dam operations would remain unchanged. Therefore, water would continue to be discharged primarily through the penstocks, as described in the LTEMP FEIS. The water discharged from the penstocks would remain warm, leading to warmer water in the Colorado River downstream of the dam. This warmer water would produce a negligible increase in temperature, as seen in **Figure 3-35**.

Figure 3-35
Swarm Charts Showing the Monthly Distribution of Predicted Glen Canyon Dam Release Temperature for All Scenarios and Traces over the Simulation Period*



Source: USGS 2024b

*Red horizontal lines indicate the means of each distribution. Widths of each distribution indicate the relative frequency of occurrence.

Cool Mix Alternative

Under the Cool Mix Alternative, adding more bypass through cool mix operations would result in a decreased total release temperature during summer periods when bypass would be utilized, as shown in **Figure 3-35**, when compared with the No Action Alternative. Under the Cool Mix Alternative, the temperature would remain cooler over a longer duration when compared with the Cold Shock Alternative and Cold Shock with Flow Spike Alternative.

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, adding more bypass through cool mix operations would result in a decreased total release temperature during summer periods when bypass would be utilized, as shown in **Figure 3-35**, when compared with the No Action Alternative. Like the Cool Mix Alternative, through cool mix operations, the temperature would remain cooler over a longer duration when compared with the Cold Shock Alternative and Cold Shock with Flow Spike Alternative. Under this alternative, the flow spike would further reduce the release temperature; however, this change would be minimal.

Cold Shock Alternative

Under the Cold Shock Alternative, similar to the Cool Mix Alternative, adding more bypass through cold shock operations would result in a decreased total release temperature during summer periods when bypass would be utilized, as shown in **Figure 3-35**, when compared with the No Action Alternative. However, the duration of cold releases under the Cold Shock Alternative would be more effective at reducing the total release temperature than the Cool Mix Alternative.

Cold Shock with Flow Spike Alternative

Under the Cold Shock with Flow Spike Alternative, similar to the Cool Mix Alternative, adding more bypass through cold shock operations would result in a decreased total release temperature during summer periods when bypass would be utilized, as shown in **Figure 3-35**, when compared with the No Action Alternative. Like the Cold Shock Alternative, the duration of cold releases under the Cold Shock with Flow Spike Alternative would be more effective at reducing the total release temperature than under the cool mix operations. Under this alternative, the flow spike would further reduce the release temperature; however, this change would be minimal.

Non-Bypass Alternative

Impacts on temperature under the Non-Bypass Alternative would be similar to those under the No Action Alternative, as shown in **Figure 3-35**. This alternative would be similar to the No Action Alternative, since the Non-Bypass Alternative would not involve the use of Glen Canyon Dam's bypass system and would instead focus on changes in release volumes.

Cumulative Effects

Impacts on temperature from the cold water alternatives would be temporary and would not have permanent, significant impacts on Lake Powell or the Colorado River. All proposed flow options would operate within the spatial and temporal bounds and under the assumptions of the existing analysis conducted in the LTEMP FEIS. There would be no cumulative impacts on temperature beyond those included in the LTEMP FEIS.

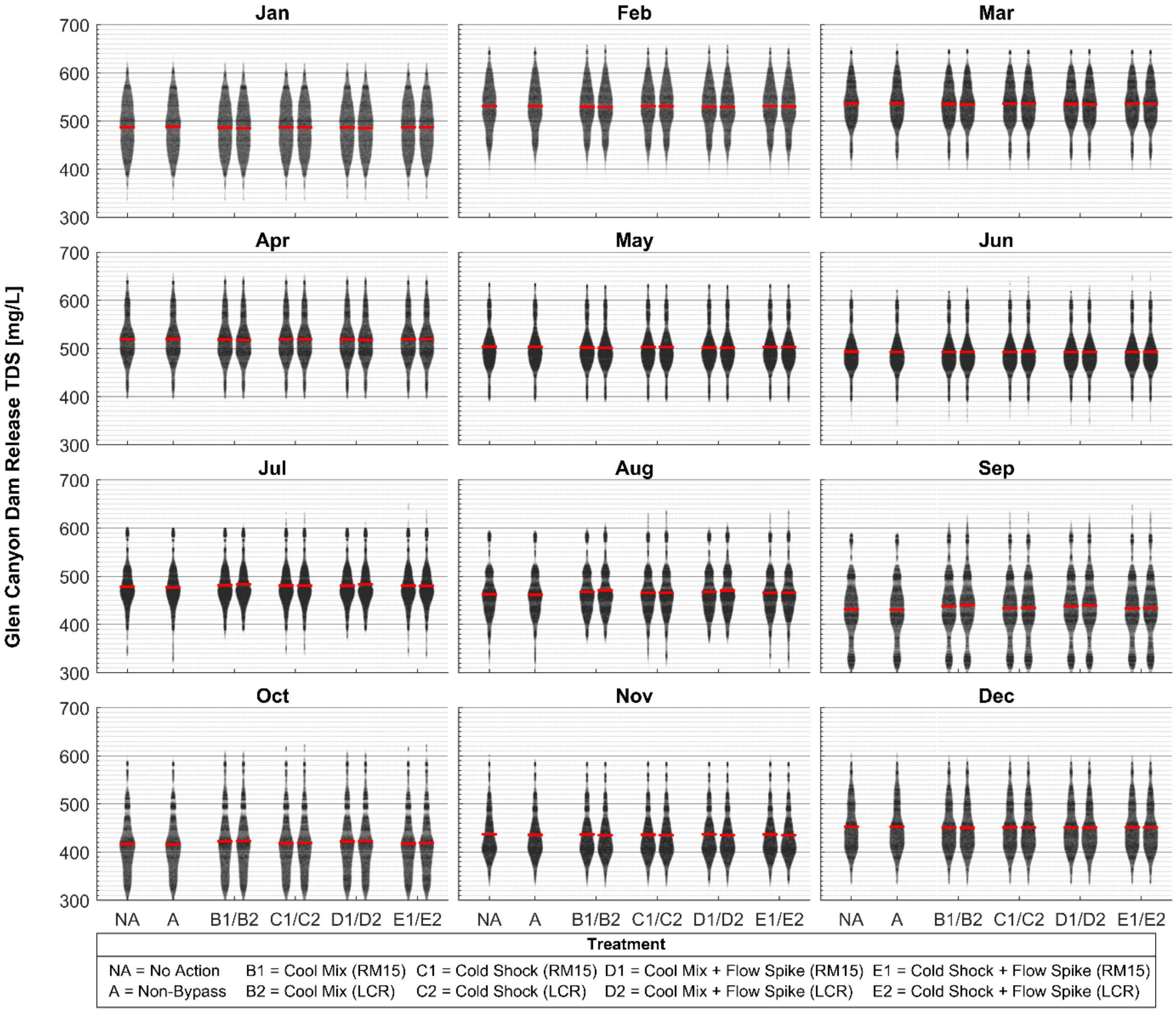
Issue 2: How would flow alterations impact salinity?

Impacts Common to All Alternatives

Under all alternatives, any increase in salinity would have negligible impacts on biological systems and meeting the Colorado River Salinity Criteria.

As shown in **Figure 3-36**, salinity would not exceed 720 mg/L under any alternatives.

Figure 3-36
Swarm Charts Showing the Monthly Distribution of Predicted Glen Canyon Dam Release Salinity* for All Scenarios and Traces over the Simulation Period**



Source: USGS 2024b

*Salinity is the measure of the amount of dissolved salt in water; TDS measures all dissolved solids in a water sample, and it is a similar constituent because it estimates the level of salt within a water sample. TDS was used in the CE-QUAL-W2 model as a proxy for salinity.

**The red horizontal lines indicate the means of each distribution. The widths of each distribution indicate the relative frequency of occurrence.

No Action Alternative

Under the No Action Alternative, Glen Canyon Dam operations would remain unchanged. Therefore, water would continue to be discharged primarily through the penstocks, as described in the LTEMP FEIS. The warmer water discharged from the penstocks would continue to produce a negligible increase in salinity.

Cool Mix Alternative

Under the Cool Mix Alternative, there would be an increase in salinity when compared with the No Action Alternative, as shown in **Figure 3-36**. While there would be an increase, salinity would remain lower than the early spring salinity concentration peaks, so the increase would be minimal.

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, there would be an increase in salinity related to the cool mix operations when compared with the No Action Alternative. There would also be a further increase in salinity due to the flow spike operations, as shown in **Figure 3-36**. While there would be an increase, salinity would remain lower than the early spring salinity concentration peaks, so the increase would be minimal.

Cold Shock Alternative

Under the Cold Shock Alternative, there would be an increase in salinity when compared with the No Action Alternative, as shown in **Figure 3-36**. This increase in salinity would also be greater than the Cool Mix Alternative. While there would be an increase, salinity would remain lower than the early spring salinity concentration peaks, so the increase would be minimal.

Cold Shock with Flow Spike Alternative

Under the Cold Shock with Flow Spike Alternative, there would be an increase in salinity related to the cold shock operations when compared with the No Action Alternative. This increase in salinity would also be greater than the Cool Mix Alternative. There would also be a further increase in salinity due to the flow spike operations, as shown in **Figure 3-36**. While there would be an increase, salinity would remain lower than the early spring salinity concentration peaks, so the increase would be minimal.

Non-Bypass Alternative

Impacts on salinity under the Non-Bypass Alternative would be similar to those under the No Action Alternative, as shown in **Figure 3-36**. This alternative would be similar to the No Action Alternative, since the Non-Bypass Alternative would not involve the use of Glen Canyon Dam's bypass system and would instead focus on changes in release volumes.

Cumulative Effects

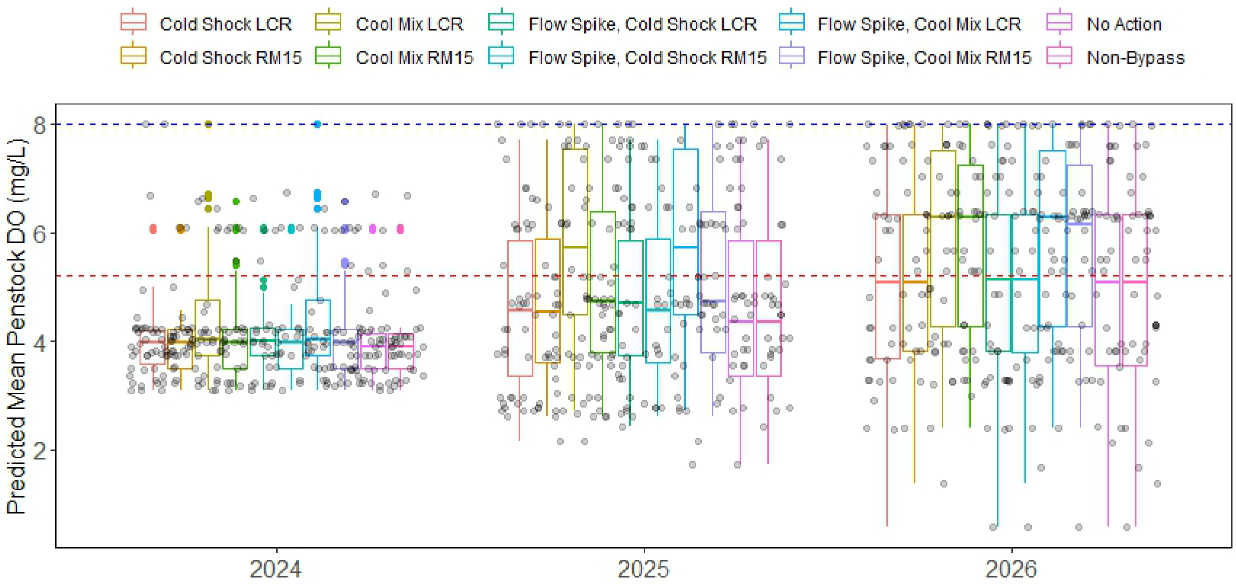
Impacts on salinity from all action alternatives would be temporary and would not have permanent, significant impacts on Lake Powell or the Colorado River. All proposed flow options would operate within the spatial and temporal bounds and under the assumptions of the existing analysis conducted in the LTEMP FEIS. There would be no cumulative impacts on salinity beyond those included in the LTEMP FEIS.

Issue 3: How would flow alterations impact DO?

Impacts Common to All Alternatives

As shown in **Figure 3-37**, the DO concentration would differ across alternatives; however, given that DO concentrations would vary more strongly across years rather than between alternatives, the management actions associated with the action alternatives would have a smaller impact on DO concentrations than other contributors to the reservoir and reservoir management dynamics. A stronger contributor to impacts on DO would be reservoir inflows and the resulting reservoir elevations.

Figure 3-37
Predictions of Mean August to October DO Concentrations in Glen Canyon Dam Outflows for Prediction Years 2024 to 2026*



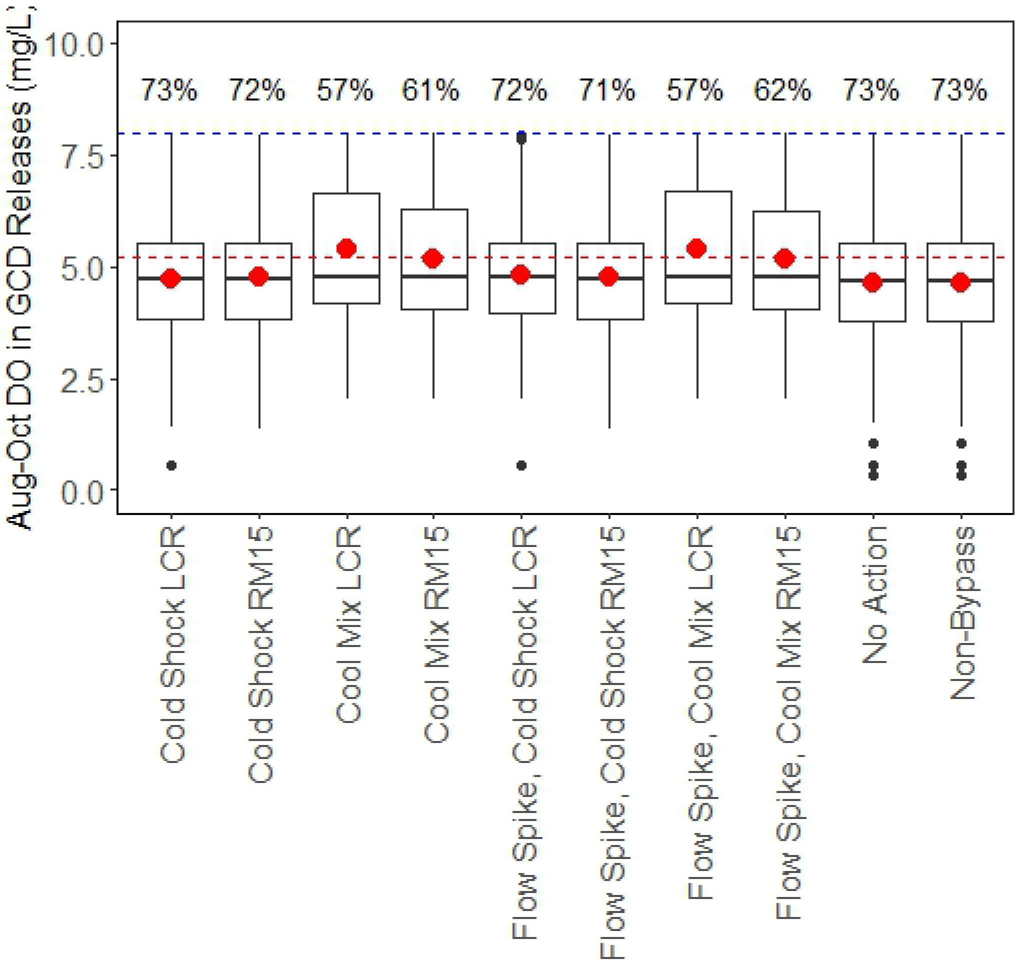
Source: GCMRC 2024a

*Unique colors for each alternative. Each point represents 1 year for a total of 30 points per box whisker (30 historical reconstructions). The dashed blue line demarcates 8 mg/L, which was the modeled concentration for days where any amount of bypass spill was implemented. The dashed red line demarcates 5.2 mg/L, which is a threshold below which oxygen concentrations are stressful to trout.

No Action Alternative

Under the No Action Alternative, Glen Canyon Dam operations would remain unchanged. Therefore, water would continue to be discharged primarily through the penstocks, as described in the LTEMP FEIS. The water discharged from the penstocks would remain warm, leading to warmer water in the Colorado River downstream of the dam. This warmer water would continue to produce releases with a lower concentration DO. As shown in **Figure 3-38**, the likelihood of low DO releases, where summertime mean DO would be less than 5.2mg/L, was 73 percent of years.

Figure 3-38
Mean August to October DO Concentrations in Glen Canyon Dam Outflows*



Source: GCMRC 2024a
*Across the entire prediction time frame under six alternatives (and sub-alternatives). Red dots indicate the mean release concentration across years and traces. Each point represents 1 year for a given hydrologic trace for a total of 150 points per box whisker (30 historical reconstructions and 5 prediction years). The dashed blue line demarcates 8 mg/L, which was the modeled concentration for days where any amount of bypass spill was implemented. The dashed red line demarcates 5.2 mg/L, which is a threshold below which oxygen concentrations are stressful to trout. The percentage of trace/year combinations where the average DO is below 5.2 mg/L is annotated above each scenario.

Cool Mix Alternative

Under the Cool Mix Alternative, low DO events, where summertime mean DO would be less than 5.2mg/L, would be less probable than the No Action Alternative and would likely occur during 57 to 61 percent of years. This is shown in **Figure 3-37** and **Figure 3-38**. Sub-alternatives that target the Little Colorado River (river mile 61), which has a likelihood of 57 percent of years, led to few years with low DO events than the sub-alternative that targets river mile 15, which has a likelihood of 61 percent of years. These differences across sub-alternatives were more pronounced in some years than others, as shown in **Figure 3-37**.

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, the impacts on DO would be similar to the Cool Mix Alternative under which low DO events, where summertime mean DO would be less than 5.2mg/L, would be likely to occur during 57 to 62 percent of years, as seen in **Figure 3-38**. Therefore, low DO events would be less probable under the Cool Mix with Flow Spike Alternative compared with the No Action Alternative.

Cold Shock Alternative

Under the Cold Shock Alternative, the impacts on DO would be similar to the No Action Alternative. Low DO events, where summertime mean DO would be less than 5.2mg/L, would be likely to occur during 72 to 73 percent of years, as shown in **Figure 3-38**.

Cold Shock with Flow Spike Alternative

Under the Cold Shock with Flow Spike Alternative, the impacts on DO would be similar to the No Action Alternative and Cold Shock Alternative. Low DO events, where summertime mean DO would be less than 5.2mg/L, would be likely to occur during 71 to 72 percent of years, as shown in **Figure 3-38**.

Non-Bypass Alternative

Impacts on DO under the Non-Bypass Alternative would be similar to those under the No Action Alternative, as shown in **Figure 3-38**. This alternative would be similar to the No Action Alternative, since the Non-Bypass Alternative would not involve the use of Glen Canyon Dam's bypass system and would instead focus on changes in release volumes.

Cumulative Effects

Impacts on DO from all action alternative would be temporary and would not have permanent, significant impacts on Lake Powell or the Colorado River. All proposed flow options would operate within the spatial and temporal bounds and under the assumptions of the existing analysis conducted in the LTEMP FEIS. There would be no cumulative impacts on DO beyond those included in the LTEMP FEIS.

Summary

The No Action Alternative and the Non-Bypass Alternative would result in similar impacts on temperature. When compared with the No Action Alternative and the Non-Bypass Alternative, adding more bypass through cool mix or cold shock operations would result in a decreased total release temperature during summer periods when bypass would be utilized. The cold shock alternatives would be more effective at reducing the release temperature than the cool mix alternatives. However, the duration of cold releases would last only as long as the use of the bypass, whereas cool mix operations would result in temperatures remaining cooler over a longer duration. The flow spike would add to the decrease in temperature under the cool mix and cold shock operations, but the change would be minimal.

There would be an increase in salinity related to the flow spikes and the cool mix and cold shock operations; of these, the cold shock would have a greater increase in salinity. However, salinity would remain lower than the early spring salinity concentration peaks. While utilizing bypass would increase the salinity concentration at times, the annual average concentration for all traces and for each management alternative would not be significantly different.

Across all alternatives, 74 percent of the years by trace combinations would be likely to have mean DO concentrations less than 5 mg/L in the late summer and early fall, which is 1,007 traces out of 1,500 traces. Low DO releases would be less likely under the Cool Mix and Cool Mix with Flow Spike Alternatives compared with the No Action, Cold Shock, and Cold Shock with Flow Spike Alternatives. Differences in the sub-alternatives were more pronounced during some years than others.

3.12 Cultural Resources

Overall conditions for cultural resources today remain similar to those described in the LTEMP FEIS. Changes from the FEIS include a more specific analysis area and the availability of more recent cultural resources data. Both changes are discussed below.

Much of the following discussion is condensed from Section 3.8, Cultural Resources, and Section 4.8, Cultural Resources, in the LTEMP FEIS (DOI 2016a). As defined in the LTEMP FEIS, cultural resources are:

> ". . . typically categorized as archaeological resources, historic [buildings and structures] and prehistoric structures, cultural landscapes, traditional cultural [places], ethnographic resources, and museum collections. Many natural resources, such as plants and plant gathering areas, water sources, minerals, animals, and other ecological resources, are also considered cultural resources, as they have been integral to the identity of Tribes in various ways. For some Tribal people, archaeological resources are considered to be markers left by their ancestors, the embodiment of those who came before and are imbued with the spirits of the ancestors. They represent a physical link to the past. The physical attributes of cultural resources are often nonrenewable, especially archaeological sites, which often represent ancestral homes for the park's traditionally associated Tribes" (DOI 2016a, p. 3.144).

Of the many laws, regulations, executive orders, and policies concerning cultural resources, the most pertinent to this project is the National Historic Preservation Act (NHPA) (54 United States Code 470x–6), as amended, and its implementing regulations (36 CFR 800). The NHPA and its implementing regulations require federal agencies to take into account the effects of their undertakings (federal undertakings or federally permitted or funded undertakings) on historic properties. Historic properties are defined in 36 CFR 800.16(l) as any district, site, building, structure, or object included in or eligible for inclusion in the National Register of Historic Places (NRHP). As such, they are a subset of cultural resources.

The regulations establish a process for consultation with the State Historic Preservation Officer (SHPO) and/or Tribal Historic Preservation Officer (THPO), interested Tribes, the Advisory Council on Historic Preservation, and other interested parties regarding an undertaking's effect on historic properties. If a project has the potential to affect historic properties, the federal agency must, in consultation with the SHPO or THPO and other interested parties, establish the area of potential affect (APE); identify historic properties within the undertaking's APE; assess what, if any, effects the undertaking may have on historic properties in the APE; and attempt to resolve adverse effects through avoidance, minimization, or mitigation of the adverse effects.

The LTEMP programmatic agreement (PA) was executed in September 2017 (Reclamation 2017) as the means of resolving adverse effects for LTEMP actions. In addition, Reclamation is developing a MOA under the LTEMP PA regarding nonnative fish control and flow actions under Glen Canyon Dam's operations.

The following analysis indicates there may be adverse effects from the proposed changes discussed in this SEIS with regards to Tribal values associated with protecting life in the Colorado River (see **Section 3.13**, Tribal Resources). The existing LTEMP PA includes provisions for new experiments and methods to resolve concerns and adverse effects on Tribal values and historic properties; consequently, Reclamation does not anticipate amending the existing PA. Further consultation with the LTEMP PA parties to the agreement will occur between the publishing of the Draft SEIS and the Final SEIS.

Analysis Area

Per the LTEMP PA, the APE for the LTEMP undertaking consists of "the area of direct and indirect effects on the character or use of historic properties on the Colorado River Corridor in the Canyons from Glen Canyon Dam to the western boundary of GCNP, including direct or indirect effects that may be caused to historic properties by the Undertaking from rim-to-rim of the Canyons." The geographic scope/analysis area for the LTEMP FEIS consisted of a larger area than the APE; it encompassed Lake Powell, Glen Canyon Dam, and the Colorado River to Lake Mead (DOI 2016a, p. 3.147).

The analysis area for direct and indirect impacts for this SEIS includes the Colorado River below Glen Canyon Dam to the inlet of Lake Mead.

Data Gathering Methods

A Class I cultural resources record search was conducted for the SEIS analysis area. Sources checked include AZSITE, an online database maintained by the Arizona State Museum (ASM); the Archaeological Records Office at ASM; the BLM Kingman Field Office; and the Arizona Department of Transportation Portal. Digital records were requested from the BLM (Arizona Strip Field Office and Parashant Office), NPS (GCNP, GCNRA, and LMNRA), and the US Forest Service (Kaibab National Forest). The Arizona and National Registers of Historic Places were also checked. In addition, historic-age topographic maps, General Land Office maps, and historic-age aerial photographs were consulted, and resources were digitized.

Resources important to Tribes, such as traditional cultural properties (TCPs) and ecological resources, including those resources from the Class I records search, will be discussed in greater detail in **Section 3.13**, Tribal Resources.

3.12.1 Affected Environment

The history and importance of Glen and Marble Canyons to humans span thousands of years and continue into the present day. The following is a summary of human history and the associated cultural resources from a Western viewpoint, as condensed from the LTEMP FEIS Section 3.8.2, Description of Cultural Resources and Site Types (DOI 2016a, pp. 3.149–3.156). Western archaeologists divide the human history of the canyons into six broad periods: Paleoindian, Archaic, Formative, Late Prehistoric, Protohistoric, and Historic.

Archaeological Resources

Archaeological resources span all six time periods mentioned above and are the physical manifestations of human life or activities on the landscape and environment. Previous research along the Colorado River began in the 19th century and these efforts continue today. Archaeological sites can be attributed from the Paleoindian through the Historic periods, and several different site types have been documented along the canyons.

The Paleoindian period spans the time of the earliest occupation of the Americas, from about 10,000–6,000 BC. Evidence of Paleoindian occupation is seen in distinctive spear points used to hunt large mammals such as mammoths. In GCNRA, six Paleoindian spear points from the Clovis, Folsom, and Plano complexes have been found (five in the northernmost part of the recreation area and one west of Lees Ferry).

The Archaic period (6,000–500 BC) was characterized by mobile hunter-gatherers who used smaller projectile points on darts to hunt game and one-hand manos and grinding slabs to process plant resources. Later sites also contain evidence of the beginning of plant cultivation. Sites include hunting blinds, lithic scatters at meadow edges and waterholes, temporary camps, rock art, and split-twig figurine caches. In GCNRA, there is also a distinctive petroglyph style called the Glen Canyon Linear Style.

The beginning of the Formative period (500 BC–AD 700) is also known as the Basketmaker period due to the peoples' extensive use of baskets, sandals, and textiles. During this period, the use of the bow and arrow and the production of pottery were new innovations, and people became more sedentary as crop cultivation became more common.

In the later Formative period (AD 700–1300), Ancestral Puebloans emerged. During this time, people relied more heavily on agriculture and constructed distinctive masonry structures and apartment-like. dwellings (pueblos). Most sites in GCNRA are Puebloan; modern Puebloans are the descendants of these ancestral peoples.

At the end of the Formative period, the climate became cooler and drier, and Ancestral Puebloans moved out of the canyon during the Late Prehistoric period (AD 1250–1540). Less sedentary groups, such as the ancestral Pai and Southern Paiute, expanded into the area from the west. Sites associated with these groups consist of camps with brush structures and roasting pits.

During the Protohistoric period (AD 1540–1776), Spanish explorers looking for gold and other resources and seeking to convert Indigenous peoples to Christianity traveled the Southwest;

however, the Glen Canyon area did not experience much of an impact because of its remoteness. At this time, the Pai and Southern Paiute were the main groups in the area.

Historic-Era Resources

The Historic period (AD 1776–1970s) began with the arrival of the Domínguez-Escalante Expedition in 1776 at what is now Lees Ferry along the Colorado River. Other Spanish and then American expeditions visited the Colorado River area in the 18th and 19th centuries. As more European and American settlers moved into the Colorado River corridor, Indigenous groups moved into smaller territories and more remote areas. The Havasupai, Hualapai, and Southern Paiute stayed to the west of Glen Canyon in and around the Grand Canyon; the Navajo lived along the east rim of the canyons. Eventually, all the Tribes were forced or coerced onto reservations and out of their much larger traditional territories. Native American archaeological sites from this period contain a mix of Indigenous and non-Native artifacts.

European and American archaeological sites show evidence of travel, mining, ranching, sheepherding, recreation, and dam construction. Lees Ferry is a river ferry crossing that was settled by John D. Lee in the late 19th century. It is listed on the NRHP as part of the Lees Ferry and Lonely Dell Ranch Historic District. The remains of the Charles H. Spencer steamboat, which was supposed to transport coal but was abandoned at Lees Ferry, are within the district.

Cultural Landscapes

Cultural landscapes are settings that humans have created in the natural world and consist of both natural and constructed elements. To Indigenous peoples, the river corridor is a cultural landscape where they have lived for millennia (DOI 2016a, p. 3.156). All of the natural world, such as plants, animals, and land formations, are important to that landscape. Evidence of past activities that have shaped that landscape can be seen in ancestral trails and habitations, fields, and prayer objects enshrined in travertine and salt. Tribal perspectives on cultural landscapes are summarized in **Section 3.13**, Tribal Resources.

Lees Ferry is a cultural landscape representing 130 years of Euro-American cultural use. It encompasses the NRHP-listed Lees Ferry and Lonely Dell Ranch Historic District. Here, the Colorado River is not bound by canyon walls; it was the only place within 400 miles that could be accessed by wagon. Historical use of the area as a farm and ferry crossing can be seen in historic buildings and the district, a cemetery, an orchard and other trees, fields, trails, and dugways. Today, river runners' access, camping, and USGS gauging stations demonstrate the continued use of the Lees Ferry landscape (DOI 2016a, p. 3.155).

Traditional Cultural Place and Ethnographic Resources

A TCP is "a building, structure, object, site, or district that may be eligible for inclusion in the National Register for its significance to a living community because of its association with cultural beliefs, customs, or practices that are rooted in the community's history and that are important in maintaining the community's cultural identity" (NPS 2022c, p. 10).

Native American peoples consider Glen Canyon (as well as the Grand Canyon) and its vicinity to be of traditional and sacred importance; this is discussed in more detail in **Section 3.13**, Tribal Resources.

Class I Results

The Class I records search demonstrated that 436 previous projects have surveyed approximately 60,463 acres, or 3.3 percent, of the analysis area for cultural resources; these were primarily archaeological resources (Tremblay et al. 2024). Of these, 82.8 percent—or 361 of these surveys—were conducted more than 20 years ago. Only 25 surveys were conducted in the last 10 years and are, therefore, considered valid. These 25 surveys encompass a total of 4,546 acres, or 0.2 percent, of the analysis area.

Previous projects included both block and linear surveys in support of numerous state, federal, municipal, and private development projects. These projects are associated with public utilities, such as gas pipelines, fiber-optic lines, and transmission lines; road and highway construction; mining operations; and numerous development projects, land and timber transfers, and environmental impact reports on federal and state lands within the analysis area.

Archaeological Sites

The records search identified a total of 3,776 archaeological sites (Tremblay et al. 2024). Of the 3,776 archaeological sites, 2,931 can be temporally affiliated with the prehistoric era, 50 are ethnohistoric, 375 are historic, 260 are multicomponent sites, and 160 could not be assigned to a temporal component. Across all sites, only three are listed on the NRHP. These consist of one prehistoric pueblo (Tusayan Ruins; AZ C:13:21[ASM]) and two historic-era properties—Grandview Mine (AZ C:13:11[ASM]) and Charles H. Spencer Steamboat (3.249.SHPO). For all other sites, 3,023 have been determined eligible for the NRHP, with an additional 94 recommended eligible. Seven sites have been determined ineligible, 34 have been recommended ineligible, and 615 are unevaluated. All resources in GCNP are eligible for the NRHP. **Table 3-39** presents the archaeological sites within the analysis area by temporal affiliation and NRHP-eligibility status.

Table 3-39
Archaeological Sites in the Analysis Area

Temporal Affiliation	Number	NRHP Listed	Determined		Recommended		Unevaluated
			Eligible	Ineligible	Eligible	Ineligible	
Prehistoric	2,931	1	2,305	3	83	34	505
Ethnohistoric	50	—	48	—	—	—	2
Historic	375	2	337	4	5	—	27
Multi-component	260	—	226	—	6	—	28
Unknown	160	—	107	—	—	—	53
Total	3,776	3	3,023	7	94	34	615

Of the 2,931 single-component prehistoric archaeological sites in the analysis area, 1,057 could only be associated generally with nonspecific Indigenous cultures, which may be pre- or post-Contact. For the remaining sites, 2 are associated with Paleoindian occupations, 104 are associated with

Archaic peoples, 15 are Basketmaker, 1,534 are Ancestral Puebloan, 183 are Cohonina, 3 are Payatan, and 33 are Cerbat (**Table 3-40**). The types of sites identified vary in function and consist of limited-activity artifact scatters; long- and short-term habitations; resource processing and lithic reduction locales; agricultural, storage, and water management features; trails; petroglyphs and pictographs; and special-use sites. **Table 3-40** provides a summary of the prehistoric site functions and cultural affiliations within the analysis area.

Table 3-40
Prehistoric Sites in the Analysis Area by Function and Cultural Affiliation

Site Function	Number	Paleo-Indian	Archaic	Basket-maker	Ancestral Puebloan	Cohonina	Patayan	Cerbat	Indigenous*
Limited activity	337	—	15	2	128	17	—	—	75
Habitation	824	—	4	1	678	37	1	9	94
Temporary habitation/camp	462	—	22	1	232	33	1	8	165
Resource procurement/ processing	561	—	12	3	149	71	—	14	312
Agricultural	130	—	1	1	98	2	—	—	28
Lithic reduction	177	2	17	1	22	4	—	—	133
Storage/cache	127	—	—	—	96	1	—	—	30
Ceremonial/special use	69	—	13	—	27	8	—	1	20
Petroglyphs/pictographs	161	—	16	6	66	1	—	—	72
Water management	6	—	—	—	2	—	—	—	4
Transportation (trails)	2	—	—	—	1	—	—	—	1
Unknown	73	—	4	—	35	9	1	1	23
Total	**2,931**	2	104	15	1,534	183	3	33	1,057

* Only associated generally with nonspecific Indigenous cultures

Of the 50 single-component ethnohistoric sites in the analysis area, eight could only be generally assigned to nonspecific Indigenous cultures. The remaining sites are associated with Havasupai (3 sites), Hopi (4 sites), Navajo (3 sites), Pai (8 sites), and Southern Paiute (24 sites) peoples and cultures. Site functions are similar to the subset of prehistoric-era sites, though with fewer types represented (**Table 3-41**). Temporary habitations (16 sites) and resource processing/procurement sites (16 sites) are the most abundant ethnohistoric sites in the analysis area.

Table 3-41
Ethnohistoric Sites in the Analysis Area by Function and Cultural Affiliation

Site Function	N	Havasupai	Hopi	Navajo	Pai	Southern Paiute	INDG*
Habitation	8	1	—	1	1	1	4
Temporary habitation/camp	16	1	2	—	5	8	—
Resource procurement/ processing	16	—	2	—	1	12	1
Agricultural	3	—	—	—	—	2	1
Storage/cache	1	—	—	1	—	—	—
Ceremonial/special use	3	1	—	1	—	—	1
Petroglyphs/pictographs	3	—	—	—	1	1	1
Total	**50**	3	4	3	8	24	8

* Only associated generally with nonspecific Indigenous cultures

A total of 375 single-component historic-era sites are in the analysis area. These sites are largely attributed to Euro-Americans (316 sites); however, sites from Indigenous groups consisting of the Havasupai, Hualapai, Hopi, Navajo, and Southern Paiute are also present (**Table 3-42**). Additionally, 316 sites could only be generally associated with nonspecific Indigenous peoples, and seven are of unknown cultural affiliation.

Historic-era sites in the analysis area are dominated by temporary camps (72 sites), but also include structural features associated with Euro-American mining claims and ventures from the early 1900s to the 1960s (**Table 3-42**). Sites with corrals, fences, stock tanks, storage facilities, and other features attest to the extent of Euro-American and contemporary Native American ranching activities and agriculture in the analysis area. Additionally, sites associated with the construction of the dams and the Grand Canyon National Park and National Recreation Areas are also present, including several utilities, water management features, and numerous transportation features, such as ferry crossings.

Table 3-42
Historic-Era Sites in the Analysis Area by Function and Cultural Affiliation

Site Function	Number	Havasupai	Hualapai	Hopi	Navajo	Southern Paiute	Indigeous*	Euro-American	Unknown
Limited activity	69	—	—	—	1	—	1	67	—
Habitation	29	5	—	—	1	—	3	20	—
Temporary habitation/camp	72	2	1	2	1	—	8	54	4
Resource procurement/ processing	8	—	—	—	2	2	3	1	—
Agricultural	2	—	—	—	—	—	—	2	—
Storage/cache	3	—	—	—	1	—	1	1	—
Ceremonial/special use	35	4	—	—	4	—	4	23	—
Petroglyphs/pictographs	6	1	—	—	1	1	—	3	—
Water management	5	—	—	—	—	—	—	5	—
Waste management (refuse piles)	13	—	—	—	—	—	—	13	—
Transportation	28	—	—	—	—	—	—	28	—
Utility	3	—	—	—	—	—	—	3	—
Livestock/ranching	33	—	—	—	1	—	1	30	1
Mining	43	—	—	—	—	—	—	43	—
Government	4	—	—	—	—	—	—	4	—
Military	1	—	—	—	—	—	—	1	—
Unknown	21	—	—	—	—	—	1	18	2
Total	**375**	12	1	2	12	3	22	316	7

* Only associated generally with nonspecific Indigenous cultures

A total of 260 multicomponent sites are also present in the analysis area. Nearly all of these (258 sites) included a prehistoric component. In addition, 85 had ethnohistoric components, and 176 had historic-era components. Cultural affiliations for the multicomponent sites were variable, with individual components representing Prehistoric Archaic (8 sites), Basketmaker (3 sites), Ancestral Puebloan (161 sites), Cohonina (17 sites), and Cerbat (1 site) peoples; ethnohistoric and historic-era components attributed to Havasupai (5 sites), Hopi (20 sites), Navajo (8 sites), Pai (20 sites), and Southern Paiute (54 sites) peoples; and 139 Euro-American historic-era components. An additional 73 individual components from these sites are associated only with indeterminate Indigenous cultures (across all three temporal categories).

Built Environment Resources

Built environment resources in the analysis area south of Glen Canyon Dam include the Lees Ferry and Lonely Dell Historic District, two cabins at the Upper Ferry Crossing, portions of the Escalante Route of the Old Spanish Trail, and multiple hiking trails.

Mapped Resources

Resources found on the historic topographic maps, General Land Office maps, and aerial photographs include buildings, corrals, fences, mining features, roads, water tanks, utility lines, trails, campgrounds, bridges, ranches, ruins and cliff dwellings, towers, wells, and other features.

3.12.2 Environmental Consequences

Methodology

Changes in flow could have direct, indirect, and cumulative impacts on cultural resources. Specifically, impacts could occur on historic properties that would alter the integrity of the characteristics that make the properties eligible for listing in the NRHP. The impacts considered in Glen Canyon in the LTEMP FEIS consisted of direct impacts from changes to terraces from flow effects and on the stability of the NRHP-listed Spencer Steamboat, indirect effects from visitors' time off the river, and cumulative effects.

Glen Canyon Dam flow effects can be seen most prominently in the reach below the dam; this is because there is less sediment in this reach to buffer the effects, and cultural resources are found close to the river below the dam (DOI 2016a, p. 4.236). In addition, visitor effects on cultural resources may occur when people camp or hike at stops during river trips; these effects are most likely in the summer when most people use the river for recreational purposes (see **Section 3.14**, Recreation).

Impact Analysis Area

The impact analysis area is the same as for the LTEMP FEIS' APE. It stretches from rim to rim of the Grand Canyon from Glen Canyon Dam to the inlet into Lake Mead.

Assumptions

The analysis assumptions include the following:

- The data available from the LTEMP FEIS and from the Class I records search are adequate for the analysis.
- Resources within 66 feet (20 meters) of the river are most likely to be impacted by changes in flows.
- Sediment availability is a good predictor of the potential aeolian transport of sediment to cover sites.

Impact Indicators

The impact indicators for cultural resources include:

- Changes in Glen Canyon Dam flow not analyzed in the LTEMP FEIS
- Number and types of archaeological sites and built environmental resources that may be impacted by changes in water flow from inundation, erosion, or exposure to elements and visitation
- Amounts of sediment potentially deposited by HFE releases

Issue 1: How would flow alterations at Glen Canyon Dam impact archaeological sites and built environment resources in Grand Canyon?

No Action Alternative

Under the No Action Alternative, Reclamation would not change Glen Canyon Dam's current operations. No new impacts on terraces in Glen Canyon, where archaeological sites are located, would occur beyond those impacts expected from current dam operations. No change would occur from the current amount of time people spend stopped during river trips; therefore, no change would occur to the potential that these people could impact historic properties. Impacts on archaeological sites and built environment resources would be the same as those resources analyzed in the LTEMP FEIS for the dam's current operations (DOI 2016a, p. 4.248).

Cool Mix Alternative

Impacts under the Cool Mix Alternative would be the same as those impacts described for the No Action Alternative. This alternative would be within the range of permitted flows under the LTEMP FEIS. Therefore, Reclamation would not anticipate additional impacts on the historic properties beyond those impacts analyzed for the LTEMP FEIS.

Cool Mix with Flow Spike Alternative

Impacts under the Cool Mix with Flow Spike Alternative would be the same as those impacts described for the No Action Alternative.

Cold Shock Alternative

Impacts under the Cold Shock Alternative would be the same as those impacts described for the No Action Alternative.

Cold Shock with Flow Spike Alternative

Impacts under the Cold Shock with Flow Spike Alternative would be the same as those impacts described for the No Action Alternative.

Non-Bypass Alternative

Based on available data, the impacts under the Non-Bypass Alternative could result in the exposure of cultural archaeological sites during low flow events which are outside those analyzed in the LTEMP FEIS. Exposure could lead to damage or disturbance from wave action, wet/dry effects, and increased visitation. Adverse effects to historic properties would be resolved under the LTEMP PA.

Cumulative Effects

None of the cold water alternatives would contribute to cumulative impacts on historic properties. No additional impacts, other than those impacts analyzed in the LTEMP FEIS, would be anticipated under the cold water alternatives. Cumulative impacts under the LTEMP FEIS, which include erosion of terraces and effects from visitor traffic, are considered negligible for the cold water alternatives (DOI 2016a, Table 4-17.2). The Non-Bypass Alternative low flows are outside those analyzed in the LTEMP FEIS and may result in the exposure of cultural resources; however, adverse effects to cultural resources would be resolved under the LTEMP PA and, therefore, would not contribute to cumulative effects.

Issue 2: How would flow alterations at Glen Canyon Dam impact sediment availability in Grand Canyon

No Action Alternative

Under the No Action Alternative, HFE releases would not change from current conditions.

Cool Mix Alternative

Under the Cool Mix Alternative, fewer and shorter fall HFE releases and more and longer spring HFE releases are expected, and sand bar growth would be smaller than under the No Action Alternative; however, the amount of sediment available daily for aeolian transport is predicted to be similar to that under the No Action Alternative (Kasprak et al. 2023).

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, sand bar growth may be more than under the alternatives without flow spikes, but available sediment would be similar to that under the No Action Alternative.

Cold Shock Alternative

Impacts under the Cold Shock Alternative are the same as those under the Cool Mix Alternative.

Cold Shock with Flow Spike Alternative

Impacts under the Cold Shock with Flow Spike Alternative are the same as those under the Cool Mix with Flow Spike Alternative.

Non-Bypass Alternative

Impacts under the Non-Bypass Alternative would be the same as those impacts described for the Cool Mix Alternative, including sand bar development.

Cumulative Effects

Sediment availability for aeolian transport is predicted to be similar across all alternatives, including the No Action Alternative. This means none of the alternatives would contribute to cumulative impacts. No additional impacts, other than those impacts analyzed in the LTEMP FEIS, would be anticipated under the alternatives (DOI 2016a, Table 4-17.2).

Summary

Impacts on archaeological sites and built environment resources would be the same under the No Action and cold water alternatives. Under the Non-Bypass alternative, resources may be exposed during the low flow events. The alternatives with flow spikes would result in more sand bar growth than the other alternatives; however, the amount of available sand for aeolian transport would be roughly the same for all alternatives.

3.13 Tribal Resources

The affected environment for Tribal resources remains the same from the LTEMP FEIS with the exception of additional information collected for the pending Class I records search discussed above in **Section 3.12**, Cultural Resources. The following discussion relies on Section 3.9, Tribal Resources, and Section 4.9, Tribal Resources, in the LTEMP FEIS (DOI 2016a), and presents information from the Class I cultural resources record search. The analysis area for Tribal resources is the same as that for cultural resources (see **Section 3.12**, Cultural Resources); it stretches from Glen Canyon Dam to the inflow into Lake Mead. Reclamation reaffirms its responsibilities to the Tribes under the CEQ memorandum titled “Memorandum on Indigenous Traditional Ecological Knowledge and Federal Decision Making” (November 15, 2021), and will work to incorporate traditional ecological knowledge as it is made available.

For the current project, Reclamation is consulting with the Tribal signatories to the PA, which include the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Consortium. See **Section 3.12**, Cultural Resources, for a discussion of the current agreement documents in place or being developed. The following analysis indicates there may be adverse effects from the proposed alternatives discussed in this SEIS with regards to Tribal values associated with protecting life in the Colorado River. The existing LTEMP PA includes provisions for new experiments and methods to resolve concerns and adverse effects on Tribal values and historic properties; consequently, Reclamation does not anticipate amending the existing PA. Further consultation with the LTEMP PA parties to the agreement will occur between the publishing of the Draft SEIS and the Final SEIS.

The focus of this SEIS is on the Colorado River below Glen Canyon Dam to Lake Mead. The Glen Canyon, Marble Canyon, and Grand Canyon cannot be separated in some cases for Tribes; therefore, the three canyons are referred to as the Canyons in this section.

3.13.1 Affected Environment

From time immemorial, the Canyons and the Colorado River have been sacred places for Native American communities. The Colorado River features prominently in the cosmology and culture of Native Americans in the Southwest (DOI 2016a, pp. 3.156–3.157). The Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Consortium all have strong cultural ties to the Colorado River and identify the Colorado River and the Canyons as a “property of traditional religious and cultural importance to an Indian Tribe” (40 CFR 800.16(i)(1)), which is often abbreviated as a TCP. For the Tribes, the Colorado River and the Canyons are living, sentient entities. They are sacred spaces, the home of their ancestors, the residence of the spirits of their dead, and the source of culturally important resources. Many Tribes see themselves as stewards of the land and the living world, including the Colorado River and the Canyons.

As an act of stewardship, several Tribes have submitted documentation of the Colorado River and the Canyons as TCPs (Hopi CPO 2001; Coulam 2011; Dongoske 2011; Maldanado 2011). For the Hopi Tribe, the Canyons are places of their ancestors; they emerged in the Grand Canyon, and several of their clans lived in the Canyons during their migration period. Archaeological sites in the Canyons are the footprints of the ancestral Hopi peoples (Hisatsinom) and still are the ancestors' homes today. The Canyons as a whole are sacred to the Hopi Tribe (DOI 2016a, pp. 3.158–3.159). The Hualapai Tribe considers the Colorado River region as a single great cultural landscape with the river as the backbone (Ha'yiđađa) (DOI 2016a, pp. 3.159–3.162).

For the Navajo Nation, the Colorado and Little Colorado Rivers are deities, and their confluence is associated with Changing Woman (DOI 2016a, pp. 3.162–3.164). Glen and Marble Canyons are home to many other deities who gave ceremonial and resource knowledge to the Navajo Nation. Traditional narratives of the Southern Paiute Consortium, which include the Kaibab Band of Paiute and the Paiute Indian Tribe of Utah, recount that they were the original inhabitants of the area along the Colorado River and are responsible for its protection (DOI 2016a, pp. 3.167–3.168). The Colorado River corridor, and its resources, is one of their most powerful natural resources.

The Colorado River is also sacred to the Zuni people (DOI 2016a, pp. 3.164–3.167). After their emergence into this world, the Zuni people traveled along the Colorado and Little Colorado Rivers on their journey to the Middle Place. The Zuni still maintain strong ties to the area, and Zuni beliefs and practices are intertwined with the ecosystem of the Canyons. The Zuni have a familial relationship with animals (including fish), soils and rocks, vegetation, and water. All aspects of the environment and the Zuni universe are interconnected and kept in balance through traditional practices.

Class I Results

This document cannot adequately convey the deep ties that each Tribe, individually, has to the Canyons and Colorado River. Words are insufficient to express that connection. Each Tribe is a sovereign government with deep and ongoing ties to the welfare of the area on many levels. Reclamation recognizes those ties and provides the means and opportunities for the Tribes to monitor the Colorado River's health on an annual basis.

The Class I literature search reenforced the importance of the Colorado River and the Canyons, especially the Grand Canyon, to multiple Tribes (Tremblay et al. 2024). TCP and ethnographic documentation has demonstrated the multiple sacred locations, traditional use areas, and traditional resources within the Canyons.

The Havasupai live in the Grand Canyon and identify themselves as Havasu *'Baaja* (People of the Blue-Green Water) for their home near Havasu Falls. Several important landscape formations and resources locations, such as salt deposits, are found within the canyon.

The Hualapai (*Hwal ʻbaia* or "Ponderosa People") live along the south rim of the Grand Canyon. Resources they have identified as TCPs include archaeological sites and the Hualapai origin site. The Tribe has identified multiple plant resources, traditional use areas, sacred places, mineral resources, animals, water sources, and others.

For the Hopi, the Grand Canyon is holy ground. The Hopi Tribe has documented the Grand Canyon as a TCP that includes archaeological sites, the Hopi Salt Mine, Lees Ferry, shrines, the Hopi origin place (*Sipapun*i), and multiple other sacred and important places.

The Navajo Nation Reservation shares a border with the Colorado River's south bank along Marble Canyon. The Tribe identifies the river as their origin place. As discussed above, the Colorado and Little Colorado Rivers are holy entities, and the Canyons are home to many Navajo deities. Resources important to the Navajo include trails, mineral sources, plant resources, and wildlife in the Canyons.

The Southern Paiute used the Grand Canyon's north rim. In the 19th century, some Southern Paiute people lived with the Hualapai when members of the Church of Jesus Christ of Latter Day Saints grabbed Paiute lands. Places used by Southern Paiutes include *Parovu* (crossing, in Paiute) upstream of Lees Ferry, *Pari* (intersection of rivers, in Paiute), Lees Ferry at the confluence of the Paria and Colorado Rivers, and trails from the river.

The Ute have ties to the Canyons, but they are not as well documented as other groups. Petroglyphs in the Canyons are known to the Ute to be ancient.

Western Apache oral history tells of a place of emergence north of the Little Colorado River where they lived. The Apache used the Grand Canyon's south rim for resources. For the Apache, the canyon is a holy place associated with a deity, and it must be protected.

As discussed above, the Zuni regard the Colorado River and the Canyons as sacred. The Zuni experience spiritual harm when there are negative impacts on the Grand Canyon. In addition, the Zuni provided the following text regarding the Zuni cultural landscape, which encompasses the LTEMP SEIS analysis area:

> To A:shiwi, Chaco Canyon is known as Heshoda Bitsulliya/Ki:whihtsi Bitsulliya and in the name K'yakwe: A:mossi, or "House of Puebloan High Priests." The greater A:shiwi Chaco traditional cultural land/waterscape is simultaneously a dynamic and diverse and inter-functional and unified geographical area densely lined and dotted with multiple intensive zones of historic significance and ongoing traditional religious and cultural importance. The interconnected and interrelated layers and dimensions of multiple intensive middle zones of the district both circularly and circuitously pivot—in space and time—on Heshoda Bitsulliya/Ki:whihtsi Bitsulliya, Chaco Canyon, while always connecting and radiating to and from the spatial anchors of Idiwana'a, the Zuni Pueblo, and Chimik´yana´kya dey´a and Kuhnin A´l´akk´wa, the Grand Canyon. The connective umbilical tissues and relations of Heshoda Bitsulliya/Ki:whihtsi Bitsulliya are vast for A:shiwi and can be topographically diagrammed and understood to extend at least from Kuhnin A´l´akk´wa, Grand Canyon, in Arizona to the west to

> Shiba:bulim´a, Bandelier National Monument, in New Mexico to the east. The historic district's northern reach extends at a minimum to the areas of Abajo (Blue) Mountains and Montezuma Canyon in southeast Utah and Alkali Canyon in southwest Colorado, and its southern reach to the area of K'y''k'yali an Yalanne, or Eagle Peak, in the central western region of New Mexico. Each of these intensive center or middle spatial zones that help diagram the outlines of the greater A:shiwi Chaco traditional cultural land/waterscape and historic district connect and convey three delineable "time periods" that are simultaneously layered and intersecting in their discernability (Curti et al. 2023: Executive Summary).

No effects on Indian Trust Assets were identified from the proposed alternatives; therefore, these are not considered further.

3.13.2 Environmental Consequences

Methodology

During consultation for the LTEMP FEIS, seven themes were identified of concern to Tribes and analyzed in the LTEMP FEIS (DOI 2016):

- Increase the health of the ecosystem in the Canyons
- Protect and preserve sites of cultural importance
- Preserve and enhance respect for life in the Canyons
- Preserve and enhance the sacred integrity of the Canyons
- Maintain and enhance healthy stewardship opportunities
- Maintain and enhance economic opportunities
- Maintain Tribal water rights and supply

The most pertinent theme for this SEIS—preserve and enhance respect for life in the Canyons—is derived from Section 4.9.3 of the LTEMP FEIS:

"For those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011). … The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni TCP. In addition, Pueblo of Zuni have identified significant social and psychological effects to their community during mechanical removal periods" (DOI 2016a, p. 4.256).

Through scoping comments, the Hopi Tribe, the Navajo Nation, the Colorado River Indian Tribes, and the Pueblo of Zuni have expressed concerns to the Department regarding the sanctity of life; they oppose lethal management actions. In general, the Tribes stressed the importance of being good stewards over the entire environment and respecting the life found therein. As an example, the Hopi Tribe has expressed concern regarding the mechanical removal of large numbers of trout and trout management flows, while also expressing an understanding of the need to effectively manage nonnative populations, if necessary, to prevent the extinction of humpback chub. The Navajo Nation looks to restore "to the extent practicable, ecological patterns and processes within their range of natural variability, including the natural abundance, diversity, and genetic and ecological integrity of the plant and animal species native to those ecosystems" following Diné Natural Law.[21]

Impact Analysis Area

The impact analysis area is the same as for the LTEMP FEIS APE. It stretches from rim to rim of the Grand Canyon from Glen Canyon Dam to the inlet into Lake Mead.

Assumptions

No impacts on water deliveries or Indian trust assets are anticipated.

Impact Indicators

The impact indicators for Tribal resources include:

- Characteristics of TCPs that may be altered by changes in flows, including the taking of life
- Number and types of cultural resources that may be impacted by changes in water flow from inundation, erosion, or exposure to elements and visitation
- Changes in habitats and vegetation due to flow changes

Issue 1: How would flow alterations for fish management at Glen Canyon Dam impact TCPs in the Grand Canyon?

The Tribes hold the Canyons sacred. Rather than interventions, they prefer nature to take its course regarding fish management (DOI 2016a, p. 4.257). In particular, the Pueblo of Zuni has expressed that the taking of life is an adverse impact on the TCP and is culturally offensive. Such actions have corresponding highly negative effects within the Pueblo of Zuni; thus, they have far-reaching consequences beyond the Colorado River itself.

No Action Alternative

Under the No Action Alternative, Reclamation would not change Glen Canyon Dam's current operations. Effects on TCPs would not be different from those effects analyzed in the LTEMP FEIS.

Cool Mix Alternative

The Cool Mix Alternative is meant to disrupt spawning before it occurs, which means there would be no taking of life.

Cool Mix with Flow Spike Alternative

Impacts under the Cool Mix with Flow Spike Alternative, such as some fish mortality, could occur in backwater or margin habitats, if fish are moved off nests.

Cold Shock Alternative

The Cold Shock Alternative could result in the mortality of eggs or larval fish.

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[21] Diné Bi Beenahaz'áanii (1 N.N.C. §§ 201-206) recognized by the Navajo Nation Council in 2002.

Cold Shock with Flow Spike Alternative

Impacts on fish under the Cold Shock with Flow Spike Alternative would be the same as for the Cold Shock Alternative.

Non-Bypass Alternative

Under the Non-Bypass Alternative, impacts on fish would be greater than under the other alternatives. Under the Non-Bypass Alternative, the flows would be intended to reduce survival of smallmouth bass eggs and fry through desiccation of eggs, abandonment of nests, and impacts on fry.

Cumulative Effects

Cumulative impacts on Tribal values would occur if Reclamation chooses flow options with expected mortality. The Zuni, in particular, have linked fish mortality in the Canyons with adverse physical, mental, and psychological effects within the Zuni Pueblo. Consequently, additional mortality would have negative cumulative impacts on the Zuni. Because the action alternatives could result in the taking of life within the Canyons, they would have an adverse impact on the Zuni culture and TCPs, if Reclamation implements the flow options with expected fish mortality. The PA includes procedures for consultation to resolve any adverse effects on the TCPs; however, because several alternatives would result in the additional taking of life within the Canyons more than the present conditions under the LTEMP dam operations, they could contribute to negative cumulative impacts on the Zuni culture and TCPs.

Other reasonable and foreseeable projects include the IG SEIS, the Colorado River Post-2026 EIS, a proposed thermal fish barrier, and proposed riparian restoration along the river. These projects are not expected to contribute to cumulative impacts on Tribal values; however, each project will undergo a separate NEPA analysis to disclose the potential impacts.

Issue 2: How would flow alterations at Glen Canyon Dam impact archaeological sites and sacred sites in the Grand Canyon?

No Action Alternative

As described in **Section 3.12**, Cultural Resources, Reclamation would not change Glen Canyon Dam's current operation under the No Action Alternative. No additional impacts beyond those analyzed in the LTEMP FEIS would occur.

Cool Mix Alternative

Impacts under the Cool Mix Alternative would be the same as those impacts described for the No Action Alternative.

Cool Mix with Flow Spike Alternative

Impacts under the Cool Mix with Flow Spike Alternative would be the same as those impacts described for the No Action Alternative.

Cold Shock Alternative

Impacts under the Cold Shock Alternative would be the same as those impacts described for the No Action Alternative.

Cold Shock with Flow Spike Alternative

Impacts under the Cold Shock with Flow Spike Alternative would be the same as those impacts described for the No Action Alternative.

Non-Bypass Alternative

The low flows proposed under the Non-Bypass Alternative are outside those analyzed in the LTEMP FEIS and may lead to the exposure of archaeological sites and sacred sites; however, any adverse effects to archaeological sites or sacred sites that are historic properties would be resolved under the LTEMP PA .

Cumulative Effects

Any potential impacts on archaeological sites or sacred sites from the cold water alternatives fall within those previously analyzed in the LTEMP FEIS. None of the cold water alternatives would contribute to cumulative impacts on archaeological sites or sacred sites in the Grand Canyon. No additional impacts, other than those impacts analyzed in the LTEMP FEIS, would be anticipated under the cold water alternatives (DOI 2016a, Table 4-17.2). The Non-Bypass Alternative may result in the exposure of archaeological sites or sacred sites; however, any adverse effects on archaeological sites or sacred sites that are historic properties would be resolved under the LTEMP PA.

Issue 3: How would flow alterations at Glen Canyon Dam impact vegetation within riparian habitats within the Grand Canyon?

No Action Alternative

Reclamation would continue Glen Canyon Dam’s current operations as described in the LTEMP FEIS under the No Action Alternative. Changes to riparian vegetation communities would follow the current trends under drought conditions and aridification. More detail of impacts on riparian vegetation can be found in **Section 3.6**, Terrestrial Resources and Wetlands.

Cool Mix Alternative

The difference in impacts on riparian vegetation communities would be minor under the Cool Mix Alternative.

Cool Mix with Flow Spike Alternative

Under the Cool Mix with Flow Spike Alternative, impacts on riparian vegetation would range from no change in Marble Canyon to a small increase in vegetation cover in the Grand Canyon. Impacts would be the same as those impacts described for the Cool Mix Alternative.

Cold Shock Alternative

Impacts under the Cold Shock Alternative would be the same as those impacts described for the Cool Mix with Flow Spike Alternative..

Cold Shock with Flow Spike Alternative

Impacts under the Cold Shock with Flow Spike Alternative would be the same as those impacts described for the Cool Mix with Flow Spike Alternative.

Non-Bypass Alternative

Under the Non-Bypass Alternative, impacts on riparian vegetation would range from a small increase in vegetation cover in Marble Canyon to a small decrease in vegetation cover in the Grand Canyon.

Cumulative Effects

Changes to riparian vegetation under any of the alternatives would be minor. No alternative would contribute to cumulative impacts on riparian vegetation community sites in the Grand Canyon. No additional impacts, other than those impacts analyzed in the LTEMP FEIS, would be anticipated under the alternatives (DOI 2016a, Table 4-17.2).

Summary

The No Action Alternative and the Cool Mix Alternative are not expected to result in the taking of the life of fish. The Cool Mix with Flow Spike Alternative, the Cold Shock Alternative, the Cold Shock with Flow Spike Alternative, and the Non-Bypass Alternative could result in fish mortality of different intensities. Cool water flows are intended to disrupt spawning and would have the least impacts on life. The Non-Bypass Alternative would have the greatest impact on life.

Impacts on archaeological sites and sacred sites in the Grand Canyon would be the same under the cold water alternatives, and overall impacts on riparian vegetation would be minor. Under the Non-Bypass Alternative, low flow may lead to the exposure of archaeological sites and sacred sites. As noted previously in this document, the existing LTEMP PA includes provisions for new experiments and methods to resolve concerns and adverse effects on Tribal values and historic properties; consequently, Reclamation does not anticipate amending the existing PA. Further consultation with the LTEMP PA parties to the agreement will occur between the publishing of the Draft SEIS and the Final SEIS.

3.14 Recreation

3.14.1 Affected Environment

The description of recreational resources in this section focuses on resources and activities found in the Colorado River corridor, from below Glen Canyon Dam downstream to Lake Mead (recreation analysis area). Recreational resources of concern include the Blue Ribbon rainbow trout fishery, boating (such as kayaking, rafting, and canoeing) from Glen Canyon Dam to Lees Ferry, whitewater boating through the Grand Canyon, and camping opportunities throughout the recreation analysis area. Recreation economics are discussed in **Section 3.15**, Socioeconomics.

Glen Canyon Reach of the Colorado River in the Glen Canyon National Recreation Area

The Glen Canyon reach of the Colorado River is an approximately 16-mile segment of the river between Glen Canyon Dam and Lees Ferry, Arizona. Recreational activities of concern in this area include rainbow trout fishing, day-rafting, boating (including motorized and nonmotorized boating and rafting), and camping.

Fishing in the Glen Canyon Reach

The Glen Canyon reach of the Colorado River supports a Blue Ribbon recreational rainbow trout fishery that attracts local, national, and international anglers. Most angling is done from boats or with the assistance of boat access, often provided by guide services. Some anglers also fish by wading or from the shore. Fish in all waters within the GCNRA and GCNP are managed by the National Park Service (NPS), in coordination with the AZGFD and the Service. The condition of the fishery within the GCNRA can be affected by the operations of Glen Canyon Dam, which is operated by Reclamation.

Dam operations and fishery management may affect the size and quality of the rainbow trout fishery and the angler experience. Since completion of the dam and the introduction of rainbow trout shortly afterward, the high quality of the rainbow trout fishery has been supported by reliable flows of cold water ranging from 6.7˚C to 15.6˚C. Recent drought conditions and aridification have resulted in warming water temperatures below Glen Canyon Dam, which could impact rainbow trout energetics and survival (Rogers 2015; Korman et al. 2022).

Trout population dynamics have also shifted in the last decade, with brown trout now occupying a greater percentage (approximately 15 percent compared with 2 to 3 percent prior to 2014) of the trout population at Lees Ferry (Strogen 2021). This has the potential to reduce young age classes of rainbow trout at Lees Ferry. The NPS currently utilizes an incentivized harvest program to encourage anglers to catch and keep brown trout in the Lees Ferry reach. The program has increased the popularity of brown trout fishing since 2016; however, the brown trout fishery in this reach is still not highly sought-after. Fishing in the remainder of this analysis refers to the rainbow trout fishery.

Fishing in the Glen Canyon reach occurs year-round. Peak usage is in April and May; however, substantial fishing has occurred from March through October in most years (Rogowski and Boyer 2020). An estimated total of 7,653 anglers used the rainbow trout fishery in 2019; of these, 5,469 were boat anglers and 2,185 were walk-in anglers (Rogowski and Boyer 2020)

The quality of the fishing experience in the Glen Canyon reach has been studied to identify which characteristics of fishing in the area are most important to participants. Studies conducted in 1987 and 2000 suggest that anglers prefer flows between 8,000 and 15,000 cfs, with the 1987 study further identifying a preference for steady, unfluctuating flows (Bishop et al. 1987, Stewart et al. 2000). High water levels, as well as rapid changes in water levels, directly affect the safety of wading anglers who could potentially be swept away by the river current. Most anglers elect not to fish in the Glen Canyon reach during HFE releases.

Day-Rafting, Boating, and Camping in the Glen Canyon Reach

In addition to fishing, the Glen Canyon reach supports recreational activities that include camping and recreational boating. The NPS estimated that 26,000 commercial angler and water-based recreational visits occurred in the area in 2021 (NPS 2022a). As water temperatures have increased in the Glen Canyon reach in the past decade, private recreational uses such as swimming and paddle boarding have also become popular.[22]

The NPS facilities at Lees Ferry consist of a boat launch ramp, campground, restroom, interpretive facilities, and hiking trails. The NPS launching facility provides the main access for trips going through the Grand Canyon and for anglers and other boaters heading upstream into the Glen Canyon reach. Aside from the courtesy dock next to the launch ramp, facilities in this area are not directly affected by river fluctuations.

There are six designated, boat-accessible-only camping areas upstream of the Lees Ferry launching facility. These areas are located on sediment terraces and beaches. **Figure 3-39** shows the general location of the six designated campsite areas. Releases of 40,000 to 45,000 cfs can create steep banks in some portions of the river, which makes access more difficult from boats to the upper sediment terraces. Eventually, most steep areas are eroded by use, restoring easy access to the terraces; however, in some locations, the banks have been steepened to such a degree that visitor access is adversely affected (DOI 2016a).

The NPS authorizes one commercial recreational river rafting concessionaire to operate in the Glen Canyon reach. The concessionaire's most popular service is a half-day guided trip that originates at Glen Canyon Dam. Trips occur in most months, but most trips occur in the summer. The concessionaire provided 2,099 trips in 2022 that serviced 41,677 passengers (**Table 3-43**). Releases of 40,000 cfs or greater create operational issues for the rafting concessionaire, including cessation of operations and the need to move mooring docks and rafts to other locations.

Table 3-43
Commercial River Rafting Annual Visitation for the Glen Canyon Reach of the Colorado River

Year	Total Number of Raft Trips	Total Number of Passengers
2022	2,099	41,677
2021*	257	4,670
2020*	149	1,620
2019	1,691	30,839
2018	2,105	41,659

Source: NPS 2022b
*Lower visitation in 2020 and 2021 compared with previous years is likely attributed to the COVID-19 pandemic.

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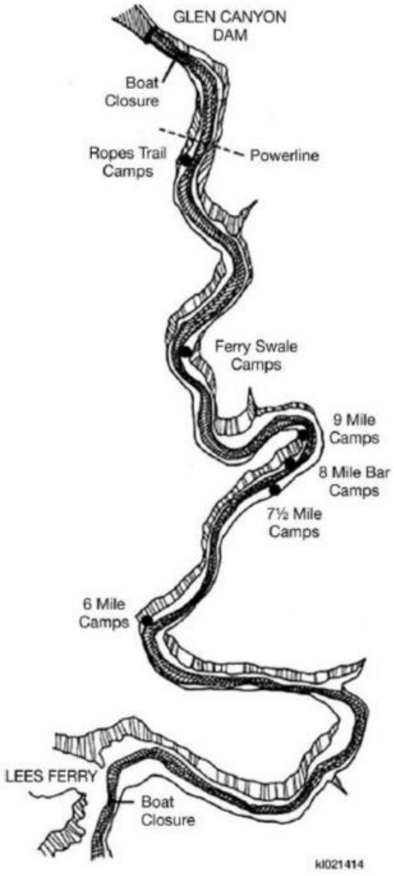
[22] Zoom call between Lucas Bair, NPS, and Noelle Crowley, EMPSi, on January 13, 2023.

Figure 3-39
Designated Campsite Areas in the Glen Canyon Reach



Source: Reclamation 2011a
Map showing designated sites on the Colorado River between Glen Canyon Dam and Lees Ferry. Boat closures are indicated by cables across the river.

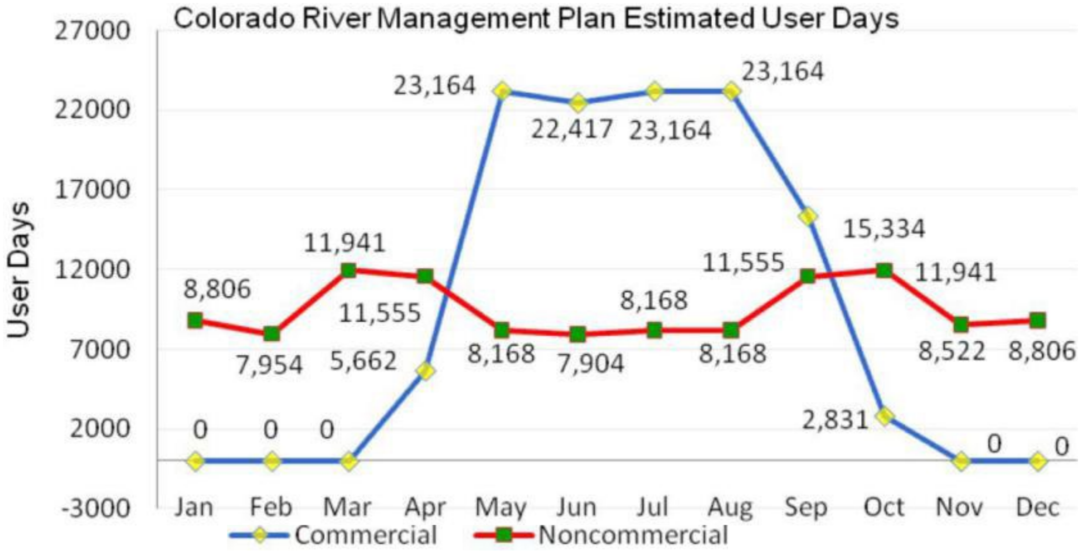
The Colorado River in Grand Canyon National Park

Boating in Grand Canyon National Park

Boating in the reach below Lees Ferry and through the Grand Canyon is internationally renowned. The NPS manages most of the reach from Glen Canyon Dam to Lake Mead, except where it is bordered on the east by the Navajo Indian Reservation and on the south by the Hualapai Indian Reservation.

Use is regulated by GCNP staff under the Colorado River Management Plan (NPS 2006a) with a lottery system. The 2006 Colorado River Management Plan for boating through GCNP governs use in both the reach from Lees Ferry (river mile 0) to Diamond Creek (river mile 226) and the reach from Diamond Creek to Lake Mead (river mile 277). Higher-use months for commercial operations extend from May through September, but there is relatively consistent use throughout the year for noncommercial boating. **Figure 3-40** shows the expected maximum amount of use allowed by the Colorado River Management Plan, as measured in user days.

Figure 3-40
Anticipated Annual Boating Use in the Grand Canyon by Month



Sources: NPS 2006, Reclamation 2011a
Estimated annual boating use in the Grand Canyon, 2006

The Colorado River Management Plan (NPS 2006a, Table 2 and Table 3) allows up to approximately 1,100 total yearly launches (598 commercial trips and 504 noncommercial trips). Up to 24,567 boaters could be accommodated annually if all trips were taken and all were filled to capacity (NPS 2016). Historically, this has not occurred.

The Colorado River corridor borders Tribal lands for nearly half the distance from the put-in at Lees Ferry to the last takeout at Pearce Ferry. The Navajo Indian Reservation borders GCNP along the eastern bank of the Colorado River from near Lees Ferry to the confluence with the Little Colorado River at river mile 61. The Hualapai Indian Reservation borders the river corridor for approximately 108 miles from upstream of National Canyon (river mile 167) to approximately river mile 274. The Hualapai Indian Reservation offers camping, fishing, hiking, and big game hunting opportunities. Hualapai River Runners offer rafting trips on the Colorado River between Diamond Creek and Pearce Ferry. The NPS coordinates with Tribal neighbors to address resource management and visitor use concerns along shared boundaries. Access permits from the Navajo Nation, Havasupai Tribe, or Hualapai Tribe are required from each respective Tribe to access and recreate on Tribal lands.

Boating Facilities

No boating facilities are within GCNP. Development along the Colorado River within the park is limited to the development at Phantom Ranch (river mile 88) and Pipe Creek (river mile 89.5). Other focal points include the launch ramp at Lees Ferry (within GCNRA), the helipad near Whitmore Wash (river mile 187) on the Hualapai Reservation, the road access and minor structures operated by the Hualapai Tribe at Diamond Creek (river mile 226), and the tourist area near Quartermaster Canyon (river mile 260).

Camping between Glen Canyon Dam and Lake Mead occurs in GCNP on undeveloped beaches (sandbars) along the Colorado River. The number and usability of campsites varies from year to year based on the magnitude of releases from Glen Canyon Dam and local topography. Additional factors include vegetation changes; erosion from tributary flooding, wind, and recreational use; and the closure of sites to protect sensitive resources (NPS 2006a).

The average annual release volume from Glen Canyon Dam was 9.1 maf from 2007 to 2019 and 8.1 maf from 2020 to 2022. The recent years of low release volumes have allowed accumulation of sand on the riverbed; sand was not redistributed to camping beaches from 2019 through 2022 due to a lack of HFE releases. From 2012 to 2018, there were more frequent HFE releases, which build more sandbars and beaches, on average, in Marble and Grand Canyons. The lack of HFE releases from 2019 through 2022 has resulted in greater erosion than deposition on the high-elevation sandbars, due to erosive flows in the main channel and gullying from side channels with no rebuilding. Also, the lack of HFE releases has contributed to more vegetation encroachment since 2018 (USGS 2023).

Of the 276 campsites referenced in Section 3.12.1.1 of the 2007 FEIS, 195 sites are still classified as "camps." Sixty-eight sites have been classified as "noncamps" due to sand erosion, vegetation overgrowth, or both; two sites could not be ascertained because of the float-by methodology used during the November 2022 NPS CRMP monitoring trip; and ten campsites were not evaluated (Kearsley 2023).

3.14.2 Environmental Consequences

Methodology

This section examines the potential effects of the No Action Alternative and action alternatives on recreation within the analysis area. Reclamation's CRMMS modeling results were used to develop potential releases and flow rates for the alternatives. The results of these analyses are used throughout this section.

Impact Analysis Area

The impact analysis area for recreation extends from the Glen Canyon Dam to the inlet of Lake Mead.

Assumptions

- The analysis assumes that the demand for recreational opportunities will either remain constant or increase over time, forming the basis for evaluating impacts on activities such as fishing, whitewater boating, and camping.
- Additional assumptions related to modeling are considered in the analysis, contributing to the accuracy and reliability of the hydrologic models used to anticipate impacts resulting from various actions.

Assumptions outlined in **Chapter 2** of the analysis, broadly categorized as general assumptions, influence the overall understanding and context of these environmental consequences.

Impact Indicators

- Flow fluctuations and changes in water levels
- Sedimentation
- Water temperatures
- Rainbow trout water temperature thresholds

Impacts Common to All Action Alternatives

Under all action alternatives, the volume of water discharged during the flow actions would have the greatest potential to impact recreation. These impacts would be temporary because flow actions would be implemented for a limited time.

Issue 1: How would flow fluctuations affect recreational opportunities, including fishing, boating, and camping?

No Action Alternative

Under the No Action Alternative, Reclamation would not make any changes to operations of Glen Canyon Dam. Therefore, water would continue to be released as described in the LTEMP FEIS (DOI 2016a).

Impacts on Fishing in the Glen Canyon Reach

Under the No Action Alternative, anglers would continue to have the same level of access as current conditions, with angler access continuing to be restricted during implementation of HFE releases. Therefore, there would likely be no change to angler satisfaction as a result of short-term flow levels and daily fluctuations. In the long term, drought conditions and aridification could result in increasingly warm water temperatures that could lead to deteriorating conditions for rainbow trout. This could negatively impact the fishery and angler satisfaction.

Impacts on Boating and Camping in the Glen Canyon Reach

The Glen Canyon reach hosts a large number of day rafters who use the pontoon-raft concessionaire that departs from near Glen Canyon Dam and travels to Lees Ferry (**Section 3.13.1**). Impacts on rafting use are related to the occurrence of HFEs, which results in lost visitor recreation opportunities and lost revenue for the rafting concessionaire. The variables influencing the level of impact are the number of HFEs and the time of year in which they occur. Spring HFEs have a greater impact than fall HFEs because visitor use is higher in the spring months. Under the No Action Alternative, HFEs would continue to be implemented as under current conditions and would be more likely to occur in the fall months, thereby limiting impacts on the concessionaire and recreational boaters in this reach.

The camping facilities at Glen Canyon are generally located above the high-water level of normal dam operations; however, HFE releases could affect these campsites through erosion of terraces combined with an absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of terraces. Under the No Action Alternative, these impacts would continue during the implementation of HFE releases.

Impacts on Boating in the Grand Canyon

River flow levels and fluctuations are important for whitewater boaters. The minimum daily flow levels under the No Action Alternative are considered only minimally adequate for Grand Canyon boating. Morning flows increase to 8,000 cfs from the overnight minimums of 5,000 cfs. However, these desired flow increases may be delayed to downstream rapids due to flow transit times. Such concerns would arise only in low-volume months, however, when minimum flow limits would be applied. Flows on most days under the No Action Alternative would exceed these limits. Extended low flows of 5,000 cfs would adversely affect navigability and trip management because of a greater risk of boating incidents. Commercial and private whitewater trip leaders have reported a preference for steady flows in the 20,000–26,000 cfs range (Bishop et al. 1987); thus, there would likely be greater perceived value to rafters when flows are within this range. The exact impacts on recreation would continue to depend on water availability for releases.

Cool Mix Alternative

Impacts on Fishing in the Glen Canyon Reach

The Cool Mix Alternative would reduce water temperatures, with the aim of achieving the target temperature of 15.5°C (60°F). This would benefit the rainbow trout fishery in the short term because rainbow trout are a cold-water species that thrives in colder water temperatures. The long-term benefits could improve water quality and enhance the rainbow trout fishery, which would likely result in higher angler satisfaction in the long term than under the No Action Alternative. More information on the impacts on water temperature and rainbow trout are described in **Section 3.5**, Aquatic Resources, and **Section 3.11**, Water Quality.

The Cool Mix Alternative would continue to operate flows within the range of operations, as outlined in the LTEMP FEIS; therefore, the impacts on fishing in the Glen Canyon reach resulting from the volume of water discharged would be the same as described under the No Action Alternative.

Impacts on Boating and Camping in the Glen Canyon Reach

The Cool Mix Alternative would continue to operate flows within the current range of operations, as outlined in the LTEMP FEIS; therefore, the impacts on rafting and camping in the Glen Canyon Reach resulting from the volume of water discharged would be the same as described under the No Action Alternative.

Impacts on Boating in Grand Canyon National Park

The Cool Mix Alternative would continue to operate flows within the current range of operations as outlined in the LTEMP FEIS; therefore, the impacts on whitewater boating in the Grand Canyon would be similar to those described under the No Action Alternative.

Cool Mix with Flow Spike Alternative

Impacts on Fishing in the Glen Canyon Reach

The Cool Mix with Flow Spike Alternative would reduce water temperatures, benefiting the rainbow trout fishery in the short term similar to the Cool Mix Alternative. However, the inclusion of flow spikes between May and July would temporarily reduce catchability during peak months, which may reduce angler satisfaction in the short term. However, the long-term benefits to the rainbow trout fishery could improve water quality and enhance the rainbow trout fishery, which would likely result in higher angler satisfaction in the long term than under the No Action Alternative. More information on the impacts of the alternatives on rainbow trout are described in **Section 3.5**, Aquatic Resources, and **Section 3.11**, Water Quality.

Impacts on Boating and Camping in the Glen Canyon Reach

The Cool Mix with Flow Spike Alternative would produce flows during implementation of up to three 8-hour flow spikes between late May and mid-July that would temporarily disrupt boating within the Glen Canyon reach. Impacts on recreational boating and the rafting concessionaire during the implementation of flow spikes would be increased compared with the No Action Alternative. Flow spikes could additionally result in increased erosion of the campsites and terraces in this reach compared with the No Action Alternative.

Impacts on Boating in Grand Canyon National Park

The Cool Mix with Flow Spike Alternative would affect a relatively small portion of the Colorado River used by boaters in the Grand Canyon. The flows, including spikes, might improve boater navigability but could temporarily limit beach usability for camping during their implementation. However, flow spikes would also have the greatest potential for sandbar growth, which would result in more available campsite areas than under the Cool Mix Alternative and the No Action Alternative.

Cold Shock Alternative

Impacts on Fishing in the Glen Canyon Reach

Although adult and juvenile rainbow trout are less susceptible to cold shocks than warmwater species, recently hatched fry and early juveniles could be negatively impacted by the sudden decrease in temperature, especially in the Glen Canyon reach if cold shock releases occur between January and June. This would likely be a short-term, temporary impact and is not anticipated to affect angler satisfaction in the long term. Long-term angler satisfaction would be affected if cold spikes consistently impacted the ability of anglers to access the area. These concerns could be mitigated by the careful selection of the timing of flows to limit impacts on recreational users. Overall, the Cold Shock Alternative would reduce water temperatures, which would likely benefit the rainbow trout fishery in the long term.

Under the Cold Shock Alternative, discharges from the dam would continue to operate at the levels described in the LTEMP FEIS; therefore, the impacts on fishing in the Glen Canyon reach resulting from the volume of water discharged would be the same as described under the No Action Alternative.

Impacts on Boating and Camping in the Glen Canyon Reach

Flows under the Cold Shock Alternative would continue to be within the range of operations analyzed in the LTEMP FEIS; therefore, the impacts on boating and camping in the Glen Canyon reach would be similar to those described under the No Action Alternative.

Impacts on Boating in Grand Canyon National Park

Flows under the Cold Shock Alternative would continue to be within the range of operations analyzed in the LTEMP FEIS; therefore, impacts on whitewater boating in the Grand Canyon would be the same as those described under the No Action Alternative.

Cold Shock with Flow Spike Alternative

Impacts on Fishing in the Glen Canyon Reach

Impacts on the rainbow trout fishery resulting from implementation of cold shocks would be similar to those described under the Cold Shock Alternative. The inclusion of flow spikes between May and mid-July could disrupt fishing during peak months, reducing angler satisfaction in the short term. The impacts of flow spikes to the rainbow trout fishery would be similar to those described under previous alternatives, including flow spike alternatives.

Impacts on Boating and Camping in the Glen Canyon Reach

The Cold Shock with Flow Spike Alternative would produce flows during implementation of up to three 8-hour flow spikes that would temporarily disrupt boating within the Glen Canyon reach. Impacts on recreational boating and the rafting concessionaire during the implementation of flow spikes would be similar to those described under the Cool Mix with Flow Spike Alternative. Flow spikes could additionally result in increased erosion of the campsites and terraces in this reach compared with the No Action Alternative.

Impacts on Boating in Grand Canyon National Park

The Cold Shock with Flow Spike Alternative would affect a relatively small portion of the Colorado River used by boaters in the Grand Canyon. The flows, including spikes, might improve boater navigability but could temporarily limit beach usability for camping during their implementation. However, flow spikes would also have the greatest potential for sandbar growth, which would result in more available campsite area than under the No Action Alternative.

Non-Bypass Alternative

Impacts on Fishing in the Glen Canyon Reach

Under the Non-Bypass Alternative, high flows are not anticipated to affect adult rainbow trout; however, they are likely to displace young and juvenile rainbow trout and expose these fish to starvation and predation or possibly displace them downstream to population centers of native fishes where they can prey on and compete with those fish. If weekend flows of 2,000 cfs occurred between January and March, they could negatively affect eggs and fry through desiccation and displace juveniles, leading to reduced survival from predation or starvation. Adult rainbow trout would not be as negatively affected as the larger fish are able to shift habitats during dramatic flow changes. Reducing the overall rainbow trout population could negatively affect the rainbow trout fishery; however, these effects are not likely to be significant overall due to the short-term nature of flow implementation. Rapid changes in water levels would directly affect the safety of wading anglers; therefore, angler satisfaction is likely to decrease during implementation of high fluctuation releases. To mitigate impacts on the food base and upstream boat travel for angling, Sunday nighttime operations are recommended. This alternative is also less likely to benefit the rainbow trout fishery by reducing water temperatures compared with the cold water alternatives.

Impacts on Boating and Camping in the Glen Canyon Reach

Under the Non-Bypass Alternative, the minimum flows of 2,000 cfs would limit the ability of boats to navigate freely within the Glen Canyon reach. This would adversely impact boating and the rafting concessionaires' operations compared with all other alternatives. These impacts would be temporary given the short-term duration of the low flow release.

Impacts on Boating in Grand Canyon National Park

Under the Non-Bypass Alternative, the minimum flows of 2,000 cfs are below the safe whitewater minimum and would adversely affect whitewater boating opportunities in GCNP and the ability of Hualapai River Runners to provide boating trips compared with all other alternatives. These low flows would adversely affect navigability and trip management in GCNP because of a greater risk of boating incidents. These impacts would be temporary given the short-term duration of the low flow release and the effect of the high- and low-volume releases on river water levels, causing them to be greatest near Glen Canyon Dam and diminishing further downstream.

Cumulative Effects

Most alternatives would result in a reduction of navigation concerns (with the exception of the Non-Bypass Alternative) and improved long-term conditions for the rainbow trout fishery. Except for the Non-Bypass Alternative's effects on boating in the Glen Canyon reach and Grand Canyon, all alternatives' contribution to cumulative effects would be negligible compared with the effects of past, present, and reasonably foreseeable future actions.

Issue 2: How would sedimentation resulting from flow fluctuations change camping opportunities in the Glen Canyon reach and Grand Canyon?

No Action Alternative

Under the No Action Alternative, Reclamation would not make any changes to operations of Glen Canyon Dam. Therefore, water would continue to be released as described in the LTEMP FEIS (DOI 2016a). HFE releases would continue to affect campsites in the Glen Canyon reach through erosion of terraces combined with an absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of terraces. This effect is exacerbated with higher fluctuation levels. Conversely, HFE releases would continue to result in greater campsite area within the Grand Canyon, although flow and fluctuation levels as well as vegetation control would affect the maintenance of campsite area.

Alternatives without Flow Spikes

Under the Cool Mix and Cold Shock Alternatives, HFE releases would be triggered and implemented according to a 1-year sediment accounting period. Compared with the No Action Alternative, alternatives without flow spikes would result in a slightly higher mass balance on average because the average HFE duration would be slightly shorter under the 1-year sediment accounting period (see **Section 3.4.2**). Therefore, impacts on camping opportunities in the Glen Canyon reach and Grand Canyon would be similar to those described under the No Action Alternative, but to a slightly greater extent due to the shorter but more frequent duration of spring HFE releases.

Alternatives with Flow Spikes

Under the Cool Mix with Flow Spike and Cold Shock with Flow Spike Alternatives, HFE releases would be triggered and implemented according to a 1-year sediment accounting period. Compared with the No Action Alternative and alternatives without flow spikes, the elevated flows associated with flow spikes would contribute to increased erosion of campsites in the Glen Canyon reach, but increased deposition in the Grand Canyon, thereby increasing available campsite area in the Grand Canyon. However, if a flow spike occurred outside the sediment accounting period, it would increase sediment export, thereby decreasing the amount of available sand to perform an HFE. This would reduce sandbar size, as HFE releases are the only mechanism for providing substantial deposition of high-elevation sandbars.

Non-Bypass Alternative

Under the Non-Bypass Alternative, trends in mass balance and sandbar building would be similar to those produced under the cold water alternatives; therefore, camping opportunities would be affected to a similar extent as under the other action alternatives.

Cumulative Effects

The action alternatives are expected to improve sediment conditions to varying degrees by conserving sediment and building sandbars at higher elevations, thereby increasing camping area within the Grand Canyon. The action alternatives' contribution to cumulative impacts, however, would be negligible compared with the effects of past, present, and reasonably foreseeable future actions.

Summary

No Action Alternative: Under the No Action Alternative, Glen Canyon Dam operations would remain unchanged, following the guidelines set in the LTEMP FEIS. In the Glen Canyon reach, implementation of HFE releases would continue to result in reduced short-term angler satisfaction, lost rafting visitor opportunities to the concessionaire, and increased erosion of campsites on terraces. In the Grand Canyon, daytime flows would continue to be above the safe whitewater minimum of 8,000 cfs, with good river conditions (between 20,000 and 26,000 cfs) occurring most of the time. HFE releases would result in a potential increase in camping area in the Grand Canyon.

Cool Mix Alternative: Under the Cool Mix Alternative, reduced water temperatures would improve water quality for rainbow trout, which would likely increase angler satisfaction in the short and long terms. Impacts on boating, the rafting concessionaire, camping in the Glen Canyon reach, and whitewater boating and camping in the Grand Canyon would be similar to those described under the No Action Alternative.

Cool Mix with Flow Spike Alternative: Under the Cool Mix with Flow Spike Alternative, benefits to the rainbow trout fishery resulting from reduced water temperatures would be the same as described under the Cool Mix Alternative. Flow spikes would reduce catchability during the peak fishing months, thereby reducing angler satisfaction in the short term. Flow spikes would also temporarily disrupt boating in the Glen Canyon reach and the ability of the rafting concessionaire to operate, as well as contribute to increased erosion of campsites compared with the No Action Alternative. Flow spikes would likely improve whitewater boating conditions in the Grand Canyon but could temporarily limit beach usability for camping during implementation. In the long term, flow spikes have the highest potential to increase camping area in the Grand Canyon.

Cold Shock Alternative: Under the Cold Shock Alternative, cold shocks would likely have adverse impacts on fry and early juveniles, which could decrease angler satisfaction in the short term; however, cooler water temperatures would likely improve water quality for rainbow trout in the long term, thereby increasing angler satisfaction in the long term. Impacts on boating, the rafting concessionaire, and camping in the Glen Canyon reach and whitewater boating and camping in the Grand Canyon would be similar to those described under the No Action Alternative.

Cold Shock with Flow Spike Alternative: Under the Cold Shock with Flow Spike Alternative, short-term reduced angler satisfaction similar to that described under the Cold Shock Alternative could occur. Flow spikes would reduce catchability during the peak fishing months, thereby reducing angler satisfaction in the short term. Flow spikes would also temporarily disrupt boating in the Glen Canyon reach and the ability of the rafting concessionaire to operate, as well as contribute to increase erosion of campsites compared with the No Action Alternative. Flow spikes would likely improve whitewater boating conditions in the Grand Canyon but could temporarily limit beach usability for camping during implementation. In the long term, flow spikes have the highest potential to increase camping area in the Grand Canyon.

Non-Bypass Alternative: Under the Non-Bypass Alternative, fry and juveniles would be negatively affected by both the high and low flows. The rapid fluctuations in water levels may also disrupt fishing during their implementation. The Non-Bypass Alternative would also be less likely to benefit the rainbow trout fishery by reducing water temperatures compared with the cold water alternatives. The low flows under the Non-Bypass Alternative could limit the ability of boats to freely navigate in the Glen Canyon reach, which would adversely impact boating and the rafting concessionaire in the short term compared with all other alternatives. In the Grand Canyon, minimum flows would be below the safe whitewater minimum, which would adversely affect whitewater boating.

3.15 Socioeconomics

3.15.1 Affected Environment

This section provides a brief socioeconomic background for two regions of influence as defined in the LTEMP FEIS: (1) the six-county region in which most recreation in the Grand Canyon area occurs, and (2) a seven-state region in which power from the Glen Canyon Powerplant is marketed.

Recreation Expenditures Analysis Area

The six-county recreation analysis area consists of Coconino and Mohave Counties in Arizona and Garfield, Kane, San Juan, and Washington Counties in Utah. This analysis area includes the GCNRA and GCNP, as well as various surrounding cities.

Population

Population growth is a factor that can drive recreational demand. **Table 3-44** presents recent and projected populations for the six-county recreation analysis area and for the states of Arizona and Utah as a whole. All counites in the analysis area, with the exception of Washington Couty, Utah, are anticipated to experience population growth rates below those of the state levels by 2040. The highest rate of population growth is anticipated in Washington County, Utah (85.2 percent), and the lowest rate of growth is anticipated in Garfield County, Utah (2.1 percent).

Table 3-44
Population in the Recreational Expenditures Analysis Area

Location	Historical Population		Projected Population		Projected Change 2020 to 2040	
	2010	2020	2030	2040	Total Change	Percentage Change
Coconino County, Arizona	134,421	145,101	155,200	159,600	14,499	10.0
Mohave County, Arizona	200,186	213,269	251,300	270,600	57,331	26.9
Garfield County, Utah	5,176	5,184	5,017	5,294	110	2.1
Kane County, Utah	7,113	7,692	8,834	9,769	2,077	27.0
San Juan County, Utah	14,715	14,541	14,712	16,186	1,645	11.3
Washington County, Utah	13,435	182,111	265,865	337,326	155,215	85.2
Arizona	6,392,017	7,151,502	8,313,800	9,206,900	2,055,398	28.7
Utah	2,772,667	3,284,823	3,879,161	4,440,560	1,155,737	35.2

Sources: US Census Bureau 2022a; Arizona Commerce Authority 2022; Kem C. Gardner Policy Institute 2022

Income

Total personal income in the analysis area in 2022 was highest for Washington County, Utah, at $10 billion; the lowest was in Garfield County at $0.29 billion (**Table 3-45**). The fastest average annual rate of growth for income from 2010 to 2022 was in Washington County, Utah (8.8 percent), and the lowest rate of growth for personal income was in San Juan County, Utah (4.0 percent). For per capita income, the highest income in 2022 was in Coconino County, Arizona ($58.993), and the lowest was in San Juan County, Utah ($35,597). The rate of average annual growth in per capita income from 2010 to 2022 was highest in Coconino County, Arizona, and Garfield County, Utah (5.8 percent for both counties), and lowest in San Juan County, Utah (4.3 percent). Per capita incomes for all counties, with the exception of Coconino County, were lower than the respective state averages in 2022. In Coconino County, income ($58,993) was slightly above that for the state of Arizona ($58,442).

Table 3-45
Income in the Recreational Expenditures Analysis Area

Location	2010	2022	Average Annual Growth Rate 2010–2022
Coconino County, Arizona			
Income (billions $)	4.7	8.5	6.9%
Per capita income ($)	34,531	58,993	5.8%
Mohave County, Arizona			
Income (billions $)	5.2	9.9	5.5%
Per capita income ($)	25,864	44,645	4.7%
Garfield County, Utah			
Income (billions $)	0.15	0.29	5.9%
Per capita income ($)	28,447	55,775	5.8%
Kane County, Utah			
Income (billions $)	0.22	0.42	5.7%
Per capita income ($)	29,894	51,164	4.6%
San Juan County, Utah			
Income (billions $)	0.32	0.51	4.0%
Per capita income ($)	21,574	35,597	4.3%
Washington County, Utah			
Income (billions $)	3.6	10.0	8.8%
Per capita income ($)	26,218	50,746	5.7%
Arizona			
Income (billions $)	216.2	430.1	5.9%
Per capita income ($)	33,774	58,442	4.7%
Utah			
Income (billions $)	88.9	201.0	7.0%
Per capita income ($)	32,038	59,457	5.3%

Source: US Department of Commerce, Bureau of Economic Analysis 2022

Employment

Employment by sector for the most recent available data is examined in **Table 3-46**. Farm employment was an equal or greater share of total employment compared with the state level for all analysis area counties, with the exception of Washington County, Utah. Notably, farm employment represented 10.5 percent of employment in San Juan County, Utah, and 7.4 percent in Garfield County, Utah, compared with a state average of 0.9 percent.

Table 3-46
Employment by Industry, 2022

Industry	Coconino County, Arizona	Mohave County, Arizona	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	Arizona	Utah
	Jobs/percentage of total jobs by county or state							
Total employment	88,910	81,675	3,907	6,101	6,836	124,640	4,287,595	2,367,996
Farm	2,088	479	289	169	715	557	27,735	21,081
	2.3%	0.6%	7.4%	2.8%	10.5%	0.4%	0.6%	0.9%
Non-Farm	86,822	81,196	3,618	5,932	6,121	124,083	4,259,860	2,346,915
	97.7%	99.4%	92.6%	97.2%	89.5%	99.6%	99.4%	99.1%
Forestry, fishing, and related	254	(D)	(D)	(D)	88	184	14,280	4,704
	0.3%	(D)	(D)	(D)	1.3%	0.1%	0.3%	0.2%
Mining	178	469	(D)	(D)	331	776	20,295	13,730
	0.2%	0.6%	(D)	(D)	(D)	0.6%	5.0%	0.6%
Utilities	196	418	34	(D)	(D)	258	12,818	5,064
	0.2%	0.5%	0.9%	(D)	(D)	(D)	(D)	0.2%
Construction	4,086	6,958	148	(D)	345	12,535	270,022	166,041
	4.6%	8.5%	3.8%	5.4%	5.0%	10.1%	6.3%	7.0%
Manufacturing	3,852	3,561	64	(D)	112	4,739	204,725	160,756
	4.2%	4.4%	1.6%	(D)	(D)	(D)	4.8%	6.8%
Wholesale trade	1,412	1,827	44	47	(D)	2,592	126,540	65,904
	1.6%	2.2%	1.1%	0.8%	(D)	(D)	(D)	2.8%
Retail trade	8,866	12,436	300	587	440	14,923	422,975	235,054
	10.0%	15.2%	7.7%	9.6%	6.4%	12.0%	9.9%	9.9%
Transportation and warehousing	2,709	3,254	61	(D)	(D)	6,249	240,127	105,686
	3.0%	4.0%	1.6%	(D)	(D)	(D)	(D)	4.5%
Information	791	769	156	47	(D)	1,351	66,692	54,369
	0.9%	0.9%	4.0%	0.8%	(D)	(D)	(D)	2.3%
Finance and insurance	2,295	3,078	74	117	151	7,884	309,879	174,506
	2.6%	3.8%	1.9%	1.9%	2.2%	6.3%	7.2%	7.4%

Industry	Coconino County, Arizona	Mohave County, Arizona	Garfield County, Utah	Kane County, Utah	San Juan County, Utah	Washington County, Utah	Arizona	Utah
	Jobs/percentage of total jobs by county or state							
Real estate and rental and leasing	4,777	5,693	177	584	(D)	10,778	272,879	154,826
	5.4%	7.0%	4.5%	9.6%	(D)	(D)	(D)	6.5%
Professional and technical services	4,012	3,643	(D)	219	167	7,458	289,301	194,639
	4.5%	4.5%	(D)	(D)	(D)	6.0%	6.7%	8.2%
Management of companies	597	295	35	39	(D)	1,344	53,464	36,775
	0.7%	0.4%	0.9%	0.6%	(D)	(D)	(D)	1.6%
Administrative and waste services	2,948	4,424	(D)	234	(D)	5,798	322,974	12,1592
	3.8%	5.4%	(D)	(D)	(D)	4.7%	7.5%	5.1%
Educational services	1,280	887	(D)	31	167	1,985	92,109	77,750
	1.4%	1.1%	(D)	(D)	(D)	1.6%	2.1%	3.3%
Health care and social assistance	9.792	9,709	(D)	201	919	14,038	476,659	193,936
	11.0%	11.9%	(D)	(D)	(D)	11.3%	11.1%	8.2%
Arts, entertainment, and recreation	3,260	(D)	64	369	(D)	2,939	85,991	51,311
	3.7%	(D)	(D)	(D)	(D)	(D)	(D)	2.2%
Accommodation and food services	14,645	8,557	1,127	1,208	(D)	10,709	317,706	145,448
	16.5%	10.5%	28.8%	19.8%	(D)	(D)	(D)	6.1%
Other services	3,774	5,424	150	727	(D)	6,910	214,742	111,237
	4.2%	6.6%	3.8%	11.9%	(D)	(D)	(D)	4.7%
Government	17,098	8,539	560	783	1,687	10,730	445,732	273,587
	19.2%	10.5%	14.3%	12.8%	24.7%	8.6%	10.4%	11.6%

Source: US Department of Commerce, Bureau of Economic Analysis 2022

Note: (D) Data not shown by the Bureau of Economic Analysis to avoid disclosure of confidential information; estimates are included in higher-level totals.

Within the service sector, accommodation and food services represented a higher percentage of jobs for all counites as compared with the respective state averages for Arizona and Utah (7.4 and 6.1 percent). In particular, this sector represented 28.8 percent of total employment in Garfield County, Utah, and 19.8 percent of employment in Kane County, Utah. All area counties, with the exception of Washington County, Utah, also had higher shares of jobs in government compared with the state averages. In particular, government jobs were 24.7 percent of total employment in San Juan County, Utah, and 19.2 percent of employment in Coconino County, Arizona, compared with 10.4 percent and 11.6 percent in Arizona and Utah, respectively.

Unemployment

At the county level, the unemployment rate in 2012 was highest in Mohave County, Arizona (11.0 percent), and lowest in Kane County, Utah (5.9 percent). In 2022, the unemployment rate was highest in Garfield County, Utah (5.9 percent), and remained lowest in Kane County as well as in Washington County, Utah (both 2.5 percent). For all counties examined, unemployment rates were higher in 2012 than in 2022. In 2022, both Arizona counties had a higher unemployment rate than the state unemployment rate, while all Utah counties, with the exception of Garfield County, had lower unemployment rates than the state.

It should be noted that data presented in this discussion include annual averages for the most recent reporting periods. Data including the 2020 timeframe may differ from historical trends due to the widespread economic effects of the recession brought about by the 2020 global COVID-19 pandemic. This event affected local and regional economies in the analysis area through severe short-term changes to employment and industrial output; the effects of this are still ongoing and not evenly distributed across industries.

Table 3-47
Annual Unemployment Trends in the Recreational Expenditures Analysis Area

Location	2012 (%)	2022 (%)
Coconino County, Arizona	8.6	4.3
Mohave County, Arizona	11.0	4.5
Garfield County, Utah	8.4	5.9
Kane County, Utah	5.9	2.5
San Juan County, Utah	7.8	4.4
Washington County, Utah	6.1	2.5
Arizona	8.3	3.8
Utah	2.3	4.8

Source: US Department of Labor, Bureau of Labor Statistics 2023

Recreation Spending and Valuation

Recreational resources of concern in the socioeconomics recreation analysis area include rainbow trout fishing and boating (such as kayaking, rafting, and canoeing) from Glen Canyon Dam to Lees Ferry and through the Grand Canyon. Recreation is discussed in **Section 3.14**. Visitors to Lees Ferry and the Grand Canyon spend large sums of money in the region purchasing gas, food and drink, lodging, guide services, and outdoor equipment when visiting the region. These expenditures impact the regional economy through direct effects, indirect effects, and induced effects. Direct effects represent a change in the final demand for the affected industries caused by the change in spending. Indirect effects are the changes in interindustry purchases as industries respond to the new demands of the directly affected industries. Induced effects are the changes in spending from households as their income increases or decreases due to the changes in production (Reclamation 2011a).

Bair et al. (2016) estimated the annual value of fishing at Lees Ferry to be $2.7 million at 2014 visitation levels. Demand for fishing was affected by the season, with per-trip values of $210 in the summer, $237 in the spring, $261 in the fall, and $399 in the winter (Bair et al. 2016).

The annual regional economic activity generated from visitors in 2021 was estimated at approximately $372 million for GCNRA and $ 1,010 million for GCNP (NPS 2022c). A portion of this activity is related to rafting and angling.

The value of recreation can also be assessed based on the quality of the recreational experience. This value represents not just the amount of money spent in the local or regional economy but also the value that potential users assign to the opportunity to use a resource. One method of measuring nonmarket value is the use of a stated preference valuation technique. One version of this is contingent valuation (CV), which is a means of eliciting the maximum dollar amount an individual would be willing to pay for a resource of a specified quantity and quality. CV methods use surveys to ascertain value by asking people about their willingness to pay for a carefully specified change in environmental amenities.

Neher et al. (2017) estimated the willingness to pay per private whitewater trip by boat through the Grand Canyon under varying flows. The willingness to pay was estimated at $628 for flows of 5,000 cfs, $1,226 for flows of 13,000 cfs, $1,382 for flows of 22,000 cfs, and $1,094 for flows of 40,000 cfs, which suggests a preference for flows between 13,000 and 22,000 cfs (Neher et al. 2017).

Nonuse Values

Nonmarket values can also be assessed for nonuse values. Nonuse values are values that may be placed on the status of the natural or physical environment by nonusers (or individuals who may never visit or otherwise use a natural resource that might still be affected by changes in its status or quality). Nonusers may assign a nonuse or passive-use economic value to a resource.

CV surveys have been applied widely in the published economics literature to estimate passive-use values associated with preserving river and lake resources. Loomis (2014) concluded that research on this subject is limited and that additional research may be warranted. The National Research Council (2005) has concluded that the results of studies using CV methods are of high quality; however, the results and findings of studies relating to the Colorado River corridor are considerably outdated. Other studies have emphasized the need for additional or updated research on the sources and magnitudes of values associated with operational goals (see additional info in National Research Council 1999).

To address these concerns, the NPS conducted a survey to determine nonuse values associated with the impacts of each of the six action alternatives examined in the LTEMP FEIS on the endangered humpback chub, sandbars in the Grand Canyon, and populations of large trout in Glen Canyon. This study found that for every 1 percent increase in humpback chub population, the marginal willingness to pay increased by $1.95, and for every 1 percent increase in sandbar protection, the willingness to pay increased by $1.58, based on a national sample. Additional details of this study and background literature are included in DOI 2016a and Duffield et al. 2016.

In addition, Loomis (2014) concluded that there is a theoretical basis for nonmarket values associated with hydropower and water. He used the example of how people can place value on maintaining the ranching and farming way of life associated with western rural communities as irrigated agriculture landscapes are correlated with open space. In addition, people may place value on the existence and well-being of farming communities. Nonmarket values associated with hydropower and water resources may also exist to the extent hydropower and developed water assist in the maintenance of Tribal values and social well-being.

The Seven-State Region of Influence

WAPA markets wholesale CRSP Act power to preference entities (WAPA, n.d.) serving approximately 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. The current socioeconomic conditions within the seven-state region (the area where electricity from Glen Canyon Dam is marketed) are described below.

Population

The total population in the seven-state region was 23.9 million in 2020, which is an increase from 21.3 million in 2010 (**Table 3-48**). Population in the region is concentrated in Arizona and Colorado, which, at 12.9 million people, had almost 54 percent of the total regional population in 2020. The regional population is projected to reach 26.9 million in 2030 and 30.0 million in 2040.

Table 3-48
Population in the Seven-State Region of Influence

Location	Historical Population		Projected Population		Projected Change 2020 to 2040	
	2010	2020	2030	2040	Total Change	Percentage Change
Arizona	6,392,017	7,151,502	8,284,861	9,247,212	2,095,710	29.3
Colorado	5,029,196	5,773,714	6,416,216	7,692,907	1,919,193	33.2
Nebraska	1,826,341	1,961,504	2,053,788	2,164,420	202,916	10.3
Nevada	2,700,551	3,104,614	3,535,890	3,723,046	618,432	19.9
New Mexico	2,059,179	2,117,522	2,136,414	2,132,755	15,233	0.7
Utah	2,763,885	3,271,616	3,879,161	4,440,560	1,168,944	35.7
Wyoming	563,626	575,851	597,260	614,820	38,969	6.8
Total	**21,334,795**	**23,956,323**	**26,903,590**	**30,015,720**	**6,059,397**	**25.3**

Sources: US Census Bureau 2022a; Arizona Office of Economic Opportunity 2018; Colorado Department of Local Affairs 2022; Drozd and Deichert 2015; Lawton 2022; University of New Mexico 2022; Kem C. Gardner Policy Institute 2022; Wyoming Department of Administration and Information 2019

Income

Arizona and Colorado generated almost 55 percent of the income in the seven-state region, together producing almost $815 billion in 2021 (**Table 3-49**). From 2010 to 2021, personal income grew across the seven-state region, with higher growth rates in Colorado (9.1 percent), Nevada (7.9 percent), and Utah (9.9 percent). Income per capita rose over the same period at a rate of 5.4 percent, increasing from $37,998 to $60,515. In 2021, per capita incomes were higher in Colorado ($70,706), Nebraska ($61,205), and Wyoming ($69,666) than the average for the region as a whole ($60,515).

Median household incomes (the income level at which half of all households earn more and half earn less) over the period from 2016 to 2020 varied between $51,243 in New Mexico to $75,231 in Colorado (US Census Bureau 2020). Median household income in the United States was $64,994 over the same period.

Table 3-49
Income in the Seven-State Region of Influence

Location	2010	2021	Average Annual Growth Rate 2010–2021
Arizona			
Income (billions of 2020$)	216.9	403.7	7.8%
Per capita income (2020$)	33,876	55,487	5.8%
Colorado			
Income (billions of 2020$)	205.9	410.9	9.1%
Per capita income (2020$)	40,790	70,706	6.7%
Nebraska			
Income (billions of 2020$)	75.5	120.2	5.4%
Per capita income (2020$)	41,248	61,205	4.4%
Nevada			
Income (billions of 2020$)	101.3	189.3	7.9%
Per capita income (2020$)	37,494	60,213	5.5%
New Mexico			
Income (billions of 2020$)	69.6	106.4	4.8%
Per capita income (2020$)	33,710	50,311	4.5%
Utah			
Income (billions of 2020$)	89.4	187.0	9.9%
Per capita income (2020$)	32,218	56,019	6.7%
Wyoming			
Income (billions of 2020$)	26.3	40.3	4.8%
Per capita income (2020$)	46,649	69,666	4.5%
Total			
Income (billions of 2020$)	785.0	1,458	7.8%
Per capita income (2020$)	37,998	60,515	5.4%

Source: US Department of Commerce, Bureau of Economic Analysis 2022

Employment

In 2020, more than 49 percent of all employment in the seven-state power marketing service territory (that is, 6.5 million jobs out of a total of 13.1 million) was concentrated in Arizona and Colorado (**Table 3-50**). Employment figures showed 401,871 jobs in Wyoming, 1.1 million in New Mexico, 1.3 million in Nebraska, and 1.8 million in Nevada; each remaining state supported over 2 million jobs. From 2012 to 2020, annual employment growth rates were higher in Arizona and Colorado (13.4 percent) than elsewhere in the seven-state region, with rates in Nevada (2.1 percent), New Mexico (0.0 percent), Wyoming (0.2 percent), Utah (3.1 percent), and Nebraska (0.5 percent) lower than the average rate of 5.0 percent.

In 2021, the service sector provided the highest percentage of employment in the seven-state region at almost 73 percent, followed by government (11.9 percent) and health care and social assistance (11.2 percent) (**Table 3-51**). Smaller employment shares were held by retail trade (9.5 percent), professional and technical services (7.3 percent), and accommodation and food services (6.8 percent). Within the region, the distribution of employment across sectors varied somewhat compared with the region as a whole. Nebraska and Wyoming had a higher percentage of employment in agriculture (4.0 percent in Nebraska and 3.5 percent in Wyoming) than the region as a whole (1.3 percent); these states had lower shares of employment in services compared with the region as whole. Service sector employment in Nevada (79.2 percent), Arizona (76.4 percent), and New Mexico (73.5 percent) was higher than in the region as a whole (72.5 percent). Nebraska (7.8 percent), Utah (7.0 percent), and New Mexico (6.5 percent) had larger-than-average shares of manufacturing sector employment, while mining was a more significant employer in Wyoming (4.6 percent) than elsewhere in the region.

Table 3-50
Employment in the Seven-State Region of Influence

Location	2012	2020	Average Annual Growth Rate 2012–2020 (%)
Arizona	1,276,249	2,644,781	13.4
Colorado	3,262,925	3,821,923	13.4
Nebraska	1,251,258	1,305,987	0.5
Nevada	1,519,198	1,770,936	2.1
New Mexico	1,067,211	1,069,680	0.0
Utah	1,706,060	2,135,409	3.1
Wyoming	396,704	401,871	0.2
Total	10,479,605	13,150,587	5.0

Source: US Census Bureau 2022b

Table 3-51
Employment in the Seven-State Region of Influence by Industry, 2021

Industry	Arizona		Colorado		Nebraska		Nevada		New Mexico		Utah		Wyoming		Total	
	Jobs	%	Jobs	%	Jobs	%	Jobs	%	Jobs	%	Jobs	%	Jobs	%	Jobs	%
Total employment	**4,055,932**	**—**	**4,945,819**	**—**	**1,330,296**	**—**	**1,875,709**	**—**	**201,142,600**	**—**	**2,229,147**	**—**	**409,176**	**—**	**215,988,679**	**—**
Non-services/ government-related industries	**509,941**	**12.6**	**540,904**	**10.9**	**253,011**	**19.0**	**212,324**	**11.3**	**29,194,100**	**14.5**	**349,489**	**15.7**	**78,697**	**19.2**	**31,138,466**	**14.4**
Farm	29,309	0.7	47,988	1.0	53,669	4.0	5,028	0.3	2,588,000	1.3	20,552	0.9	14,277	3.5	2,758,823	1.3
Forestry and agricultural services	13,832	0.3	13,423	0.3	10,929	0.8	1,937	0.1	927,600	0.5	4,358	0.2	3,323	0.8	975,402	0.5
Mining	17,894	0.4	37,994	0.8	2,340	0.2	18,132	1.0	923,600	0.5	11,812	0.5	18,824	4.6	1,030,596	0.5
Construction	253,184	6.2	276,197	5.6	82,748	6.2	120,249	6.4	11,673,300	5.8	156,909	7.0	29,989	7.3	12,592,576	5.8
Manufacturing	195,722	4.8	165,302	3.3	103,325	7.8	66,978	3.6	13,081,600	6.5	155,858	7.0	12,284	3.0	13,781,069	6.4
Services-related industries	**3,099,749**	**76.4**	**2,895,813**	**58.6**	**904,077**	**68.0**	**1,486,244**	**79.2**	**147,900,500**	**73.5**	**1,608,824**	**72.2**	**256,568**	**62.7**	**156,665,531**	**72.5**
Utilities	12,720	0.3	9,401	0.2	1,287	0.1	4,526	0.2	598,200	0.3	5,036	0.2	2,551	0.6	633,721	0.3
Wholesale trade	115,142	2.8	120,434	2.4	42,323	3.2	43,982	2.3	6,309,900	3.1	61,996	2.8	8,547	2.1	6,702,324	3.1
Retail trade	413,565	10.2	341,676	6.9	130,940	9.8	185,306	9.9	19,120,800	9.5	227,274	10.2	39,259	10.0	20,458,820	9.5
Transportation and warehousing	224,294	5.5	181,227	3.7	70,099	5.3	137,427	7.3	10,403,700	5.2	97,325	4.4	16,124	3.9	11,130,196	5.2
Information	59,769	1.5	89,824	1.8	20,268	1.5	21,137	1.1	3,414,000	1.7	46,605	2.1	4,197	1.0	3,655,800	1.7
Finance and insurance	290,236	7.2	251,294	5.1	87,581	6.6	103,909	5.5	11,721,200	5.8	159,236	7.1	26,587	6.5	12,640,043	5.9
Real estate and rental and leasing	234,832	5.8	238,959	4.8	56,945	4.3	110,419	5.9	10,100,700	5.0	131,835	5.9	27,667	6.8	10,901,357	5.1
Professional and technical services	269,961	6.7	381,312	7.7	67,787	5.1	109,638	5.9	14,812,500	7.4	177,495	8.0	19,159	4.7	15,837,852	7.3
Management of companies	44,165	1.1	52,152	1.1	21,111	1.6	32,573	1.7	2,754,000	1.4	33,989	1.5	2,192	0.5	2,940,182	1.4

Industry	**Arizona**		**Colorado**		**Nebraska**		**Nevada**		**New Mexico**		**Utah**		**Wyoming**		**Total**	
	Jobs	**%**	**Jobs**	**%**	**Jobs**	**%**	**Jobs**	**%**	**Jobs**	**%**	**Jobs**	**%**	**Jobs**	**%**	**Jobs**	**%**
Administrative and waste services	313,831	7.7	211,660	4.3	65,274	4.9	132,423	7.1	12,426,500	6.2	118,472	5.3	14,540	3.6	13,282,700	6.2
Educational services	85,070	2.1	77,829	1.6	23,642	1.8	21,845	1.2	4,684,400	2.3	75,217	3.4	4,106	1.0	4,972,109	2.3
Health care and social assistance	459,980	11.3	359,593	7.3	145,717	11.0	160,792	8.6	22,880,500	11.4	185,491	8.3	30,657	7.5	24,222,730	11.2
Arts, entertainment, and recreation	81,541	2.0	100,129	2.0	24,070	1.8	55,322	3.0	4,157,100	2.1	48,191	2.2	8,233	2.0	4,474,586	2.1
Accommodation and food services	293,749	7.2	281,218	5.7	79,624	6.0	276,961	14.8	13,554,000	6.7	135,066	6.1	35,231	8.6	14,655,849	6.8
Other services	200,894	5.0	199,105	4.0	67,409	5.1	89,984	4.8	10,963,000	5.5	105,596	4.7	17,518	4.3	11,643,506	5.4
Government	**446,242**	**11.0**	**509,102**	**10.3**	**173,208**	**13.0**	**177,141**	**9.4**	**24,048,000**	**12.0**	**270,834**	**12.2**	**73,911**	**18.1**	**25,698,438**	**11.9**

Source: US Department of Commerce, Bureau of Economic Analysis 2022

Unemployment

In 2022, unemployment was lower in Utah (2.1 percent), Nebraska (2.4 percent), Wyoming (3.5 percent), and Colorado (3.6 percent) than the rest of the United States (3.7 percent) (**Table 3-52**).

Table 3-52
Unemployment Rates in the Seven-State Region of Influence, 2022

Location	Unemployment Rate (%)
Arizona	3.9
Colorado	3.6
Nebraska	2.4
Nevada	4.6
New Mexico	4.3
Utah	2.1
Wyoming	3.5
United States	3.7

Source: US Department of Labor, Bureau of Labor Statistics 2022

3.15.2 Environmental Consequences

Methodology

Recreational Use Values and Economic Contributions

Estimation of the use values associated with potential changes in recreational resources under each alternative used a benefits transfer method; this method involved applying existing use value data or estimates for a particular time period, site, level of resource quality, or combination thereof at an original or study site to a policy site for which data are not available. The benefits transfer method involved choosing study and policy sites with similar socioeconomic and environmental characteristics, similar recreational activities, and similar ranges of changes in recreational quality. Additional details for this approach are included in DOI 2016a.

The net economic value of recreation was estimated for Glen Canyon (from Glen Canyon Dam to Lees Ferry), Upper Grand Canyon (from Lees Ferry to Diamond Creek), and Lower Grand Canyon (from Diamond Creek to Lake Mead) based on the GCRec_Full utility program[23] output. The program uses the mean monthly release from Glen Canyon Dam and the presence or absence of daily fluctuations exceeding 10,000 cfs per day during the month to predict the economic value of day-use rafting and angling in Glen Canyon and the economic value of commercial and private whitewater boating in the Upper Grand Canyon. These calculations are repeated for each month in

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[23] The GCRec_Full utility model uses the recreation value relationships for Glen Canyon and Upper Grand Canyon estimated by Bishop et al. (1987). The utility uses the mean monthly release from Glen Canyon Dam and the presence or absence of daily fluctuations exceeding 10,000 cfs per day during the month to predict the economic value of day-use rafting and angling in Glen Canyon and the economic value of commercial and private whitewater boating in the Upper Grand Canyon. See Reclamation 2017, Appendix L for additional information.

the period of analysis and for each hydrologic trace. This information is provided along with qualitative information about the recreational experience by alternative.

Based on the recreation section analysis, it is not anticipated that a substantial change in recreation visitation will occur by alternative. As a result, no analysis of regional economic contributions is included in this SEIS. This is because the economic contribution analysis is based on a change in visitation levels and the associated direct spending.

Environmental Nonuse Values

Economists have long recognized that wildlife species, especially rare, threatened, and endangered species, have economic value beyond just viewing. This is supported by a series of legal decisions and technical analyses. The US Court of Appeals in 1989 first clarified that the US Department of the Interior, in assessing damages in natural resource damage assessment cases, should include what it termed as "passive use values"—that is, existence values provided to nonusers of the species—as a compensable value in addition to any use value. The term *passive values* is interchangeable with the term *nonuse values*. This is consistent with well-established economic theory showing that people derive value from passive use or nonuse as well as active uses of resources (Krutilla 1967). Environmental nonuse value is examined based on the CV study prepared for the LTEMP FEIS, as well as information from existing literature (for example, Loomis 2014).

Potential changes to the sandbar size and humpback chub protection by alternative, as analyzed in **Section 3.8**, Threatened and Endangered Species, and **Section 3.4**, Geomorphology/Sediment, were examined utilizing modeled willingness to pay data. The analysis is presented in a qualitative format due to a lack of quantitative input information for humpback chub population size changes and other environmental factors.

Hydropower Economic Impacts

Discussion of impacts from hydropower generation changes on the economic value of electric energy are addressed in **Section 3.3.2**, Energy and Power economic impacts. Additional information on power marketing, including wholesale and retail rates, is included in the LTEMP FEIS and incorporated by reference (DOI 2016a).

Impact Analysis Area

The impact analysis area consists of two separate areas, the six-county recreation analysis area and the seven-state hydropower analysis area, as defined in **Section 3.15.1**, Affected Environment.

Assumptions

Under all alternatives, the NPS sets the number of whitewater boating trips in the Grand Canyon, and demand exceeds available permits. It is, therefore, not anticipated that the number of boat trips and associated recreational spending associated with this use would vary by alternative. No further analysis is provided for recreation's economic contributions due to the lack of change in the direct spending across alternatives.

Impact Indicators

- Net recreation value for whitewater boaters and anglers in the Colorado River
- Nonuse environmental value

Issue 1: How would management decisions affect recreational use values?

No Action Alternative

Under the No Action Alternative, Reclamation would not make any changes to Glen Canyon Dam's operations. Therefore, water would continue to be released, as described in the LTEMP FEIS (DOI 2016a). As noted in **Section 3.14**, Recreation, anglers, boaters, and campers would continue to have the same level of access for recreation. Under the No Action Alternative, HFE releases would continue to be implemented the same as under current conditions, and would be more likely to occur in the fall months, thereby limiting impacts on the concessionaire and recreational boaters in the Glen Canyon reach. The exact impacts on recreation in the Grand Canyon reach would continue to depend on water availability for releases. Access for anglers would continue to be disrupted by HFE releases. As a result, no change would occur in the short term to the recreational experience and associated value.

In the long term, drought conditions and aridification could result in increasingly warm water temperatures that could lead to deteriorating conditions for rainbow trout, which could negatively impact the fishery and angler satisfaction and value associated with this use. The exact impacts on recreation and the associated value would, however, continue to depend on water availability for releases.

In terms of the estimated net value for boaters and anglers, the net value for the 50-month analysis period was calculated at $366.76 million for whitewater boaters and $19.03 million for anglers.

Cool Mix Alternative

As detailed in **Section 3.14**, Recreation, a long-term reduction in water temperature could improve water quality and enhance the rainbow trout fishery, which would likely result in higher angler satisfaction than under the No Action Alternative. Impacts on fishing, as well as whitewater boating, in the Glen Canyon and Grand Canyon reaches resulting from the volume of water discharged would be the same as described under the No Action Alternative. Compared with the No Action Alternative, this would result in minimal changes to the net value for anglers and whitewater boaters for all reaches (**Table 3-53**).

Table 3-53
Total Mean Net Economic Value for 50-Month Analysis Period ($ Million Net Present Value, 2023)

	River Mile 15				Little Colorado River			
	Whitewater Boaters		Anglers		Whitewater Boaters		Anglers	
	Value ($)	Change from No Action (%)	Value ($)	Change from No Action (%)	Value ($)	Change from No Action (%)	Value ($)	Change from No Action (%)
Cool Mix Alternative	359.83	-1.9	18.56	-2.5	366.30	-0.1	18.56	-2.5
Cool Mix with Flow Spike Alternative	366.30	0.0	22.32	17.5	366.30	-0.1	18.56	1.5
Cold Shock Alternative	366.30	-0.1	19.31	1.5	366.34	-0.1	18.56	-2.5
Cold Shock with Flow Spike Alternative	366.30	-0.1	19.31	1.5	366.34	-0.1	18.56	-2.5
Non-Bypass Alternative	366.34	-0.1	18.56	-2.5%	366.34	-0.1	18.56	-2.5%

Source: USGS and Reclamation 2023

Note: The USGS worked in conjunction with Reclamation's model results for the operating period from October 2024 to December 2027. The data presented are the average net value out of 30 modeled traces.

Cool Mix with Flow Spike Alternative

As discussed in **Section 3.14**, Recreation, under the Cool Mix with Flow Spike Alternative, the inclusion of flow spikes between May and July may reduce angler satisfaction in the short term, thereby impacting the net value for this use. However, improved water quality could enhance the rainbow trout fishery, which would likely result in higher angler satisfaction in the long term compared with the No Action Alternative.

Impacts on recreational boating and the rafting concessionaire during the implementation of the flow options could include increased temporary disruptions, especially in the Glen Canyon Reach, impacting the net value for this use in the short term; long-term impacts would be minimal.

Estimates for the net value for anglers include a 17 percent increase in value in the Glen Canyon reach and a 1.5 percent increase in the Lower Grand Canyon reach **(Table 3-53)**. A minimal change would occur for the whitewater boating value.

Cold Shock Alternative

Under the Cold Shock Alternative, as detailed in **Section 3.14**, Recreation, some long-term increases in angler satisfaction would likely occur due to the reduced water temperature for the Glen Canyon reach.

Compared with the No Action Alternative, boating would have minimal changes in terms of satisfaction and value (**Table 3-53**).

Cold Shock with Flow Spike Alternative

Impacts on the rainbow trout fishery resulting from implementation of cold shocks would be similar to those impacts described under the Cold Shock Alternative. The inclusion of flow spikes between

May and July could disrupt fishing during peak months, potentially reducing angler satisfaction in the short term. The impacts of flow spikes on the rainbow trout fishery would be similar to those impacts described under the previous alternatives, including the Flow Spike Alternative.

Impacts on recreational boating and the rafting concessionaire during the implementation of flow spikes would be similar to those described under the Cool Mix with Flow Spike Alternative. Flow spikes may cause erosion or deposition of sandbars along camping areas, depending on the volume of the flow released.

The Cold Shock with Flow Spike Alternative would affect a relatively small portion of the Colorado River used by boaters in the Grand Canyon. Impacts on boater navigability and beach usability would be limited.

Impacts on angler and boating net economic value would be the same as that described in the Cold Shock Alternative (**Table 3-53**).

Non-Bypass Alternative

Under the Non-Bypass Alternative, some short-term impacts could occur for angler satisfaction; however, minimal changes are anticipated long term to angler satisfaction, as discussed in **Section 3.14**, Recreation.

The high and low fluctuations of water under the Non-Bypass Alternative could impact the boater experience in both the Glen Canyon and Grand Canyon reaches. This alternative may negatively affect the boating experience in the Glen Canyon reach, as unpredictability could pose challenges for boaters navigating through the area. The minimum flows of 2,000 cfs would limit the ability of boats to navigate freely in the Glen Canyon reach. This would adversely impact boating and the rafting concessionaires' operations compared with all other alternatives. These impacts would be temporary due to the short-term duration of the low flow release. While overall changes to visitation numbers may not occur, whitewater boating opportunities in GCNP could have temporary limitations, and Hualapai River Runners' ability to provide boating trips could be impacted.

Cumulative Effects

Impacts on recreation from the alternatives would be temporary in nature and would have minimal impacts on the use value associated with whitewater boating recreation in the recreation analysis area. Some impact improvements could occur to angler satisfaction and the associated net value, particularly in the Glen Canyon reach. There would be no cumulative impacts on recreation beyond those impacts included in the LTEMP FEIS.

Issue 2: How would management decisions affect environmental nonuse values?

No Action Alternative

Under the No Action Alternative, operations of Glen Canyon Dam would not change. Although population levels of humpback chub are likely the highest since construction of Glen Canyon Dam, invasions of nonnative species, especially smallmouth bass, could lead to the decline of some population centers of native fish species, such as near the mouth of the Little Colorado River. See **Section 3.8**, Threatened and Endangered Species, for additional details. As a result, nonmarket values associated with the humpback chub may decrease in the long term. This includes a reduction in the nonuse value associated with the preservation of species, as discussed in the methods section.

Other nonmarket values may also be impacted in the long term. HFE releases could continue to impact sandbar development and the associated values, as discussed in the LTEMP FEIS (DOI 2016a). Nonmarket values may differ for different groups. Based on Jones et al. (2016), respondents who are supportive of hydropower, concerned about the health effects of air pollution, and concerned about ways of life for Native American entities and rural western communities are more likely to support the continuation of current patterns of dam operations and assign a higher value to this operation. Additionally, individuals owning property in the region around Glen Canyon Dam are considerably more likely to support continuation of dam operations. These people are more likely to receive the benefits of Glen Canyon Dam hydropower at their property and are, therefore, more likely to be personally affected by the economic viability of communities that receive low-cost hydropower (Jones et al. 2016).

Cool Mix Alternative

Under the Cool Mix Alternative, nonmarket values associated with humpback chub are not likely to be negatively affected. The presumed distributions of this species remain about the same and are expected to persist under this alternative.

In terms of sandbars and the associated values, sandbar volume would continue to increase, albeit in smaller, more frequent increases relative to the No Action Alternative; this would result in the potential for slight increases in the associated nonmarket value. **Section 3.4**, Geomorphology/Sediment, provides additional details.

For values associated with climate change, nonmarket values would be impacted by an increase in carbon emissions due to the need to secure alternative power sources. This alternative represents the greatest level of increased emissions, as modeled in **Section 3.17**, Climate Change. Similarly, this alternative represents the greatest potential for other values associated with rural ranching and famers, or other area residents who may value continued current operations of the dam.

Cool Mix Alternative with Flow Spike

Impacts on the values associated with the humpback chub from the Cool Mix Alternative with Flow Spike would be the same as described above. The addition of flow spikes would result in potential short-term impacts on larvae and juvenile humpback chub, but no population-level impacts are anticipated. As a result, the associated values would be maintained.

Modeling predicts that sandbar formation at the Little Colorado River under both the Cool Mix and Cold Shock flow spike alternatives would eventually surpass sandbar formation under the alternatives that do not include flow spikes. As a result, values associated with sandbars would be increased compared with the No Action Alternative. As discussed, values associated with continued current operations of the dam could be impacted under this alternative. For values associated with climate change, carbon dioxide equivalent (CO_2e) emissions would be reduced slightly compared with the Cool Mix Alternative but elevated above the No Action Alternative.

Cold Shock Alternative

Under the Cold Shock Alternative, potential impacts would occur for values associated with the humpback chub. The level of impact depends on the extent and timing of the cold shock, which is also discussed in **Section 3.8**, Threatened and Endangered Species.

Sandbar volume would continue to increase, albeit in smaller, more frequent increases relative to the No Action Alternative. This increase would support increased values compared with the No Action Alternative.

Compared with the No Action Alternative, increased carbon emissions would occur; this is due to the need to secure alternative sources of energy due to reduced hydropower production. However, these increases under the Cold Shock Alternative would be lower than those increases described in the Cool Mix Alternative, as discussed in **Section 3.17**, Climate Change. Likewise, impacts on the people who value continued dam operations would occur, but at a lower level than under the Cool Mix Alternative.

Cold Shock with Flow Spike Alternative

Under the Cold Shock with Flow Spike Alternative, the use of cold-shock events could reduce growth and survival of young humpback chub and razorback sucker. However, the effect is not expected to be a population-level effect; therefore, impacts on the associated values would be minimal.

As discussed in the Cool Mix with Flow Spike Alternative, modeling predicts that sandbar formation at the Little Colorado River under the flow spike alternatives would eventually surpass the sandbar formation under the alternatives that do not include flow spikes. As a result, values associated with sandbars would be increased compared with the No Action Alternative. As discussed, values associated with continued current operations of the dam could be impacted under this alternative. Emissions under the Cool Mix with Flow Spike Alternative would be slightly lower than those increases described in the Cool Mix Alternative, as discussed in **Section 3.17**, Climate Change, but still elevated above the No Action Alternative, impacting associated nonmarket values.

Non-Bypass Alternative

Under the Non-Bypass Alternative, there is the potential for short-term impacts on humpback chub juveniles from flow changes, such as exposure to predators; however, the effect of these high flows is expected to be minimal. Trends in sandbar building under the Non-Bypass Alternative would be similar to those produced under other action alternatives. As a result, no long-term changes to associated values are anticipated.

No change is anticipated to carbon emissions or values associated with continued dam operations under this alternative; this is because hydropower operations would continue as they would under the No Action Alternative.

Cumulative Effects

Cumulative effects of these flow alternatives on threatened and endangered fish would likely be temporary and beneficial overall, with minimal changes to the values associated with the humpback chub. For sandbars, minimal changes could occur to associated values, with impacts dependent on the timing and duration of the flow spikes.

Under all action alternatives, with the exception of the Non-Bypass Alternative, values associated with continued hydropower and dam operations in the current setting (e.g., those reliant on hydropower) would have a potential to be impacted due to changes to these conditions.

3.16 Environmental Justice

3.16.1 Affected Environment

Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (59 *Federal Register* 7629, February 11, 1994; US 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.

Analysis consists of two steps: (1) screening of populations within the analysis area to identify the presence of communities for further environmental justice consideration, and (2) review of impacts to determine the potential for disproportionate adverse impacts on these communities.

As in the 2016 FEIS, the environmental justice analysis area is defined by those counties that may be affected by changes in the operation of hydropower facilities and/or changes in hydropower costs. The environmental justice analysis area is comprised of 11 counties total: Apache, Coconino, Mojave, and Navajo Counties, Arizona; Cibola, McKinley, and San Juan Counties, New Mexico;, and Kane, San Juan, and Washington Counties, Utah.

Each county was screened to identify the presence of low-income, minority, and Native American populations that would meet the criteria for identification as populations for further consideration for environmental justice concerns.

This section identifies environmental justice communities in the analysis area based on the following criteria:

- Minority populations – Guidance from the Council on Environmental Quality (CEQ) in 1997 states that minority or low-income populations should be identified where either (1) the minority or low-income population of the affected area exceeds 50 percent, or (2) the minority or low-income population percentage of the affected area is meaningfully greater than the minority population percentage in the general population or other appropriate unit of geographic analysis. The total minority populations are defined as the total population minus those who identify as White, of non-Hispanic descent. For the meaningfully greater analysis, Reclamation used 110 percent of the minority percentage of the geographic reference area as the threshold for meaningfully greater. For Arizona, New Mexico, and

Utah, 110 percent of the total minority population is 51.3 percent, 70.4 percent, and 25.0 percent, respectively.

- Low-income populations – Low-income populations are defined relative to the annual statistical poverty thresholds from the US Census Bureau (CEQ 1997). The guidance does not provide criteria for determining low-income populations as specifically as it does for minority populations. Therefore, for this analysis, low-income populations are defined as people whose income is less than or equal to twice (200 percent of) the federal poverty level. For this analysis, populations are considered low-income populations when (1) 50 percent of the population is classified as low income, or (2) any geographic area of analysis has a low-income percentage of the population equal to or higher than the reference area.
- Tribal populations – Federally recognized Tribes are often considered environmental justice populations in and of themselves. When possible, they are included in the analysis as separate minority populations.
- Indigenous populations – For this analysis, additional screening was utilized to review US Census Bureau data for Indigenous populations: those who identify as American Indian or Alaska Native alone or in combination with one or more other races. Reclamation also used a threshold analysis and meaningfully greater analysis to identify Indigenous populations that meet the criteria for environmental justice consideration. For this analysis, populations are considered to meet the criteria for environmental justice consideration when (1) 50 percent of the population is Indigenous, or (2) any geographic area of analysis has an Indigenous population percentage equal to or higher than the reference area.

Table 3-54 provides an overview of the environmental justice screening results for the 11-county environmental justice analysis area.

Overall, all 11 analysis area counties (4 Arizona counties, 3 New Mexico counties, and 4 Utah counties) are identified as environmental justice communities, based on the criteria described above. As such, the analysis area has 11 environmental justice populations at the county level. Further, Coconino County, Arizona, and San Juan, Garfield, and Kane Counties, Utah, are identified as environmental justice communities based on both indicators of Indigenous and low-income populations. Apache County, Arizona; Navajo, Cibola, and McKinley Counties, New Mexico; and San Juan County, Utah, are identified as environmental justice communities based on all three indicators of minority, Indigenous, and low-income populations. See **Table 3-54** for more information; details for each indicator are provided below.

Additional information is also provided below on Tribal populations with the potential to be affected by the proposed management.

Table 3-54
Analysis Area Environmental Justice Screening Results (2022)

Geographic Area	Minority Population Percentage of Geographic Area (Meaningfully Greater Percentage)	Indigenous Population Percentage of Geographic Area	Low-Income Population Percentage of Geographic Area	Meets Criteria for Environmental Justice Communities of Concern?
Reference Area				
Arizona	47.0 (51.7)	5.9	30.8	-
New Mexico	64.4 (70.8)	11.5	38.8	-
Utah	23.2 (25.5)	2.1	23.9	-
Apache County, Arizona	81.8*	74.5*	57.9*	Yes
Coconino County, Arizona	47.0	28.1*	36.0*	Yes
Mohave County, Arizona	24.5	3.7	37.8*	Yes
Navajo County, Arizona	58.1*	45.6*	49.6*	Yes
Cibola County, New Mexico	81.9*	44.7*	51.2*	Yes
McKinley County, New Mexico	92.0*	80.6*	59.0*	Yes
San Juan County, New Mexico	63.8	42.2*	49.2*	Yes
Garfield County, Utah	11.7	3.0*	36.3*	Yes
Kane County, Utah	8.8	2.3*	32.4*	Yes
San Juan County, Utah	56.2*	48.7*	43.1*	Yes
Washington County, Utah	17.2	2.0	26.4*	Yes

Sources: US Census Bureau 2023a, 2023b, 2023c

*Meets the criteria for environmental justice community of concern.

Minority Population

In Arizona, Apache and Navajo Counties had total minority populations that exceeded the meaningfully greater threshold of 51.7 percent (81.8 percent and 47.0 percent, respectively). Cibola and McKinley Counties, New Mexico, had total minority populations (92.0 and 81.9 percent, respectively) that exceeded the meaningfully greater threshold of 70.8 percent. However, it is important to note that all three New Mexico counties had total minority populations well above 50 percent, ranging from 58.1 percent to 92.0 percent. One of the four Utah counties within the environmental justice analysis area, San Juan County, had a total minority population (56.2 percent) that exceeded the meaningfully greater threshold of 32.2 percent and is considered an environmental justice community. Compared with the state and other counties within the analysis area, Garfield, Kane, and Washington Counties, Utah, had smaller total minority populations, ranging from 8.8 to 17.2 percent. Overall, five counties had total minority populations that met the criteria for consideration as environmental justice communities.

To provide environmental justice population data at a finer geographic scale, Census Bureau data was also gathered at the census tract level. **Map 3-1** displays the minority populations at the census tract level.

Indigenous Population

In Arizona, all counties, excluding Mohave County, had Indigenous populations exceeding the state average Indigenous population (5.9 percent). In New Mexico, all counties had Indigenous populations exceeding the state average Indigenous population (11.5 percent). Cibola and San Juan Counties, New Mexico, had Indigenous populations exceeding the state average by over 30 percent. The Indigenous population was highest in McKinley County, New Mexico (80.6 percent). In Utah, all counties, excluding Washington County, had Indigenous populations exceeding the state average (2.0 percent), and the Indigenous population in San Juan County was notably higher than the other analysis area counties. **Map 3-2** displays the Indigenous populations at the census tract level. Overall, nine of the counties had total Indigenous populations that met the criteria for consideration as environmental justice communities.

It should be noted that the information above pertains to those counties that met or exceeded thresholds for total Indigenous populations. Additional Tribal populations at the Tribe and reservation levels are identified in the *Tribal Populations* section below.

Low-Income Population

All 11 analysis area counties had low-income populations that exceeded their respective state averages (Arizona: 30.8 percent; New Mexico: 38.8 percent; and Utah: 23.9 percent). As such, all counties had low-income populations that met the criteria for consideration as environmental justice communities. The total low-income population ranged from 26.4 percent in Washington County, Utah, to 59.0 percent in McKinley County, New Mexico. **Map 3-3** displays low-income populations at the census tract level.

Tribal Populations

As described above, two counties had Indigenous populations that did not exceed respective state averages. In Mohave County, Arizona, the total Indigenous population was 3.6 percent in 2021, falling below the state average of 5.8 percent. While the meaningfully greater criteria for Indigenous populations was not met at the county level, it is important to note the county overlaps with the Kaibab, Fort Mohave, and Hualapai Indian Reservations. Reservations meet the criteria for further consideration as environmental justice populations. Similarly, in Washington County, Utah, the total Indigenous population was 1.7 percent in 2021, falling below the state average of 2.2 percent. However, a portion of the Paiute Indian Reservation is in western Washington County and would be considered an environmental justice population for further consideration.

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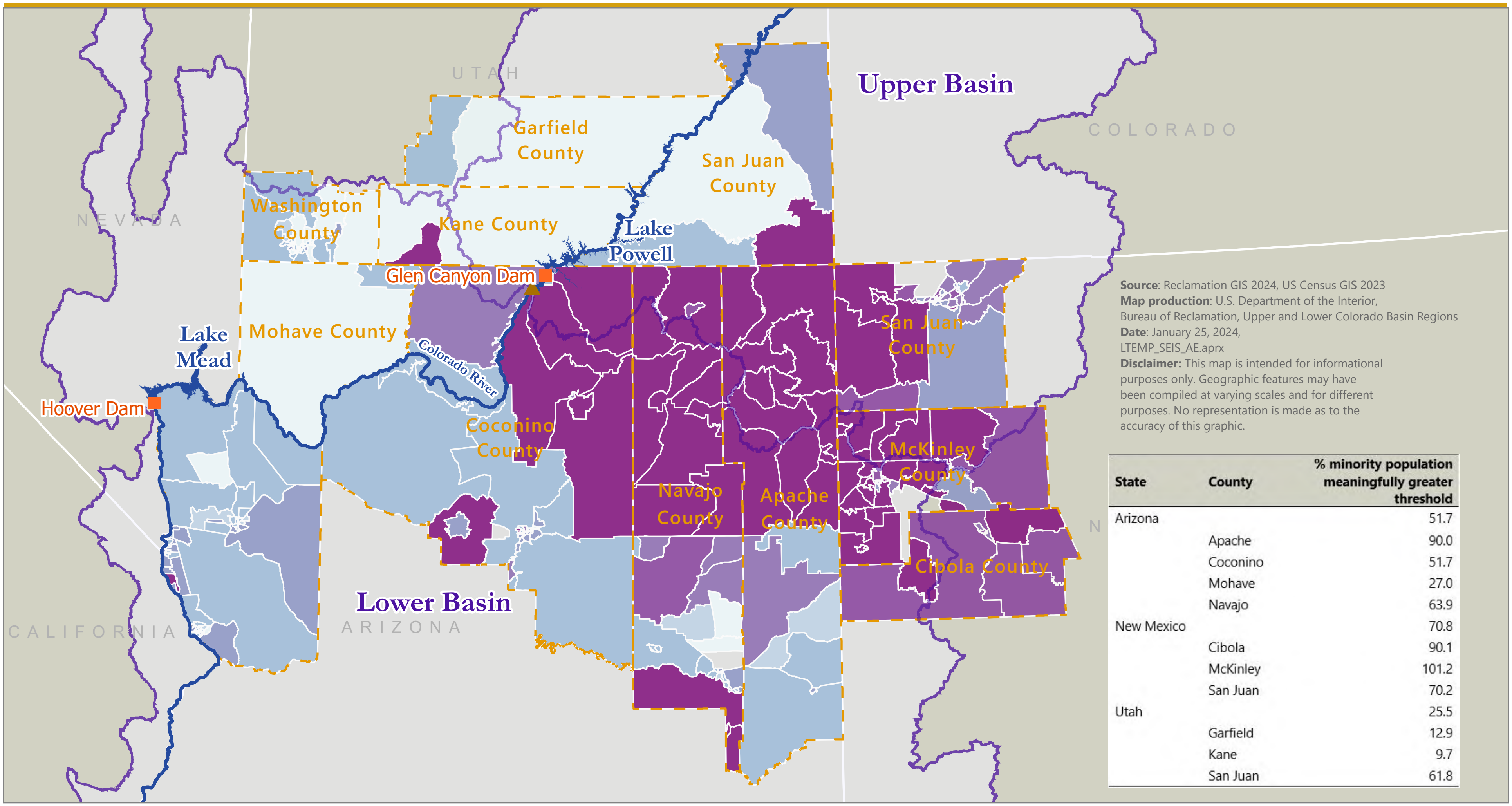
Map 3-1: Minority Populations for Environmental Justice Consideration



Source: Reclamation GIS 2024, US Census GIS 2023
Map production: U.S. Department of the Interior, Bureau of Reclamation, Upper and Lower Colorado Basin Regions
Date: January 25, 2024,
LTEMP_SEIS_AE.aprx
Disclaimer: This map is intended for informational purposes only. Geographic features may have been compiled at varying scales and for different purposes. No representation is made as to the accuracy of this graphic.

State	County	% minority population meaningfully greater threshold
Arizona		51.7
	Apache	90.0
	Coconino	51.7
	Mohave	27.0
	Navajo	63.9
New Mexico		70.8
	Cibola	90.1
	McKinley	101.2
	San Juan	70.2
Utah		25.5
	Garfield	12.9
	Kane	9.7
	San Juan	61.8

% of the population identifying as a racial and/or ethnic minority at the census tract level

- ▭ 0-9.7
- ▭ 9.8-12.9
- ▭ 13-26.9
- ▭ 27-50
- ▭ 50.1-70
- ▭ 70.1-90
- ▭ 90.1-100

- ⬚ Environmental justice study area: counties that may be affected by changes in the operation of hydropower facilities and/or changes in hydropower costs.
- Colorado River Basin, Upper and Lower Basins
- Stream or river
- ■ Dam
- ▲ Lees Ferry

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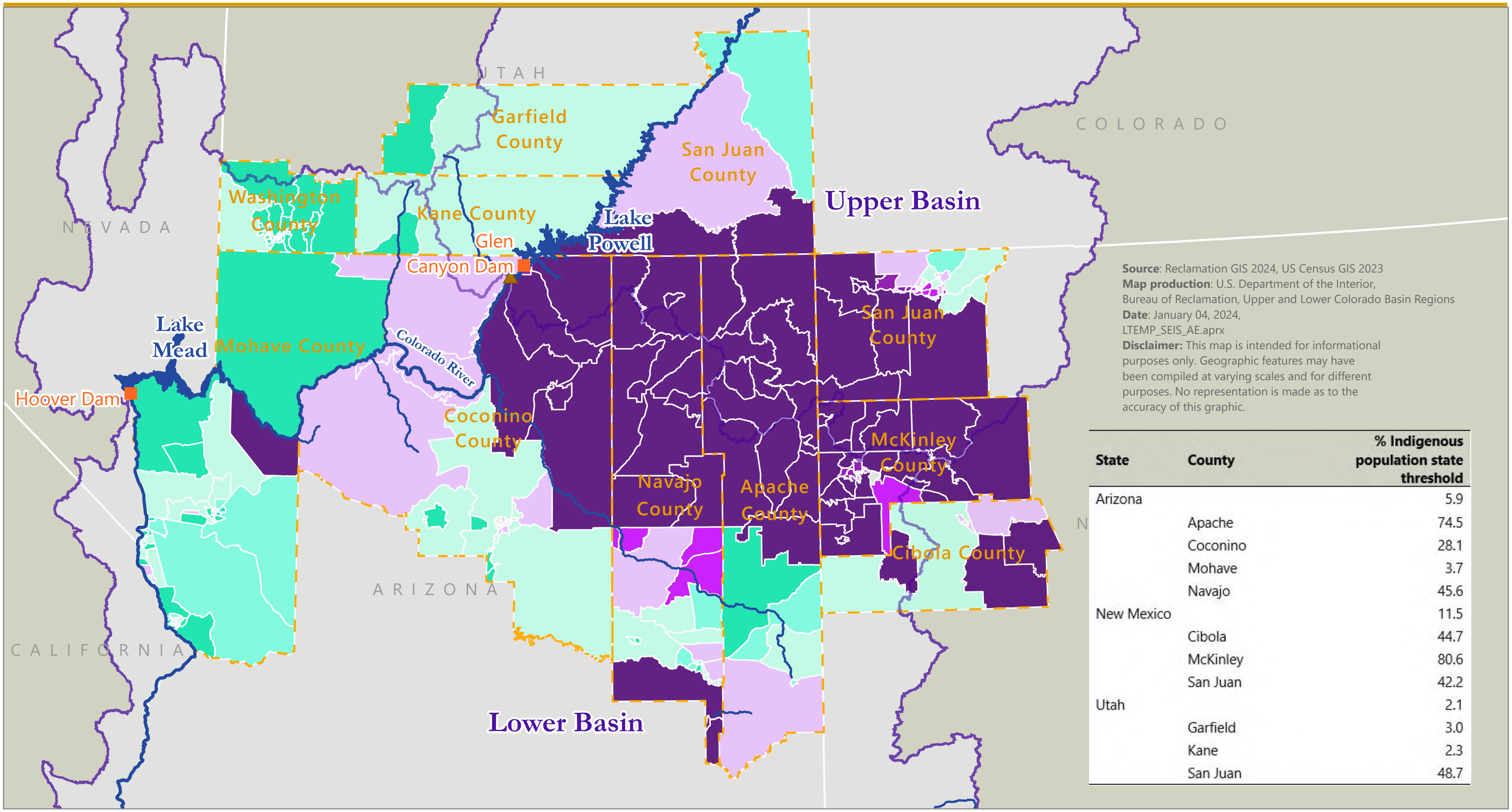
Map 3-2: Indigenous Populations for Environmental Justice Consideration



Source: Reclamation GIS 2024, US Census GIS 2023
Map production: U.S. Department of the Interior, Bureau of Reclamation, Upper and Lower Colorado Basin Regions
Date: January 04, 2024,
LTEMP_SEIS_AE.aprx
Disclaimer: This map is intended for informational purposes only. Geographic features may have been compiled at varying scales and for different purposes. No representation is made as to the accuracy of this graphic.

State	County	% Indigenous population state threshold
Arizona		5.9
	Apache	74.5
	Coconino	28.1
	Mohave	3.7
	Navajo	45.6
New Mexico		11.5
	Cibola	44.7
	McKinley	80.6
	San Juan	42.2
Utah		2.1
	Garfield	3.0
	Kane	2.3
	San Juan	48.7

% of the population identifying as an American Indian or Alaska Native (alone or in combination with one or more races) at the census tract level

- 🟩 0.0 - 0.2
- 🟩 2.3 - 3.8
- 🟩 3.9 - 10.0
- 🟪 10.1 - 28.0
- 🟪 28.1 - 49.9
- 🟪 50.1 - 74.4
- 🟪 74.5 -100

▭ Environmental justice study area: counties that may be affected by changes in the operation of hydropower facilities and/or changes in hydropower costs

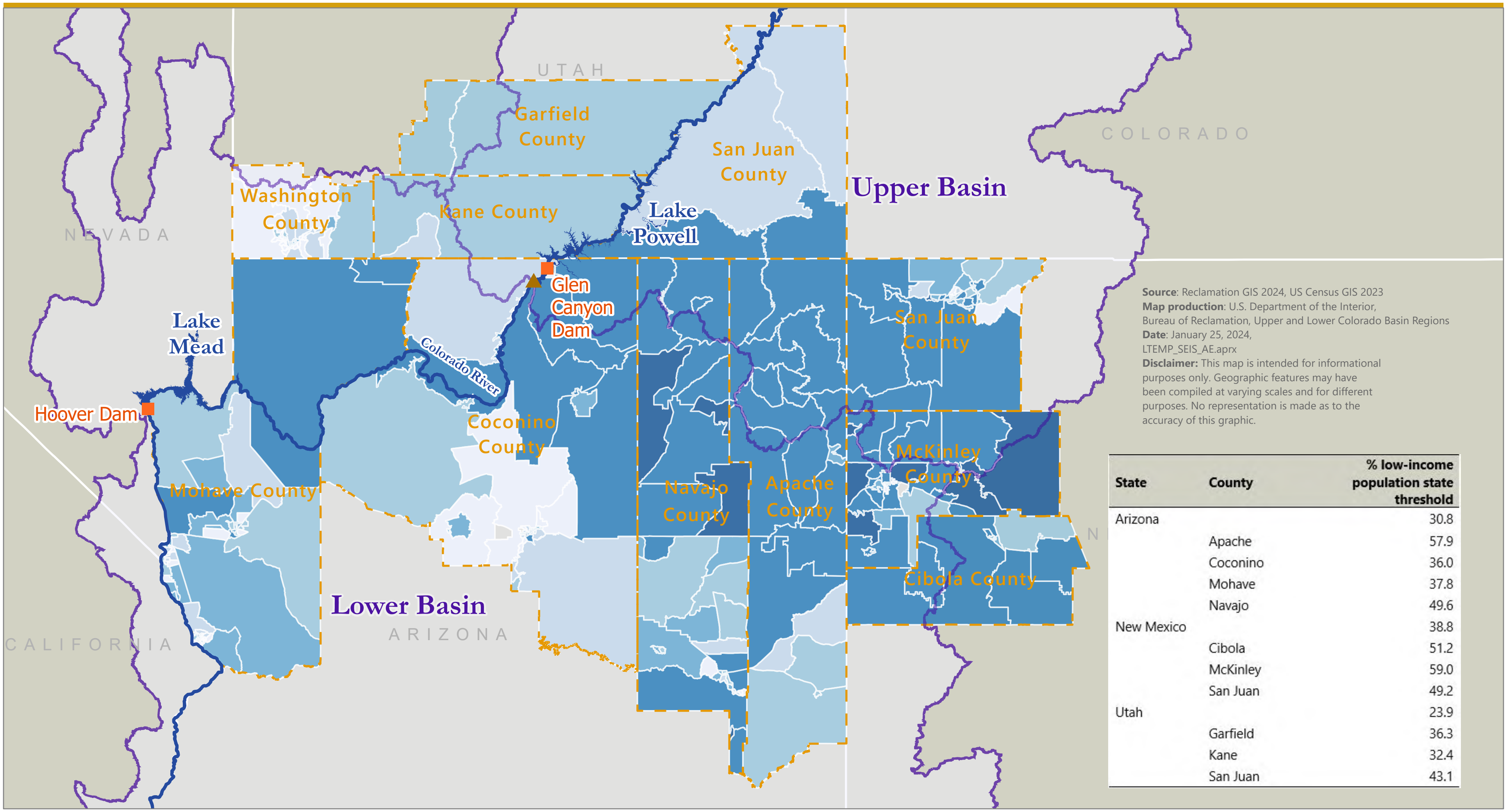
Colorado River Basin, Upper and Lower Basins

Stream or river

🟧 Dam

▲ Lees Ferry

Map 3-3: Low-Income Populations for Environmental Justice Consideration



Source: Reclamation GIS 2024, US Census GIS 2023
Map production: U.S. Department of the Interior, Bureau of Reclamation, Upper and Lower Colorado Basin Regions
Date: January 25, 2024,
LTEMP_SEIS_AE.aprx
Disclaimer: This map is intended for informational purposes only. Geographic features may have been compiled at varying scales and for different purposes. No representation is made as to the accuracy of this graphic.

State	County	% low-income population state threshold
Arizona		30.8
	Apache	57.9
	Coconino	36.0
	Mohave	37.8
	Navajo	49.6
New Mexico		38.8
	Cibola	51.2
	McKinley	59.0
	San Juan	49.2
Utah		23.9
	Garfield	36.3
	Kane	32.4
	San Juan	43.1

% of the population identifying as living at or below 200% of the federal poverty level at the census tract level

- ▢ 0-23.8
- ▢ 23.9-32.3
- ▢ 32.4-40
- ▢ 40.1-50
- ▢ 50.1-75
- ▢ 75.1-89.8

- ⌜ ⌟ Environmental justice study area: counties that may be affected by changes in the operation of hydropower facilities and/or changes in hydropower costs.
- Colorado River Basin, Upper and Lower Basins
- Stream or river
- ■ Dam
- ▲ Lees Ferry

Apache, Coconino, and Cibola Counties, New Mexico, and Kane County, Utah, had indigenous populations that exceeded environmental justice thresholds. Within these counties, there are Hopi Tribe, Havasupai Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Consortium Tribal reservation and off-reservation trust lands. As described in **Section 3.13.1**, the Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Navajo Nation, Pueblo of Zuni, and Southern Paiute Consortium all have strong cultural ties to the Colorado River. **Section 3.12** and **Section 3.13** provide more detailed information on cultural and Tribal resources.

Additionally, tribal members receive hydropower from WAPA, including hydropower from Glen Canyon Dam. It is important to note that Glen Canyon Dam is one component of a larger hydropower system and is included with other powerplants for marketing purposes. Capacity and energy from Glen Canyon Dam are bundled and marketed by WAPA as the Salt Lake City Area Integrated Projects (SLCA/IP) to end-use consumers across Arizona, Colorado, Nebraska, New Mexico, Nevada, Utah, and Wyoming.

In the 2016 LTEMP FEIS, Tribal populations with the potential to be affected by project management include those who receive annual SLCA/IP allocations. A comprehensive list of the annual SLCA/IP allocations to American Indian Tribes and benefit information were provided in the 2016 LTEMP FEIS (DOI 2016a, Appendix K, Attachment 12). The Tribes identified are also listed below:

- Ak-Chin Indian Community
- BIA Colorado River Agency
- San Carlos Irrigation Project
- Alamo Navajo Chapter
- Canoncito Navajo Chapter
- Cocopah Indian Tribe
- Colorado River Indian Tribes
- Confederated Tribes of the Goshute Reservation
- Duckwater Shoshone Tribe
- Ely Shoshone Tribe
- Fort Mojave Indian Tribe
- Ft. McDowell Mojave-Apache Indian Community
- Gila River Indian Community
- Havasupai Tribe
- Hopi Tribe
- Hualapai Tribe
- Jicarilla Apache Tribe*
- Las Vegas Paiute Tribe
- Mescalero Apache Tribe
- Nambe Pueblo
- Navajo Agricultural Products Industries
- Navajo Tribal Utility Authority
- Paiute Indian Tribe of Utah
- Pascua Yaqui Tribe
- Picuris Pueblo
- Pueblo De Cochiti
- Pueblo of Acoma
- Pueblo of Isleta
- Pueblo of Jemez
- Pueblo of Laguna
- Pueblo of Pojoaque
- Pueblo of San Felipe
- Pueblo of San Ildefonso
- Pueblo of San Juan
- Pueblo of Sandia
- Pueblo of Santa Clara
- Pueblo of Santa Domingo
- Pueblo of Taos

- Pueblo of Tesuque
- Pueblo of Zia
- Pueblo of Zuni
- Quechan Indian Tribe
- Ramah Navajo Chapter
- Salt River Pima-Maricopa Indian Community
- San Carlos Apache Tribe
- Santa Ana Pueblo
- Skull Valley Band of Goshute Indians
- Southern Ute Indian Tribe
- Tohono O'odham Utility Authority*
- Tonto Apache Tribe
- Ute Indian Tribe
- Ute Mountain Ute Tribe
- White Mountain Apache Tribe
- Wind River Reservation
- Yavapai Apache Nation
- Yavapai Prescott Indian Tribe
- Yomba Shoshone Tribe

Tribal members receive a significant portion of their electricity from WAPA, which currently targets an allocation of 55 percent of total Tribal electrical use to the 57 Tribes or Tribal entities currently receiving an allocation of power from SLCA/IP; this includes power from Glen Canyon Dam.

Ten Tribes operate their own electric utilities and receive power directly from WAPA. Power received directly from WAPA tends to be lower cost than other resources. A reduction in WAPA power allocation, therefore, translates into higher costs for Tribal utilities.

The remaining 47 Tribes have a benefit crediting arrangement. In a benefit crediting arrangement, the Tribe's electric service supplier takes delivery of the SLCA/IP allocation and in return gives an economic benefit or a payment to the Tribe. In other words, for Tribal customers without utility status, WAPA enters into third-party arrangements among WAPA, the Tribe, and another utility that can receive delivery of the power. Ideally, arrangements are made with local utilities in an area, such as a rural electric cooperate or investor-owned utility (however, exceptions apply for various reasons). Under benefit crediting agreements, the traditional utility receives WAPA power on behalf of the Tribe; subsequently, the utility receives the benefit of the lower-cost power and transfers the economic benefit of federal hydropower to the Tribe. Historically, Tribes had been marginalized and excluded from traditional marketing plan efforts; therefore, benefit crediting provides an administrative solution allowing Tribes to participate.

3.16.2 Environmental Consequences

The analysis of potential environmental justice impacts follows guidelines described in the CEQ's *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). To comply with Executive Order 12898, Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations (59 *Federal Register* 7629, February 11, 1994), the CEQ (1997) instructs agencies to determine whether minority or low-income populations might be affected by a proposed action and, if so, whether there might be disproportionately high and adverse human health or environmental effects on them. The analysis method has three parts: (1) a description of the geographic distribution of low-income and minority populations in the affected area; (2) an assessment to determine whether the impacts of changes in operation would produce impacts that are high and adverse; and (3) if impacts are high and adverse, a determination as to whether these impacts disproportionately affect minority and low-income populations.

This section relies on analysis in other resource sections to identify whether any of the alternatives are likely to have adverse human health or environmental impacts. These impacts are discussed in the context of potential for disproportionate adverse impacts on identified environmental justice communities. The environmental consequences analysis also incorporates information by reference from the 2016 LTEMP FEIS and the SMB EA (Reclamation 2023b), where applicable.

Impact Analysis Area

The impact analysis area is the same as that described in **Section 3.16.1**. The analysis of environmental justice issues considered impacts within the 11-county environmental justice analysis area in which disproportionately high and adverse human health and environmental effects on minority and low-income populations may occur (including Apache County, Coconino County, Mohave County, and Navajo County in Arizona; Cibola County, McKinley County, and San Juan County in New Mexico; and Garfield County, Kane County, San Juan County, and Washington County in Utah).

Other potential impacts related to environmental justice include changes in Tribal electricity retail rates and impacts on Tribal resources and values. Using CEQ guidelines, the impact assessment determined whether each alternative would produce impacts that are high and adverse. If impacts were high and adverse, a determination was made as to whether these impacts would disproportionately affect minority and low-income populations by comparing the proximity of locations where any high and adverse impacts are expected with the location of low-income and minority populations. If impacts are not high and adverse, there can be no disproportionate impacts on minority and low-income populations.

Assumptions

- Information to determine exactly which facilities at which replacement generation would occur is not available. All replacement generation would occur in the WECC region.

Impact Indicators

- Disproportionate and adverse human health or environmental impacts

Issue 1: How would changes in hydropower generation affect environmental justice communities?

No Action Alternative

As described in **Sections 3.3.2** and **3.15.2**, no changes would be made to Glen Canyon Dam operations under the No Action Alternative. Power generation would continue, similar to historical levels, with slight variations dependent on water availability and constraints outlined in the LTEMP FEIS. Revenue from energy sales would also continue to be generated similar to historical levels, with slight variations dependent on consumer demands, generation levels, and constraints outlined in the LTEMP FEIS.

As described in **Section 3.9.2**, the existing air quality conditions would continue for communities near Glen Canyon Dam, including environmental justice communities, and there would be no change in emissions of criteria pollutants due to changes at the Glen Canyon Dam facility.

Under the No Action Alternative, there would be no disproportionate adverse impacts on minority or low-income populations.

Impacts Common to Cold Water Alternatives

Compared with current conditions, all four cold water alternatives would include passing more water through the river outlet works where energy is not generated. Each flow scenario studied would reduce the energy generation and increase the amount of replacement energy required to meet demand in the interconnected transmission and distribution system. Under all cold water alternatives, there is potential for direct, indirect, and cumulative impacts on environmental justice communities as a result of changes to Glen Canyon Dam operations and reduced energy generation. These include financial impacts, changes to air quality through air emissions from replacement power, changes to Tribal resources, changes to regional economic activity related to recreation, and changes to use and nonuse values (Refer to **Sections 3.3**, **3.9**, **3.13**, and **3.15**).

As described in **Section 3.3.2**, changes in operation at Glen Canyon Dam would reduce available generating capacity at Glen Canyon Dam to varying degrees under all cold water alternatives. The financial impacts from the flow options would vary, depending on the reduction in the amount of power generated and the cost to purchase power from replacement sources.

Costs associated with reductions in electricity generation no longer provided by Glen Canyon Dam would mean changes in retail rates charged by WAPA customer utilities and, consequently, changes in the electric bills of residential customers. Changes in retail electricity rates and the corresponding impacts on residential customer bills would depend on the timing and magnitude of capacity expansion (DOI 2016a). However, cost of additional capacity required under the action alternatives to replace lost capacity at Glen Canyon Dam would have negligible impacts on electric bills paid by residential customers.

Further, impacts on environmental justice communities as a result of reduced power generation and resulting financial impacts would also depend on the degree to which environmental justice populations within the analysis area rely on power generation from Glen Canyon Dam and associated revenue. As noted in the 2016 FEIS, the amount of power sold by WAPA to customer utilities varies considerably (DOI 2016a, 4-383). Potential impacts would be experienced to a different degree by some utility groups. For instance, utility groups that are allocated a large fraction of their generation resources from Salt Lake City Area Integrated Projects include Tribal utilities and other small utilities (DOI 2016a, 4-383).

Environmental justice communities, including Tribal communities, may have less capacity to compensate for impacts resulting from changes to Glen Canyon Dam operations, including but not limited to decreased power generation, revenue loss, and increased retail rates. More detailed information can be found in Appendix K of the 2016 FEIS, as well as **Section 3.3**. Such rate impacts may be modeled by WAPA and made available for the Final SEIS.

As described in **Section 3.9.2**, reductions in hydropower generation from Glen Canyon Dam resulting from proposed flow alterations would result in air quality impacts due to the need for replacement power using generation sources with greater air emissions. Replacement power would most likely be provided from natural gas powerplants, with a smaller portion supplied by coal-fired powerplants. Renewable generation such as wind, solar, or other environmentally friendly sources may also be used for replacement power. Specific impacts on environmental justice communities would depend on the replacement energy source, location of emissions, and proximity to environmental justice communities. However, information to determine exactly which facilities at which replacement generation source would be used is not available. Because potential air quality impacts are anticipated to be negligible, environmental justice communities would not experience disproportionate adverse air quality impacts.

Impacts Common to All Action Alternatives

All action alternatives (the four cold water alternatives and the Non-Bypass Alternative) would involve changes to Glen Canyon Dam operations to disrupt smallmouth bass spawning. As described in **Section 3.13.2**, the action alternatives would result in negligible impacts on Tribal resources, including TCPs and cultural resources. However, under all action alternatives there could be smallmouth bass mortality and/or deterrence of smallmouth bass spawning. Fish mortality would disproportionally impact Tribal populations, for instance the Pueblo of Zuni, who hold the Canyons sacred and view fish mortality as an adverse impact on the TCP (the Colorado River). Overall, potential impacts on Tribal resources are not anticipated to result in disproportionate, adverse impacts on environmental justice communities.

As described in **Section 3.13.2 and Section 3.14.2**, all action alternatives would contribute to prevention of smallmouth bass establishment below Glen Canyon Dam, thereby contributing to the protection of native fish populations. Additionally, under all action alternatives, cold water below Glen Canyon Dam during and after releases would benefit rainbow trout populations and temporarily move ecological processes toward pre-drought conditions. All communities, including environmental justice communities, could benefit from the aforementioned impacts. All action alternatives are not anticipated to affect the regional economy resulting from boating in the Grand Canyon; as a result, there would be no subsequent impacts on environmental justice communities.

Potential impacts on environmental justice communities that differ among the action alternatives are discussed below.

Cool Mix Alternative

Compared with the other action alternatives, the Cool Mix Alternative would result in the most impacts on power generation. Because financial impacts are directly correlated with impacts from power generation, the Cool Mix Alternative would result in financial impacts due to loss in economic value of electrical energy. Of the action alternatives, the Cool Mix Alternative would result in the second-most financial impacts (see **Section 3.3.2**). A reduction in power generation capacity would need to be replaced by purchases and generation from other sources. As noted in **Section 3.3.2**, replacement energy sources needed to cover decreases in power generation, ultimately leading to decreased funds available in the Basin Fund, could result in increased cost to customers and, in some cases, may trigger a cost-recovery charge. The Cool Mix Alternative would result in the second-most potential impacts on environmental justice communities.

The Cool Mix Alternative would result in the greatest increase in air emissions and other criteria pollutants, compared with the No Action Alternative. As such, potential air quality impacts on environmental justice communities would be greater under the Cool Mix Alternative.

As described in **Section 3.5**, under the Cool Mix Alternative reduced water temperatures would improve water quality for rainbow trout, which would likely increase angler satisfaction in the short and long terms. Impacts on boating, the rafting concessionaire, and camping in the Glen Canyon reach and whitewater boating and camping in the Grand Canyon would be similar to those described under the No Action Alternative. As a result, there would be no recreational impacts on environmental justice communities.

Cool Mix with Flow Spike Alternative

Impacts on environmental justice communities would be similar to those described above, would depend on the same factors, and would generally be similar to those discussed under the Cool Mix Alternative. As described in **Section 3.3**, the Cool Mix with Flow Spike Alternative would result in the second-most impacts on power generation and the most financial impacts. As a result, impacts on environmental justice communities due to changes in power generation and the associated economic value of electrical energy would be greatest under the Cool Mix with Flow Spike Alternative.

Additionally, while flow spikes would benefit rainbow trout populations, they may reduce the quality of recreational experiences in terms of angling access. For environmental justice communities, impacts on angling access could be experienced differently. For instance, a low-income community could be less able to adjust to access issues that require them to travel further or utilize more financial resources to maintain access.

Cold Shock Alternative

As described in **Section 3.3**, of the action alternatives, the Cold Shock Alternative would have the third-fewest impacts on modeled power generation. As a result, the Cold Shock Alternative would result in the third-fewest potential financial impacts on environmental justice communities.

Cold Shock with Flow Spike Alternative

As described in **Section 3.3**, the Cold Shock with Flow Spike Alternative would have the second-fewest impacts on power generation. As a result, this alternative would have the second-fewest potential financial impacts on environmental justice communities.

Short-term impacts on environmental justice communities as a result of changes to angling access would be the same as those described under the Cool Mix with Flow Spike Alternative.

Non-Bypass Alternative

Compared with the No Action Alternative and action alternatives, impacts on recreation would be greatest under the Non-Bypass Alternative; however, this alternative would result in the fewest impacts on hydropower generation and the economic value of electrical energy. This is because the Non-Bypass Alternative explores a hydropower flow option that does not involve the use of Glen Canyon Dam's bypass system and instead focuses on changes in release volumes to disturb smallmouth bass spawning. Because the bypass system would not be used and, instead, there would be changes in release volume, under this alternative there would be an estimated economic value gain for electrical energy of around $0.97 million. Compared with the action alternatives, the Non-Bypass Alternative would result in the fewest potential financial impacts on environmental justice communities. All communities, including environmental justice communities, could potentially experience economic benefits under this alternative.

As described in **Section 3.9.2**, under the Non-Bypass Alternative the total LTEMP-related average air emissions would be reduced over the 5-year project timeline. Therefore, under this alternative, there is potential for improved air quality. All communities, including environmental justice communities, could benefit from potential air emissions reductions. Under the Non-Bypass Alternative, there would be no disproportionate impacts on environment justice communities.

As described in **Section 3.13.2**, the Non-Bypass Alternative would have the greatest potential impacts on fish and subsequent impacts on life. As described in **Section 3.13.2**, some Tribal populations, such as the Zuni Pueblo, experience adverse physical, mental, and psychological effects associated with fish mortalities and disruption to the fish lifecycle. As a result, the Non-Bypass Alternative would result in the greatest potential for disproportionate impacts on some Tribal populations from fish mortality.

As described in **Section 3.5.2**, the Non-Bypass Alternative would be less likely to benefit the rainbow trout fishery by reducing water temperatures, compared with the cold water alternatives. The low flows under this alternative would result in short-term impacts on boating, whitewater boating, and rafting access. Therefore, this alternative would result in the most potential for recreational impacts on environmental justice communities.

Cumulative Effects

As described in **Section 3.13.1**, cumulative impacts on Tribal values would occur under alternatives that disrupt spawning or result in fish mortality. The Zuni, in particular, have linked fish mortality in the Canyons with adverse physical, mental, and psychological effects within the Zuni Pueblo. Because the action alternatives could result in the taking of life within the Canyons, they would have an adverse impact on the Zuni culture and TCPs if Reclamation implements the flow options with expected fish mortality (see **Section 3.13.2**).

To assess whether environmental justice populations are particularly vulnerable and, as a result, likely to experience disproportionate adverse impacts in terms of resources and resource uses, it is helpful to consider sensitivity and exposure to potential impacts. Environmental justice populations, especially Tribal populations, may be impacted in ways the general population is not. As noted above, the Zuni Pueblo has the potential to be affected by changes to flow operations (exposure). Further, because of the cultural and spiritual connection to the life within the Canyons, the magnitude of impacts is increased for the Zuni Pueblo, resulting in increased sensitivity to potential fish mortality.

Therefore, cumulative disproportionate, adverse impacts on environmental justice communities, such as the Zuni Pueblo, would occur under the action alternatives.

Additionally, socioeconomic and environmental trends independent of this SEIS will contribute to cumulative effects. Electricity generation and human health in the Southwest are inextricably linked to water resources. In the Southwest, severe drought, aridification, wildfire, and temperatures have increased and are anticipated to continue to increase, and the area will remain vulnerable to water shortages and changes in hydrologic conditions. Trends of population growth have affected—and will continue to affect—the demand for electricity. Environmental justice communities, including Native American communities, are among the most at risk from climate change, often experiencing the worst effects because of higher exposure, higher sensitivity, and lower adaptive capacity for historical, socioeconomic, and ecological reasons (EPA 2017; USGCRP 2018; CDC 2021).

Potential impacts from the action alternatives would contribute to the cumulative effects of and be compounded by other state and federal projects related to water resources in the Lower and Upper Colorado River Basin, including those in the environmental justice study area. For example, in 2023, Reclamation published the IG SEIS. The environmental justice analysis area for this SEIS and the IG SEIS overlap. While the IG FEIS has not yet been published, the IG Draft SEIS noted the potential for impacts on environmental justice communities associated with potential water shortages from annual release volumes. The modeled water shortages analyzed in the IG SEIS are separate from this SEIS analysis, because the LTEMP only analyzes sub-annual releases. However, it is important to consider that changes in hydropower generation from the action alternatives are a component of the existing and potential future challenges related to Colorado River water resources that exist for environmental justice communities in the Southwest, including within the Glen Canyon Dam environmental justice analysis area.

Summary

Under all cold water alternatives, there is potential for direct, indirect, and cumulative impacts on environmental justice communities as a result of changes to Glen Canyon Dam operations and reduced energy generation. For the cold water alternatives, these include financial impacts, changes to air quality through air emissions from replacement power sources, changes to Tribal resources, changes to regional economic activity related to recreation, and changes to use and nonuse values (see **Sections 3.3**, **3.9**, **3.13**, and **3.15**). For the Non-Bypass Alternative, potential direct, indirect, and cumulative impacts on environmental justice communities as a result of changes to Glen Canyon Dam operations would include changes to Tribal resources, potential air emissions reductions, increased power generation, potential gains in the economic value of electrical energy, changes to regional economic activity related to recreation, and changes to use and nonuse values.

Because all 11 counties in the environmental justice analysis area meet one or more criteria for consideration as environmental justice populations, the action alternatives would impact environmental justice populations.

Impacts on environmental justice communities vary depending on capacity and revenue loss. Compared with the No Action Alternative, reductions in hydropower would be greatest under the Cool Mix with Flow Spike Alternative and least under the Non-Bypass Alternative. Financial impacts on Tribal customers would be higher than those on non-Tribal customers under the action alternatives. Impacts would depend on the degree to which Tribal customers rely on power from

Glen Canyon Dam, or the degree to which they receive financial benefits directly in relation to hydropower energy produced from Glen Canyon Dam.

Changes in river and reservoir recreational visitation might disproportionately impact low-income and minority populations, including Tribal communities, in the environmental justice analysis area. Temporary changes in access to culturally important Tribal resources and other areas of significance to Tribes may also impact Tribal members.

Overall, for the majority of resources and resource uses, impacts on minority, low-income, and Indigenous populations are not anticipated to be disproportionately adverse.

3.17 Climate Change

3.17.1 Affected Environment

Changes in operations at Glen Canyon Dam may have the potential to alter GHG emissions from other sources of electricity that can produce different levels of GHGs compared with hydroelectric power. Glen Canyon Dam reduces carbon dioxide (CO_2) emissions by about 1.4 to 3.5 million metric tons in an average year (DOI 2016a, Section 3.16), which equates to about 0.1 to 0.3 percent of the 11-state total emissions (EPA 2023a).

The planning area is within the Lower Colorado River Basin, where climatic conditions are driven by topography. Higher elevations are characterized by cold winters, cool summers, and abundant precipitation as snowfall, while lower elevations are characterized by mild winters, hot summers, and low rainfall (DOI 2016a, Section 3.1.3). The arid Lower Colorado River Basin is marked by episodes of intense drought and precipitation. Mid to late summers (July–September) are marked by late-afternoon thunderstorms of the North American monsoon season that supply 30 to 50 percent of annual precipitation. Elevation dramatically shapes the amount of precipitation and its relative contribution to runoff, so that 85 percent of annual runoff comes from the 15 percent of the Basin's area that is in the mountain headwaters (Kunkel et al. 2022).

Climate change is having serious consequences on the region's scarce water supplies. Higher temperatures have resulted in the region's aridification. Aridification describes a period of transition and an evolving baseline to an increasingly water-scarce environment, and a future of extreme events, such as droughts and floods (Colorado River Research Group 2018). Snowpack at high elevations plays a critical role in supplying water for lower arid region. Warming temperatures have driven decreases in snowpack, earlier snowmelt, higher-elevation snow lines, more winter rain events, increased peak winter flows, and reduced summer flows. Earlier spring snowmelt and higher temperatures have consequences during the summer that can lead to increased numbers of forest fires. Impurities in snow, such as dust or soot, enhance solar radiation absorption and melting rates. Sources of dust deposited on snowpack in the high mountains likely include nearby lands where soil-disturbing activity[24] has made the land susceptible to wind erosion and dust from the deserts of the

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[24] Activities such as exploration and development of energy resources, off-road vehicle use, agriculture, and grazing serve to destabilize soils, making them more susceptible to wind erosion (Duniway et al. 2019).

Colorado Plateau along with prevailing westerlies, and to dust from other southwestern deserts to some extent (USGCRP 2023).

Climate change refers to the change in the state of the climate, as determined by changes in its properties (e.g., temperature or precipitation) that persist for an extended period (IPCC 2021). Humans are estimated to have caused approximately 1.8°F (1.1°C) of global warming above preindustrial levels. At the current rate of warming, the temperature is likely to reach 2.7°F (1.5°C) in the near term (2024-2040). Observed increases in well-mixed GHG concentrations since around 1750 are unequivocally caused by human activities (IPCC 2021). GHGs trap absorbed radiation and result in warming of the atmosphere. The principal GHGs that enter the atmosphere due to human activities, including fossil fuel power generation, include CO_2, CH_4, nitrous oxide (N_2O), and other trace gases.

In 2021, Reclamation updated the climate and hydrology projections across the West using approaches that align with previous such reports (IPCC 2011 and 2018) and new techniques, data, and analyses. Under scenarios with higher GHG concentrations, increases in temperature are more severe (warmer) than in scenarios with lower GHG concentrations. In both the higher and lower scenarios, average temperatures are projected to increase across the West and annual precipitation is projected to decline in the Southwest (Reclamation 2021b).

3.17.2 Environmental Consequences

Methodology

The analysis of GHG emissions and climate change was conducted based on the latest CEQ guidance which improves transparency in reporting impacts). This guidance recommends that the NEPA analyses incorporate a quantitative climate change analysis in planning and environmental review processes, as appropriate, including the reporting of GHG emissions and the social cost of GHGs to disclose climate impacts (CEQ 2023).

Potential impacts on climate change associated with dam operations were compared in terms of GHG emissions for each alternative relative to emissions for the No Action Alternative. Glen Canyon Dam operation does not generate GHG emissions, but dam operations can indirectly affect climate change, regionally and globally, through varying contributions to the total mix of power generation in the region, which also includes coal-fired, natural gas-fired, hydroelectric, nuclear, and renewable generation sources. Similar to air emission factors, average GHG emission factors over the life of the Glen Canyon Dam were assumed to present a reasonable approximation. Over time, older and higher-emitting facilities are replaced by new zero- or lower-emission sources, and emissions-reduction equipment on existing facilities is upgraded.

To compute total GHG emissions under the alternatives, emissions were estimated using the methodology outlined in **Section 3.9**, Air Quality, for estimating air emissions, which used both the WECC Emissions & Generation Resource Integrated Database (eGRID) composite emission factors, as well as the WECC eGRID emission factors specific to coal power generation—coal power generation used to represent the highest emissions scenario. Composite GHG emission factors from the WECC region for 2021 were estimated to be 723.38 pounds per megawatt-hour (lb/MWh) for CO_2, 0.057 lb/MWh for CH_4, and 0.008 lb/MWh for N_2O. Coal power generation emission factors from the WECC region for 2021 were estimated to be 2,293 lb/MWh for CO_2, 0.254 lb/MWh for CH_4, and 0.037 lb/MWh for N_2O.

CO_2e, defined as the ratio of heat trapped by one unit mass of the GHG to that of one unit mass of CO_2 over a specific time period, is a measure used to compare various GHGs' heat-trapping impact and estimate their total effect on climate change. This analysis uses the conversion factors from the Intergovernmental Panel on Climate Change Sixth Assessment Report (CO_2 equals 1 for both 100- and 20-year time frames; CH_4 equals 29.8 for 100-year time frame and 82.5 for 20-year time frame, and for CH_4; and N_2O equals 273 for both 100- and 20-year time frames) (IPCC 2021).

Impact Analysis Area

Emissions are considered on an 11-state area regional basis; replacement power generation facilities may be anywhere in the region.

Assumptions

- The local climate would follow existing trends.
- The reservoir level would not change significantly under any proposed alternative.
- Power replacement would be 1:1 (i.e., 1 MWh of generation lost from the Glen Canyon Dam would be replaced by 1 MWh from another facility).
- Information to determine exactly which facilities at which replacement generation would occur is not available. All replacement generation would occur in the WECC region.
- The average GHG emissions per MWh from power generation on the regional grid will not change significantly during the temporal extent of the project.

Impact Indicators

- Change in the expected amount of power produced in MWh and GHG emissions produced to generate an equivalent amount of replacement power from other generation types.

Issue 1: How would flow alternation at the Glen Canyon Dam affect climate change through changes to GHG emissions?

No Action Alternative

Under the No Action Alternative, the existing level of hydropower generation would continue at its current level; therefore, as shown in **Table 3-55**, there would zero emissions of GHGs from other power generation sources under this alternative.

Table 3-55
No Action Alternative GHG Emissions

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	0.00	0.00
N_2O (metric tons)	0.00	0.00
CO_2(metric tons)	0.00	0.00
100-year CO_2e (metric tons)	0.00	0.00
20-year CO_2e (metric tons)	0.00	0.00
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0000	0.0000
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0000	0.0000

Sources: EPA 2023b; EMPS staff calculations

Cool Mix Alternative

River mile 61

Under the Cool Mix Alternative (river mile 61), a 1.58 percent reduction in total 5-year hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-56**, this reduction would be equal to 75,801,88 metric tons of CO_2e for the 100-year time horizon and 76,126.76 metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0039 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 240,806.36 metric tons of CO_2e for the 100-year time horizon and 242,271.63166 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0122 percent of the 11-state region total annual emissions.

Table 3-56
Cool Mix Alternative at Little Colorado River (River Mile 61)

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	5.94	26.48
N_2O (metric tons)	0.83	3.86
CO_2 (metric tons)	75,408.88	239,034.19
100-year CO_2e (metric tons)	75,801.88	240,806.36
20-year CO_2e (metric tons)	76,126.76	242,271.63
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0039	0.0122
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0039	0.0122

Sources: EPA 2023b; EMPSi staff calculations

River mile 15

Under the Cool Mix Alternative (river mile 15), a 1.00 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-57**, this reduction would be equal to 47,863.29 metric tons of CO_2e for the 100-year time horizon and 48,068.43 metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0024 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 152,051.44 metric tons of CO_2e for the 100-year time horizon and 152,976.65metric tons of CO_2e for the 20-year time horizon, which would represent 0.0077 percent of the 11-state region total annual emissions.

Table 3-57
Cool Mix Alternative at River Mile 15

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	3.75	16.72
N_2O (metric tons)	0.53	2.44
CO_2 (metric tons)	47,615.14	150,932.45
100-year CO_2e (metric tons)	47,863.29	152,051.44
20-year CO_2e (metric tons)	48,068.43	152,976.65
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0024	0.0077
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0024	0.0077

Sources: EPA 2023b; EMPSi staff calculations

Cool Mix with Flow Spike Alternative

River mile 61

Under the Cool Mix with Flow Spike Alternative at Little Colorado River, a 1.41 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-58,** this alternative would result in an increase of 67,618.14metric tons of CO_2e for the 100-year time horizon and 67,907.94metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0034 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 214,808.35metric tons of CO_2e for the 100-year time horizon and 216,115.43metric tons of CO_2e for the 20-year time horizon, which would represent 0.0109 percent of the 11-state region total annual emissions.

Table 3-58
Cool Mix with Flow Spike Alternative at Little Colorado River (River Mile 61)

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	5.30	23.62
N_2O (metric tons)	0.74	3.44
CO_2 (metric tons)	67,267.56	213,227.51
100-year CO_2e (metric tons)	67,618.14	214,808.35
20-year CO_2e (metric tons)	67,907.94	216,115.43
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0034	0.0109
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0034	0.0109

Sources: EPA 2023b; EMPSi staff calculations

River mile 15

Under the Cool Mix with Flow Spike Alternative at river mile 15, a 0.96 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-59**, this alternative would result in an increase of 46,141.58 metric tons of CO_2e for the 100-year time horizon and 46,339.34metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0023 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 146,581.93 metric tons of CO_2e for the 100-year time horizon and 147,473.86 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0075 percent of the 11-state region total annual emissions.

Table 3-59
Cool Mix with Flow Spike Alternative at River Mile 15

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	3.62	16.12
N_2O (metric tons)	0.51	2.35
CO_2 (metric tons)	45,902.35	145,503.19
100-year CO_2e (metric tons)	46,141.58	146,581.93
20-year CO_2e (metric tons)	46,339.34	147,473.86
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0023	0.0075
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0023	0.0075

Sources: EPA 2023b; EMPSi staff calculations

Cold Shock Alternative

River mile 61

Under the Cold Shock Alternative at Little Colorado River (river mile 61), a 0.71 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-60**, this alternative would result in an increase of 33,925.66 metric tons of CO_2e for the 100-year time horizon and 34,071.07 metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0017 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 107,774.57 metric tons of CO_2e for the 100-year time horizon and 108,430.37 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0055 percent of the 11-state region total annual emissions.

Table 3-60
Cold Shock Alternative at Little Colorado River (River Mile 61)

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	2.66	11.85
N_2O (metric tons)	0.37	1.73
CO_2 (metric tons)	33,749.77	106,981.43
100-year CO_2e (metric tons)	33,925.66	107,774.57
20-year CO_2e (metric tons)	34,071.07	108,430.37
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0017	0.0055
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0017	0.0055

Sources: EPA 2023b; EMPSi staff calculations

River mile 15

Under the Cold Shock Alternative at river mile 15, a 0.48 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-61**, this alternative would result in an increase of 23,104.60 metric tons of CO_2e for the 100-year time horizon and 23,203.62 metric tons of CO_2e for the 20 year time horizon, for the composite grid generation emissions scenario, representing 0.0012 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 73,398.36 metric tons of CO_2e for the 100-year time horizon and 73,844.98 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0037 percent of the 11-state region total annual emissions.

Table 3-61
Cold Shock Alternative at River Mile 15

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	1.81	8.07
N_2O (metric tons)	0.25	1.18
CO_2 (metric tons)	22,984.81	72,858.20
100-year CO_2e (metric tons)	23,104.60	73,398.36
20-year CO_2e (metric tons)	23,203.62	73,844.98
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0012	0.0037
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0012	0.0037

Source: EPA 2023b; EMPSi staff calculations

Cold Shock with Flow Spike Alternative

River mile 61

Under the Cold Shock with Flow Spike Alternative at Little Colorado River (river mile 61), a 0.57 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-62**, this alternative would result in an increase of 27,408.88 metric tons of CO_2e for the 100-year time horizon and 27,526.35 metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0014 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 87,072.15 metric tons of CO_2e for the 100-year time horizon and 87,601.97 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0044 percent of the 11-state region total annual emissions.

Table 3-62
Cold Shock with Flow Spike Alternative at Little Colorado River (River Mile 61)

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	2.15	9.57
N_2O (metric tons)	0.30	1.39
CO_2 (metric tons)	27,266.78	86,431.36
100-year CO_2e (metric tons)	27,408.88	87,072.15
20-year CO_2e (metric tons)	27,526.35	87,601.97
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0014	0.0044
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0014	0.0044

Sources: EPA 2023b; EMPSi staff calculations

River mile 15

Under the Cold Shock with Flow Spike Alternative at river mile 15, a 0.45 percent reduction in hydropower generation would result in an increase in GHG emissions from other sources of power generation. As shown in **Table 3-63**, this alternative would result in an increase of 21,455.78 metric tons of CO_2e for the 100-year time horizon and 21,547.73 metric tons of CO_2e for the 20-year time horizon, for the composite grid generation emissions scenario, representing 0.0011 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in an increase of 68,160.41 metric tons of CO_2e for the 100-year time horizon and 68,575.16 metric tons of CO_2e for the 20-year time horizon, which would represent 0.0035 percent of the 11-state region total annual emissions.

Table 3-63
Cold Shock with Flow Spike Alternative at River Mile 15

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	1.68	7.49
N_2O (metric tons)	0.24	1.09
CO_2 (metric tons)	21,344.54	67,658.80
100-year CO_2e (metric tons)	21,455.78	68,160.41
20-year CO_2e (metric tons)	21,547.73	68,575.16
Percentage of annual 11-state region total annual emissions 100-year CO_2e	0.0011	0.0035
Percentage of annual 11-state region total annual emissions 20-year CO_2e	0.0011	0.0035

Sources: EPA 2023b; EMPSi staff calculations

Non-Bypass Alternative

Under the Non-Bypass Alternative, the implementation of HFE releases routed through the generation facility would result in a 0.29 percent increase in hydropower generation compared with the No Action Alternative. An increase in hydropower generation could reduce power generation from GHG-emitting sources. As presented in **Table 3-64**, in the composite grid generation emissions scenario there would be a potential reduction of 13,769.42 metric tons of CO_2e for the 100-year time horizon and 13,828.43 metric tons of CO_2e for the 20-year time horizon, representing 0.0007 percent of the 11-state region total annual emissions. For the coal generation emissions scenario, this alternative would result in a reduction of 43,742.49 metric tons of CO_2e for the 100-year time horizon and 44,008.66 metric tons of CO_2e for the 20-year time horizon, representing 0.0022 percent of the 11-state region total annual emissions.

Table 3-64
Non-Bypass Alternative

GHGs	Grid Generation Average Emissions Scenario	Coal Generation Average Emissions Scenario
CH_4 (metric tons)	-1.08	-4.81
N_2O (metric tons)	-0.15	-0.70
CO_2 (metric tons)	-13,698.03	-43,420.58
100-year CO_2e (metric tons)	-13,769.42	-43,742.49
20-year CO_2e (metric tons)	-13,828.43	-44,008.66
Percentage of annual 11-state region total annual emissions 100-year CO_2e	-0.0007	-0.0022
Percentage of annual 11-state region total annual emissions 20-year CO_2e	-0.0007	-0.0022

Sources: EPA 2023b; EMPSi staff calculations

Cumulative Effects

In this analysis, the potential impacts on climate change associated with dam operations have been discussed in terms of indirect impacts from other power generation sources in the power grid; therefore, the climate change impacts are cumulative in nature. Past, present, and reasonably foreseeable future action that would result in GHG emissions would contribute to cumulative impacts from under each alternative. Among the action alternatives, the Cool Mix Alternative at Little Colorado River (river mile 61) would result in the highest cumulative climate change impacts, followed by the Cool Mix with Flow Spike Alternative at river mile 15, while; the Non-Bypass Alternative would result in the smallest cumulative climate change impacts. Under the Non-Bypass Alternative, potential reduction in GHG emissions would countervail contributions to GHG emissions from past, present, and reasonably foreseeable future actions to result in the smallest cumulative impacts on climate change.

Summary

Potential impacts on climate change associated with dam operations were compared in terms of GHG emissions for each alternative relative to emissions for the No Action Alternative. While the Glen Canyon Dam operation does not generate GHG emissions, dam operations can indirectly affect climate change, regionally and globally, through varying contributions to the total mix of power generation from sources that emit GHGs.

Chapter 4. Consultation and Coordination

4.1 Introduction

This chapter describes Reclamation's public involvement program and coordination with specific federal, state, and local agencies, along with Tribal consultations.

4.2 General Public Involvement Activities

The public involvement program leading to this Draft SEIS included project scoping, consultation, and coordination with Tribes, federal and state agencies, stakeholders, and the public. Reclamation developed and implemented a public involvement plan to satisfy the public participation requirements set forth in NEPA and to establish a consistent and constant level of engagement with interested parties and stakeholders. The multifaceted approach consisted of informational materials, consultation and coordination meetings, general and stakeholder outreach, and media relations. This approach also included incorporating public comments received during the SMB EA.

A variety of informational materials to educate and inform audiences about the study and related issues were employed. The existing GCDAMP website was updated and maintained for this SEIS. It contained project documents, points of contact, scoping materials, and the project schedule. An electronic mailing list was used to notify interested parties of website postings, project meetings, and documents. A project email account was maintained live during the entire period of preparing this SEIS for interested parties to express opinions, ask questions, and submit comments.

Reclamation published a Notice of Intent to prepare an SEIS in the *Federal Register* on October 4, 2023. A 30-day scoping comment period was held from October 4, 2023, to November 3, 2023. Reclamation notified interested parties of the NOI and scoping comment period through an email notification to the project mailing list on October 5, 2023. The email consisted of the NOI and information on two public webinars.

Reclamation held two virtual public webinars during the scoping period. One meeting was held on October 18, 2023, from 5:00 p.m. to 6:30 p.m. mountain daylight time, and 37 people attended. The second virtual public meeting was held on October 20, 2023, from 11:00 a.m. to 12:30 p.m. mountain daylight time, and 60 people attended. The webinars included an opening statement, a presentation that summarized the NOI, a range of hydrologic and operational scenarios that informed people about the SEIS analysis, an overview of potential alternatives being considered in the SEIS, information on the SEIS process schedule, and a question-and-answer session. The webinars were recorded and published on the GCDAMP website.

Public comments were accepted during the comment period by email and mail. A scoping summary report was prepared to summarize all public comments received during scoping. Reclamation made the public scoping comments and the scoping summary report available for public viewing in an accessible format on the project website.

This Draft SEIS is available for public review on the project website. Reclamation will hold three virtual public meetings to provide opportunities to learn more about the project, provide analysis, speak with Reclamation managers and resource specialists, and ask questions. Public comments will be accepted for 45 calendar days following the EPA's publication of the Notice of Availability in the *Federal Register*. Comments may be provided by email to LTEMPSEIS@usbr.gov or by mail to Bureau of Reclamation, Attn.: LTEMP SEIS Project Manager, 125 South State Street, Suite 800, Salt Lake City, Utah 84138.

4.3 Cooperating Agency Involvement

In compliance with NEPA and its implementing regulations, Reclamation worked with sixteen cooperating agencies in the preparation of this SEIS. As described in **Chapter 1**, cooperating agencies included the BIA, NPS, Service, WAPA, State of Nevada, Arizona Game and Fish, Salt River Project, UAMPS, Upper Colorado River Commission, Colorado River Board of California, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, and Pueblo of Zuni. In developing the Draft SEIS, Reclamation hosted five cooperating agency virtual meetings to obtain data, information, resource analyses, and review of internal documents. Additionally, individual agencies provided specific assistance, including the following:

- The Service has jurisdiction by law and special expertise with respect to the ESA, biological resources within the analysis area, and its administration of several wildlife refuges in the analysis area. The Service provided resource expertise and worked closely with Reclamation in developing a biological assessment to support consultation under Section 7 of the ESA.
- Given its jurisdiction of NPS units within the Basin and administration of recreation on Lake Powell and Lake Mead, the NPS provided data and analysis of potential impacts on resources under its management.
- WAPA provided models for Glen Canyon Dam to aid in resource-specific modeling. WAPA also provided hydroelectric modeling to assess impacts on power generation and revenue across the major generation facilities in the Upper Basin.

While not a cooperating agency, the USGS contributed expertise and resource modeling support based on their role as the science and monitoring provider to the Glen Canyon Dam Adaptive Management Program.

4.4 Tribal Consultation and Coordination

For purposes of this NEPA process, Reclamation is consulting and coordinating with Tribes who participated in the LTEMP FEIS. These include the Havasupai Tribe of the Havasupai Reservation, Arizona; Hopi Tribe; Hualapai Tribe; Kaibab Band of Paiute Indians; Navajo Nation; and Zuni Tribe. Representatives of various Indian Tribes also attended the scoping meetings in October 2023. Two Tribes provided Reclamation with written comments during the scoping process. Several of the Tribes are also cooperating agencies.

4.4.1 Summary of Tribal Consultation and Coordination

Formal Tribal consultation began on November 8, 2023, with a letter from the Upper Colorado Basin Regional Director. Informal consultation with representatives of the Tribes has occurred throughout the process via monthly calls, coordination meetings, LTEMP PA meetings, formal and informal phone calls, and emails. Reclamation has received signed cooperating agency letters from all but one of the Tribes invited to be Cooperating Agencies.

4.5 ESA Section 7 Consultation

In 2016, the Service finalized ESA Section 7 consultation for the LTEMP FEIS due to impacts on the threatened and endangered species. Reclamation initiated interagency consultations per 16 U.S. Code 1531 with FWS in January 2023 while writing the SMB EA. The SMB EA contained alternatives similar to the LTEMP SEIS, but this SEIS includes a non-bypass flow option not considered in the SMB EA. Consultation through meetings and letter exchanges with FWS on this LTEMP SEIS began in July 2023, and is ongoing. Reclamation is currently writing a biological assessment, with an anticipated finalization of the biological opinion in Spring 2024.

The ESA Section 7 interagency consultations (16 U.S. Code 1531) were initiated with the Service in January 2023. They continued through a series of meetings and email exchanges, during which listed species were identified, actions and action areas were discussed, and conservation measures were developed. A biological assessment was developed in relation to LTEMP. Consultation is ongoing with an anticipated finalization of the biological opinions in the spring 2024.

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List of Preparers

The Draft SEIS was prepared by Reclamation with resource modeling and analysis support from the Service, BIA, NPS, WAPA, State of Nevada, AZGFD, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians Tribe, Navajo Nation, Pueblo of Zuni, Salt River Project, UAMPS, Upper Colorado River Commission, and Colorado River Board of California. The following is a list of preparers who developed significant background material and various sections, or they participated, to a significant degree, in the preparation of this Draft SEIS.

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Glossary

acre-foot (af)—Volume of water (43,560 cubic feet) that would cover 1 acre to a depth of 1 foot.

adaptive management—A method for examining alternative strategies for meeting measurable biological goals and objectives, and then, if necessary, adjusting future conservation management actions according to what is learned.

affected environment—Existing biological, physical, social, and economic conditions of an area that are subject to change, both directly and indirectly, as the result of a proposed human action.

algae—Simple plants containing chlorophyll; most live submerged in water.

alluvium—Sedimentary material transported and deposited by the action of flowing water.

ambient—Surrounding natural conditions (or environment) in a given place and time.

amphibian—A vertebrate animal that has a life stage in water and a life stage on land. (Examples include salamanders, frogs, and toads.)

annual flow-weighted average concentration—A weighted average of monthly total dissolved solids (TDS) concentrations for a year, where the weight for each month is based on the relative flow for each month.

backwater—A relatively small, generally shallow area of a river with little or no current.

base load—Minimum load in a power system over a given period of time.

Basin States—In accordance with the Colorado River Compact of 1922, the Colorado River Basin within the United States consists of those parts of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming within and from which waters drain naturally into the Colorado River. These seven states are referred to as the Basin States. *See also* Colorado River Compact of 1922.

biological assessment (BA)—A document identifying the likely effects of a proposed federal action on threatened and endangered species. To facilitate compliance with Section 7(a)(2) of the Endangered Species Act (ESA), federal agencies must prepare a BA pursuant to Section 7(c)(1) of the ESA. *See also* Endangered Species Act.

biological opinion (BO)—A document stating the opinion of the United States Fish and Wildlife Service (Service) and/or the National Marine Fisheries Service as to whether a federal action is likely to jeopardize the continued existence of a threatened or endangered species or result in the destruction or adverse modification of critical habitat.

bypass flows—Saline agricultural return flows from the Wellton-Mohawk Irrigation and Drainage District that are routed to the Cienega de Santa Clara in Mexico to ensure compliance with the salinity provisions of Minute 242 of the 1944 Water Treaty.

bypass tubes—Another term for river outlet works.

candidate species—A plant or animal species that is not yet officially listed as threatened or endangered under the ESA but is undergoing status review by the Service.

capacity—The maximum amount of energy that can be instantaneously produced.

catch—At a recreational fishery, refers to the number of fish captured, whether they are kept or released.

channel (watercourse)—An open conduit either naturally or artificially created that periodically or continuously contains moving water, or that forms a connecting link between two bodies of water. Some terms used to describe natural channels are river, creek, run, branch, and tributary. Natural channels may be single or braided. Two terms used to describe artificial channels are canal and floodway.

Cladophora—Filamentous green alga important to the food chain in the Colorado River downstream of Glen Canyon Dam.

Colorado River Basin (Basin)—The drainage area of the Colorado River system. The Basin occupies an area of approximately 250,000 square miles in the southwestern United States and 3,500 square miles in northwestern Mexico. The Colorado River Compact of 1922 divided the Colorado River system into two subbasins: the Upper Basin and the Lower Basin. It also divided the seven states within the Basin into the Upper Division and the Lower Division. Upper Division States include Colorado, New Mexico, Utah, and Wyoming; Lower Division States include Arizona, California, and Nevada. Additionally, 30 federally recognized Tribes are in the Basin.

Colorado River Basin Project Act of 1968 (CRBPA)—An act authorizing construction of a number of water development projects, including the Central Arizona Project (CAP), and requiring the Secretary to develop the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, or Long-Range Operating Criteria (LROC).

Colorado River Basin Salinity Control Forum—The organization dedicated to controlling Colorado River salinity; it consists of representatives of the seven Basin States.

Colorado River Compact of 1922—The agreement concerning the apportionment of the use of the waters of the Colorado River Basin, dated November 24, 1922, and executed by commissioners for Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming. It was approved and proclaimed effective by Herbert Hoover, the president of the United States, and representative of the United States for purposes of the Compact, on June 25, 1929.

Colorado River Simulation System (CRSS)—An operational model of the Colorado River Basin based on a monthly time step.

Colorado River system—The portion of the Colorado River and its tributaries within the United States as defined in the Colorado River Compact of 1922.

compact—The Colorado River Compact of 1922.

compact point—The reference point designated by the Colorado River Compact of 1922 as dividing the Colorado River Basin into two subbasins, the Upper Basin and the Lower Basin. The compact point is Lee Ferry, Arizona. *See also* Lee Ferry Compact Point.

conductivity—A measure of water's ability to pass an electrical current.

Consolidated Decree—A decree entered by the United States Supreme Court on March 27, 2006, in the case of *Arizona v. California,* 547 US 150 (2006), incorporating all applicable provisions of the earlier-issued decisions and decrees in the matter. The Supreme Court reached a decision in the case of *Arizona v. California* in 1963 and implemented this decision in a 1964 decree, which was supplemented over time after its adoption.

contractors—Those who hold entitlements to Colorado River water. Contractors consist of the federal government, states, Indian Tribes, and various public and private entities that are recognized under the Consolidated Decree, hold a Section 5 Contract with the Secretary, or have a Secretarial Reservation of water. *See also* Consolidated Decree.

conveyance loss—Water that is lost in transit from a pipe, canal, conduit, or ditch by leakage or evaporation. If the water is lost due to leakage, it may be considered return flow if it percolates to an aquifer and is available for reuse. If the water evaporates, it is considered consumptive use.

cooperating agency—With respect to the National Environmental Policy Act of 1969, as amended (NEPA) process, an agency that has jurisdiction by law or special expertise concerning an aspect of a proposed federal action and that is requested by the lead agency to participate in the preparation of an environmental impact statement (EIS).

covered species—Those species addressed in the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) for which conservation measures would be implemented and for which authorization for "take" is being requested under Section 10 of the ESA. *See also* take.

criteria—Standards used for making a determination.

critical habitat—Specific areas with physical or biological features essential to the conservation of a listed species and that may require special management considerations or protection. These areas have been legally designated via *Federal Register* notices.

cubic foot per second (cfs)—A measure of water flow equal to 1 cubic foot of water passing a point on the stream in 1 second of time.

cultural resource—A building, site, district, structure, or object significant in history, architecture, archaeology, culture, or science.

dead pool—Elevation at which water cannot be regularly released from a reservoir, which would effectively preclude Colorado River diversions to downstream users.

dead storage—Reservoir space from which stored water cannot be evacuated by gravity.

delta sediment—Deposit formed at the mouth of the Colorado River and other rivers where they enter Lake Powell, or Lake Mead.

depletion—Loss of water from a stream, river, or basin resulting from consumptive use.

deposition—Settlement of material out of the water column and on to the streambed. Occurs when the energy of flowing water is unable to support the load of suspended sediment.

discharge (flow)—Volume of water that passes a given point within a given period of time; expressed in this SEIS in cubic feet per second (cfs). *See also* cubic foot per second.

dissolved oxygen (DO)—Amount of free oxygen found in water; perhaps the most commonly employed measurement of water quality. Low DO levels adversely affect fish and other aquatic life. The ideal dissolved oxygen for fish life is between 7 milligrams per liter (mg/L) and 9 mg/L; most fish cannot survive when DO falls below 3 mg/L.

diversion(s)—Colorado River water withdrawn from the mainstream, including water diverted from reservoirs or drawn from the mainstream by underground pumping.

domestic use—Refers to the use of water for household, stock, municipal, mining, milling, industrial, and other like purposes; excludes the generation of electrical power.

draw down—Lowering of a reservoir's elevation; process of depleting a reservoir or groundwater storage.

ecosystem—Complex system composed of a community of fauna and flora and that system's chemical and physical environments.

electric power system—Physically connected facilities for electricity generation, transmission, and distribution that are operated as a unit under one control.

electrical demand—Energy requirement placed upon a utility's generation at a given instant or averaged over any designated period of time.

endangered species—A species or subspecies whose survival is in danger of extinction throughout all or a significant portion of its range.

Endangered Species Act (ESA)—The Endangered Species Act (ESA) of 1973 (16 USC 1531–1544), as amended; under Section 9, it provides for the prohibition of "take" of any fish or wildlife species listed as threatened or endangered under the ESA unless specifically authorized by regulation. *See also* take.

energy—What is produced by power plants; measured in kilowatt hours.

epilimnion—Thermal layering of water in lakes and streams. *See also* stratification.

firm energy or power—Non-interruptible energy or power guaranteed by the supplier to be available at all times except for reasons of uncontrollable forces or "continuity of service" contract provisions.

flood—An overflow or inundation that comes from a river or other body of water, and causes or threatens damage. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a river or stream. A relatively high flow as measured by either gage height or discharge quantity.

flow—Volume of water passing a given point per unit of time expressed in cubic foot per second. *See also* cubic foot per second.

forage fish—Generally, small fish that reproduce prolifically and are consumed by predators.

fore bay—Impoundment immediately above a dam or hydroelectric plant intake structure. The term is applicable to all types of hydroelectric developments (storage, run-of-river, and pumped storage).

fry—Life stage of fish between the egg and fingerling stages.

full pool—Volume of water in a reservoir at maximum design elevation.

gaging station—Specific location on a stream where systematic observations of hydrologic data are obtained through mechanical or electrical means.

gigawatt-hour (GWh)—One billion watt-hours of electrical energy.

headwater—The source and upper part of a stream.

historic property—Any district, site, building, structure, or object listed on or eligible for listing on the National Register of Historic Places (36 CFR 800.16(l)(1)).

hydropower—The use of water to produce electricity.

hypolimnetic zone—The deep portion of a lake or reservoir volume generally classified as below the level of the thermocline.

hypolimnion—Thermal layering of water in lakes and streams; the lower stratum of the water column of a reservoir. This layer is generally undisturbed, and respiration and decomposition predominate. *Also see* stratification.

important farmlands—Prime farmland, unique farmland, farmland of statewide importance, and farmland of local importance, as defined by the United States Department of Agriculture Natural Resources Conservation Service (formerly the Soil Conservation Service). The categorization of farmland is based on a soil classification system that accounts for the physical and chemical characteristics of the land and the suitability of the land for producing crops. Important farmlands are afforded special protection due to their importance to agricultural production.

impoundment—Body of water created by a dam.

in situ—In archaeology, and as used in this SEIS, an artifact that has not been moved from its original place of deposit.

incidental take—Defined under the ESA as take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity" (50 CFR 17.22 and 17.32). *See also* take.

Indian trust assets (ITAs)—"Legal interests" in "assets" held in "trust" by the federal government for federally recognized Indian Tribes or individual Indians.

inflow—Water flowing into a lake or reservoir from a river and/or its tributaries, or water entering a river from tributaries.

irrigated area—The gross farm area upon which water is artificially applied for the production of crops, with no reduction for access roads, canals, or farm buildings.

irrigation—The controlled application of water to arable lands to supply water requirements not satisfied by rainfall.

juvenile—Young fish older than 1 year but not having reached reproductive age.

kilowatt-hour (kWh)—One thousand watt-hours of electrical energy.

land cover type—A classification system to describe vegetation and other habitat types (such as cottonwood willow, honey mesquite, and marsh).

landscape character—Overall visual appearance of a given landscape based on the form, line, color, and texture associated with the landscape's vegetation, landforms/water, and human-made modifications. These factors give the area a distinctive quality that distinguishes it from its immediate surroundings.

Law of the River—As applied to the Colorado River, a body of documents the Secretary uses to carry out the responsibility to manage the mainstream waters of the Lower Basin pursuant to applicable federal law. The Secretary is vested with this responsibility. This collective set of documents comprising numerous operating criteria, regulations, and administrative decisions included in federal and state statues, interstate compacts, court decisions and decrees, an international treaty, and contracts with the Secretary apportions the Colorado River waters and regulates the use and management of the Colorado River among the seven Basin States and Mexico.

lead agency—An agency initiating and overseeing the preparation of an EIS. For this SEIS, Reclamation is the lead agency for compliance with NEPA.

Lee Ferry Compact Point—Identified the reference point that marks the division between the two subbasins—the Upper Basin and the Lower Basin—created by the division of the Colorado River Basin in the Colorado River Compact of 1922. This reference point is in the mainstream Colorado River in Arizona, 1 mile below the confluence of the Colorado River with the Paria River.

Lees Ferry Gaging Station—The site of the United States Geological Survey (USGS) stream gage (Lees Ferry Gaging Station) in Arizona on the Colorado River upstream of its confluence with the Paria River, downstream of Glen Canyon Dam. Also, the location of Colorado River ferry crossings (1873 to 1928).

limnology—Scientific study of physical characteristics and the biology of lakes, ponds, and streams.

load—Amount of electrical power or energy delivered or required at a given point.

magnitude—A number characteristic of a quantity and forming a basis for comparison with similar quantities, such as flows.

mean monthly flow—Average flow for the month, usually expressed in cubic feet per second.

mean sea level (msl)—The average height of the surface of the oceans and seas measured throughout all stages of the tidal cycle, determined from hourly readings of tidal height, and computed over a long (usually 19-year) period. It is used as a datum plane (that is, it serves as the reference surface from which elevations and depths are measured).

median—Middle value in a distribution, above and below which lie an equal number of values.

megawatt (MW)—One million watts of electrical power (capacity).

megawatt-hour (MWh)—One million watt-hours of electrical energy.

Mesozoic era—The second-to-last era of earth's geological history, lasting from about 252 to 66 million years ago, comprising the Triassic, Jurassic, and Cretaceous periods.

metalimnion—Thermal layering of water in lakes and streams. *See also* stratification.

milligram per liter (mg/L)—Equivalent to one part per million.

National Environmental Policy Act of 1969, as amended (NEPA)—Law requiring federal agencies to integrate environmental values into their decision-making processes by considering the environmental impacts of their proposed actions and reasonable alternatives to those actions. To meet this requirement, federal agencies prepare a detailed statement known as an environmental impact statement, or EIS.

National Register of Historic Places (NRHP)—The Nation's official list of cultural resources worthy of preservation. Authorized under the National Historic Preservation Act of 1966, the NRHP is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect our historic and archaeological resources. Properties listed on the NRHP include districts, sites, buildings, structures, and objects that are significant in American history, architecture, archaeology, engineering, and culture.

natural flow—The flow of any stream un-depleted by human activities.

non-system water—Waters originating from outside the Colorado River system.

normal condition—When the Secretary has determined that there is available for annual release 7.5 million acre-feet (maf) to satisfy consumptive use in the Lower Division States pursuant to Article II(B)(1) of the Consolidated Decree.

oligotrophic—A body of water characterized by low dissolved plant nutrient and organic matter, and rich in oxygen at all depths.

Paleontological resources—Any fossilized remains, traces, or imprints of organisms preserved in or on the earth's crust.

Paleozoic era (541–252 million years ago)—Means ancient life. The oldest animals on earth appeared just before the start of this era.

Pangea—A supercontinent that existed from about 300 to 200 million years ago and included most of the continental crust of the earth.

peak flow—Maximum instantaneous flow in a specified period of time.

peak load—Maximum electrical demand in a stated period of time.

penstock—Conduit pipe used to convey water from the reservoir through the dam under pressure to the turbines of a hydroelectric plant.

percentile—A statistical term. A descriptive measure that splits ranked data into 100 parts, or hundredths. For example, the 10th percentile is the value that splits the data in such a way that 10 percent of the values are less than or equal to the 10th percentile.

piscivorous—Habitually feeding on fish.

PM_{10} (PM10)—Particulate matter (PM) (dust particles) standard that includes particles with a diameter of 10 micrometers or less.

power—Electrical capacity generated, transferred, or used.

probability—In this SEIS, the relative frequency with which a range of modeled values occurs. For example, the probability of Lake Mead's elevation exceeding 1,180 feet msl in June 2005 is equal to the number of modeled elevations greater than 1,180 feet msl in June 2005, divided by the total number of modeled elevations in June 2005.

public involvement—Process of obtaining citizen input into each stage of development of planning documents. Required as a major input into any EIS.

Quaternary period—A geologic time period that encompasses the most recent 2.6 million years, including the present day.

ramp rate—The rate of change in instantaneous output from a powerplant. The ramp rate is established to prevent undesirable effects due to rapid changes in loading or, in the case of hydroelectric plants, discharge.

rated head—Water depth for which a hydroelectric generator and turbines were designed.

reach—A specified segment of a river, stream, channel, or other water conveyance facility.

recruitment—Survival of young plants and animals from birth to a life stage less vulnerable to environmental change.

reregulating reservoir—A reservoir for reducing diurnal fluctuations resulting from the operation of an upstream reservoir for power production.

resampling—The digital process of changing the sample rate or dimensions of sampled data (for example, digital imagery or audio) by temporarily or areally analyzing and sampling the original data.

reserved water—In the case of Indian reservations, rights based on the doctrine of Indian reserved rights; in the case of federal establishments other than Indian reservations, a federal reservation of water for use on property under federal jurisdiction.

reservoir—A pond, lake, or basin, either natural or artificial, for the storage, regulation, and control of water.

return flow—The portion of water previously diverted from a river or stream and subsequently returned to that river or stream; it is available for consumptive use by others.

return flow credit—In the accounting of consumptive use in the Lower Basin, Colorado River water that is returned to the river and is available for consumptive use by others in the year in which it was diverted is credited against a water user's total diversions.

revenue—The total income generated by a business or organization from its primary activities, such as sales of goods or services. It is a crucial financial metric, representing the money earned before deducting expenses.

riffle—A stretch of choppy water caused by an underlying rock shoal or sandbar.

riparian—Of, on, or pertaining to the bank of a river, pond, or lake.

river mile—Numbered along the Colorado River from south to north starting with RM 0.0 at the Southerly International Boundary (SIB) with Mexico. Dam locations are noted at their respective river miles.

river outlet works—Dam structures that conduct water from the reservoir to the river without passing through a powerplant; also referred to as jet tubes, bypass tubes, or outlet works.

river stage—Water surface elevation of a river above a datum.

runoff—That part of the precipitation that appears in surface streams. It is the same as streamflow unaffected by artificial diversions, storage, or other works of humans in or on the stream channels.

sacred site—A specific location identified by a Native American Tribe as sacred for its religious significance to, or ceremonial use by, a Native American religion.

salinity—A term used to refer to the dissolved minerals in water; also referred to as total dissolved solids (TDS). *See also* total dissolved solids.

sandbar—A long, narrow deposition of sediment within a river.

Secretary—The Secretary of the Department of the Interior, and duly appointed successors, representatives, and others with properly delegated authority.

Section 10(a)(1)(B) permit—The section of the ESA that authorizes the Service to issue nonfederal entities a permit for the incidental take of endangered and threatened wildlife species. This permit allows the nonfederal entity to proceed with an activity that is legal in all other respects, but that results in the "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity." *See also* take.

sediment—Unconsolidated solid material that comes from weathering of rock and is carried by, suspended in, or deposited by water or wind.

sediment load—Mass of sediment passing through a stream.

seepage—Relatively slow movement of water through a medium, such as sand.

spawn—To lay eggs, especially fish.

spills—Water releases from a dam in excess of powerplant capacity.

spillway—Overflow facility at a dam, usually consisting of a sill at the full-reservoir elevation.

spinning reserves—Available capacity of generating facilities synchronized to the interconnected electric system so that it can be called upon for immediate use in response to system problems or sudden load changes.

stage—Reservoir elevation.

standards—A means established by authority as a rule for the measure of quality, such as cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water.

storage—Water artificially impounded in surface or underground reservoirs for future use. Water naturally detained in a drainage basin, such as groundwater, channel storage, and depression storage. The term "drainage basin storage" or simply "basin storage" is sometimes used to refer collectively to the amount of water in natural storage in a drainage basin. *See also* conservation storage and dead storage.

stormwater—Consists of water that originates from precipitation, such as heavy rain or snow.

stratification—Thermal layering of water in lakes and streams. Lakes usually have three zones of varying temperature: (1) epilimnion—top layer with essentially uniform warmer temperature, (2) metalimnion—middle layer of rapid temperature decrease with depth, and (3) hypolimnion—bottom layer with essentially uniform colder temperatures.

streamflow—The discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than runoff, as streamflow may be applied to discharge whether it is affected by diversion or regulation.

suspended load—Sediment that is supported by the upward components of turbulence in a stream and that stays in suspension for an appreciable length of time.

tail water—Water immediately downstream of the outlet from a dam or hydroelectric powerplant where the water is more similar to that in the reservoir than farther downstream.

take—As defined by the ESA, a means to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct (16 United States Code 1531[18]).

thermocline—The zone of maximum change in temperature in a waterbody, separating upper (epilimnetic) from lower (hypolimnetic) zones.

threatened species—A species or subspecies that is likely to become endangered in the foreseeable future.

total dissolved solids (TDS)—Dissolved materials in the water, including ions such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium. In many instances, the term "TDS" is used to reflect salinity, since these ions are typically in the form of salts.

traces —Multiple time series of forecasted streamflow used in hydrological modeling. Multiple traces are sometimes referred to as an ensemble.

traditional cultural place—A type of historic property that is rooted in a community's history and important to that community's cultural identity.

tributary—River or stream flowing into a larger river or stream.

turbidity—Cloudiness of water, measured by how deeply light can penetrate into the water column from the surface.

turbine—A rotary mechanical device that uses water flow to turn and convert it into useful energy.

Visual resources—Physical features that make up the visible landscape (features such as land, water, vegetation, topography, and human-made features such as buildings, roads, utilities, and structures) as well as the response of viewers to those features.

Water Year—That period of 12 months ending September 30 of each year.

Waters of the United States—In accordance with the Clean Water Act, waters of the United States include (1) all waters that may be susceptible to use in interstate or foreign commerce; (2) all interstate waters, including interstate wetlands; (3) all other waters, such as intrastate lakes, rivers, streams (including intermittent streams), mud flats, sand flats, wetlands, sloughs, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which could affect interstate or foreign commerce, including any such waters; (4) all impoundments of waters otherwise defined as waters of the United States; (5) tributaries of waters identified in this SEIS; (6) the territorial seas; and (7) wetlands adjacent to waters (other than waters that are themselves wetlands) identified in this SEIS.

watershed—The drainage area upstream of a specified point on a stream.

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Appendix A

Evaluation of LTEMP SEIS Alternatives on Smallmouth Bass

Appendix A. Evaluation of LTEMP SEIS Alternatives on Smallmouth Bass

This information is preliminary or provisional and is subject to revision. It is being provided to meet the need for timely best science. The information has not received final approval by the US Geological Survey (USGS) and is provided on the condition that neither the USGS nor the US government shall be held liable for any damages resulting from the authorized or unauthorized use of the information. For additional information, see Eppehimer et al. 2024.

A.1 Methods and Assumptions

A.1.1 Glen Canyon Dam operational alternatives being analyzed in the LTEMP SEIS

- No Action Alternative
- Cool Mix Alternative[a]
- Cool Mix with Flow Spike Alternative[a]
- Cold Shock Alternative[a]
- Cold Shock with Flow Spike Alternative[a]
- Non-Bypass Alternative

[a] All four of these options include the change to the sediment accounting window and could be implemented to target different reaches through the Little Colorado River confluence reach. For analysis, Reclamation has analyzed targets of river mile 15 (where river mile 0 is Lee Ferry) and river mile 61 (Little Colorado River confluence, where river mile 0 is Lee Ferry).

A.1.2 General smallmouth bass modeling details

- The smallmouth bass flow option alternatives are designed to target smallmouth bass (*Micropterus dolomieu*); however, other warmwater invasive fish species with similar temperature requirements are likely to be reduced under temperature-based smallmouth bass flow options.
- Smallmouth bass have been observed laying eggs at water temperatures as low as 15 degrees Celsius (°C) (59 degrees Fahrenheit [°F]) in some systems; however, water temperatures of 16°C (61°F) or greater are typically required for smallmouth bass to lay eggs. For example, in the Green and Yampa Rivers, the earliest observed hatch was always after the first day when temperatures increased above 16°C (61°F) during a 7-year study across three river reaches

(Bestgen and Hill 2016). Water temperatures of 16°C (61°F) or greater are also required for young of year to grow significantly, if hatched. Growth of smallmouth bass at a temperature of 16°C (61°F) is marginal. Therefore, if a fish is hatched and maintained at approximately 16°C (61°F) for the length of a typical growing season, it would be very unlikely to grow large enough to survive the winter (Shuter et al. 1980; Dudley et al. 2014).

- Glen Canyon Dam release temperatures (using the penstocks, river outlet works, or a combination) used in the smallmouth bass population growth model are estimated for every day of the year using a model that relies on spring inflow (April–July) into Lake Powell, the day of year, and the depth as predictors; the model was fitted to 225 Lake Powell temperature profiles from 2000 to 2021 (Eppehimer et al. *in review*).
- Downriver warming of water released from Glen Canyon Dam is estimated using a model developed by Dibble et al. (2021), adapted from a monthly to daily scale by calculating the average daily solar insolation and daily air temperatures from the Page weather station.
- The amount of water that needs to be released through the river outlets and the penstocks will vary based on the lake's elevation and the distribution of water temperatures through the water column (these factors determine the temperature of the water being released), the time of year (air temperature and solar radiation), and the daily discharge; all of these determine how quickly a given amount of water warms as it travels downriver (Dibble et al. 2021; Mihalevich et al. 2020).
- For modeling of the Cool Mix and Cold Shock Alternatives, Reclamation assumed the river outlet works could be operated at half-tube increments, and that each tube had a capacity of 3,150 cubic feet per second (cfs).
- The smallmouth bass population growth model is run on a 16-month time step beginning in January. To run the model for 2027, inflow, outflow, and elevation were added for October 2027–April 2028. For water year 2028, 8 million acre-feet annual inflows were assumed, following monthly volumes determined by a log-transformed linear model fit to 2000–2021 historical inflows. For water year 2028, 7.48 million acre-feet annual outflows were assumed, with monthly volumes determined by Long-Term Experimental and Management Plan Record of Decision guidelines. Elevations were calculated using the Colorado River Simulation System (CRSS) water balance equation for Lake Powell given a starting elevation (September 2027) and subsequent monthly inflows and outflows. Given the minimal variation in monthly inflow and outflow during the October to April intervals and the fact that this period is primarily used to calculate starvation days, which are primarily a function of reservoir elevations, these assumptions have minimal impacts on lambda estimates; they would not be expected to change the bypass required under a smallmouth bass alternative.

A.1.3 Cool mix-specific modeling details

- Within the smallmouth bass model, flows are triggered when temperatures at the target river mile are predicted to rise about 15.5°C (60°F). The target of 15.5°C (60°F) was chosen to account for variation in water temperature releases and warming rates. Also, this target increases the likelihood that water temperatures would remain near or below 16°C (61°F) at the target river mile.

- In practice, flows would likely be implemented at a weekly scale. They likely would need to be planned many weeks in advance, with adjustments closer to a week of implementation. These adjustments would only involve lowering the bypass volume, if less bypass is needed than initially estimated. Differences among weekly flows in a month are typically greatest during June and early July, when the temperature profile in Lake Powell is developing. To more accurately reflect actual implementation, but also not require running multiple weeks of hydropower maximization within each month, Reclamation post-processed daily bypass estimates from the smallmouth bass model so that flows were simulated to occur all month long, if smallmouth bass flows were triggered before or at the month's halfway mark. The flows were simulated to start in the subsequent month if smallmouth bass flows were triggered after the month's halfway mark. Furthermore, all days within a month had bypass equal to the median of the month (rounded up to the higher value if a month had 28 or 30 days); exactly half the days were at one value and the other half were at another value. Comparison of total bypass between raw and post-processed output suggested a minimal change to overall bypass across all 30 traces, with the amount of bypass subtly increasing in some traces and decreasing in other traces.
- On triggering, water is released from both penstocks and river outlets works to maintain a daily average water temperature below 15.5°C (60°F) at the targeted river mile. Temperatures closer to the dam would be cooler in the main river. The goal of these temperature targets is to prevent recruitment of smallmouth bass, ideally by preventing smallmouth bass spawning. The amount of water released through the river outlets is based on predicted temperatures at the river outlets and penstocks at the time of the flow, and the expected warming based on the Dibble et al. (2021) temperature model and day-specific solar insolation and air temperature values. The amount of water released would be the minimum amount of bypass required to meet the water temperature goal. Hydropower releases were always assumed to be 2,000 cfs for the cold water alternatives.
- When all four river outlet works are available and the daily total discharge (that is, the sum of the penstock and river outlet releases) is greater than 8,500 cfs, the target temperature of 15.5°C (60°F) at the Little Colorado River is almost always achievable.
- If monthly volumes are below 8,000 cfs and water temperatures at penstock depth are greater than 23°C (73°F), it may only be possible to maintain daily average water temperatures below 15.5 °C (60°F) from below the dam through river mile 45 in Marble Canyon. Smaller volumes of water warm more quickly, and it is not always possible to release water cold enough to overcome this warming.
- If only two river outlet works are available and daily total discharges are high, the target temperature may also only be achievable in upper Marble Canyon. For example, if the daily total discharge is 10,500 cfs, water temperature at the penstock is 20°C (68°F), water temperature at the outlet tube is 11°C (52°F), and both river outlet works are used, water temperature in June would remain below 15.5°C (60°F) through river mile 40.

A.1.4 Cold shock-specific modeling details

- Within the smallmouth bass model, flows are triggered when temperatures at the target river mile are predicted to rise above 15.5°C (60°F). Cold shocks are intended to disrupt spawning behavior by quickly cooling the river for a protracted period.
- In practice, flows would likely be implemented at a weekly scale and need to be planned many weeks in advance. They likely would need to be planned many weeks in advance, with adjustments closer to a week of implementation. These adjustments would only involve lowering the bypass volume, if less bypass is needed than initially estimated. To more accurately reflect actual implementation, but also not require running multiple weeks of hydropower maximization within each month, Reclamation post-processed daily bypass estimates from the smallmouth bass model so that cold shocks were simulated to occur all month long if smallmouth bass flows were triggered before or at the month's halfway mark and simulated to start in the subsequent month if smallmouth bass flows were triggered after the month's halfway mark.
- On triggering, cold shocks occurred every weekend for a total of 12 weekends. Each cold shock lasted 48 hours, with a transition to normal flows outside these times. For modeling of the cold shock alternatives, Reclamation assumed that up to 12,600 cfs were released as bypass while recognizing that the capacity for long-term releases could be slightly higher or lower (**Table 1**) in practice. Within a month, the amount of bypass calculated for cold shocks was the minimum required (tested in half-tube increments) to lower the temperature below 13°C (55°F) at the targeted river mile in all weekends, or 12,600 cfs if a lesser volume did not meet this condition. Hydropower releases were always assumed to be 2,000 cfs during the cold shock.
- If water temperatures at the penstock depth are greater than 23°C (73°F) and only two outlet tubes are available, it is likely impossible to achieve a cold shock daily, average water temperature below 13°C (55°F) through Lees Ferry (river mile 0).
- If water temperatures at the penstock depth are greater than 23°C (73°F) and three outlet tubes are available, it may be possible to achieve a cold shock daily average water temperature below 13°C (55°F) from the dam through river mile 15 in upper Marble Canyon.

A.1.5 Flow spike-specific details

- Under the alternatives with flow spikes, up to three 8-hour flow spikes could be implemented in combination with a cool mix or cold shock, if sufficient water is available. The flow spike would be expected to disrupt spawning in margin habitats that may be warmer than the mainstream river. During a flow spike, as much water as possible would be released through the penstocks and river outlets (up to 45,000 cfs). A flow spike could be replaced by a High-Flow Experiment (HFE) release if doing so would maximize benefits to sediment, and it is timed appropriately to affect smallmouth bass spawning.
- Flow spikes are expected to be most effective if timed earlier in the potential reproductive cycle of smallmouth bass. For modeling, Reclamation assumed there would be two flow spikes in the first month that smallmouth bass flows were triggered in a given year, and one

flow spike in the following month (if smallmouth bass flows were still triggered in that month).

- In the Cold Shock with Flow Spike Alternative, the flow spike (or HFE release) transitions into the cold shock for that given week.
- Flow spikes would only occur during May, June, July, August, and September, because margin habitat can be significantly warmer than the mainstream river during these months.
- Analysis of flow disturbance on smallmouth bass lambda was estimated using a Lees Ferry tailwater discharge-velocity model with 5- by 5-meter resolution (Kaplinski et al. 2022a, 2022b; Nelson et al. 2016). No such model exists for downriver sections of the Colorado River in Grand Canyon; therefore, for a given Glen Canyon Dam discharge, Reclamation assumed the proportions of river-wetted area and proportions of water velocities were the same for all reaches. Depending on the target location in the river, this assumption may not be accurate. Reclamation estimated smallmouth bass spawning habitat disturbance under Glen Canyon Dam flow scenarios assuming nesting in habitat with water velocity less than 0.1 meters per second (m/s) (Miller and Brewer 2021; Lukas and Orth 1995; Winemiller and Taylor 1982), and assuming drying or velocities more than 0.3 m/s (Miller and Brewer 2021; Lukas and Orth 1995) would cause nest abandonment by guarding males and subsequent nest failure, assuming 100 percent mortality of offspring (Knotek and Orth 1998; Lukas and Orth 1995; Winemiller and Taylor 1982).
- This model incorporated habitat available at baseflow conditions with load following discharges and habitat disturbance by subsequent increases or decreases in discharge. Smallmouth bass can renest multiple times during a spawning season (Lukas and Orth 1995); therefore, Reclamation assumed three nesting opportunities per spawning season, allowing smallmouth bass to renest if their nest was disturbed by flows. This was estimated using an equation for proportion of offspring remaining for a given flow: $((1-x)+x*(1-x)*2/3+x*x*(1-x)*1/3)$, where x represents the estimated proportion of spawning habitat disturbed.

A.1.6 Non-bypass details

- Analysis of flow disturbance on smallmouth bass lambda was estimated using a Lees Ferry tailwater discharge-velocity model with 5- by 5-meter resolution (Kaplinski et al. 2022a, 2022b; Nelson et al. 2016). No such model exists for downriver sections of the Colorado River in Grand Canyon; therefore, for a given Glen Canyon Dam discharge, Reclamation assumed the proportions of river-wetted area and proportions of water velocities were the same for all reaches. Depending on the target location in the river, this assumption may not be accurate. Reclamation estimated smallmouth bass spawning habitat disturbance under Glen Canyon Dam flow scenarios, assuming nesting in habitat with water velocity less than 0.1 m/s (Miller and Brewer 2021; Lukas and Orth 1995; Winemiller and Taylor 1982), and assuming drying or velocities more than 0.3 m/s (Miller and Brewer,2021; Lukas and Orth 1995) would cause nest abandonment by guarding males and subsequent nest failure, assuming 100 percent mortality of offspring (Knotek and Orth 1998; Lukas and Orth 1995; Winemiller and Taylor 1982).

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A.2 Results

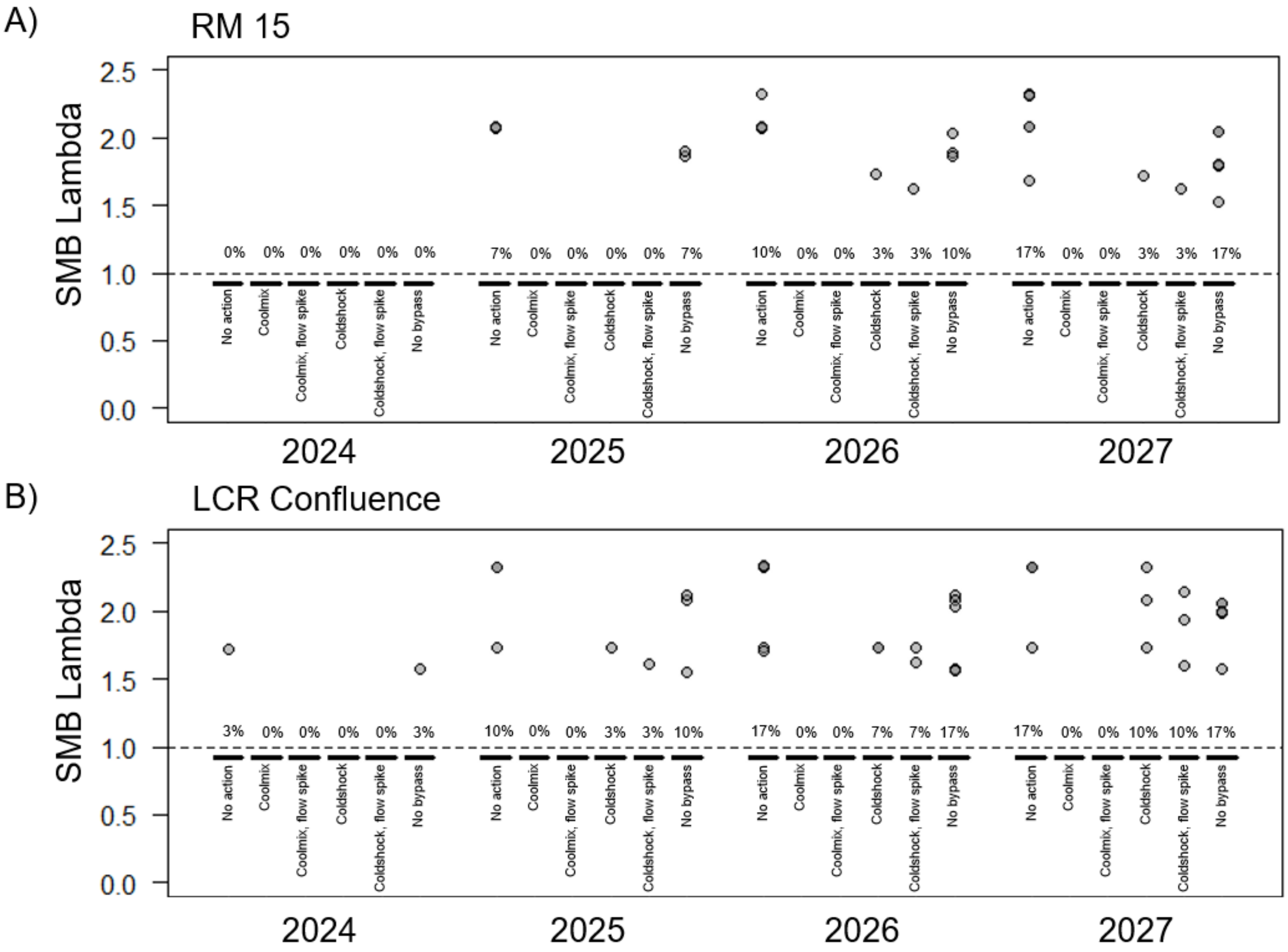
A.2.1 Smallmouth bass population growth at river mile 15

The model predicts that smallmouth bass population growth at river mile 15 is less than 1 in all 4 years in 5 out of 30 traces under the No Action Alternative. Across 30 traces, each lasting 4 years, there were only 10 total years under the No Action Alternative in which smallmouth bass populations were predicted to increase (**Figure 1A**). The cool mix alternatives resulted in no predicted population growth for 100 percent of traces and years. The cold shock alternatives are expected to allow for population growth in one trace in 2026 and one trace in 2027. The addition of flow spikes reduced these estimated lambdas, but did not stop population growth. Similarly, the within-powerplant capacity flow fluctuations (non-bypass) reduced estimated lambdas when compared with no action, but did not stop population growth.

A.2.2 Smallmouth bass population growth at the Little Colorado River confluence

The model predicts that smallmouth bass population growth at the Little Colorado River confluence is less than 1 in all 4 years in 7 out of 30 traces under the No Action Alternative. Due to downriver warming of water temperatures, more traces (and more years within traces) have population growth at this location than at river mile 15. Across 30 traces, each lasting 4 years, there were only 13 total years under the No Action Alternative in which smallmouth bass populations were predicted to increase at the Little Colorado River confluence (**Figure 1B**). The cool mix alternatives resulted in no predicted population growth for 100 percent of traces and years. Under the cold shock alternatives, there were 6 years in which smallmouth bass populations were predicted to increase. The addition of a flow spike reduced these estimated lambdas, but did not stop population growth. Similarly, the within-powerplant capacity flow fluctuations (non-bypass) reduced estimated lambdas when compared with no action, but did not stop population growth.

Figure 1
Forecast of Potential Annual Smallmouth Bass Population Growth Rate



Note: Forecasts of the potential annual smallmouth bass population growth rate (lambda) at (A) river mile 15 and (B) the Little Colorado River reaches of the Colorado River under the No Action, Cool Mix, Cool Mix with Flow Spike, Cold Shock, Cold Shock with Flow Spike, and Non-Bypass Alternatives. The gray, horizontal, dashed line denotes lambda = 1. Lambda greater than 1 indicates population growth. For each of the 30 hydrologic traces, Reclamation estimated the population growth rate based on forecasted daily water temperature. Reclamation summarized these results using a box-and-whisker plot in which the dark line represents the median, the boxes represent the upper and lower 25 percent quantiles, and the whiskers extended to twice the interquartile range, with dots representing traces with more extreme values. All box-and-whisker plot interquartile ranges are below 1, and therefore appear compressed. Only extreme values (dots) are above 1. The numbers above the dashed, horizontal 1 line represent the percentage of traces (rounded to the nearest percent; out of 30 traces) in which lambda was predicted to be greater than 1 for that year and scenario.

This information is preliminary or provisional and is subject to revision.

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