RECLAMATION
Managing Water in the West

Review Draft Environmental Assessment for Cooperating Agencies

Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020

U.S. Department of the Interior
Bureau of Reclamation
Upper Colorado Region
Salt Lake City, Utah

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Mission Statements

The U.S. 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.

Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020

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Executive Summary

To be completed after cooperating agencies review

1.0 Introduction

1.1 Background

The Department of the Interior (Interior), acting through the Bureau of Reclamation (Reclamation), is proposing to develop and implement a protocol for high-flow experimental releases from Glen Canyon Dam to better determine whether and how sand conservation can be improved in the Colorado River corridor downstream of Glen Canyon Dam including areas within Grand Canyon National Park (74 FR 69361; see Appendix A). Under the concept of high flow experimental releases, sand stored in the river channel is suspended by high-volume dam releases and a portion of the sand is redeposited in downstream reaches as sandbars and beaches, while another portion is transported downstream by river flows. These sand features and associated backwater habitats provide key wildlife habitat, protect archaeological sites, enhance riparian vegetation, and provide camping opportunities along the Colorado River in Grand Canyon National Park.

The action area or geographic scope of this environmental assessment (EA) is a 294-mile reach of the Colorado River corridor from Glen Canyon Dam downstream to the Lake Mead inflow near Pearce Ferry (Figure 1). Glen Canyon Dam impounds the Colorado River about 16 miles upstream from Lees Ferry, Coconino County, Arizona. This action area includes Glen Canyon National Recreation Area (GCNRA) in a 15-mile reach from Glen Canyon Dam to the Paria River; and Grand Canyon National Park (GCNP), a 277-mile reach from the Paria River downstream from Lees Ferry to the Grand Wash Cliffs near Pearce Ferry. In terms of geomorphic features, Glen Canyon encompasses a 16-mile reach from the dam to the Paria River; Marble Canyon is a 61-mile reach from the Paria River to the Little Colorado River; and Grand Canyon is a 217-mile reach from the Little Colorado River to near Pearce Ferry.

Glen Canyon Dam was authorized by the *Colorado River Storage Project Act of 1956* (CRSPA; 43 U.S.C. § 620). The CRSPA authorized the Secretary of the Interior (Secretary) to:

> *"…construct, operate, and maintain the dam for the purposes…of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact…providing for the reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of*

the foregoing purposes…"

The CRSPA, as well as a number of Federal statutes and legislative authorities affect the manner in which Glen Canyon Dam is operated and the manner in which water is apportioned to the seven basin states and Mexico. These authorities are collectively known as the "Law of the River," which is a collection of Federal and State statutes, interstate compacts, court decisions and decrees, an international treaty with Mexico, and criteria and regulations adopted by the Secretary.

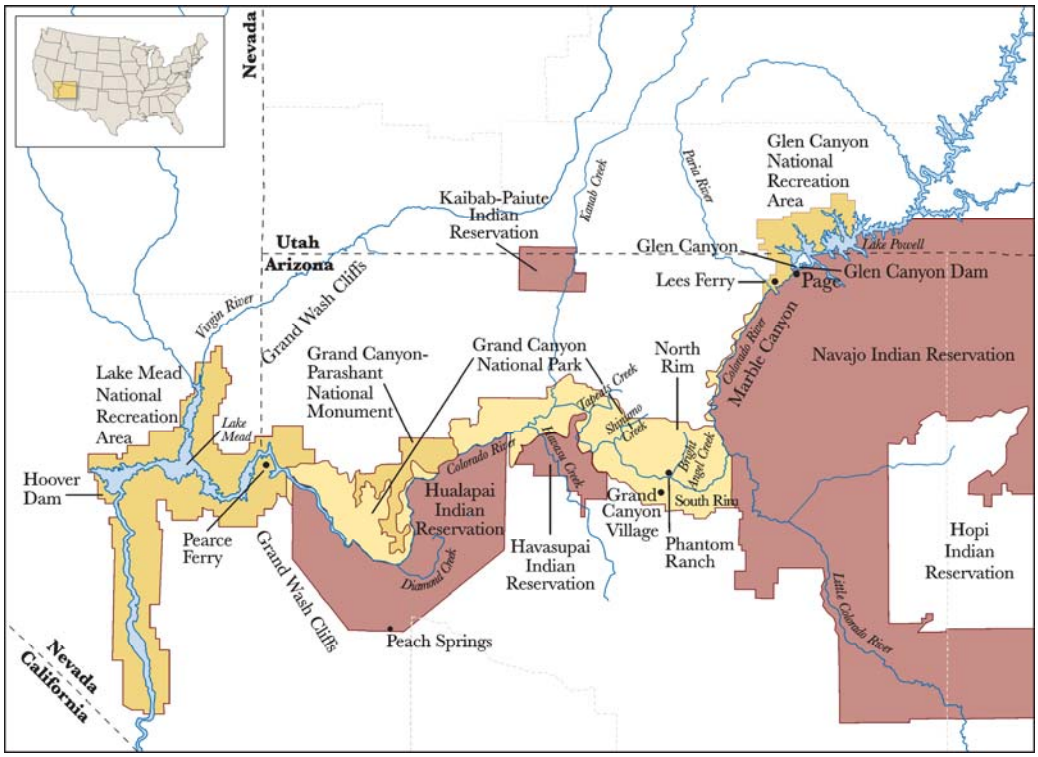


Figure 1. Geographic scope of the proposed action, showing places referenced in the text. Map courtesy of U.S. Geological Survey.

In 1970, *Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs Pursuant to the Colorado River Basin Project Act of September 30, 1968* (P. L. 90-537) were established to govern operation of reservoirs along the Colorado River. Annual operating plans prepared under the 1968 Act include the requirement to:

> *"…reflect appropriate consideration of the uses of the reservoirs for all purposes, including flood control, river regulations, beneficial consumptive uses, power production, water quality control, recreation, enhancement of fish and wildlife, and other environmental factors."* (Article 1(2))

An important function and purpose of Glen Canyon Dam is to generate hydroelectric power. Water released from Lake Powell through the dam's eight hydroelectric turbines generates power marketed by Western Area Power Administration (Western). From the time of the dam's completion in 1963 to 1990, the dam's daily operations were primarily undertaken to maximize generation of hydroelectric power in accordance with Section 7 of the CRSPA, which requires hydroelectric powerplants to be operated "so as to produce the greatest practicable amount of power and energy that can be sold at firm power and energy rates."

In the early 1980s, Reclamation undertook the Uprate and Rewind Program to increase powerplant capacity at Glen Canyon Dam. As part of an Environmental Assessment and Finding of No Significant Impact (FONSI; U.S. Department of the Interior 1988), Reclamation agreed to not use the increased capacity until completion of a more comprehensive study on the impacts of historic and current dam operations. The Glen Canyon Dam Environmental Studies (GCES) Phases I and II were conducted from 1982 to 1995 to evaluate the effect of the uprate and rewind and dam operations on downstream resources. The GCES concluded that dam operations were adversely affecting natural and recreational resources and that modified operations would better protect those resources (Bureau of Reclamation 1988). These studies also brought forth concerns about the effects of dam operations on the resources of GCNP and GCRA and highlighted the need to evaluate the effects on species listed pursuant to the *Endangered Species Act of 1973, as amended* (ESA; 16 U.S.C. § 1531 *et seq.*). As a result of these studies, Reclamation agreed to maximum authorized releases of 31,500 cfs, and the potential of 33,200 cfs that resulted from the uprate and rewind was not implemented.

In 1992, President George H.W. Bush signed the *Grand Canyon Protection Act* (GCPA; Reclamation Projects Authorization and Adjustment Act Of 1992, Title XVIII – Grand Canyon Protection, §§ 1801–1809) in recognition of the potential detrimental effects of dam operations on downstream resources. Section 1802(a) of the GCPA authorized that:

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

Section 1804(a) of the GCPA required completion of an Environmental Impact Statement (EIS) evaluating alternative operating criteria, consistent with existing law, that would determine how the dam would be operated consistent with the purposes for which the dam was authorized and the goals for protection of GCNP and GCNRA. The *Operation of Glen Canyon Dam Final Environmental Impact Statement* was completed in March 1995 (Bureau of Reclamation 1995) with the preferred alternative, called the Modified Low Fluctuating Flow Alternative (MLFF), selected. As articulated in the

Record of Decision, issued on October 9, 1996 (U.S. Department of the Interior 1996), "The goal of selecting a preferred alternative was not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability." The 1995 Biological Opinion (U.S. Fish and Wildlife Service 1995) identified a program of experimental flows as an element of the Reasonable and Prudent Alternative that included provisions for high-volume dam flows termed "beach-habitat building flows" (BHBFs) and "habitat maintenance flows" (HMFs); BHBFs were releases that exceeded the powerplant capacity designed to build sandbars and beaches, and HMFs were releases up to powerplant capacity designed to maintain these sand features. These actions were also discussed in the EIS and the Record of Decision. This biological opinion was replaced by a new Biological Opinion in 2008 (U.S. Fish and Wildlife Service 2008) and subsequently supplemented in 2009 (U.S. Fish and Wildlife Service 2009). A more complete history of high-flow releases is provided in section 1.5 of this EA.

Section 1805(b) of the GCPA also requires the Secretary to undertake research and monitoring to determine if modified dam operations are actually achieving the resource protection objectives of the Final EIS and Record of Decision, i.e., mitigating adverse impacts, protecting, and improving the natural, cultural, and recreational values for which GCNP and GCRA were established. These provisions of the GCPA were incorporated into the 1996 Record of Decision and led to the establishment of the Glen Canyon Dam Adaptive Management Program (AMP). The AMP includes the Adaptive Management Work Group, a Federal Advisory Committee to the Secretary, and the Grand Canyon Monitoring and Research Center (GCMRC) as a research branch of the AMP under the U.S. Geological Survey (USGS). Monitoring and research conducted by these organizations since 1996 have improved the understanding of riverine geomorphology and how dam operations might assist in the conservation of sand below the dam.

In proposing the protocol described in this EA, it is important to recognize that all dam operations, including those proposed here, must be implemented in compliance with other specific provisions of existing federal law applicable to the operation of Glen Canyon Dam. These requirements are specifically mandated in Section 1802(b) of the GCPA.

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

Since 1999, the Colorado River Basin has experienced prolonged and historic drought conditions. In response to several years of below-normal runoff and declining reservoir

conditions and at the direction of the Secretary, Reclamation completed a Final EIS and Record of Decision in 2007 on the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (U.S. Department of the Interior 2007). These interim guidelines were adopted in December 2007 and are anticipated to be in effect through September 2026 to provide better operational management of Lake Powell and Lake Mead. The provisions of the 1995 EIS and 1996 Record of Decision that led to MLFF, as well as the 2007 EIS and Record of Decision that proposed adoption of interim guidelines and coordinated operations establish the foundation for the No Action alternative defined in this EA.

This EA describes the current environmental conditions in Glen, Marble, and Grand Canyons downstream from Glen Canyon Dam, and discloses the direct, indirect, and cumulative environmental impacts that could result from the proposed action and alternatives. It describes how the proposed action (i.e., protocol for high-flow experimental releases from Glen Canyon Dam) is designed to determine how sand conservation can best be achieved in the Colorado River corridor in GCNP and GCNRA and the impacts that would result from these high-flow releases.

This EA was prepared by Reclamation in compliance with the *National Environmental Policy Act of 1970* (NEPA; 42 U.S.C. 4321 *et seq.*) and the Council on Environmental Quality regulations for implementing NEPA (40 CFR 1500-1508) and the Department of the Interior regulations implementing NEPA (43 CFR Part 46). This EA is not a decision document; one of three decisions will be made based on the EA:

1. A finding of no significant impact and the protocol goes forward as proposed;

2. An environmental impact statement if the proposed action could result in significant impacts; or

3. A decision to withdraw the proposal on the basis of environmental impacts disclosed in this document.

1.2 Purpose of and Need for Action

The Department of the Interior (Interior), acting through the Bureau of Reclamation (Reclamation), is proposing to develop and implement a protocol for high-flow experimental releases (HFEs) from Glen Canyon Dam for a 10-year period, 2011–2020. This protocol takes a multi-year, multi-experimental approach using short-duration, high-volume releases from Glen Canyon Dam during sediment[1]-enriched conditions in the channel of the Colorado River downstream of the dam.

[1] For the purpose of this EA, the term "sediment" means the solid inorganic and organic material that comes from weathering of rocks and vegetation and is carried by and settled in water. In this case, sediment consists of a mixture of varying coarseness of sand (inorganic material) and fine and coarse particulate organic matter (organic material consisting mostly of plant matter). The terms sand and sediment are used interchangeably in this EA, unless otherwise specified.

The purposes of this action are: 1) to develop and implement a protocol that determines when and under what conditions to conduct experimental high volume releases, and 2) to evaluate the effectiveness of conducting these experiments in conserving sediment to benefit downstream resources in Glen, Marble, and Grand Canyons.

This action is needed to take advantage of future sediment-enriched conditions in the Colorado River with experimental high flow tests that will improve the understanding of the relationships between high dam releases and sediment conservation. The information developed through this action will assist Interior in making future decisions on when and how to conduct multi-year, multi-event high flow experimental releases and how to evaluate benefits to downstream resources.

1.3 Related Actions, Projects, Plans and Documents

Related actions, projects, plans, and documents are identified in this EA in order to better understand other ongoing activities that may influence, relate to, or affect the proposed action. These actions, project, plans, and documents are related to ongoing activities of state and federal agencies, as well as American Indian Tribes.

The action proposed in this EA is tiered from two environmental impact statements including Reclamation's 1995 EIS on the operation of Glen Canyon Dam (Bureau of Reclamation 1995) and the associated 1996 Record of Decision (U.S. Department of the Interior 1996); and Reclamation's 2007 EIS on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead (Bureau of Reclamation 2007a) and the associated 2007 Record of Decision (U.S. Department of the Interior 2007). The 1996 Record of Decision implemented the MLFF to govern releases from Lake Powell at short time increments, down to daily and hourly releases. The 2007 Record of Decision governs annual releases from Lake Powell in coordination with Lake Mead. There is also an ongoing program of experimental releases from Glen Canyon Dam in effect from 2008 through 2012, under an EA and FONSI (Bureau of Reclamation 2008).

The following summarizes related actions relative to Reclamation's environmental compliance on the operation of Glen Canyon Dam from 1982 through 2008:

- Final Environmental Assessment and Finding of No Significant Impact, Uprate and Rewind Program to Increase Powerplant Capacity at Glen Canyon Dam (Bureau of Reclamation 1988).
- Final Environmental Impact Statement on the Operation of Glen Canyon Dam, March 1995 (Bureau of Reclamation 1995) and Record of Decision, October 1996 (U.S. Department of the Interior 1996).
- Final Environmental Assessment and Finding of No Significant Impact, Glen Canyon Dam Beach/Habitat-Building Test Flow, February 1996 (Bureau of Reclamation 1996).

- Reinitiation of ESA Section 7 consultation to conduct a Habitat Maintenance Flow (HMF) as a fall test powerplant release of 31,000 cfs for 72 hours, November 5, 1997.
- Reinitiation of ESA Section 7 consultation to conduct a Low Steady Summer Flow of 8,000 cfs (June 1–September 4, 2000) and 1-day 30,000 cfs spikes before (May 2000) and after (September 2000).
- Final Environmental Assessment and Finding of No Significant Impact, Proposed Experimental Releases from Glen Canyon Dam and Removal of Non-Native Fish, 2003-2006 (Bureau of Reclamation 2002).
- Supplement to the 2004 Environmental Assessment and Finding of No Significant Impact, Proposed Experimental Actions For Water Years 2005–2006 Colorado River, Arizona, In Glen Canyon National Recreation Area And Grand Canyon National Park (Bureau of Reclamation 2004).
- Final Environmental Impact Statement on the Proposed Adoption of Colorado River Interim Guidelines For Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, November 2007 (Bureau of Reclamation 2007a) and Record of Decision, December 2007 (U.S. Department of the Interior 2007).
- Final Environmental Assessment and Finding of No Significant Impact for Experimental Releases from Glen Canyon Dam, Arizona, 2008 through 2012 (Bureau of Reclamation 2008).

The following are related actions identified by the National Park Service (NPS). This EA is not expected to negatively affect or impede these management actions and plans. The NPS is a cooperating agency in this EA and all actions identified in this document are being coordinated with that agency.

- General Management Plan (GMP): The park's 1995 GMP set as an objective the management of the Colorado River corridor through Grand Canyon National Park to protect and preserve the resource in a wild and primitive condition. (NPS 1995).
- Grand Canyon National Park Resource Management Plan (RMP) (1997): The RMP is the primary resource stewardship action plan that provides long term guidance and protection for natural, cultural and recreational resources of GCNP. (NPS 1997)
- Colorado River Management Plan: This EA is consistent with the goals and objectives outlined in the NPS Colorado River Management Plan (CRMP; Grand Canyon National Park 2006. The CRMP management objectives emphasize managing river recreation to minimize impacts to resources while providing a quality river visitor experience. The Colorado River corridor will be managed to provide a wilderness-type experience in which visitors can intimately relate to the majesty of the Grand Canyon and its natural and cultural resources. Visitors traveling through the canyon on the Colorado River will have the opportunity for a variety of personal outdoor experiences, ranging from solitary to social, with little influence from the modern world. The Colorado River corridor will be protected and preserved in a wild and primitive condition. . To ensure these salient objectives are met, the NPS must

determine, through a research, monitoring and mitigation program, what impacts are occurring, how these impacts alter resource condition, and how adverse impacts can be effectively mitigated. The NPS has developed a detailed plan that includes individual and integrated resource-monitoring components.

- Draft Native Fish Management Plan (2010), including:
  - Translocation of humpback chub to Shinumo Creek and Havasu Creek: juvenile humpback chub have been translocated from the Little Colorado River to Shinumo Creek. Plans are in place to make an additional translocation to Havasu Creek. This translocation action is a conservation measure related to Reclamation's 2008 BO and 2009 Supplemental BO.
  - Mechanical removal of non-native fish including trout from Bright Angel Creek: Non-native fish are being removed from Bright Angel Creek to restore and enhance the native fish community that once flourished in Bright Angel Creek and to reduce predation and competition on endangered humpback chub from non-native fish.
- 1988 Backcountry Management Plan: This plan describes provisions for back country use, resource and wilderness management within Grand Canyon National Park. The plan is being updated in 2011.
- 2010 Vegetation Management Plan: The plan includes management of invasive plants along the Colorado River corridor and tributaries and targets restoration of disturbed lands with the park.

The Arizona Game and Fish Department (AGFD) is also a cooperating agency in this EA. The following are related actions identified by that State agency. This EA is not expected to negatively affect or impede these management actions and plans.

- Proposed changes to bag limits: the AGFD has proposed to its Commission a change in size limits and bag limits for trout in the Lees Ferry reach. This proposed change is designed to better manage abundance and size of trout in the blue ribbon trout fishery and to reduce the numbers of trout emigrating downstream to habitat occupied by humpback chub, where they prey upon and compete with this endangered fish species.
- Intra-Service consultation on stocking of sport fish in the State of Arizona. Of particular interest to this action is the proposed stocking of salmonids (trout species) in Colorado River tributaries.

1.4 Agency Roles and Responsibilities

Five agencies within Interior and one within the U.S. Department of Energy have responsibilities under the Grand Canyon Protection Act, and undertake operations pursuant to the Act. The role of each responsible agency under the GCPA is briefly addressed below.

1.4.1 Department of the Interior

1.4.1.1 Bureau of Indian Affairs

The Bureau of Indian Affairs' (BIA) mission, among other objectives, includes enhancing quality of life, promoting economic opportunity, and protecting and improving trust assets of American Indian Tribes and individual American Indians. This is accomplished within the framework of a government-to-government relationship in which the spirit of Indian self-determination is paramount. As part of the AMP, BIA's Western Regional Office is committed to working hand-in-hand with interested tribes and other participating agencies to ensure that this fragile, unique, and traditionally important landscape is preserved and protected.

1.4.1.2 Bureau of Reclamation

Reclamation operates Glen Canyon Dam in accordance with the additional criteria and operating plans specified in section 1804 of the Grand Canyon Protection Act as well as in accordance with approved experimental plans. Glen Canyon Dam is also operated consistent with and subject to numerous compacts, federal laws, court decisions and decrees, contracts and regulatory guidelines collectively known as the "Law of the River."

1.4.1.3 National Park Service

The NPS manages units of the national park system and administers resource-related programs under the authority of various federal statutes, regulations, and executive orders and in accordance with written policies set forth by the Secretary and the Director of the NPS, including the NPS Management Policies 2006 and the NPS Director's Orders. The NPS manages GCNP and GCRA under the Organic Act (16 U.S.C. §§ 1 and 2-4, as amended); other acts of Congress applicable generally to units of the national park system; and the legislation specifically establishing those park units (16 U.S.C. §§ 221-228j and 16 U.S.C. §§ 460dd through 460dd-9 (2006)). The Organic Act directs the NPS to *"promote and regulate the use of . . . national parks . . . in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."* The agency emphasis is not only on preserving species and habitat, but also on maintaining natural processes and dynamics that are essential to long-term ecosystem perpetuation.

1.4.1.4 U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (USFWS) provides Endangered Species Act (ESA) conservation and associated consultation and recovery leadership with various stakeholders primarily to benefit four ESA-listed species in Grand Canyon: humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), southwestern willow flycatcher (*Empidonax trailii extimus*), and Kanab ambersnail (*Oxyloma haydeni kanabensis*). The USFWS provides Fish and Wildlife Coordination Act planning assistance for important fish and wildlife resources.

1.4.1.5 U.S. Geological Survey

The Grand Canyon Monitoring and Research Center (GCMRC) of the U.S. Geological Survey (USGS) was created to fulfill the mandate in the GCPA for the establishment and implementation of a long-term monitoring and research program for natural, cultural, and recreation resources of GCNP and GCRA. The GCMRC provides independent, policy- neutral scientific information to the AMP on: (a) the effects of the operation of Glen Canyon Dam and other related factors on resources of the Colorado River Ecosystem using an ecosystem approach, and (b) the flow and non-flow measures to mitigate adverse effects. GCMRC activities are focused on: (a) monitoring the status and trends in natural, cultural and recreation resources that are affected by dam operations, and (b) working with land and resource management agencies in an adaptive management framework to carry out and evaluate the effectiveness of alternative dam operations and other resource conservation actions.

1.4.2 Department of Energy

1.4.2.1 Western Area Power Administration

The Western Area Power Administration (Western) markets and delivers hydroelectric power and related services within a 15-state region of the central and western United States. It is one of four power marketing administrations within the U.S. Department of Energy having the role to market and transmit electricity from multi-use water projects to retail power distribution companies and public authorities. Its transmission system carries electricity from 55 hydropower plants operated by the Bureau of Reclamation, U.S. Army Corps of Engineers, and the International Boundary and Water Commission. Together, these plants have a capacity of 10,600 megawatts.

Western has built several parts of the important corridor known as Path 15 that connects power grids in the Southwest and Pacific Northwest (the rest was privately built by Pacific Gas and Electric). Western also owns and operates many electric power substations like the Mead substation to distribute power within the region. Western and its energy-producing partners are separately managed and financed. In addition, each water project maintains a separate financial system and records.

1.5 Previous High-Flow Experiments

Reclamation and its collaborators within the AMP have conducted numerous experimental releases from Glen Canyon Dam that helped to inform the design of the proposed protocol described in this EA. The prior high-flow releases were described as beach/habitat-building flows (BHBFs) and habitat maintenance flows (HMFs) (Bureau of Reclamation 1995). A BHBF was a scheduled high release of short duration designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. Magnitudes of BHBFs exceeded the powerplant capacity and were at least 10,000 cfs greater than the allowable peak discharge in a minimum release year. An HMF was a short-term high release in spring,

within the powerplant capacity, intended to transport and deposit sand for maintaining camping beaches and fish and wildlife habitat. For the purpose of this EA, all of these releases are considered high-flow experiments (HFEs). The history of their occurrences is as follows:

- 1996 HFE, 45,000 cfs for 7 days, March 26-April 2, 1996.
- 1997 HFE, 31,000 cfs for 72 hours, November 5-7, 1997.
- 2000 HFE, 31,000 cfs for 72 hours, May 2-4, 2000.
- 2000 HFE, 31,000 cfs for 72 hours, September 4-6, 2000.
- 2004 HFE, 41,000 cfs for 60 hours, November 21–23, 2004.
- 2008 HFE, 41,500 cfs for 60 hours, March 5–7, 2008.

The first HFE was held March 26 to April 7, 1996 and included pre- and post-release steady flows of 8,000 cfs for 4 days each and a 7-day steady release of 45,000 cfs. Dam releases were increased and decreased gradually relative to the peak release in order to minimize damage to resources. The coordinated effort of scientists to evaluate the effects of the 1996 HFE on physical, biological, cultural, and recreational resources were documented by Webb and others (1999) and in Ecological Applications (Vol. 11, No. 3, June, 2001). The 1996 HFE revealed the need for a sediment enrichment condition prior to an HFE and it also showed that sandbar and beach building could be accomplished in less than 7 days.

The findings of the 1996 HFE led to the decision to conduct the 2004 HFE when a sediment enrichment condition existed. The second HFE was held November 21–23, 2004, and included a 60-hour release of 41,000 cfs. The 2004 HFE was conducted shortly after a large amount of sediment was delivered by the Paria River and it helped test the hypothesis that maximum sediment conservation would occur with a high flow shortly after the sediment was deposited in the mainstem. Suspended sediment concentrations during the 2004 experiment were 60 to 240 percent greater than during the 1996 experiment, although there was less sediment in suspension below RM 42. The 2004 experiment resulted in an increase of total sandbar area and volume in the upper half of Marble Canyon, but further downstream, where sand was less abundant, a net transfer of sand out of eddies occurred that was similar to that observed during the 1996 experiment (Topping et al. 2006).

The third HFE was held March 5-7, 2008, and included a 60-hour release of 41,500 cfs. The 2008 HFE was timed to take advantage of the highest sediment deposits in a decade, and was designed to better assess the ability of these releases to rebuild sandbars and beaches that provide habitat for endangered wildlife and campsites for the Grand Canyon. The 2008 HFE was preceded by a sediment budget that was greater than the 2004 HFE and the net storage effect of the 2008 high-flow was positive. Although sandbar erosion occurred after the March 2008 HFE due to higher monthly volumes, it was noted that the erosion rate slowed during the steady 8,000 cfs releases in September–October. Results of the 2008 HFE were summarized by Melis et al. (2010) and detailed in a number of USGS Open File Reports (Grams et al. 2010; Hilwig and Makinster et al. 2010a, 2010b; Korman et al. 2010; Ralston 2010; Rosi-Marshall et al. 2010; Topping et

al. 2010).

Three habitat maintenance flows (HMFs) were held, including one in 1997 and two in 2000. The 1997 release was held as a fall powerplant release of 31,000 cfs for 72 hours, November 5-7, 1997. The May 2-4 and September 4-6, 2000 HMFs were held in associations with a low steady summer flows of 8,000 cfs from June 1 through September 4, 2000. The steady summer flows were designed to warm shoreline habitats for native and endangered fishes, especially humpback chub, and the HMFs were designed to maintain habitats, export invasive nonnative fish, and evaluate ponding of tributary inflows. A series of test flows with higher than normal winter daily fluctuations from January through March was also conducted from 2003 to 2005 to manage the Lees Ferry trout population (Korman et al. 2010).

Water stored in Lake Powell can be released through Glen Canyon Dam in three ways: (1) through eight penstocks that lead to hydroelectric generators (powerplant) with a combined authorized capacity of 31,500 cfs, (2) through the river outlet works or four bypass tubes with a combined capacity of 15,000 cfs, and (3) over the two spillways with a combined capacity of 208,000 cfs. Most releases are made through the powerplant. Spillway releases can only be made if the reservoir is sufficiently high to top the spillways. Hence, an HFE that exceeds the powerplant capacity would, in nearly all cases, invoke the bypass tubes to achieve the desired flow magnitude. Neither the bypass tubes nor the spillway are equipped with hydropower generating capability.

1.6 Role of Adaptive Management in HFE Implementation

The protocol for high-flow experimental releases will be conducted as a component of the ongoing implementation of the Glen Canyon Dam Adaptive Management Program. The AMP is administered through a designated senior Department of the Interior official who chairs the Adaptive Management Work Group (AMWG). The AMWG provides advice and recommendations to the Secretary of the Interior relative to the operation of Glen Canyon Dam in accordance with the additional criteria and operating plans specified in Section 1804 of the GCPA, and to the exercise of other authorities under existing laws in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established, including but not limited to natural and cultural resources and visitor use, as provided in Section 1802 of the Act.

The details of the protocol and the role of the AMWG in its implementation are provided in section 2.2.6 of this EA. Fundamentally, the decision to conduct an HFE under this protocol is made by the Department. This decision will be based on a determination by scientists and federal managers of the suitability of the hydrology, sediment, and other resource conditions. This intersection of scientists and managers is a fundamental principle of adaptive management and uses the best available scientific information to make decisions about dam management. The AMWG will continue its role as advisory to the Secretary on the 10-year protocol and the adaptive management process. The 10-year high-flow protocol lays the foundation for a process of “learning by

doing," which is a second fundamental principal of adaptive management.

A Science Plan is attached to this EA for the HFE protocol (see Appendix B). This plan addresses research and monitoring activities necessary to evaluate HFEs both as individual and as related experiments. The plan was developed through the adaptive management program as part of the overall science-planning process used by the GCMRC to provide independent, objective science support to the AMP. This plan was drawn from the FY 2011 and FY 2012 Work Plans of the AMP. Similar science plans were developed for the experimental flow treatments and mechanical removal activities in WY's 2002-2004 (USGS 2003) and the 2008 HFE (USGS 2007). In addition, a Strategic Science Plan has been developed to support the Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007-2011 (USGS 2009).

Development of the Science Plan likely would benefit from the convening of a workshop of scientists and managers as was done in 2005 (Melis et al. 2005) and 2007 (U.S. Geological Survey 2007). Highly qualified scientists with expertise in fields of science pertinent and relevant to Grand Canyon issues would ensure the credibility of the Science Plan. The adaptive management program has a group of eminent scientists, the Science Advisors, who would provide valuable additional expertise. Managers with familiarity of Colorado River resource management challenges would ensure that the Science Plan addressed important resource and management concerns.

In 2005, as part of long-range experimental planning, GCMRC conducted an assessment of the current knowledge on resource responses to various management actions in Grand Canyon (e.g., BHBFs, HMFs) (Melis et al. 2005). This assessment concluded that predicting the direction of response for hydropower capacity and replacement costs for a BHBF or HMF was very certain, and predicting response direction for physical resources (i.e., sediment and water temperature) was relatively certain or uncertain. However, the assessment also concluded that response direction for the aquatic food base and fish were uncertain or highly uncertain. This knowledge assessment has not been reevaluated since 2005, and the knowledge of some resources has improved. However, while response by sediment to high flows is fairly well understood, responses by biotic resources continue to be less well understood. Hence, it is important to remember that for this high-flow release protocol, designed HFEs may effectively conserve sediment but will likely invoke uncertainties for biotic resources.

Reclamation has conducted three high flow tests in 1996, 2004, and 2008. These tests have shown valuable findings about resource responses, but these have also revealed unknowns and uncertainties that need to be addressed as part of this protocol. Key research questions that should be addressed in the Science Plan include, but should not be limited to:

- Research Question #1: Given that sandbars are naturally dynamic and go through cycles of building and eroding, can a protocol of frequent high flows under sediment enriched conditions be effective in sustaining these dynamic habitat features?

The goal of this experimental protocol is to identify a long-term program of high flows under sediment-enriched conditions for improving downstream resource conditions.

- Research Question #2: Is sediment conservation more effective following a sediment enrichment period in context of multi-year, multi-event experiments?

Previous high-flow tests were conducted under depleted to enriched sediment conditions, and there is a strong need to determine if sediment conservation is more effective when a release is made during enriched sediment conditions and as frequently as possible.

- Research Question #3: Is sediment conservation more effective when an HFE is held in rapid response to sediment input from the Paria River?

A rapid response HFE has not been tested, in which a high-flow release is made during a sediment-laden flood from the Paria River. This approach is hypothesized to redeposit a range of sediment sizes including coarse sand and fine organic matter that will help to build sandbars and beaches and provide nutrients for riparian plants and backwaters. Multiple rapid response HFEs in a given year could conserve a greater proportion of sediment before it is transported downstream. A rapid response HFE will require accurate monitoring of the Paria River, coordinated dam operations, and public notices to ensure safety for recreational users.

- Research Question #4: How can erosion of sandbars after an HFE be minimized or offset?

Sandbars and beaches rebuilt with previous high-flow tests eroded shortly afterward, and a better strategy is needed to conserve sediment and protect and enhance other key resources.

- Research Question #5: What is the effect of a fall HFE on the food base at Lees Ferry?

Monitoring of the spring 1996 and 2008 HFEs showed scouring of a large portion of the food base that was followed by 2-4 months of recovery during spring and summer. Designed effects monitoring was not conducted before, during, and after the November 2004 HFE. There is concern that a fall HFE would scour the food base at a time when photoperiodicity and hence, photosynthesis are reduced, and recovery of the food base would be delayed until the following spring.

- Research Question #6 What is the effect of a fall HFE on the trout population at Lees Ferry?

Fish monitoring around the November 2004 HFE showed lower than normal

survival and condition of rainbow trout, although there were many confounding factors at the time (warm dam releases from low reservoir, low dissolved oxygen, trout suppression flows, mechanical removal of trout). A fall HFE should be tested for its effects on the trout population.

- Research Question #7: What effect would consecutive HFEs (spring followed by fall, or fall followed by spring) have on the food base and trout population at Lees Ferry?

Consecutive HFEs have not been conducted. The 1996, 2004, and 2008 HFEs were spaced several years apart. The interval between HFEs was sufficient time for the system to recover. Impacts of a consecutive fall and spring event could be severe on the food base and trout population and needs to be tested.

- Research Question #8: What is the relationship of high-release magnitude and duration on the extent of food base scouring in the Lees Ferry reach?

High-flow releases of 41,000 to 45,000 cfs were shown to scour about 90 percent of the food base on sediments and much of the food base on rock substrates in the Lees Ferry reach. The relationship of the extent of scouring and flow magnitude is important information as a potential management tool for stimulating production. Hence, flow magnitude of less than 41,000 cfs should be evaluated to determine the scouring effect on the food base.

- Research Question #9: Is it possible to manage the Lees Ferry trout population with a spring HFE held at slightly different times?

The peak of rainbow trout spawning in Lees Ferry is early March. High-flow release prior to spawning can cleanse the spawning beds of fines and increase survival of eggs and alevins, whereas high flows during the latter stages of incubation can affect incubation rates and survival of eggs and alevins. The effect of high releases timed to trout incubation is important information as a potential management tool for managing the trout population.

- Research Question #10: What is the effect of HFEs on humpback chub and native fish populations located downstream of Glen Canyon Dam?

Ongoing research and monitoring of humpback chub and native fish populations downstream of Glen Canyon Dam have shown that the status and trends of these populations are influenced by complex interactions of river flows, temperature, water clarity, tributary influences, and nonnative predators and competitors. The humpback chub population declined from about 11,000 adults in 1989 to about 5,050 adults 2001, and has subsequently stabilized and increased to 7,650 adults in 2008. Focused investigations are needed to better understand how aspects of an HFE (timing, magnitude, duration, frequency) affect these native fish populations, including nearshore habitat, escapement of young from the Little Colorado River,

food base, and predation and competition by nonnative fish species.

1.7 Public Involvement

As part of the adaptive management process, Reclamation has conducted three HFEs, in 1996, 2004, and 2008. Each of these actions has had public involvement that has helped to provide feedback to high-flow experiments and has helped to inform the development of this protocol. The effects of each HFE have been documented in order to provide this information to the scientific community and to the public for the 1996 HFE (Webb et al. 1999; Ecological Applications, Vol. 11, No. 3, June, 2001), and for 2004 and 2008 HFEs (Gloss et al. 2005; Korman et al. 2010; Makinster et al. 2010a, 2010b; Ralston 2010; Rosi-Marshall et al. 2010). Prior public involvement and peer-reviewed scientific publications have helped to better inform the development and implementation of this HFE protocol.

The idea for this protocol was first presented to the public, agencies, and tribes beginning with an announcement from the Secretary of the Interior, Ken Salazar, on December 10, 2009. This announcement was followed by a *Federal Register Notice* on December 31, 2009 (74 FR 69361) to develop an experimental protocol and to hold a public meeting of the AMWG in Phoenix, Arizona, on February 3-4, 2010 in order to provide scoping information for the EA process. Scoping from prior high-flow experiments was also included and used to discover alternatives, identify issues that needed to be analyzed in the EA, and to help develop mitigation measures for potentially adverse environmental impacts. Reclamation also had a meeting with the local businesses in Glen Canyon on August 20, 2010, where comments on the proposed action were received (Bureau of Reclamation 2010).

In addition to scoping, Reclamation also used available information from an ongoing assimilation and synthesis of information by the U.S. Geological Survey on the three HFEs in Grand Canyon (Schmidt et al. in preparation). To benefit from the preliminary findings of this synthesis, a workshop was held in Salt Lake City on June 15-16, 2010. The information from of this workshop, as well as ongoing communications with GCMRC and the researchers involved in the synthesis, has also been used in this EA.

1.8 Relevant Resources and Issues

Reclamation has utilized the scoping results from prior NEPA analyses, as well as knowledge gained from prior experimental releases from the dam (e.g. Gloss et al. 2005; Korman et al. 2010; Makinster et al. 2010a, 2010b; Ralston 2010; Rosi-Marshall et al. 2010; Webb et al. 1999) to determine the relevant resources and issues for analysis in this environmental assessment. Prior high-flow experiments (HFEs) were conducted in 1996, 2004, and 2008. Table 1 presents the list of relevant resources analyzed in this EA.

Table 1. List of resources and issues evaluated.

NATURAL RESOURCES	CULTURAL RESOURCES	SOCIOECONOMIC RESOURCES
Water Resources	Historic Properties	Hydropower
Water Quality	Traditional Cultural Properties	Recreation (including Public Safety)
Air Quality		
Sediment		
Vegetation		
Terrestrial Invertebrates and Herptofauna		
Aquatic Food Base		
Fish		
• Humpback Chub		
• Razorback Sucker		
• Non-Listed Native Fishes		
• Trout		
• Other Nonnative Fishes		
• Fish Habitat		
Birds		
Mammals		

1.9 Authorizing Actions, Permits or Licenses

Implementation of this proposed action would require a number of authorizations or permits from various federal and state agencies and Indian tribal governments. Any field work within the boundaries of GCNP or GCRA will require permits from the NPS. Tribal permits from the Hualapai Tribe or Navajo Nation would be needed for any field work within reservation boundaries. Researchers working with threatened or endangered species would have to obtain a permit from the USFWS. Researchers working with resident fish or wildlife species would need an Arizona Game and Fish Department (AGFD) permit. No other permits are known to be required at this time.

1.10 Limitations to Conducting an HFE

1.10.1 Dam Maintenance

The amount of water that can be released at a given time depends on the status of the release infrastructure of Glen Canyon Dam. There are eight generators (units) at the Glen Canyon powerplant through which water is released. The combined release capability of these eight units, when all are available, is currently 31,000 cfs. The capacity of the

powerplant is usually 31,500 cfs, but Unit 6 has been "derated," and currently is capable of generating 125 MW with a maximum release of approximately 3,000 cfs (about 75 to 80 percent of its previous capacity). There are four river bypass tubes at Glen Canyon Dam, which have a combined capacity of 15,000 cfs.

Maintenance at the Glen Canyon powerplant is an ongoing activity. All units undergo annual maintenance whereby these units are unavailable for a period of about 3 weeks each year as this work is performed. Annual maintenance is not performed in the months of January, July, August, and December, as these are peak power demand months.

Ongoing maintenance also includes more substantive activities than the annual maintenance schedule. The turbine runners on all eight units at Glen Canyon are currently being replaced. Turbine runner replacement is a major activity, and it generally takes nearly a year to complete one runner replacement. Turbine runner replacement has been scheduled over an 8-year period. Three of the eight runners have now been replaced. Unit 7, the fourth of eight, is expected to be completed in January 2011. The final four turbine runner replacements are scheduled to take place between February 2011 and May 2014. There have been schedule delays in accomplishing the first four turbine runner replacements. Delays could occur in completing the final four runner replacements.

Reclamation has to periodically maintain each of the eight units of the Glen Canyon Dam powerplant. During the time that a unit is being maintained, it is put out of operation and no water is passed from the penstock and through that unit, thus, reducing the total volume that can be released from the dam. Reclamation has a 5-year maintenance schedule for the powerplant (Table 2) that includes scheduled outages for maintenance during the months of April and November (the months during which high flow experiments under the proposed action would take place) from the present through April 2015. Table 2 shows that at least one unit will be unavailable during November and April of every year from April 2011 through April 2014. Hence, maximum possible releases (powerplant and river bypass) for April and November, 2011, are expected to be 34,000 to 42,000 cfs. Maximum releases for 2012 to 2014 are expected to be 42,000 cfs, and maximum expected releases for 2014 and 2015 are 46,000 cfs.

Table 2. Glen Canyon powerplant unit outage schedule - April and November, 2011–2015 (red shaded areas indicate unit outages). Kcfs = thousands of cubic feet per second.

Unit Number	Apr 2011	Nov 2011	Apr 2012	Nov 2012	Apr 2013	Nov 2013	Apr 2014	Nov 2014	Apr 2015
1									
2									
3									
4									
5									
6 (limited)									
7									
8									
Units Available	5 to 7	5 to 7	7	7	7	7	7	8	8
Powerplant Capacity	19 to 27 Kcfs	20 to 27 Kcfs	27 Kcfs	27 Kcfs	27 Kcfs	27 Kcfs	27 Kcfs	31 Kcfs	31 Kcfs
Powerplant plus River Bypass Capacity	34 to 42 Kcfs	35 to 42 Kcfs	42 Kcfs	42 Kcfs	42 Kcfs	42 Kcfs	42 Kcfs	46 Kcfs	46 Kcfs

1.10.2 Sediment and Flow Limitations

The principal driving variables of this protocol are sediment and flow. In order for an HFE to be conducted, a minimum amount of sediment must be available in the river channel and a certain amount of water must be available in the system to generate a release of sufficient magnitude and duration to resuspend and deposit the sediment stored in the river channel. An HFE is not likely to be conducted if these conditions of sediment and water are not suitable. The role of these variables in the decision-making process of this protocol is described in section 2.2 of this EA.

1.10.3 Condition of Resources

The condition of both physical and biological resources must be taken into account by the Department as part of a decision to conduct an HFE. While the condition of physical resources (i.e., sediment budget) necessary to conduct or not conduct an HFE can be determined with a relatively high degree of certainty, the condition of biological resources that might warrant reconsideration of an HFE is not as well understood. As discussed in section 1.6, the expected response by biological resources in general cannot

be predicted with much certainty. However, if a specific key resource is identified in decline or in less than desirable condition, it is reasonable to expect that this will be detected through core monitoring and appropriately considered in the HFE decision-making process. Examples of compromised resources are an unusually high or low survival of trout, a severely depleted food base, or a declining population of humpback chub.

1.10.4 Other Possible Limitations

There may be additional limitations to conducting an HFE other than those described above. Because the protocol includes a decision strategy that should take into account relevant and related actions and effects, a short-term priority may arise that could preclude an HFE.

Reclamation is also currently engaged with cooperating agencies in a process to develop a strategy for managing the numbers of trout in Grand Canyon to minimize the effects of predation and competition on the endangered humpback chub. Reclamation has drafted an environmental assessment and is currently in consultation with the USFWS and in government-to-government consultation with the American Indian Tribes on this action. The series of workshops and meetings held with scientists and managers as part of this process indicate that both flow and non-flow actions will be necessary to manage trout numbers.

The action regarding trout will be important in two ways. First, the trout management efforts may involve flow-based actions. Any flow-based action will need to be analyzed to determine if it will affect sediment transport as assessed in this EA. Second, HFEs that could result from this HFE NEPA process have the possibility to increase trout numbers. Any needed measures to manage trout increases should be conducted consistent with the trout management efforts underway in the nonnative fish EA. As each EA proceeds, the pertinent analyses will draw from one another.

2.0 Description of Alternatives

This section describes the alternatives considered in this Environmental Assessment. A No Action Alternative is the present operation of Glen Canyon Dam under all approved NEPA compliance processes and ESA consultations. The Proposed Action Alternative is the development and implementation of the proposed protocol for high-flow experimental releases from Glen Canyon Dam.

2.1 No Action Alternative

The No Action Alternative is the continued operation of Glen Canyon Dam in accordance with the 1996 Record of Decision on operation of Glen Canyon Dam (U.S. Department of the Interior 1996), and the 2007 Record of Decision for interim guidelines for lower basin shortages and the coordinated reservoir operations (U.S. Department of the Interior 2007). In addition, a 5-year program of experimental dam releases is in effect from 2008 to 2012 through an Environmental Assessment and Finding of No Significant Impact (Bureau of Reclamation 2008) that deviates from the 1996 ROD in two ways: (1) an experimental high flow test of approximately 41,500 cfs for a maximum duration of 60 hours beginning March 4, 2008, and (2) steady flows in September and October of each year, 2008 through 2012.

Elements of the MLFF are summarized in Table 3, and the hydrograph for 2008–2010 is presented in Figure 2, as an illustration of this operation. Dam releases during the 5-year period (2008–2012) consist of MLFF from January 1 to August 31 (except for 60-hour HFE in March 2008). Steady flows, adjusted to available water volume, are to be released for all 5 years in September and October through 2012. The MLFF was the selected alternative of the 1996 ROD because it reduces daily flow fluctuations that will protect or enhance downstream resources while allowing limited flexibility for hydropower operations. The 5-year experimental program was implemented in 2008 to further test an HFE and to provide steady flows in fall that are thought to provide stable habitat for juvenile humpback chub.

The 2008 Biological Opinion on the 5-year experimental program concluded that the implementation of the March 2008 HFE and the 5-year implementation of MLFF with steady releases in September and October was not likely to jeopardize the continued existence of the humpback chub or the Kanab ambersnail, and was not likely to destroy or adversely modify designated critical habitat for the humpback chub (U.S. Fish and Wildlife Service 2008). The 2008 Opinion was supplemented as a result of a Court Order of May 26, 2009 in a Supplemental Opinion (U.S. Fish and Wildlife Service 2009) that affirmed the 2008 Opinion. The Court remanded the incidental take statement back to the Service, and a revised Incidental Take Statement was issued in 2010 (U.S. Fish and Wildlife Service 2010) with incidental take exceeded if the population of humpback chub (≥200 mm [7.87 in] TL) in Grand Canyon drops below 6,000 adults based on ASMR (Coggins et al. 2006).

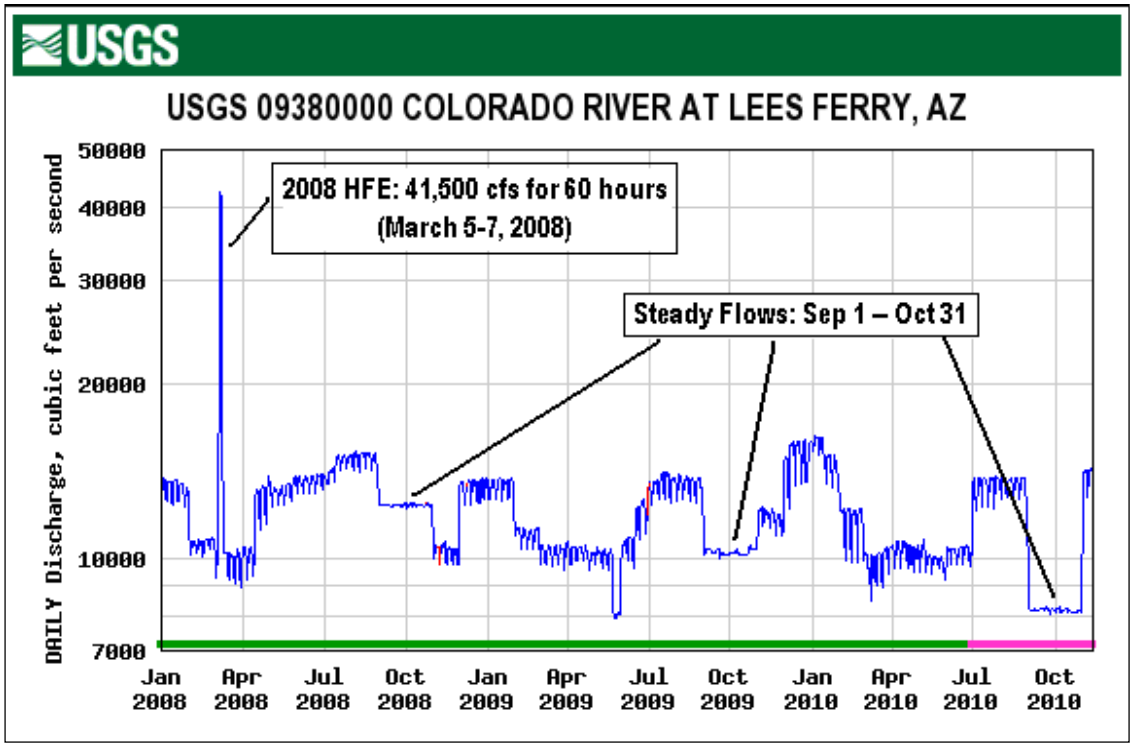


Figure 2. Mean daily discharge of the Colorado River at Lees Ferry from January 1, 2008 to November 11, 2010, showing the 2008 HFE, the September-October steady flows, and the intervening releases under modified low fluctuating flows (MLFF).

Table 3. Summary of Modified Low Fluctuating Flows Criteria.

	Unrestricted Fluctuating Flows		Restricted Fluctuating Flows					Steady Flows	
	No Action	Maximum Power Capacity	High	Moderate	Modified Low	Interim Low	Existing Monthly Volume	Seasonally Adjusted	Year-Round
Minimum releases (cfs)[1]	1,000 Labor Day–Easter [2]3,000 Easter–Labor Day	1,000 Labor Day–Easter [2]3,000 Easter–Labor Day	3,000 5,000 8,000 Depending on monthly volume, firm load, and market conditions	5,000	6,000 between 7 a.m. and 7 p.m. 5,000 at night	6,000 between 7 a.m. and 7 p.m. 5,000 at night	8,000	[3]8,000 Oct-Nov 6,500 Dec 11,000 Jan-Mar 12,500 Apr 18,000 May-Jun 12,500 Jul 9,000 Aug-Sep	Yearly volume prorated[4]
Maximum releases (cfs)[5]	31,500	33,200	31,500	31,500 (may be exceeded during habitat maintenance flows)	25,000 (exceeded during habitat maintenance flows)	20,000	Monthly volumes prorated	18,000 (exceeded during habitat maintenance flows)	Yearly volume prorated[4]
Allowable daily flow fluctuations (cfs/24 hours)	30,500 Labor Day–Easter 28,500 Easter–Labor Day	32,200 Labor Day–Easter 30,200 Easter–Labor Day	15,000 to 22,000	±45% of mean flow for the month not to exceed ±6,000	[6]5,000 6,000 or 8,000	[6]5,000 6,000 or 8,000	[7]±1,000	[7]±1,000	[7]±1,000
Ramp rates (cfs/hour)	Unrestricted	Unrestricted	Unrestricted up, 5,000 or 4,000 down	4,000 up 2,500 down	4,000 up 1,500 down	2,500 up 1,500 down	2,000 cfs/day between months	2,000 cfs/day between months	2,000 cfs/day between months
Common elements	None	None	Adaptive management (including long-term monitoring and research) Monitoring and protecting cultural resources Flood frequency reduction measures Beach-habitat building flows New population of humpback chub Further study of selective withdrawal Emergency exception criteria						

[1] In high volume release months, the allowable daily change would require minimum flows (cfs).
[2] Releases each weekday during recreation season (Easter to Labor Day) would average not less than 8,000 cfs for the period from 8 a.m. to midnight.
[3] Based on an 8.23 million acre-foot year (maf); in higher release years, additional water would be added to each month, subject to an 18,000 cfs maximum.
[4] For an 8.23 maf year, steady flow would be about 11,400 cfs.
[5] Maximums represent normal or routine limits and may necessarily be exceeded during high water years.
[6] Daily fluctuation limit of 5,000 cfs for monthly release volumes less than 600,000 acre-feet; 6,000 cfs for monthly release volumes of 600,000 to 800,000 acre-feet; and 8,000 cfs for monthly volumes over 800,000 acre-feet.
[7] Adjustments would allow for small power system load changes.

2.2 Proposed Action: Protocol for High-Flow Experimental Releases

2.2.1 Development of HFE Protocol

The Proposed Action is the continued operation of Glen Canyon Dam in accordance with prior NEPA decisions, with the inclusion of a protocol for high-flow experimental releases from Glen Canyon Dam for the period 2011–2020. The proposed action is intended to meet the need for high-flow experimental releases, but restrict those releases to limited periods of the year when the highest volumes of sediment are most likely available. Additional attention is given to ensure that other resources would not be unduly or unacceptably impacted or that any such impacts could be sufficiently mitigated. Annual releases would follow the MLFF preferred alternative as described in the 1996 ROD with the added refinement of steady flows as identified in the 2008 Biological Opinion and the 2009 Supplemental Biological Opinion. The timing of high-flow releases would be March/April or October/November; the magnitude would be from 31,500 cfs to 45,000 cfs. The duration would be from less than one hour to 96 hours.

This protocol is intended to be experimental in nature in order to learn how to incorporate high releases into future dam operations in a manner that effectively conserves sediment in the long-term. A number of hypotheses may be tested through this experimental protocol, including the timing of a high release to the delivery and availability of sediment in the river channel. Two approaches are: (1) the "store and release" approach that allows sediment to become stored in the channel over time before a high release, and (2) a "rapid response" approach in which a high release is timed to coordinate with a flood event in the Paria River. The store and release approach was used for the three prior HFEs and has been shown to be effective at redepositing sediment. The second approach has not been tried but is considered to have scientific merit. This rapid response alternative requires a short notice for dam operators, researchers, and downstream recreational users. The rapid response alternative is described in Section 2.3 below.

Developing this protocol is important in order to implement a strategy for high-flow releases over a period of time longer than one year or one event. In the past, Reclamation has done three single-event HFEs and the benefits to sediment have been temporary. One purpose for this protocol is to assess whether multiple, sequential, predictable HFEs conducted under consistent criteria can better conserve sediment resources while not negatively impacting other resources.

A protocol in science and medicine, by definition, is a formal set of rules and procedures to be followed during a particular research experiment. These experimental HFEs would lead to a better understanding of how to conserve sediment in the Grand Canyon by building on knowledge acquired from previous adaptive management experiments. Sand deposited as sandbars is a primary component of the historic Colorado River ecosystem, and determining how sediment conservation can be achieved in areas within GCNP downstream of Glen

Canyon Dam is a high priority of the AMP and Interior. Previous HFEs from Glen Canyon Dam were conducted in 1996, 2004, and 2008. Other high flow releases, at or near powerplant capacity, were conducted in 1997 and 2000. These HFEs provided valuable information and have increased our understanding of responses by physical and biological resources to high-flow releases. For the purpose of this proposed action, all dam releases from 31,500 cfs to 45,000 cfs fall within the range of HFEs.

The Colorado River downstream of Glen Canyon Dam is depleted of its natural sediment load, and ongoing clear dam releases further deplete sediment delivered to the main channel by periodic tributary floods. High dam releases mobilize sand stored in the main river channel and redeposit it as sandbars and beaches that form associated backwater habitats. Sandbars and beaches provide key wildlife habitat, protect archeological sites and vegetation structure, and provide camping opportunities in Grand Canyon. One of the best tools available for rebuilding sandbars is to use dam operations to release short-duration high flows, preferably after sediment-laden tributary floods deposit new sand into the main channel. Development and implementation of this protocol builds on information gathered from the previous HFEs, and is designed to further evaluate the hypothesis that repeated high-flow releases conducted under conditions of sediment enrichment in Grand Canyon result in cumulative increases in sandbar area and volume. This protocol is designed as a multi-year, multi-experiment approach, and constitutes the next logical step in adaptive management with respect to high-flow testing.

2.2.2 Models to Assist Decision-Making for HFEs

Mathematical models were used in two ways in the store and release approach to help develop and implement this protocol: (1) to develop the protocol, historic sediment and hydrologic data were used to estimate the frequency, magnitude, and duration of high flows that could be implemented to maximize the potential for sandbar building with the available sand supply, and (2) to implement the protocol, contemporary sediment data and forecasted hydrologic data were used to determine whether suitable sediment and hydrology conditions exist for a high-flow experimental release.

The two basic inputs for the modeling are the sediment which in this case is restricted to inputs from the Paria River and the water input or hydrology, which is taken from the Colorado River Simulation System (CRSS) (Bureau of Reclamation 2007b). A flow routing model (Wiele and Smith 1996) was used to simulate water passing downstream. The sediment budget model (Wright et al. 2010) was used to integrate the flow routing with the sediment inputs and outputs to determine whether or not a sediment mass balance is achieved for HFEs (see Appendix E).

To develop the protocol, the hydrology model was used to develop dam release scenarios a 10-year period under dry, moderate, and wet conditions (Grantz and Patno 2010). The three hydrology time series were then used in conjunction with sediment input data (low, moderate, high) from the Paria River to create nine different sediment/hydrology combinations for input into the sediment budget model. It measures sediment inputs and

outputs for three river reaches where sand is tracked: (1) from Lees Ferry/Paria River (RM 0) to RM 30, (2) from RM 30 to Little Colorado River (RM61), and (3) from Little Colorado River to RM 87. For the purposes of this EA, only the first two reaches were used.

The same mathematical models will be used to implement the protocol and to help make decisions whether or not to conduct an HFE under the storage and release approach. These models are based on a series of decision points, driven principally by available sand storage and water volume. Because high-flow releases may be conducted under a variety of sand storage conditions, models are necessary for designing the release hydrograph shape. In a year with relatively high sand storage a "larger" release would be warranted as compared to a year with less sand storage. Wright and Grams (2010) demonstrated how the sand storage model can be used in conjunction with a flow routing model (Wiele and Smith 1996) to estimate sand storage conditions for a range of dam operations. Water supply forecasts and models are needed to make these projections and the uncertainty associated with these will need to be considered in the decision-making process (see disaggregation using hydrology model Grantz and Patno 2010). The modeling is described in Appendices D and E of this EA.

2.2.3 Types and Occurrences of HFEs

2.2.3.1 Store and Release Approach

Thirteen types of HFEs were evaluated for the store and release approach through modeling (Table 4). These provide a range of magnitude and duration for HFEs that may occur in March/April or October/November. The range of 41,000–45,000 cfs represents the range of high releases for the HFEs conducted in 1996 (45,000 cfs), 2004 (41,000 cfs), and 2008 (41,500 cfs). The duration range of 60–96 hours is within the range of time for high releases associated with the HFEs of 1996 (7 days), 2004 (60 hrs), and 2008 (60 hrs), but HFEs of less than 60 hours have not been conducted. An HFE with a magnitude greater than 31,000 cfs and less than 41,000 cfs has also not been conducted.

Table 4. Flow magnitude and duration for 13 possible HFEs used with the sediment/hydrology model.

HFE No.	Flow Magnitude (cfs)	Duration (hours)	HFE No.	Flow Magnitude (cfs)	Duration (hours)
1	45,000	96	8	45,000	1
2	45,000	72	9	41,500	1
3	45,000	60	10	39,000	1
4	45,000	48	11	36,500	1
5	45,000	36	12	34,000	1
6	45,000	24	13	31,500	1
7	45,000	12			

Model runs were done using dry, moderate, and wet hydrology settings for representative years of low (1983, 862,000 metric tons), moderate (1990, 1,334,000 metric tons), and high (1934, 1,649,000 metric tons) sediment input. Each run was evaluated against 13 described HFEs to determine their possible occurrence in the months of April or November, 2011–2020. The type of HFE possible was determined by the volume of available sediment and the forecasted hydrology, as predicted through the modeling process. The model evaluates each of the 13 HFE types sequentially starting with the highest magnitude and duration of release. For example, the initial run determines if there is enough sediment available to release an HFE of 45,000 cfs for 96 hours. If enough sediment is available to achieve a positive mass balance, that magnitude and duration of HFE can be implemented. If the model run does not conclude that enough sediment is available to achieve a positive mass balance, the next HFE type is evaluated by the model. This is repeated until an HFE scenario is reached that can be implemented with the available sediment, or it is determined that an HFE cannot be implemented. There is an assumption here that water is not limiting because reallocation of water from other months will be used to ensure that sufficient water is available for the HFE.

The results of modeling simulations for nine traces of sediment and hydrology (Table 5) do not necessarily reflect what may happen during the 10-year HFE protocol period. It is highly unlikely that the same sediment/hydrology condition will persist for the full 10-year period, and it is also unlikely that each sediment/hydrology condition will be equally represented. However, this table provides an insight into the potential frequency, magnitude, and duration of HFEs. These model runs also indicate a potential of consecutive HFEs, either within the same year or between years. Another important finding is that there is the potential of up to 5 or 6 sequential HFEs. This has important implications for impact analysis, given that consecutive HFEs have not been conducted at Glen Canyon Dam. Given the uncertainty of resource responses to multiple, consecutive HFEs, adaptive management monitoring will be used to weigh the risk of additional HFEs against the learning that can be acquired from their implementation.

The total number of occurrences for each HFE from Table 5 shows that certain types of HFEs are more likely to occur than others. Of the total number of HFEs for all nine sediment/hydrology traces (Figure 3), an HFE of 45,000 for 96 hours is 2.4 times more likely to occur than any other type of HFE. The second most likely type to occur is an HFE of 45,000 cfs for 1 hour. Based on sediment/hydrology conditions, modeling results indicate that HFEs in the range of 31,500 cfs to 39,000 cfs have a low chance of occurring.

Table 5. Type of HFE by month for each of the nine traces of sediment (Low, Moderate, High) and hydrology (Dry, Moderate, Wet). See Table 4 for descriptions of HFEs.

Month/Year	Low, Dry	Low, Mod.	Low, Wet	Mod, Dry	Mod., Mod.	Mod., Wet	High, Dry	High, Mod.	High, Wet
4/1/2011	5	5					7	7	
11/1/2011	2	2		6	6		6	6	
4/1/2012									
11/1/2012		7							
4/1/2013	6	13		1	2	1	8		
11/1/2013	3	8	4	1	2	1	1	1	1
4/1/2014	11			1	1		2	8	3
11/1/2014	1	1	7	8	8		6	8	
4/1/2015							2	7	1
11/1/2015	1		4	8		1			
4/1/2016	12	8	8	5	1			12	9
11/1/2016			8				1	1	1
4/1/2017	9	8			8		9	10	
11/1/2017	7	7				4	1	1	1
4/1/2018			7	8		1	4	9	1
11/1/2018	4	3	3	1	1		6	7	8
4/1/2019						1			
11/1/2019	9	7		1	1				
4/21/2020	1	1	1			2			
11/1/2020	2	2	1	5	6	1	6	7	1
No. of HFEs	14	13	9	11	10	8	13	13	9

The numbers of HFEs for the nine sediment/hydrology traces indicate that HFEs are most likely to occur during high sediment/dry hydrology conditions, followed by low sediment/dry hydrology, low sediment/moderate hydrology, and high sediment/moderate hydrology (Figure 4). These conditions of suitability reveal the influence of hydrology and the consequent magnitude of dam releases. HFEs are most likely to occur in years of dry to moderate hydrology because lower seasonal releases from the dam cause less ongoing export of sediment. Low year-round dam releases allow for a greater accumulation of sediment than high releases which have higher velocity and a greater scouring effect.

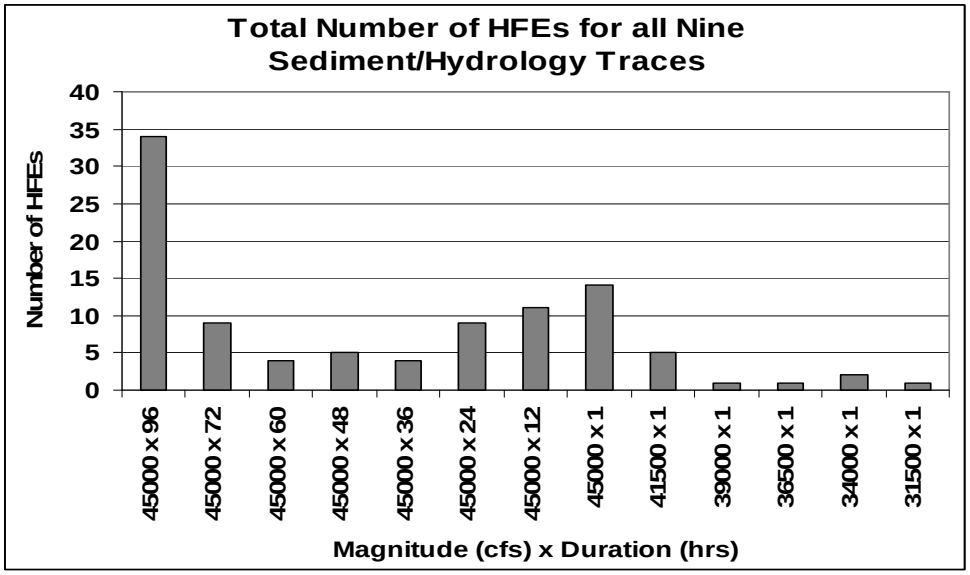


Figure 3. Total numbers of HFEs for all nine sediment/hydrology traces combined.

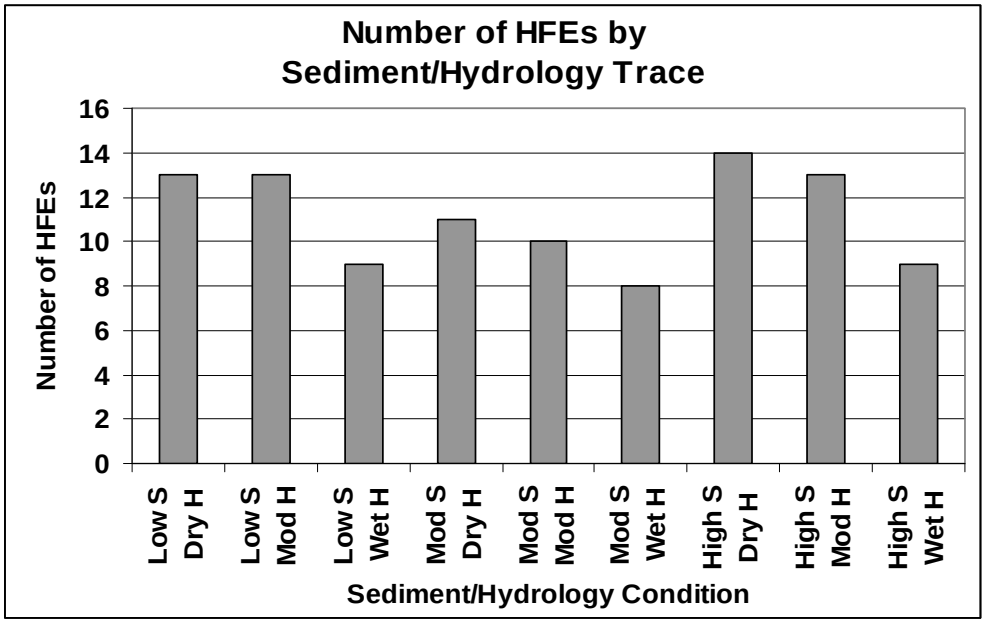


Figure 4. Numbers of HFEs for each of the nine sediment/hydrology traces. The numbers shown in this figure are out of a total possible 20 HFEs (i.e., 2/year for 10 years).

2.2.3.2 Rapid Response HFE

As presented in full in Section 2.3 of this EA, during the NEPA process for the development of this HFE Protocol, Western developed and proposed a "rapid response" high flow release, limited to the power plant capacity of approximately 33,200 cfs, triggered by a specific flooding threshold on the Paria River. Reclamation has identified what it considers to be the key elements of Western's proposal and is incorporating those elements into a modified "rapid response" component of the proposed action alternative. Western's proposed alternative is fully described, and as submitted for Reclamation's consideration, in Section 2.3 below.

In order to test the flow trigger paradigm in comparison to the sediment trigger paradigm, an HFE based on Paria River high flows is included as a component of the proposed action. Such an HFE would be based either on a specific Paria River flood magnitude or Paria River measured sediment load. Reclamation believes that there is sufficient experimental value in testing such an approach. However, Reclamation has determined that a rapid response HFE trigger that is based solely on specific Paria River flows (and therefore without consideration of sediment loads either in the Paria or the mainstem) does not meet the purpose and need for the HFE protocol because of scientific and operational uncertainties not yet fully analyzed and because the most practical time of year for testing this hypothesis (July-Sept.) is outside of the established months proposed for experimental releases.

Implementation of this component will require further analysis through the adaptive management program to develop the information needed to verify and ensure that a flood from the Paria River contains sufficient sediment loads to benefit downstream resources. Reclamation proposes to test as part of the proposed action, whether sand could be conserved by combining flow releases from the Dam within the power plant capacity, with a flood from the Paria River, so that the combined releases would yield a discharge ranging from 33,300 to over 38,000 cfs. This 'rapid release' HFE is adapted from Western's proposal to test **a** water-driven paradigm during the July through September peak season for Paria River high flow events, but is constrained to the established test windows of March-April and October-November.

Therefore, in addition to the 13 HFE types described in section 2.2.3.1, two alternate HFE approaches would be considered both using a release from Lake Powell of 33,200 cfs with a duration of one day or less. This flow and duration are within the range of HFEs shown in Table 4 above. The two 'rapid response' HFE scenarios are as follows:

1. The protocol model shows that appropriate sediment trigger is present and that conditions are suitable for an HFE during the established experimentation windows of March-April and October-November. Under this scenario, the rapid response HFE would be tested by scheduling an HFE later in the release period (e.g., late November). This planned HFE would include a contingency that if a suitable high flow event occurs earlier during the established experimentation windows on the Paria and dam releases can be matched to that high flow prior to the scheduled HFE, the 'rapid response' release would be implemented, with appropriate safety measures taken. Under this HFE scenario, Reclamation would

monitor weather patterns and other sediment information to determine if and when a sediment-rich Paria River flood is likely to occur. If an appropriate sediment-rich Paria flood is likely to occur, Reclamation would make its best efforts to have the HFE release coincide with the Paria flood. If the appropriate sediment-rich Paria River flood does not occur, then the HFE release could proceed without the Paria River sediment input at the end of the month during the experimentation window and at the corresponding flow level described for that type of HFE of the 13 described in Section 2.2.3.1.

2. The protocol model shows that the modeled sediment trigger is NOT present, but there are sediment-enriched flows in the Paria River within the established experimentation windows, In this case, a rapid response release would be considered.

> *[Editor's note: The following information pertaining to the 'rapid response' experiment speaks to effects, uncertainties and commitments and therefore for the public release will likely be relocated elsewhere in the EA, primarily in Chapter 3. Appropriate reorganization of these discussions will occur following cooperating agency review. Nevertheless, Reclamation is seeking CA input on the content of the following information.]*

Under the rapid release component analyzed as part of the proposed action, Reclamation and other management agencies would need to put river users and other members of the public on notice that a high flow release could occur in a particular month. The HFE release could be more accurately predicted as weather forecasts materialized, thus providing the opportunity to notify river users as possibly-triggering weather events were nearing the Paria River drainage. Reclamation and other agencies will carefully consider all safety issues associated with this alternative to protect river users by providing sufficient notice.

As proposed by Western, (see Section 2.3), this power plant capacity (or equivalent) release, coupled with high flows on the Paria River, could be made 'at a moment's notice.' Such a rapid response would have to occur in a matter of a few hours, and would likely have negative impacts on private property, recreation and safety, and dam operations. NPS has indicated in the course of the HFE Protocol EA preparation that having 3 weeks' notice in order to fully inform the public and mitigate negative impacts is the most desirable course of action. Prior to the actual initiation of any rapid response HFE, an appropriate warning system will be developed. An effective response will require coordination with dam operators and notices to anglers, boaters, rafters, and recreationists to ensure public safety.

Execution of such an experimental release is procedurally difficult, as it involves timing power plant capacity with the Paria River flows within a narrow window of time. There is a risk that the time required to ramp up to power plant capacity would miss catching the high flow peak altogether.

Accordingly, the rapid response HFE component will require further development through adaptive management. However, Reclamation has incorporated the concept of testing this approach into the proposed action alternative should suitable conditions occur during the established high flow experiment windows, with October being the likeliest month for suitable Paria River flows. Consideration of whether to test the approach would occur as part of the decision and implementation component of the protocol described in Section 2.2.4

above. Additionally, during the implementation of the proposed action, Reclamation commits to continue to evaluate the results of any 'rapid-response HFEs" and use such results and other relevant information as it considers whether to further expand this sub-alternative to consider additional experimental release periods (particularly during the July-September period) or whether to adopt a "flow-only" Paria River trigger.

Reclamation believes that an experimental approach utilizing Paria River flood flows that may already contain high levels of sediment should be tested as part of a thorough approach to adaptive management experimentation. These sediment-rich flood flows could be valuable for two primary reasons. First, the flows eliminate the need to re-suspend sediment in the river flow for downstream distribution because the sediment is already carried in the Paria River in a suspended state. Second, these flows offer the opportunity to achieve the benefits of higher-volume HFEs without using as much Colorado River water from Lake Powell as would normally be needed to achieve a higher-volume HFE. This is because the Colorado River flow from Lake Powell would be combined with a Paria River flood to produce an HFE. In other words, assuming the correct timing could be achieved (and that safety and other dam operation issues are addressed), the modified rapid response component could produce results similar to a HFE release of approximately 40,000-45,000 cfs using only approximately 33,200 cfs of water from Lake Powell. This advantage could be particularly helpful for conducting HFE releases in low water release years. Another advantage would be the savings to hydropower generation because the bypass tubes may not need to be employed (or would be utilized at a lesser volume depending on powerplant capacity limitations) because of the added water volume from the "matched" Paria River flows.

One potential uncertainty associated with this alternative is the limited understanding of how much sediment is carried by Paria River flood flows at a given time. This area of uncertainty would be explored and refined through the adaptive management process.

2.2.4 Decision-Making Process

The HFE protocol is a decision-making process that consists of three components: (1) planning and budgeting, (2) modeling, and (3) decision and implementation. The following three subsections describe each of these components.

2.2.4.1 Planning and Budgeting Component

The first component of the HFE protocol is planning and budgeting (Figure 5). The HFE EA and the Science Plan contained within the EA provide the foundation for the protocol. An important aspect of planning is the development and implementation of research and monitoring activities appropriate to monitor the effects of the HFEs. An annual agency report assimilates and synthesizes the information on the status and trends of key resources and an annual status review is conducted. This information is provided to the Interior to assist with the decision and implementation component of this protocol. Funding for HFEs is determined through the AMP in a biannual budget process. Interior will be prepared to

conduct an HFE if conditions are appropriate.

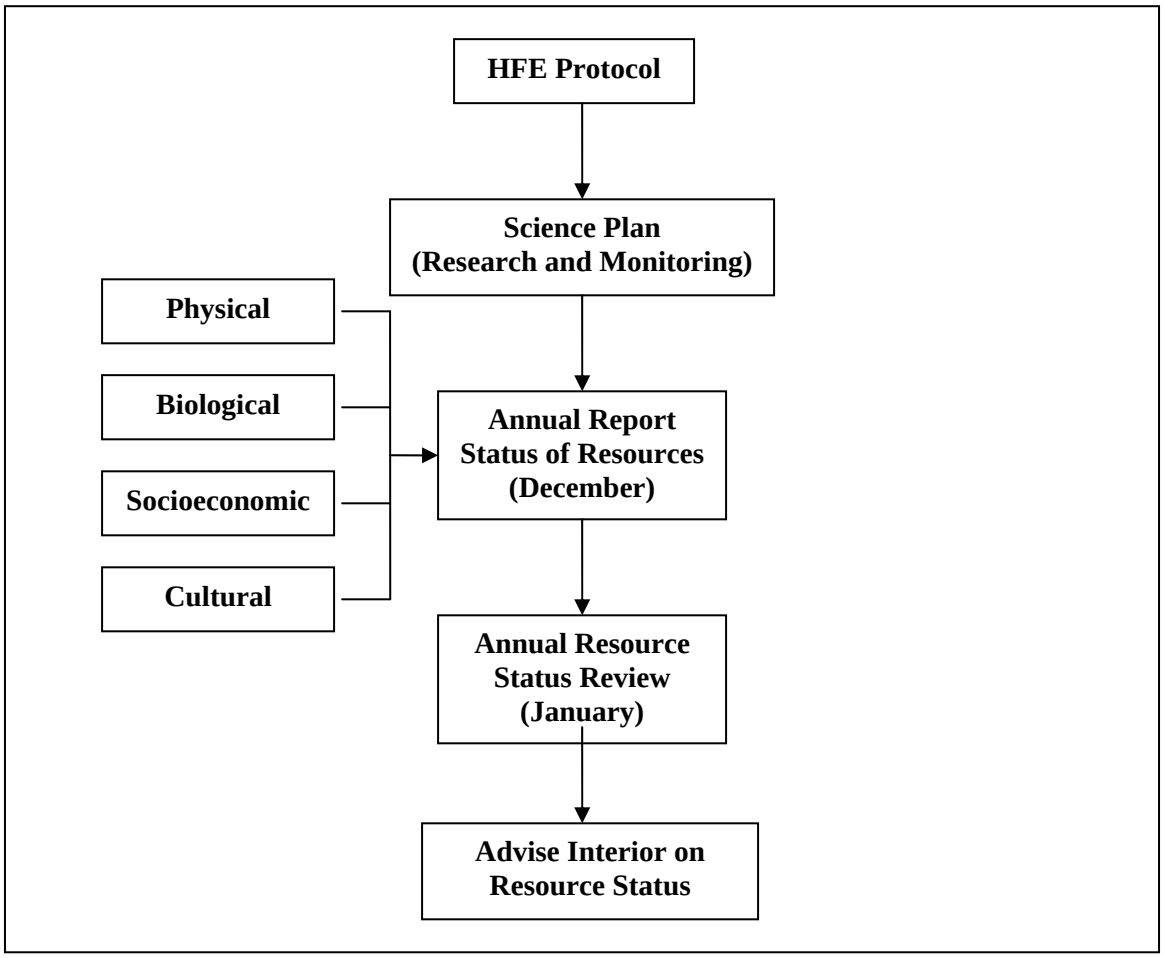


Figure 5. Planning and preparation component for the HFE protocol.

2.2.4.2 Modeling Component

The modeling component is based on six key analysis points associated with two sand budget accounting periods and two flood windows. The sand budget is the net amount of sand in metric tons that has accrued in the river channel over some period of time. The two sand accrual periods would be July through October and December through March (Figure 6), and the two high release windows would be October through November and March through April. Sand availability at the onset of each release window is determined by the amount of sand received from the Paria River during the accrual period less the amount transported downstream to the Little Colorado River as estimated by the sand routing model. Sand in Grand Canyon received from the Little Colorado River is viewed as an added benefit to the amount received from the Paria River, and the tributary input cycle largely follows the same accrual periods as the Paria River. For the purposes of this model, however, sand inputs from the Little Colorado River would not drive the model for a high-flow release. The flow

windows of April and November were selected because these occur at the end of each of the two sediment accounting periods and at a time that allows for the greatest amount of sediment to have been delivered from the Paria River and the Little Colorado River.

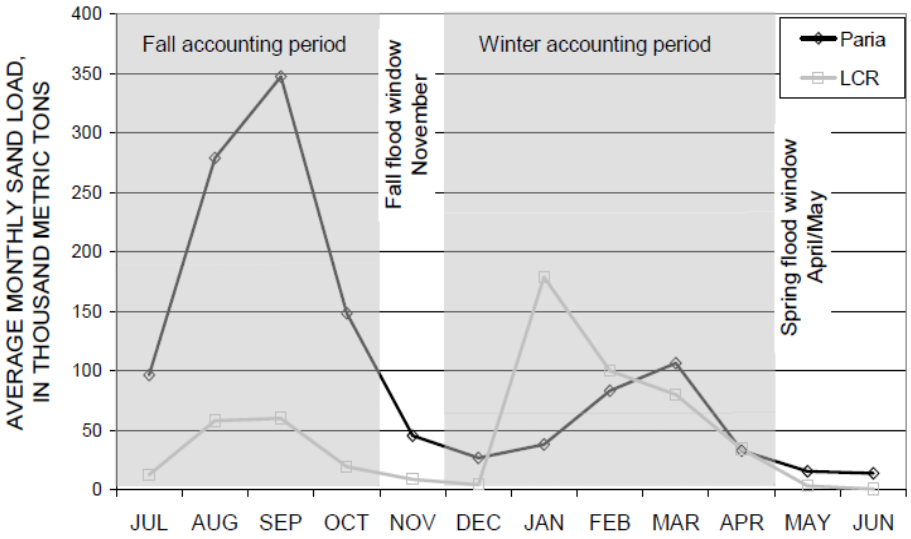


Figure 6. The two sand accounting periods and the two high-release periods with average monthly sand loads for the Paria River and the Little Colorado River (Personal communications, Scott Wright).

The sand-budget "accounting periods" are antecedent to the two flow windows and may be of different durations, as was described for the November 2004 HFE and the March 2008 HFE (Topping et al. 2010). The term "accounting period" is defined as the period from the zero time at which sand budgeting begins until the beginning of the rising limb (i.e., increased rate of dam release to achieve a given flow magnitude) of a controlled flood. As described in Topping et al. (2006a), the 2004 HFE was designed to test the hypothesis that a sufficiently large single-season input of sand from the Paria River could be retained in the channel of the Colorado River through reduced dam releases and then redistributed onto sandbars during a relatively short-duration artificial flood released from Glen Canyon Dam. Therefore, the accounting period antecedent to the 2004 HFE began at the beginning of the sediment-input season on July 1, 2004, and extended until the start of the rising limb of the November 2004 HFE.

The design of the 2008 HFE was different from the design of the 2004 HFE. The accounting period antecedent to the 2008 HFE began upon recession of the 2004 HFE and extended until the start of the rising limb of the March 2008 HFE. Planning for the 2008 HFE started in response to the extremely large quantity of sand supplied by the Paria River in October 2006, and is an example of how a large amount of sediment input can trigger an HFE. For the purpose of this protocol, the sand accounting period carries over an ongoing balance of stored sediment and does not reset to zero with every period.

It is important to note that this modeling strategy describes the process for triggering single HFEs. Also, this modeling exercise does not predict the timing, magnitude, or duration of future HFEs. Because the sediment inputs are driven by individual storm events, the precise timing, frequency and sequence of HFEs cannot be determined in advance because of the unpredictable nature of sediment input from the Paria River in concert with water availability. The decision-making process for a 1-year period is presented in Figure 7 and described below as six phases:

Phase 1 – Fall accounting period. The fall accounting period is from July 1 to September 30. Beginning on July 1 each year, monitoring data will be used to track the sand storage from Paria River inputs in Marble Canyon.

Phase 2 – October-November flood window. Beginning October 1, sand storage and forecast hydrology are evaluated to determine whether conditions are suitable for an HFE. If the model outcome (sand storage coupled with predicted hydrology) shows that the mass balance of sediment is positive, then water forecasts and modeling would be used to project the end of the sediment accounting period for a range of high release hydrographs. A positive mass balance is defined as a condition in which the amount of sediment being delivered by tributaries into the system equals or exceeds the amount being exported from the system by ongoing dam operations and HFEs. If it is determined that a high-flow release could be conducted while still maintaining a positive sand budget, then the decision point proceeds to Phase 3, which also allows for other factors (biological, economic, societal) to be considered in the planning process. Until a decision for an HFE is made, sand storage will be reevaluated to refine the estimated HFE magnitude and duration. The model will select the HFE of the highest magnitude and duration that will allow a positive sand mass balance.

Phase 3 – Fall flood implementation. If the ultimate decision to conduct a high-flow release is made, this phase also would consist of further refining the magnitude and duration of the hydrograph and conducting scientific studies before, during, and following the release.

Phase 4 – Spring accounting period. The spring accounting period is December 1 to February 28. As with the fall accounting period, monitoring data would be used to track the sand storage conditions in Marble Canyon during this time period. This accounting would be conducted regardless of whether or not a previous October or November HFE was conducted such that two HFEs could theoretically occur in the same year. The accounting would continue to consider sand storage conditions present at the end of phase 2 or 3.

Phase 5 – March-April flood window. The evaluation in this phase is the same as for the fall high release window. That is, a high release could be conducted if data and model predictions suggest a high release could occur while still maintaining a positive sand budget. If no tributary inputs were included in this period, a spring HFE would likely not occur, and the process would begin again on July 1. If a high release is triggered, we

proceed to Phase 6.

Phase 6 – Spring flood implementation. This phase is essentially the same as phase 3.

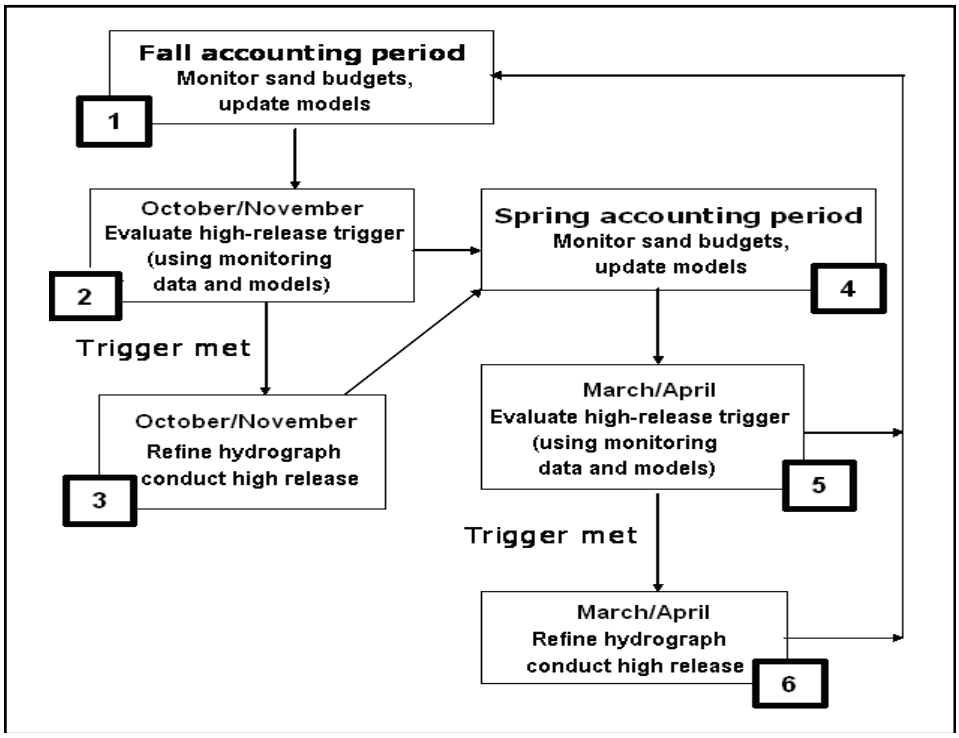
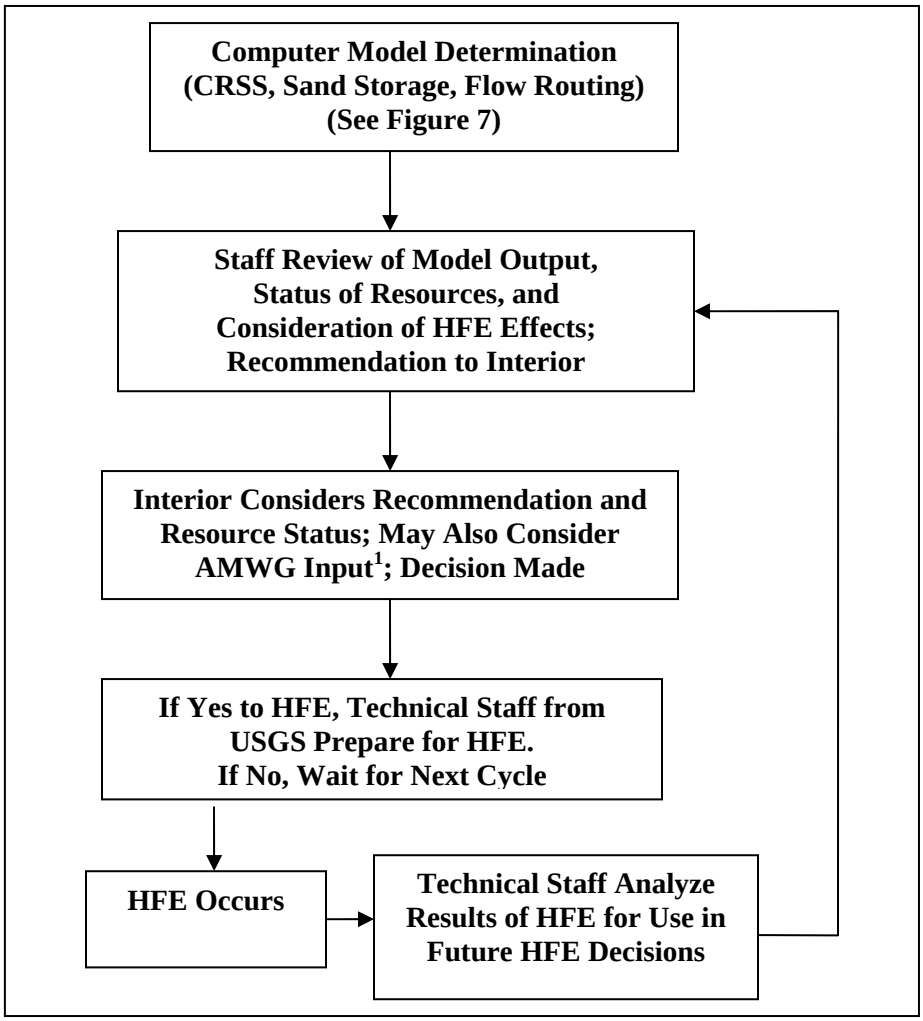


Figure 7. Modeling component of HFE protocol. Includes two sand budget accounting periods and two high-release windows. Each box and decision point is described in detail in the text (Personal communication, Scott Wright). "Refine hydrograph" means that an HFE is identified for a month and water is reallocated from other months, as necessary.

2.2.4.3 Decision and Implementation Component

The third component of the protocol is decision and implementation component for conducting an HFE (Figure 8). The output from the model runs described in Figure 7 is used to determine if sediment and hydrology conditions are suitable for an HFE. Because the model only considers water and sediment, the purpose of this protocol component is to consider potential effects on other resources. The model output would be provided to Interior staff, who would consider the status and trends of key resources before making a recommendation to Interior. Interior would consider the staff recommendation and resource status, and may also consider input from the AMWG before making a decision to conduct or not conduct an HFE. If the decision is made to conduct an HFE, the technical staff of the USGS would prepare to conduct monitoring and research. If not, reevaluation would occur during the next accounting window or large Paria River flood. For each HFE, technical staffs would analyze results and integrate information of other HFEs for use in future HFE decisions.



[1]Issues and concerns expressed at annual AMWG meeting and other consultations, as appropriate.

Figure 8. Decision and implementation component of HFE protocol.

2.2.5 Criteria for High-Flow Releases

2.2.5.1 Trigger Criteria

- Previous triggering criteria for HFEs (2004 and 2008) were based on specific targets for sand storage.
- Alternative criterion is to trigger high-flow releases in years when a positive annual sand budget can be maintained for Marble Canyon, even if an HFE is conducted.
- Marble Canyon is a logical choice for the monitoring reach because it is immediately downstream from the first major tributary (Paria River) and is thus the reach most vulnerable to long-term erosion.
- This criterion is preferable to a strict numerical target because: 1) it protects against HFEs contributing to long-term declines in overall sand storage, and 2) it allows for HFEs of different "size" to be implemented during years with different sand storage conditions.
- To test the rapid response approach, sediment-rich floods in the Paria River

2.2.5.2 Time of Year

- Previous HFEs have occurred during the fall (2004) and spring (1996, 2008). These are logical "high release windows" based on the seasonal pattern of sand supply from the tributaries (Topping et al. 2010).
- Tributary flooding is typically greatest in the late summer and early fall such that a fall window is most advantageous for managing this sand supply.
- Tributary flooding can also occur in winter and spring such that a spring window allows for flexibility in managing this sand supply as well.
- The accounting periods are the time frames for which the sand storage conditions would be monitored to provide information for decision making during the high release windows.

2.2.5.3 Frequency

- Frequency of future high-flow releases would be tied to future tributary sand supply, future basin hydrology, and future dam operations. Because of the inherent uncertainty in all of these drivers, it is difficult to precisely define the expected frequency of HFEs, although for the purpose of the impact analysis, the likely occurrence of multiple HFEs is described in section 3.1.4.
- Long-term records of Paria River sand loads, 1925–2008 (Topping et al. 2010; Topping 1997) suggest an average annual sand supply of 1.0–1.5 million metric tons, but with substantial variability. Mainstem monitoring data for years 2003-2009 indicate an annual average sand load at the lower end of Marble Canyon (RM 61) of about 500,000 metric tons (not including the floods in 2004 and 2008).

- Based on the criterion outlined above, floods would only occur in years with a positive sand budget in Marble Canyon, thus the Paria River inputs must exceed the mainstem export during normal operations plus the export during HFEs. The HFEs in 2004 and 2008 exported about 600,000 and 800,000 metric tons of sand from Marble Canyon, respectively.
- HFE hydrographs could be implemented that export less sand by reducing the peak and/or duration. A reasonable estimate for the minimum export during a flood, for purposes of this rough estimate, is around 300,000 metric tons.
- Thus, for an HFE to occur in a given year, the Paria River sand supply would need to be greater than about 800,000 metric tons. In the 84-year record for the Paria River, an annual sand supply of 800,000 metric tons was exceeded 50 times, or 60 percent of years. This estimate is likely an upper bound on the frequency of HFEs; that is, floods would not likely occur more frequently over the long-term. However, during certain periods, HFEs could occur more frequently, or less frequently, depending on tributary sand supply, basin hydrology, and dam operations.

2.2.5.4 Magnitude

- High-flow release hydrographs should be designed based on sand storage in the system leading up to a given HFE. In years with large tributary sand inputs and low volume water releases, sand storage is likely to be greatest and would allow for flood hydrographs with higher peaks and longer durations.
- In years when sand storage is positive but not as large, a hydrograph with a lower peak and shorter duration would be appropriate.
- The overarching goal would be to maximize sand transport during HFEs because this sand is available for deposition onto sandbars without exporting more sand than is available.
- Near real-time data and models will be used in the decision-making process to design a high release hydrograph that attempts to optimize sandbar building.

2.2.5.5 Other Considerations for Conducting an HFE

- Additional experimentation is necessary to determine the most effective hydrograph shape for building sandbars.
- Previous HFEs had peak flows of 41,000–45,000 cfs and durations of 7 days (1996) and 2.5 days (2004 and 2008). To facilitate adaptive management, it would be desirable to experiment with a broader range of peak flows and durations.
- Several powerplant capacity (~31,000 cfs) spikes have been released from the dam but they were not designed for sandbar building. Further evaluation of powerplant capacity releases is needed. For example, in years with only slightly positive sand storage, a powerplant capacity release with a very short duration (a few hours) could be tested. The maximum peak and duration would depend on sand storage and water supply conditions.

- Testing of peak flows greater than 45,000 cfs is scientifically justified, but is constrained by current low reservoirs levels such that the spillways are inaccessible. Higher peak flows should be considered in the future if reservoir levels permit. Maximum duration would depend on the available sand storage as well as water supply conditions. Duration would be constrained so as not to export more sand than is available. Based on the sand transport data from the 2004 and 2008 HFEs, most high releases would warrant durations of only a few days or less.
- The high-release trigger protocol is based on sand storage in Marble Canyon, which primarily depends on the sand supply of the Paria River. It is desirable to have contingencies built for the Little Colorado River because it is the other major sand supplying tributary below the dam.
- In many instances the Little Colorado and Paria Rivers flood simultaneously. In cases where the Marble Canyon trigger is on the border of being met, it may be useful to consider recent Little Colorado River inputs in the decision-making process.
- If an extremely large flood occurs on the Little Colorado River, then this information should be taken into consideration. It may be deemed acceptable to conduct an HFE that results in a slightly negative sand budget for Marble Canyon in order to take advantage of sand supplied by the Little Colorado River.

2.2.6 Implementation of Protocol

Implementation of the protocol for HFEs from Glen Canyon Dam will be done in concert with coordinated river operations. Reclamation prepares an Annual Operating Plan (AOP) each year that describes the past year's annual releases and projects the current year's annual release. Since 1970, the annual volume of water released from Glen Canyon Dam has been made according to the provisions of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (LROC) that includes a minimum objective release of 8.23 maf.

The interim guidelines for lower basin shortages and the coordinated reservoir operations (U.S. Department of the Interior 2007) implements relevant provisions of the LROC for an interim period through 2026. This allows Reclamation to modify these operations by allowing for potential annual releases both greater than and less than the minimum objective release under certain conditions.

A more thorough description of Reclamation's process for determining and implementing annual release volumes is available in the 2007 EIS and Record of Decision and the Biological Opinion (U.S. Fish and Wildlife Service 2007). Based on the conditions and criteria of the interim guidelines and coordinated reservoir operations, projected monthly Glen Canyon Dam release volumes for the period 2009–2012 are provided in Table 6 for dry, medium, and wet conditions.

Table 6. No Action Glen Canyon Dam releases under dry (7.48 maf), median (8.23 maf), and wet (12.3 maf) conditions, 2009-2012 (U.S. Department of the Interior 2007a).

	Annual Releases								
	7.48 maf			8.23 maf			12.3 maf		
Month	Mean (cfs)	Min (cfs)	Max (cfs)	Mean (cfs)	Min (cfs)	Max (cfs)	Mean (cfs)	Min (cfs)	Max (cfs)
Oct	7,502	5,300	10,300	9,758	6,800	12,800	9,378	6,800	12,800
Nov	7,563	5,900	10,900	10,083	7,100	13,100	9,075	7,100	13,100
Dec	9,378	6,800	12,800	13,011	9,000	17,000	12,503	9,000	17,000
Jan	12,503	9,000	17,000	13,011	9,000	17,000	17,510	14,200	22,200
Feb	8,470	7,800	13,800	10,804	7,800	13,800	13,903	13,700	21,700
Mar	9,378	6,800	14,800	9,758	6,800	12,800	14,776	11,400	19,400
Apr	7,563	5,900	10,900	10,083	7,100	13,100	14,551	12,200	20,200
May	9,378	6,800	12,800	9,758	6,800	12,800	14,880	11,500	19,500
Jun	9,075	7,100	13,100	10,924	7,900	13,900	17,009	14,900	22,900
Jul	12,503	9,000	17,000	13,824	9,800	17,800	19,776	16,600	24,600
Aug	12,503	9,000	17,000	14,637	10,600	18,600	23,883	20,900	25,000
Sep	9,075	7,100	13,100	10,588	7,600	13,600	21,056	19,400	25,000

2.2.7 Mitigation Measures in Proposed Action

2.2.7.1 Possible Effects Addressed Through Protocol

The protocol for high-flow experimental releases strives to avoid or minimize impacts and thus reduces the potential for negative impacts to the human environment. Where possible, the decisional strategy and the described HFEs are designed to optimize sand conservation in Grand Canyon National Park, while minimizing negative impacts to, and striving to benefit, other resources. The following are aspects of the protocol that either intentionally or coincidentally help to optimize resource conservation and avoid negative impacts. Impacts not addressed through refinement of the proposed action are otherwise identified in section 3 and mitigation is described for these in section 3.6 of this EA.

- **HFE Timed to Maximum Sediment Input.** High-flow releases are scheduled for March/April or October/November to take advantage of those time periods when the sediment budget is expected to be the highest, based on historic sediment input from key tributaries. High-flow releases at these time periods would be less likely to deplete sediment in the channel and lead to a declining sediment budget.
- **HFE Duration to Use Less Water.** The magnitude and duration of a given HFE will be determined from the amount of sediment in the system and the least amount of water necessary to suspend and redeposit that sediment on sandbars and beaches. Based on prior HFEs (e.g., 1996, 45,000 cfs for 7 days), long-duration flows are not

necessary since suspension and redeposition of sediment occurs in less than about 4 days. Shorter duration flows use less water volume and minimize hydropower impacts.

- **Reduced Dispersal of Tamarisk Seeds.** High-flow releases prior to May and after September are outside of the seed production period for tamarisk, an invasive riparian plant in Grand Canyon, and will likely result in less distribution of seeds through the canyon and a lower level of seedling establishment.
- **Trout Response Uncertain to Timing.** Prior spring HFEs, in March or April, have resulted in increased survival and recruitment of rainbow trout in the Lees Ferry reach. The single HFE in November may have reduced survival and recruitment from normal of other years. A healthy robust trout population is important to the recreational fishery, but over-population by trout can lead to fish in poor condition, a depleted food base, and escapement to downstream reaches where the trout can prey on young of the endangered humpback chub. Predation by nonnative fish is recognized by Reclamation in a nonnative fish control conservation measure identified in the 2008, 2009, and 2010 biological opinions. Reclamation is currently developing a separate EA that will contain mechanisms for control of nonnative fish.
- **Timing Reduces Effects to Recreation.** This protocol identifies March/April and October/November as the most likely months for an HFE. The March/April time periods occurs prior to and during the start-up of the fishing and boating season in Grand Canyon, and the October/November period occurs during a reduced level of recreational activity in the Colorado River through Grand Canyon.

2.2.7.2 Monitoring

The high-flow releases are part of a long-term experimental strategy to better understand the responses by downstream resources to HFEs. A Science Plan has been developed to describe monitoring and evaluation of the impacts of the proposed action throughout the Colorado River corridor from Glen Canyon Dam to Pearce Ferry. Effects to Lake Powell will be monitored and evaluated as part of the ongoing program of GCMRC. Monitoring and evaluation of these releases will be done in a scientific manner that will include appropriate sampling designs and data analyses, integrated across resources and HFEs. The high-flow experimental releases will be evaluated independently and comprehensively to better understand the impacts to the physical, biological, cultural, and recreational resources of the Colorado River corridor downstream of Glen Canyon Dam. Evaluation will include data collections before, during, and after each release, where appropriate, and the concept of replication will be incorporated into study design, where possible.

Adverse impacts that may have long-lasting damaging impacts to resources will be identified and avoided, wherever possible. However, some aspect(s) of these HFEs may have short-term impacts on certain resources. Actions that have adverse impacts on resources will need to be mitigated. The actions that would be taken to mitigate adverse impacts of the high-flow releases on resources would need to comply with appropriate guidelines and legislation, including the Endangered Species Act, Grand Canyon Protection Act, and National Historic Preservation Act.

2.2.7.3 Mitigation

Under NEPA, mitigation means reducing, eliminating, or compensating for the impact of an alternative (40 CFR 1508.20). Mitigation measures incorporated into the proposed action are designed to accomplish these objectives. More complete descriptions of potential impacts of the proposed action are contained in the various resource areas in section 4.0. The following actions are incorporated into the EA as part of mitigation to avoid or minimize potential adverse effects:

- **Purchase Alternative Sources of Energy.** Hydropower reduction will be offset by purchase of alternative energy. Hydropower demand is generally greatest during summer months (May-September) and winter months (December-February); and lowest during spring months (March/April) and fall months (October/November). An HFE held in March/April or October/November will occur in a period of low hydropower demand. Hydropower costs will be incurred with an HFE because of the inability to fluctuate releases in response to peak demands. The magnitude and duration of an HFE will determine the cost. A shorter duration HFE will have lower costs because MLFF can be resumed sooner. A high magnitude, long duration HFE will have higher costs because of the inability to correspond hydropower production with demand.
- **Relocate Kanab Ambersnails and Habitat.** A population of the endangered Kanab ambersnail (*Oxyloma haydeni kanabensis*) currently exists at Vasey's Paradise, about 48 miles downstream of Glen Canyon Dam. The vegetation occupied by the snails occurs above the elevation that is inundated with flows that exceed the powerplant capacity of about 31,500 cfs. Hence, flows above the powerplant will likely inundate occupied habitat and export some individuals downstream. Reclamation proposes to temporarily relocate snails that would be inundated and possibly exported by an HFE to higher elevations at Vaseys Paradise, as necessary. Further mitigation commitments could develop as a result of the completion of formal consultation with the USFWS under the ESA. Mitigation actions for the November 2004 HFE included moving 4 percent of the total habitat of plants and animals. The current proposed mitigation will repeat the 2004 mitigation measures for the Kanab ambersnail.
- **Public Outreach.–**Recreational activities related to angling in the Lees Ferry reach and whitewater rafting in GCNP increase seasonally in April and decrease in October. An HFE held in March/April or October/November would not affect as many recreational users as one held between April and October. To minimize impacts and ensure public safety, advance notices of a planned HFE will be made to recreational users.
- **Science Plan and Monitoring.** Through the adaptive management process, the Science Plan will continue to develop and evolve. The GCMRC will address unknowns and uncertainties associated with various aspects of HFEs and their effects on physical, biological, cultural, and socioeconomic resources. Ongoing core monitoring, as well as additional monitoring as necessary, will be implemented to ensure that negative impacts are detected and future HFEs are appropriately designed.

2.3 Alternatives Eliminated from Further Consideration

The Western Area Power Administration (Western) submitted a proposed alternative to Reclamation. For the reasons described in Section 2.2.3.2 above, Reclamation has eliminated this alternative from further consideration. Reclamation has, however, identified what it considers to be key elements from Western's proposal. These concepts are contained in the Rapid Response Alternative described in Section 2.2.3.2.

In the interest of completeness, the full version of Western's alternative is described below.

2.3.1 Paria River Augmentation or Rapid Response Experiment

A challenge in prescribing a controlled flood for building sandbar habitats is that the flooding mechanism that is needed to transport sediment into these fan-eddy complexes throughout Marble and Grand Canyons also transports sediment further downstream and out of the system. As can be seen in Table 1, previous high flow releases in 2004 and 2008 resulted in greater accumulations of sand in reaches further downstream of Glen Canyon Dam, especially in the western Grand Canyon (represented as river-mile 225 in Table 1).

It may be possible to improve the overall benefits of controlled high releases by favoring sediment deposition in more upstream reaches, especially Marble Canyon (represented as river-mile 30 and 61 in Table 1), increasing the effectiveness of processes that build and maintain ecologically important sandbar habitats, and promote ecological productivity downstream of Glen Canyon Dam.

As described previously, under the "store and transport" method, that HFE alternative would mobilize sand deposited in the main channel of the Colorado River from its main tributary, the Paria River, that has accumulated on the river bed and in eddies. Under this method controlled high flow releases from Glen Canyon Dam (ranging from 31,500 cfs to 45,000 cfs) would be used to mobilize stored sand and deposit that sand at higher elevations in sand bars.

An alternative HFE approach, referred to here as the Paria River flood augmentation method , consists of controlled releases from Glen Canyon Dam of 33,200 cfs that would occur in coordination with sediment-rich floods in the Paria River. Coordinating controlled releases with flooding in the Paria River has the potential to transport suspended sediment at high concentrations to downstream reaches and deposit the sediment into ecologically significant sandbar complexes. The alternative HFE approach would increase ecological benefits of controlled flood events by introducing variability in the timing, frequency, magnitude, and duration of HFEs. Introducing this variability in flood events has the potential to build and maintain sandbar complexes through increased deposition of fine sands and cohesive sediments, as well as provide a mechanism for organic material transport into backwater habitats that is critical for productivity in the river.

TABLE 1. Input and Export of Sand in Marble and Grand Canyon Reaches Associated with 2004 and 2008 High Flows

Reach	Sand Input and Export (million metric tons) 2004	2008
Inputs prior to high flow		
Paria River	0.617±0.062	3.350±0.335
Upper Marble Canyon Tributaries	0.062±0.031	0.335±0.168
Lower Marble Canyon tributaries	0.044±0.022	0.096±0.048
Little Colorado River	0.180±0.018	3.021±0.302
Eastern Grand Canyon lesser tributaries	0.037±0.019	0.081±0.041
Combined east and west-central Grand Canyon tributaries	0.102±0.019	0.372±0.186
Total Input	*1.04*	*7.26*
Exports prior to high flow		
River-mile 30	0.296±0.015	2.490±0.125
River-mile 61	0.226±0.011	2.051±0.103
River-mile 87	0.481±0.024	4.317±0.216
River-mile 225	0.427±0.021	3.586±0.179
Exports during high flow		
River-mile 0	0.020±0.001	0.048±0.002
River-mile 30	0.476±0.024	0.651±0.033
River-mile 61	0.657±0.033	0.879±0.044
River-mile 87	0.622±0.031	1.197±0.060
River-mile 225	0.689±0.034	1.055±0.053
Total Export	*1.12*	*4.64*
Net change		
River-mile 0-30	-0.073±0.133	+0.592±0.663
River-mile 30-61	-0.067±0.105	+0.307±0.353
River-mile 61-87	+0.021±0.112	+0.518±0.766
River-mile 87-225	+0.089±0.161	+1.059±0.508
Total Net Change	*-0.07*	*2.61*

Source: Tables 2, 6, and 7 in Topping et al. (2010)

Possible advantages of the Paria River flood augmentation HFE method include the following:

- Redistribute and conserve fine, organically rich and ecologically important sediments in Marble Canyon and the Eastern Grand Canyon. Fine sediments are usually transported downstream quickly as wash load. Under the alternative, these fine sediments would be retained for longer periods in channel margin deposits, and above the normal operational range of flows. Because these sediments would be above the normal high water stage, they would be released more slowly and in a more sustained fashion through erosional processes associated with wind and surface runoff.

- Stimulate primary and secondary production by flushing, but not scouring substrates.

- Conserve sand in high elevation environments in Marble Canyon (above typical operational stages).

- Enhance sandbar stability with deposition of finer sediments that have greater cohesiveness.

- Provide variability in flooding and deposition processes rather than a set, predetermined flow.

The two HFE methods can be viewed as two different paradigms for sediment management. What follows will be a description of (1) the potential benefits of our proposed approach; (2) considerations regarding flood frequency, magnitude, duration, and timing; (3) hypotheses that should be tested when comparing the effectiveness of the Paria River flood augmentation alternative and the store and transport alternative; and (4) incorporating adaptive management during implementation of HFE experimentation.

POTENTIAL BENEFITS OF THE PARIA RIVER FLOOD AUGMENTATION HFE METHOD

The Paria River flood augmentation HFE method would take advantage of the fact that the Paria River transports a high concentration of fine sands during floods. Thus, coordinating controlled flood releases should result in higher suspended sediment concentrations in downstream reaches. The Paria River is also the major source of fine, cohesive sediments (silts, muds, and clays) to the Colorado River in Marble Canyon (Akahori et al. 2008). Under normal operations, these fine sediments are transported relatively quickly far downstream and out of the system as wash load. Coordinating controlled releases with Paria River floods has the potential to deposit a greater proportion of these fine sediments in sandbar complexes.

The Paria River and the Little Colorado River are the two major tributaries that contribute sediment to the Colorado River downstream of Glen Canyon Dam (Topping et al. 2010). Coordinating flood releases with the Paria River has the advantage of depositing

sediment in Marble Canyon, and with more frequent flooding events, eventually transporting sediments down to the Grand Canyon reach. Coordinating controlled flood releases with the Little Colorado River would contribute to building sandbars in the Grand Canyon reach, but also has the potential to erode sandbars in the Marble Canyon reach.

This HFE method also is expected to flush algal and accumulated organic material from the Glen Canyon Dam to Lees Ferry reach and this material would be deposited together with Paria River sediments at higher elevations. Shannon et al. (1996) found that over 60% of the algal standing crop upstream of the confluence with the Little Colorado River is located between Glen Canyon Dam and the Paria River confluence.

The inclusion of cohesive and organic materials into sandbars has the potential to stabilize sandbars from wind and water erosion during normal operational flow periods (Akahori et al. 2008), as well as to retain organic matter in sediment deposits that can then serve as a source of this material to support secondary and primary productivity in ecologically important habitats. Armored reaches of rivers, such as the Colorado River below Glen Canyon Dam, are often depleted of nutrients and experience declines in productivity through time. Increasing the storage of nutrient-rich organic materials in ecologically important habitats could help reduce the severity of this trend. In addition, the occasional flushing of algal beds and shearing of dead or senescent growth may stimulate productivity of those beds with concomitant increases in the macroinvertebrates which serve as the food base of many other aquatic organisms including trout and humpback chub.

The premise upon which the Paria River flood augmentation HFE method is based is that coordination of a controlled release with Paria River floods and associated sediment inputs is an important way to conserve sediment. Previously, it was proposed that low steady releases from the dam (e.g., 8,000 to 10,000 cfs) follow Paria River inputs to retain sediments in Marble Canyon until a BHBF could be implemented. Our proposal is an alternative way to store those sediments while maintaining operational flexibility. In addition, the lag between sediment inputs and previously implemented BHBFs (several months at a minimum) have resulted in the downstream transport of sediments, especially the finer, organically rich sediments. Although evidence suggests these sediments have been accumulating in the Western Grand Canyon, their ecological significance in this downstream-most reach has not been demonstrated.

CONSIDERATIONS

The Paria River flood augmentation HFE method is consistent with scientific recommendations that have been made based on evidence from the previous HFEs conducted since the 1990s, with the largest HFEs occurring in 1996, 2004, and 2008. These HFEs ranged from 42,000 to 45,000 cfs (i.e., maximum powerplant capacity plus full bypass) and have been called beach habitat building flows (BHBFs). For the Colorado River downstream of Glen Canyon Dam, sand input is the most important limiting factor for building and maintaining sandbar habitats and the role of a controlled release flood is to maximize sand transport and deposition rates. There are two basic ways to conduct a controlled release:

1. Allow several tributary flood inputs to occur in order to accumulate sediment in the system and then implement a controlled release flood, or

2. Coordinate the controlled release flood with tributary flood inputs.

The first approach was prescribed in the Glen Canyon Dam Environmental Impact Statement (EIS) and associated record of decision; however, since publication of the EIS, evidence gathered for HFEs has shown that sand from tributary inputs does not accumulate over time in the system, because flows from normal dam operations tend to flush finer sands out of the system (Rubin et al. 2002). Topping et al. (2010) concluded the following:

> *"Therefore, "more sand" could be achieved directly by augmentation from sand trapped in the reservoir impounded by Glen Canyon Dam or perhaps indirectly by following each large tributary input of sand with short-duration controlled floods. Frequent short-duration controlled floods under sand-enriched conditions could result in the downstream propagation (into the downstream half of Marble Canyon and into Grand Canyon) of the gains in total eddy-sandbar area and volume observed in the upstream half of Marble Canyon during the 2004 controlled-flood experiment."*

Topping's conclusion suggests that the second approach is better for prescribing controlled release floods, which is to coordinate controlled high releases with large tributary inputs of sand delivered primarily by flood events in the Paria River.

The building and maintenance of sand bar complexes is best achieved by having high suspended sand concentrations in the river during a flood. Suspended sand concentrations are affected by two factors:

1. Sand supply, which is affected by bed shear stress (i.e., the ability to scour sediment from pools and maintain sediments in suspension during flood), the percentage of the riverbed area covered by sand, and upstream sand inputs

2. Median particle size (or particle size distribution) as finer sands are easier to transport than coarser sands.

The effects of these two factors have been studied in detail during previous HFEs with results indicating that the median particle size exerts primary control on suspended sand concentrations. In fact, evidence has shown that a greater suspended sand concentration can be achieved if the median particle size is less, even with less sediment in the system (Topping et al. 2010).

There are four main factors to consider in prescribing a controlled flood release: magnitude, duration, frequency, and timing.

Flood magnitude

The magnitude of a controlled flood release has two primary functions: to scour sand from the bed of deep pools and to raise the water surface elevations such that sands can be deposited at high elevations on sandbar complexes (this is referred to as the "redistribution process"). Topping (1997) presents detailed hydrologic information on the Paria River including return period information on peak discharges. Bankfull discharge of 3,178 cfs has a recurrence value of 2.2 years, while discharges of 500, 1,000, 2,000, and 5,000 cfs have recurrence values of 0.2, 0.5, 1.0, and 7 years, respectively. The alternative HFE prescribes a release of 33,200 cfs9 from Glen Canyon Dam that will combine with the flood flow of the Paria River to yield a total discharge that ranges from approximately 33,300 to over 38,000 cfs.

Note that the variability in Paria River flood magnitudes will occasionally produce a flood magnitude that is roughly comparable to the magnitude of BHBFs (i.e., 42,000 cfs), but the alternative HFEs would have higher sediment concentrations than would the BHBFs whose sediments are obtained entirely from the scouring of sand stored on the river bed and along channel margins. In addition, observations during previous BHBFs have indicated that algal beds were scoured from the gravel and cobble beds. Under the alternative HFE, flood magnitudes above the Paria River where most primary production occurs would be limited to 33,500 cfs, which may be insufficient to scour algal beds. Thus, the alternative HFE we propose could achieve flows capable of depositing sediments at high elevations while limiting the scouring of algal beds that appeared to increase spawning opportunities for trout.

In September 2000, following a 4-day release of 31,000 cfs, evidence of the "redistribution process" of sands was detected using side-scan sonar measurements that were similar to results from the 1996 HFE (Topping et al. 2010). Additionally, the work of Hazel et al. (2010) suggests floods greater than 25,000 cfs can deposit sands at "high elevation zones" in sandbar complexes, so the magnitude of the proposed alternative HFE should be able to carry out both functions of the redistribution process needed to build and maintain sandbar habitats.

Flood duration

The 1996 HFE was conducted for 7 days. Results indicated that the majority of the finer sediments that were on the river bed and in channel margin deposits were completely washed out of the system. The 2004 and 2008 HFEs were shortened to 2.5 days to limit the flushing of fine sediments. Flood duration must be sufficiently long to convey sands to downstream reaches, but must be short enough to limit the flushing of sand out of the system. In implementing the alternative HFE, high releases from the dam should not last much longer than the Paria River flood to minimize sediment transport out of the system. Paria River

9 Note that this magnitude may not be achievable in the short-term because at least one turbine will be down for maintenance at all times during the next few years.

floods can vary in duration from a few hours (the typical flood) to rare multiday events. Consideration should be given to HFEs that are less than one day long to better match Paria inputs; however, this may not be practical from an operational standpoint. The effects of flood durations of less than 1 day on sandbar habitats is currently not known, but would err towards the side of conserving sediment within the system.

Flood frequency

Coordinating controlled flood releases with flooding in the Paria River would result in an increase in HFEs and potentially in several HFEs in some years. Previous HFEs have occurred at much lower frequencies. The actual frequency will depend on the trigger used for a powerplant capacity release. The information on flood magnitude presented above suggests that triggers of 500, 1,000, and 2,000 cfs would produce an average of 5, 2, and 1 HFEs per year, respectively. Higher triggers of 3,178 cfs (bankfull discharge) and 5,000 cfs would result in HFEs, on average, every 2 or 7 years, respectively. More frequent floods better represent the hydrology under pre-dam conditions, and in combination with the variability in flood magnitude, has the potential to periodically deposit sands at varying elevations in the sandbar complexes.

Flood Timing

The seasonal timing of floods has implications on sediment transport as well as ecological processes. The Paria River has a baseflow discharge ranging from 3.5 to 35 cfs with flood discharges ranging from 200 to over 5,000 cfs (Graf et al. 1991, Topping 1997). Summer and fall floods in the Paria River are typically the result of monsoonal storms and these floods deliver as much as 90% of the annual sediment load, while winter floods typically deliver 50% of the annual flow volume (Graf et al. 1991). Sediment contributions from the Paria River vary significantly by month with the greatest contributions occurring in August and September and lesser contributions occurring during other months of the year (Figure 1; Wright and Grams 2010). Year-to-year variability in the hydrology of the Paria River is partially affected by El Niño-Southern Oscillation (ENSO) patterns that typically increase the variability in fall floods. In addition to this year-to-year variability, there has been a long term pattern in decreasing intensity of tropical cyclone storms resulting in decreased peak flood magnitudes since the early 1940s (Graf et al. 1991).

Implementation of the Paria River flood augmentation HFE method requires the development of a Paria River trigger. The goal is to implement controlled releases in coordination with Paria River floods that deliver high suspended sediment loads. This trigger could be based on flood magnitude or Paria River sediment load. Given considerations described previously, it would be advantageous to coordinate controlled releases with summer and fall floods because the sediment loads are much greater. This suggests that a single discharge in the Paria River may not be an adequate trigger for coordinating controlled releases as summer and fall peak discharges are often smaller than winter peak discharges, but carry more sediments. In addition, the variation in base flow magnitude affects what might be considered a “flood,” and, rather than establishing a fixed flow as a trigger, some

percentage increase relative to the base flow might be more appropriate (see Figure 2 for Paria River hydrographs). However, anytime the Paria River reaches bankfull conditions (3,180 cfs) or greater, coordinated controlled flood releases should be implemented to take advantage of the extra floodplain sediments that would be introduced into the system.

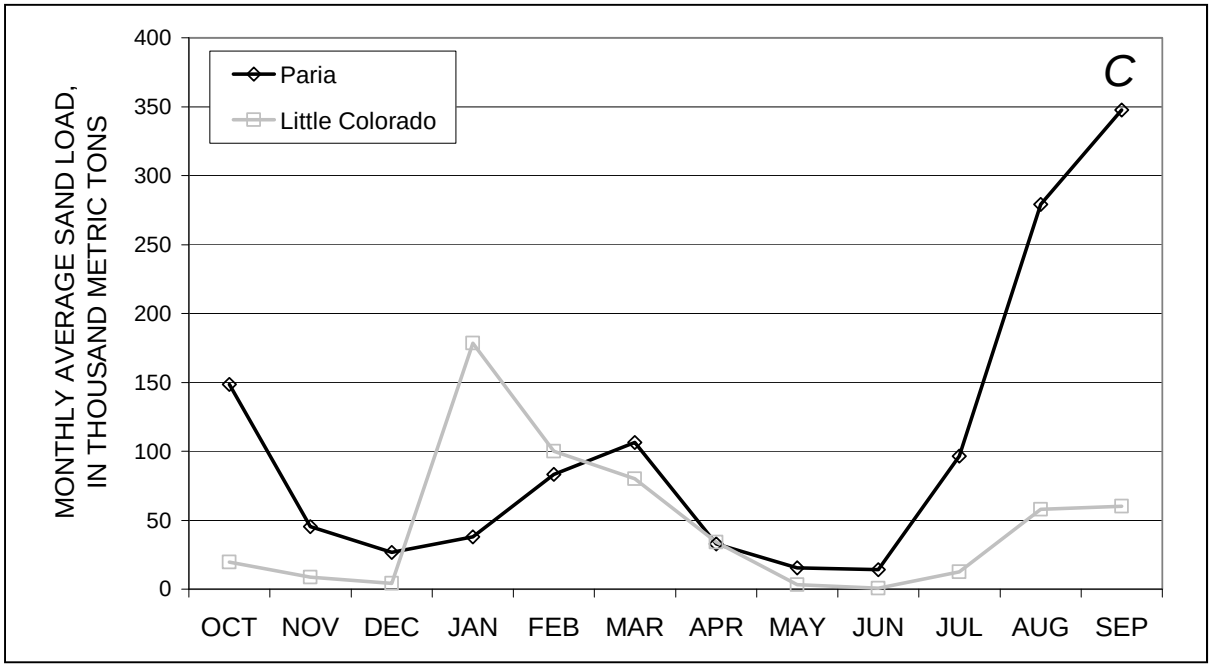


FIGURE 2. Average monthly Paria and Little Colorado River sand loads (Source: Wright and Grams 2010).

Implementation of the Paria River flood augmentation HFE method would require the ability to respond quickly to a Paria River flood. Water travel time from the USGS gage on the Paria River at Kanab, Utah (USGS stream gage 09381800) to the confluence with the Colorado River at Lees Ferry (USGS stream gage 09382000) was estimated as 6 hours during a recent flood in August 2010. Using measurements of Graf (1997), a 33,200 cfs release is estimated to take about 5 hours to reach the Paria River confluence.

HYPOTHESIS TO BE TESTED FOR THIS HIGH FLOW EXPERIMENTS METHOD

An experimental study design should be developed that identifies the approach to testing the two alternative HFEs. Data should be gathered that can objectively measure the relative performance of the two alternatives with regard to key ecosystem and sediment management objectives. The performance of the HFE alternatives should also be compared to that of previous BHBF experiments. Measured variables should include the following:

- The net change in the area and volume of sandbars above normal operational stages after HFEs in different portions of the Grand Canyon, including Marble Canyon.
- Net transport of sediments out of the Grand Canyon during HFEs.
- Size fractions of sediments transported during HFEs.

(a

(b

(c

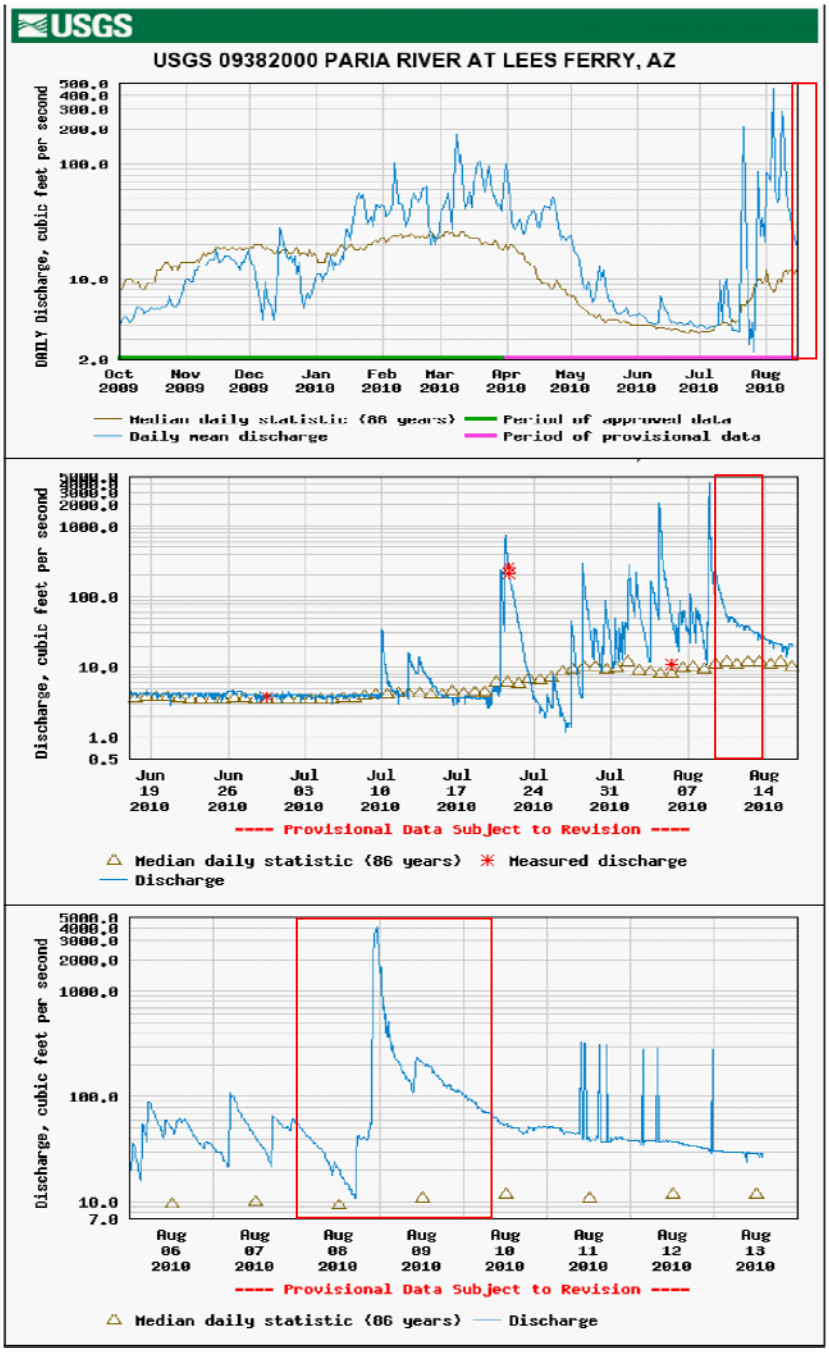


FIGURE 1. Hydrographs for the Paria River at Lees Ferry (USGS stream gage 09382000) with (a) daily averaged discharge for WY 2010, along with 15 minute discharge data for (b) the months of June and August 2010, and (c) for a week in early August 2010. The red box denotes similar time periods in each figure (note the effect of daily averaging on discharge axis).

- Size fractions of sediments deposited in sandbars above normal operational stages during an HFE.
- The persistence of sandbars above normal operational stages after an HFE.
- The condition of habitats important to native fishes and ecological processes before and after an HFE.
- Primary and secondary productivity in the Lees Ferry Reach and in humpback chub habitats before and after an HFE.

An Adaptive Management Approach to High Flow Experimentation

We propose to implement the two experimental approaches according to a scientifically determined schedule over several years. These experiments will determine which of the two sediment paradigms best achieves the sediment goals described earlier. Each HFE implemented will bring information and new understanding regarding the best timing, duration, and magnitude needed to achieve sediment-related goals.

As information is gathered and data are analyzed, scientific uncertainty will be reduced. As this occurs, the appropriate response will be to modify the HFE protocol accordingly. An adaptive management approach to river restoration that has been successfully used before is known as Adaptive Environmental Assessment and Management (AEAM).

As described by the Trinity River Restoration Project: "The AEAM approach to management relies on . . . scientists, managers, and policy makers jointly identifying and bounding management problems in quantifiable terms." This adaptive approach to management recognizes that the information on which decisions are based is almost always incomplete. The AEAM process relies on monitoring changes in the ecosystem, and also in developing and testing hypotheses about the causes of those changes, in order to promote desired outcomes.

The result of an AEAM process is informed decisions and increasing certainty regarding the best management practices. Again, referring to the process described at Trinity River: "A well-designed AEAM process:

1. defines goals and objectives in measurable terms;

2. develops hypotheses, builds models, compares alternatives, designs system manipulations and monitoring programs for promising alternatives;

3. proposes modifications to operations that protect, conserve and enhance the resource;

4. implements monitoring and research programs to examine how selected management actions meet resource management objectives; and

5. uses the results of steps 1-4 to further refine ecosystem management to meet the stated objectives.

The intention of the AEAM organization is to provide a process for cooperative integration of water control operations, resource protection, monitoring, management, and research."

For the AEAM process related to Glen Canyon HFE experiments, the two sediment paradigms will be tested; the Paria River Flood Augmentation Method and the Store and Transport Method. Given the variation in sediment delivery from the Paria River and the variation in annual release volumes from Glen Canyon Dam, the tests of these paradigms will take several years. The AEAM process would be used to modify management actions. The adaptive assessment and management team would be the Grand Canyon Monitoring and Research Center and the Adaptive Management Working Group. These scientists and managers would evaluate the results of HFEs' effects on the building of beaches and sandbars, creation and maintenance of aquatic habitats for native fishes, and biological productivity.

SUMMARY

Table 2 presents a summary of anticipated effects of the Paria River flood augmentation HFE method on various resources downstream of Glen Canyon Dam. The proposed alternative HFE plan has the potential to build and maintain ecologically important sandbar complexes with greater efficiency than the current plan for BHBFs. Coordination with Paria River floods has the advantage of delivering high suspended sediment concentrations downstream, which has been shown to exert primary control on the building of sandbar complexes in previous HFEs. The flow magnitude of the proposed alternative HFE is slightly lower than the previous BHBFs but evidence from previous HFEs suggests that sand deposition at high elevations zones is achievable. Additionally, the alternative HFE plan will result in more frequent high flow events and more variability with respect to their magnitude, frequency, and timing, which can potentially deliver a greater amount of sediments to sandbar complexes. Coordinating controlled releases with Paria River floods should also result in a greater transport of fine, cohesive sediments along with organic material that can help stabilize sandbars as well as enhance productivity in backwater habitats.

TABLE 2. Anticipated Effects of the Paria River Flood Augmentation High Flow Experiment on Resources Downstream of Glen Canyon Dam

Resource	Anticipated Effect
Food base	Algal bed coverage increases because there is reduced scouring relative to higher magnitude HFEs.
	Primary and secondary productivity increases because of the removal of dead and senescent vegetative material with subsequent growth response.
	Primary and secondary productivity increases because of greater retention of organic materials associated with very fine sediment deposited in sand bars.
Trout spawning	Decline in spawning habitat as algal bed coverage increases.
	Flows are not of sufficient magnitude to significantly scour gravel beds and create new spawning habitat, thus, reducing the likelihood of an increase in trout production as seen with previous HFEs.
Trout condition	Increased food base results in better condition.
Native fishes	Increased food base results in better condition and survival.
Sandbar distribution and size	Increase in the areal coverage of sandbars in Marble Canyon. Size and location is relatively more variable than
Sandbar stability	More stable sand bars because of replenishment from more frequent high, sediment-rich flows.
	Sand bars have longer retention time because of the incorporation of silts and clays in the bar matrix.
Recreational beaches	Increase in recreational beaches in Marble Canyon.

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3.0 Affected Environment and Environmental Consequences

This chapter describes the environmental consequences of developing and implementing a protocol for high-flow experimental releases from Glen Canyon Dam, and compares these releases to taking no further action for the period 2011 through 2020. The action area or geographic scope of this EA is the Colorado River corridor from Glen Canyon Dam downstream to the Lake Mead inflow near Pearce Ferry. Detailed information on resources affected by the proposed action is provided below. This chapter is organized by resource categories, including natural resources, cultural resources, and socioeconomic resources. Each of these categories is further divided into specific resources for the impact analysis, as described in Table 1. In addition to addressing resource-specific impacts, this EA also addresses ten issues identified in public scoping (see section 4.1), as required by federal regulations 40 CFR 1501.7 and 40 CFR 1508.25.

In order to better define the proposed action for NEPA analysis, four principal attributes of an HFE are identified—timing, magnitude, duration, and frequency. Timing refers to time of year, magnitude is the peak flow, duration is the length of the peak flow, and frequency is how often HFEs are conducted and considers the interval of time between HFEs. The first three attributes (timing, magnitude, and duration) are analyzed for a single HFE, and the fourth (frequency) also is included in the analysis of multiple HFEs. There are also potential interactions among these four attributes that are analyzed for certain resources. Ramping rate is not considered in this EA because the rate at which water is released from the dam to increase or decrease flow is determined by the 1996 ROD and the MLFF operating criteria (see Table 3).

There are a large number of possible HFEs and combinations of HFEs that could be triggered through the decision-making process, and it is not possible to perform NEPA analysis on all combinations. Therefore, the impact analysis of this EA is based on three levels that include an evaluation of attributes for: (1) a single HFE, (2) two consecutive HFEs, and (3) more than two consecutive HFEs over the 10-year period. The uncertainty associated with this assessment increases along with the number of consecutive HFEs, particularly if those HFEs are of magnitude and duration not previously tested.

The six HFEs that have been conducted in Grand Canyon have been independent single events. The impacts of these HFEs were evaluated and documented, and used to provide baseline information for the impact analysis of this EA (Table 7). Studies of impacts of these HFEs were variable and more complete for some events than others. A synthesis of the three higher magnitude HFEs is in preparation (Schmidt et al. in preparation).

Table 7. Summary of existing information on key aquatic resources for all HFEs from Glen Canyon Dam. Conclusion is based on weight-of-evidence evaluation of likely impacts. Additional citations can be found in sections 3.2.14—3.2.16.

Parameter	**1996 HFE**	**1997 HFE**	**2000 HFE**	**2000 HFE**	**2004 HFE**	**2008 HFE**
Timing	**Mar-Apr**	**Nov**	**May**	**Sept**	**Nov**	**Mar**
Magnitude	**45,000 cfs**	**30,000 cfs**	**31,000 cfs**	**31,000 cfs**	**41,000 cfs**	**41,500 cfs**
Duration	**7 days**	**3 days**	**3 days**	**3 days**	**60 hours**	**60 hours**
Likely impacts to:						
Aquatic food base	Scouring; temporary (1-8 mo.) reduction in abundance/biomass[3,4]	No effects detected[10]	No effects detected[12,13]	Some taxa/reaches negatively affected (unknown recovery period)[13]	No pre/post sampling. Possible delayed recovery due to timing.	Reduced biomass, recovery after 16 mo; improved fish food quality[20].
Non-listed native fish	Temporary habitat shifts during HFE; no lasting population effects[1]	Not studied.	No pre/post sampling.	Displacement of small-bodied fish from backwaters[14]	No pre/post sampling. No evidence for lasting impacts (abundance stable or increasing since 2004 [15,16,17])	Abundance increased through September, but no pre-HFE sampling[19]
Endangered fish	No population effects detected[5]; Creation of backwater habitat [7,8]	Not studied.	No pre/post sampling.	No effects detected[14].	Short-term displacement[18] No evidence for lasting impacts (abundance stable or increasing since 2004 [15,16,17]).	Creation of backwater habitat6[,8]; Abundance increased through September, but no pre-HFE sampling[19]
Trout	Displacement of small-bodied fish[3] possible improvement of YOY survival[3,6]	No effects detected[9]	No effects detected[11]	No effects detected[11]	Displacement of YOY, minor decline in condition, no change in abundance (all sizes)[2]	Increased YOY survival from compensatory response[6]; temporary decline (ca. 3-4 mo.) in condition[17]
Other nonnative fish	Displacement of small-bodied fish[1]	Not studied.	No pre/post sampling.	Displacement of small-bodied fish from backwaters, short-term population reduction[14]	Not studied, No evidence for lasting impacts (abundance stable or decreasing since 2004 [15,16,17])	Abundance increased through September, but no pre-HFE sampling[19]

[1] Hoffnagle et al. 1999
[2] Makinster et al. 2007
[3] McKinney et al. 1999
[4] Blinn et al. 1999
[5] Valdez and Hoffnagle 1999
[6] Korman et al. 2010
[7] Andrews et al. 1999
[8] Brouder et al. 1999
[9] Speas et al. 2004
[10] Shannon et al. 1998
[11] Speas et al. 2002
[12] Rogers et al. 2003
[13] Shannon et al. 2002
[14] Trammell et al. 2002
[15] Lauretta and Serrato 2006
[16] Ackerman 2008
[17] Makinster et al. 2010a
[18] GCMRC, unpublished data
[19] Grams et al. 2010
[20] Rosi-Marshall et al. 2010

3.1 Natural Resources

Natural resources are those physical, chemical, and biological components of the action area that individually and collectively comprise the ecosystem and contribute to the values of GCNP and GCRA. Based on a review of all natural resources in the action area, only those resources likely to be directly, indirectly, or cumulatively affected by the proposed action are described herein. These include water resources, water quality, air quality, sediment, vegetation, terrestrial invertebrates and herptofauna, aquatic food base, fish, birds, and mammals.

3.1.1 Water Resources under No Action

This environmental assessment is tiered off prior NEPA analyses, including Reclamation's 1995 EIS and the associated 1996 Record of Decision on the operation of Glen Canyon Dam, Reclamation's 2007 EIS on interim guidelines for lower basin shortages and the coordinated operations for Lakes Powell and Mead and the associated 2007 Record of Decision, and the 2008 EA for experimental releases from 2008 through 2012. Full descriptions of the methods used for water resources modeling and other resources are described in prior documents (Bureau of Reclamation 1995, 2008). The details of annual and monthly projected water resources and dam operations are provided in those documents and only a summary is provided here. Annual releases from the dam would be the same under either alternative as noted in section 2.2, only monthly and hourly release volumes would differ. Table 6 presents the most probable future values if no action is taken.

3.1.2 Water Resources under Proposed Action

Annual releases from the dam would be the same under either alternative, only monthly and hourly release volumes would differ when an HFE is conducted. Expected changes in levels of Lakes Powell and Mead are expected to be minor and have small temporary effects. The greatest differences in the elevation of Lake Powell would occur in April or November when the reservoir would decrease a maximum projected 2.6 feet as a result of the proposed high-flow releases. The effect on Lake Mead would be an increase of up to 2.5 feet in April or November. However because the HFE would not affect the overall volume of water released from Lake Powell, elevations of both Lakes Powell and Mead would be approximately the same at the end of the year under both alternatives. Reclamation's conclusion is that the proposed action is not likely to adversely affect water resources.

3.1.3 Water Quality under No Action

Current water quality conditions of the Colorado River below Glen Canyon Dam are driven by dam releases as reflected by the elevation of Lake Powell. At moderate and high reservoir levels, water is drawn from the cold lower layer or hypolimnion and ranges from about 9ºC to 12ºC. During 2004 and 2005, lowered reservoir levels began to withdraw warmer water from near the surface of Lake Powell and in November of 2005, release temperature was nearly 15ºC. As long as reservoir elevations remain above levels observed in 2004 and 2005, the temperature of water released from the dam is expected to be 9–12ºC.

A suite of water quality parameters is measured as part of monitoring of Lake Powell and the Colorado River below the dam (Vernieu et al. 2005). Concentrations of various parameters vary depending on reservoir elevation and the level of river inflow to the reservoir. The most notable parameters are low dissolved oxygen and high nitrogen concentrations that are neutralized within the first 3-5 miles below the dam. Water quality is not identified as a problem, except with very low reservoir elevations, such as those seen in November 2005, when dissolved oxygen was exceptionally low and may have caused stress in trout of the Lees Ferry population.

3.1.4 Water Quality under Proposed Action

An HFE would draw a certain volume of water from Lake Powell at a faster rate than under normal MLFF operations. Because of the large volume of cold hypolimnetic water, water quality effects during a single HFE would likely include a slight reduction in downstream temperature and a slight increase in salinity. During the year following a single HFE, salinity levels would decrease slightly, downstream temperatures would return to the no action condition, and dissolved oxygen concentrations could increase slightly. The increase in the dissolved oxygen concentration from fluctuating flows is the result of down-ramping.

The water below the penstock withdrawal zone is typically cooler than the upper level of the reservoir and more saline with a marked reduction of dissolved oxygen concentrations. Releases from the powerplant following the 1996 high flow test showed reduced water density and higher dissolved oxygen concentrations; the result of lowering the depth of chemical stratification in the reservoir. Similar positive water quality impacts are projected under the proposed action.

A high-flow release >41,000 cfs is expected to scour most of the algae and plant material in the Lees Ferry reach, as was observed with the March-April 1996 HFE (Blinn et al. 1999). This resulted in an increase in photosynthesis net metabolism (Brock et al. 1999) that temporarily increased the amplitude of daytime production of oxygen and nighttime production of carbon dioxide in the Lees Ferry reach (Marzolf et al. 1999), but this did not negatively affect aquatic communities. Based on findings from prior HFEs, Reclamation's conclusion is that the proposed action is not expected to adversely impact water quality.

3.1.5 Air Quality under No Action

The EPA's Air Quality System and National Emission Inventory databases show high air quality in the Grand Canyon region. However, recent declines in air quality throughout the western U.S. have also affected the canyon. In the 1980s, the Navajo Generating Station at Page, Arizona, (15 miles away) was identified as the primary source of air pollutants that contributed to between 50 percent and 90 percent of the Grand Canyon's air quality problems. In 1999, the Mohave Generating Station in Laughlin, Nevada (75 miles away) settled a long standing lawsuit and agreed to install end-of-point sulfur scrubbers on its smoke stacks; this action helped to reduce air pollutants to the Grand Canyon area. A primary source of particulates to the air is also automobile emissions.

3.1.6 Air Quality under Proposed Action

The primary effect of an HFE on air quality is the amount of additional emissions from coal or gas-fired powerplants making up the amount of hydropower lost from releasing water through the bypass tubes. The assessment done here presumes that all power or energy replaced comes from coal-fired generation, whereas replacement power is likely to come from a mix of coal, gas, and other generation that would collectively have lower emissions. In 1996, the duration of the HFE was 7 days (168 hours) and the estimated additional CO_2 emissions from the concurrent loss of hydropower were 109,438 metric tons from the loss of an estimated 109,000 MW/hrs (Harpman 1999). The HFEs proposed in this action would be of shorter duration. Table 8 illustrates the estimated additional CO_2 inputs from high flows of 45,000 cfs using formulas for conversions provided by EPA (undated) of 2,249 pounds of CO_2 emitted for every MWh produced.

In order to put the amount of CO_2 produced through replacement power in perspective, it is informative to use the March 2008 HFE as an example. It is estimated that 41 GWh had to be replaced for the 2008 HFE. This amount of power produced additional carbon emissions of about 45,800 tons, or less than 0.02 percent of the 261,687,000 tons annually emitted from coal-fired powerplants in the region. The amount of CO_2 emissions from the proposed HFEs range from a high of 62,535 metric tons to 651 metric tons, which are estimated to be about 0.02 percent to less than 0.01 percent, respectively. Two HFEs within the period of a year would double the amount of CO_2 production, but the maximum emissions would be less than 0.05 percent of the total annual emissions from coal-fired powerplants in the region. Reclamation's conclusion is that the proposed action is not expected to adversely impact air quality.

Table 8. Megawatt hours of lost electrical generation and subsequent additions of CO_2 from power generated using a coal-fired plant. A total of 2,249 pounds of CO_2 is emitted for every MWh produced (EPA). 1 metric ton = 2,240 pounds.

Duration of 45,000 cfs HFE (hours)	MW/hrs of lost generation	Metric Tons of CO_2
96	62,285	62,535
72	46,714	46,902
60	38,928	39,084
48	31,142	31,267
36	23,357	23,451
24	15,571	15,634
12	7,785	7,816
1	648	651

3.1.7 Sediment under No Action

Sediment research in the Grand Canyon has been ongoing for the last 25 years (Topping et al. 2007, 2010). Virtually the entire sediment load of the Colorado River is retained in Lake Powell, and the only sediment source to Grand Canyon is from local tributaries. These tributaries deliver sediment to the Colorado River with greater amounts in spring and fall. Gemorphologists have determined that there is a high rate of transport of this sediment from the Grand Canyon as a result of ongoing dam operations. Mass balance sand budgets in the Colorado River through Grand Canyon vary within and among years, depending on the amount of tributary sediment input and the monthly volume releases from the dam. Because of this dynamic nature, it is not possible to provide an estimate of the sediment budget as representative of the river channel.

Some geomorphologists believe that Grand Canyon sandbars will continue to degrade due to the existence of the dam; others hypothesize that dam operations, particularly high flows, may be used to rebuild, conserve, or enhance sandbars, particularly when combined with significant tributary sediment inputs (Topping et al. 2006). As stated above, an underlying purpose of this and prior experimental dam releases is to test such hypotheses, measure rates of sand deposition and erosion, as well as to observe changes in sandbar topography over time in relation to dam operations. Erosion of sandbars can be attributed to the limited amount of sand that enters the system and the ongoing dam operations (MLFF) that continually transports sediment downstream. It is well understood that fluctuating flows transport more sediment than steady flows of the same volume (Wright et al. 2008). Under the No Action Alternative with no HFEs, uninterrupted sediment erosion would occur and beaches and sandbars would decrease in area and volume as in the periods between HFEs in Figure 9.

3.1.8 Sediment under Proposed Action

The protocol evaluated in this EA is designed to provide experiments that will determine how best to conserve sand and sediment in Grand Canyon. An hypothesis to be tested with this action is that multiple HFEs under sediment enriched conditions will rebuild, conserve, and better maintain sandbar, backwaters, and camping beaches. The antecedent sediment enrichment and the net change in sand budget for the 2004 HFE (41,000 cfs for 60 hrs) and 2008 HFE (41,500 cfs for 60 hrs) provide insight into the possible effect of an HFE on sand storage in each of four reaches of the Colorado River (Table 9; Topping et al. 2010). Comparing antecedent conditions between these years illustrates the importance of sediment enrichment prior to an HFE; the 2004 HFE with less sediment storage caused a net negative effect to sand storage, whereas the 2008 HFE was positive. These results indicate that the effect to sediment from an HFE will depend on sediment enrichment at the time of the high-flow release. The models that will be used to trigger the determination for a possible HFE take sand storage into consideration as a major driver. In 2004, the amount of sand transported by the HFE was greater than the amount imported by tributary enrichment, although the amount was negligible because the level of uncertainty exceeds the amount (Topping et al. 2010).

Reclamation believes that these high-flow experimental releases are critical in determining the potential for long-term sustainability of the sediment supply in Grand Canyon. Topping et al. (2006) found that in the 1996 high flow test under depleted sediment concentrations, volumes of high elevation bars were increased at the expense of lower elevation portions of upstream sandbars. In 2004, moderately enriched sediment concentrations in upper Marble Canyon produced sandbars in many cases larger than the 1996 deposits, but downstream of RM 42 only 18 percent of sandbars were larger than those produced in the 1996 high flow test (Topping et al. 2006). Their final conclusion was that "…in future controlled floods, more sand is required to achieve increases in the total area and volume of eddy sandbars throughout all of Marble and Grand Canyons." Such condition existed as a result of significant sediment inputs during 2006 and 2007, in advance of the 2008 HFE. If no action is taken during sediment enrichment, recent tributary sediment inputs eventually will be transported downstream to Lake Mead with no high elevation sandbar rebuilding.

Table 9. Sand budgets for each reach during the 2004 and 2008 CFE sand-budgeting periods. Antecedent sand enrichment (columns 2 and 5) show the amount of sand imported by tributaries during the accounting period. Net change in sand storage (columns 3 and 5) reflects the amount of sand remaining in excess of the imported amount (+) or less than the imported amount (-) (Topping et al. 2010).

Reach	Antecedent 2004 HFE sand enrichment in reach with propagated uncertainty during the accounting period (million metric tons)	Net change in sand storage during 2004 HFE sand-budgeting period with propagated uncertainty (million metric tons)	Antecedent 2008 HFE sand enrichment in reach with propagated uncertainty during the accounting period (million metric tons)	Net change in sand storage during 2008 HFE sand-budgeting period with propagated uncertainty (million metric tons)
	Less than before 2008 CFE		More than before 2004 CFE	
upper Marble Canyon	+0.383±0.108	-0.073±0.133	+1.195±0.628	+0.592±0.663
lower Marble Canyon	+0.114±0.048	-0.067±0.105	+0.535±0.276	+0.307±0.353
eastern Grand Canyon	-0.014±0.048	+0.021±0.112	+0.836±0.662	+0.518±0.766
combined east-central and west-central Grand Canyon	+0.156±0.096	+0.089±0.161	+0.917±0.395	+1.059±0.508

With respect to the retention of sandbars thus created, Figure 9 shows the total sandbar volume at 12 sites in Marble Canyon from 1990 through 2006. Several conclusions are evident with respect to sandbar volume at these sites.

1. There is currently more sediment in these sandbars above 25,000 cfs than prior to the first HFE in 1996. Mid-elevation and total storage volumes are similar to 1996 levels.
2. In contrast to the declining trend in total sediment storage prior to 1996, the HFEs of 1996, 1997, 2000, and 2004 have each increased the amount of sand storage, for both mid-elevation and high elevation deposits.
3. Initial increases in sand storage decline rapidly, with half of the initial increases in total sediment storage eroded within 6 months of the 1996 HFE and within 15 months of the 2004 HFE.

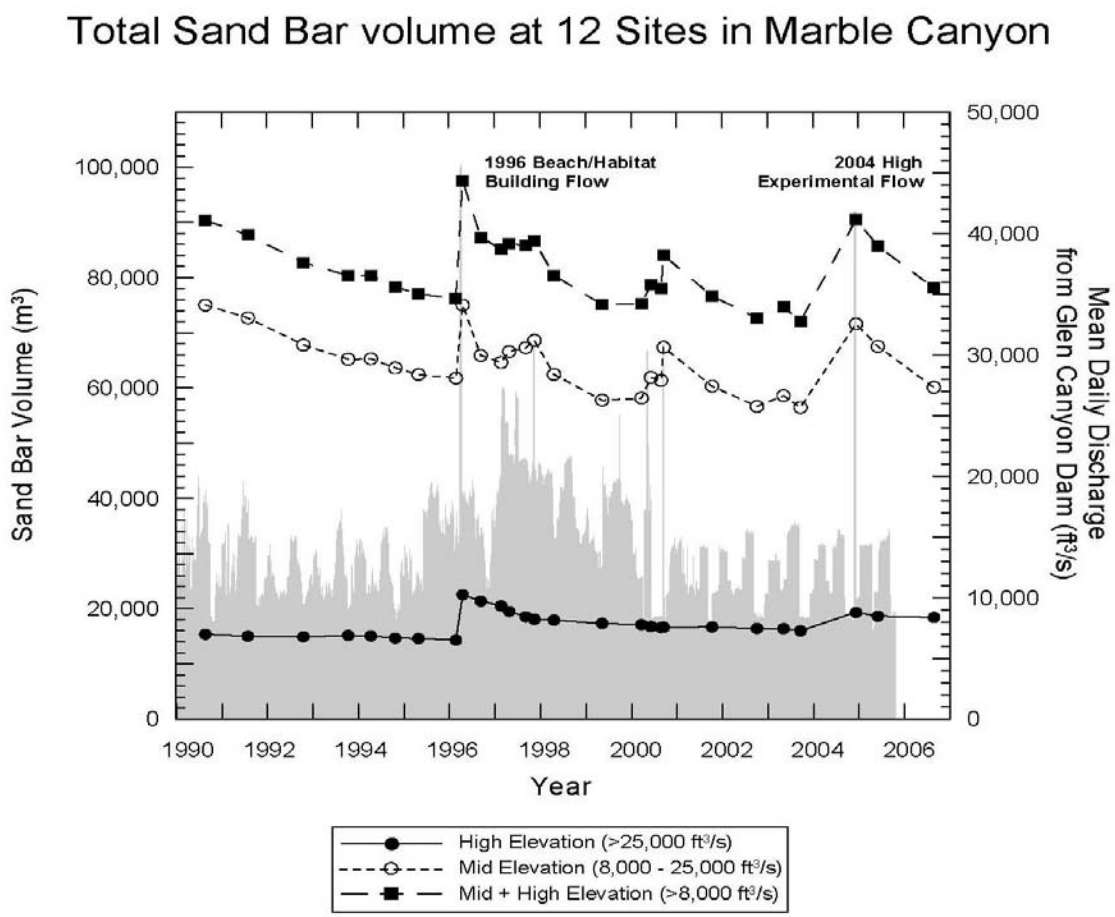

Figure 9. Total sandbar volume at 12 sites in Marble Canyon. *Source*: J. Hazel, preliminary data courtesy of Northern Arizona University.

The high flows that followed the 1996, 2004, and 2008 HFEs have been implicated in the rapid erosion of sandbars (Schmidt et al. 2004; Topping et al. 2010). Following the 1996 HFE, maximum daily releases usually reached 20,000 cfs during water year 1996 and exceeded 20,000 cfs for much of water year 1997, and following the 2004 HFE, high fluctuating winter releases, designed to disadvantage nonnative trout spawning, reached daily maxima of 20,000 cfs for the January through March 2005 period (Bureau of Reclamation 2008b). These high flows effectively transported large amounts of sediment downstream. In contrast, Glen Canyon Dam releases during 2006 and 2007 had low annual volumes and MLFF constraints which reduce the amount of sediment transported downstream, allowing sediment accumulation in the Colorado River mainstem above the Little Colorado River confluence and RM 30 (U.S. Geological Survey 2007b).

While it is generally expected that positive sandbar building will occur during the high flow test, it is difficult to predict the locations where sandbar building will occur, how long those impacts will persist, what benefits will accrue, and whether high flows will enable long-term sediment conservation. It is expected that monitoring and research activities will be followed by analysis and modeling to address these and other questions.

Based on prior experimental flows, sediment would likely be entrained quickly and efficiently by the proposed high-flow releases. Suspended sediment concentrations within the river and eddies would be expected to decrease after the river stage reaches its peak. This response is expected to vary from that measured in 1996 due to current abundant sediment supply in the river. This protocol is expected to better address the uncertainties of sediment input into the system and the conditions that trigger an HFE. For example, prior to the 2008 HFE, sand storage on average throughout Marble and Grand canyons was substantially greater than that preceding the 2004 HFE (Personal communication, David Topping). As of August 2007, about 1.75 million metric tons (mmt) of fine sediment relative to October 2006 was still situated above the confluence of the Little Colorado River, with about 1.5 mmt above RM 30 (U.S. Geological Survey 2007b). These conditions presented an opportunity to evaluate impacts of a high-flow release under more sediment-rich conditions than observed during previous experiments.

Based on the results of HFEs conducted in 1996, 2004, and 2008, an HFE would likely increase the number and size of sandbars and campsites immediately after the event. For example, the 1996 HFE created areas suitable for 84 new campsites, while destroying three others (Kearsley et al. 1999). A key question is whether an HFE under sediment enriched conditions might result in larger or more lasting effects.

Under the protocol described in this EA, two or more consecutive HFEs are likely to occur. Based on modeling, a visual representation of the frequencies of described types of HFEs is shown in Figure 10 for moderate sediment with dry, moderate, and wet hydrology. This comparision illustrates the types of HFEs and their frequencies possible over a 10-year period under different hydrology conditions. These figures illustrate the effect of hydrology on the same amount of sediment. A dry hydrology condition means lower monthly and daily releases with low water velocity that allows for less downstream transport and a greater amount of sediment accumulation. A wet hydrology condition means higher volume releases that transport more sediment on a daily basis and deplete the sediment budget in the channel. It should be noted that the numbers, frequency, magnitude, and duration of HFEs shown in Figure 10 are not likely to occur because a consistent condition of sediment/hydrology is unlikely over a 10-year period. Nevertheless, these illustrate the range of possibilities for single as well as multiple HFEs.

This analysis of model runs provides insight into the possible occurrences of HFEs over a 10-year period. The opportunity for an HFE differs among months, mostly because of sediment supply, but there are several instances where the HFE is limited by availability of water. In these instances water could be moved from other months to allow the HFE to occur. Hence, the output of model runs will need to be accompanied by hydrologic considerations that may enable decisions to be made about an HFE through redistribution of small amounts of water in cases where water supply is borderline.

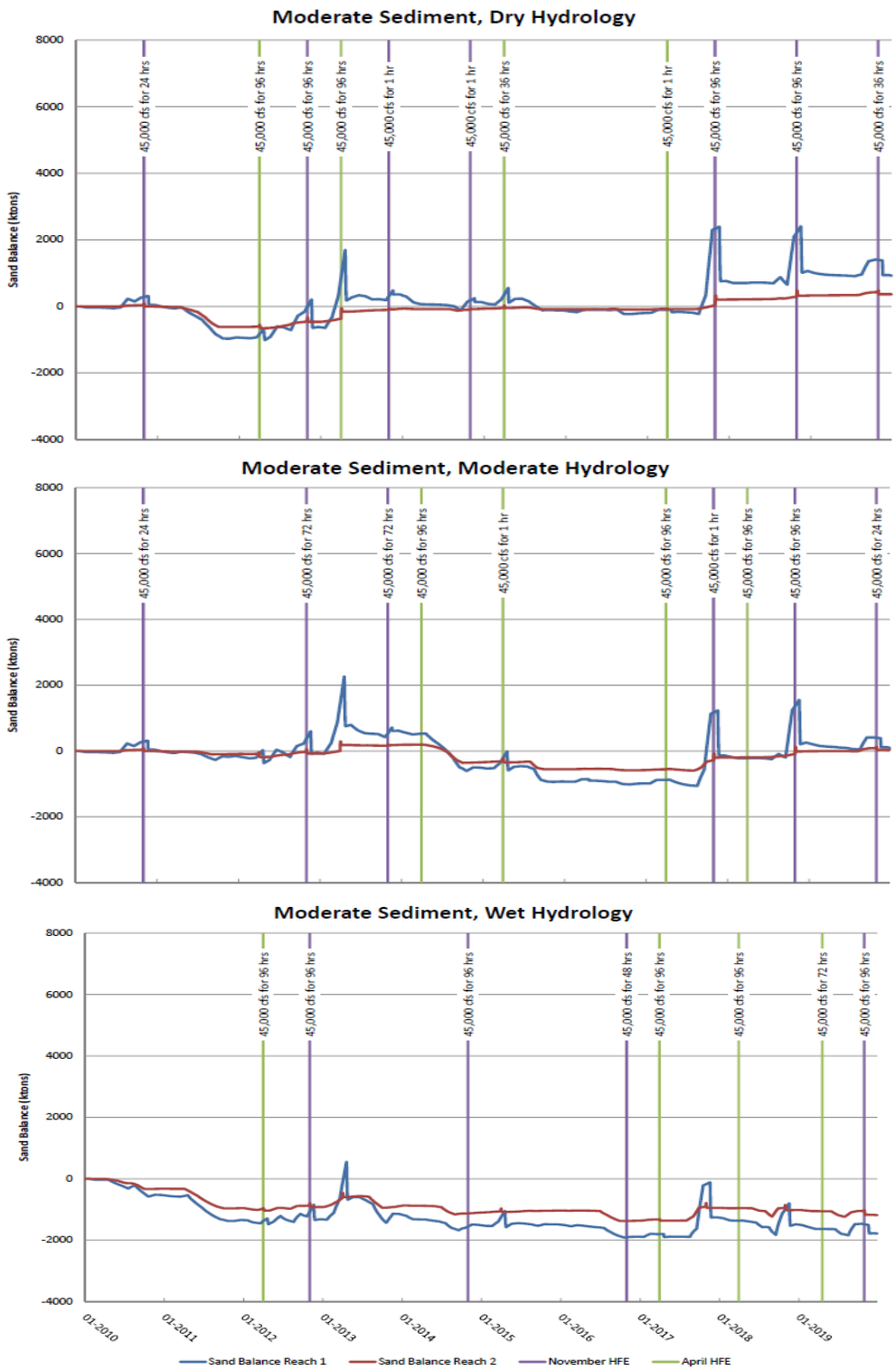

Figure 10. Occurences of described HFEs from model runs for moderate sediment with dry, moderate, and wet hydrology in reaches 1 and 2.

- ***Effects of Proposed Action on Backwaters***

Backwaters may be important rearing habitat for native fish due to lower water velocity, warmer water, and higher levels of biological productivity than the main river channel. The importance of backwaters in Grand Canyon with respect to native fish is uncertain, and a key question associated with the proposed action is how HFEs function to form and maintain backwaters and how much the fish use and need these features. Backwaters are created as water velocity in eddy return channels declines to near zero with falling river discharge, leaving an area of stagnant water surrounded on three sides by sand deposits and open to the main channel environment on the fourth side. Reattachment sandbars are the primary geomorphic feature that functions to isolate these near shore habitats from the cold, high velocity main channel environment.

Backwater numbers vary spatially among geomorphic reaches in Grand Canyon and tend to occur in greatest number in river reaches with the greatest active channel width, including the reach immediately downstream from the Little Colorado River (RM 61.5-77; McGuinn-Robbins 1994). Numbers and size of backwaters also vary temporally as a function of sediment availability and hydrology, and their size can vary within a year at a given site. In the absence of high-flow releases, backwaters would probably continue to fill with sediment and eventually transition to marsh-like habitats (Stevens et al. 1995).

Goeking et al. (2003) found no relationship between backwater numbers and flood frequency; although backwater size tends to be greatest following high flows and less in the absence of high flows due to filling of backwaters with sediment eroded from surrounding sandbars. Considering both area and number, however, no net positive or negative trend in backwater availability was noted during 1935 through 2000. At the decadal scale, several factors confound interpretation of high flow impacts on backwater bathymetry, including site-specific relationships between flow and backwater size, temporal variation within individual sites, and high spatial variation in reattachment bar topography (Goeking et al. 2003). Efficacy of high flow tests at creating or enlarging backwaters also depends on antecedent sediment load and distribution, hydrology of previous years (Rakowski and Schmidt 1999) and post-high flow river hydrology, which can shorten the duration of backwaters to a few weeks depending on return channel deposition rates or erosion of reattachment bars (Brouder et al. 1999).

While it is shown that HFEs help to form a larger number of deeper and larger backwaters (Schmidt et al. 1999), the persistence of backwaters is influenced by the post-HFE flows. The 1996 HFE was followed by MLFF, whereas the 2008 HFE was followed by September-October steady flows from 2008 through 2012, as implemented through the 2008 Biological Opinion to benefit young humpback chub. Whereas the 1996 HFE resulted in creation of 26 percent more backwaters potentially available as rearing areas for Grand Canyon fishes, most of these newly created habitats disappeared within two weeks due to reattachment bar erosion (Brouder et al. 1999; Hazel et al. 1999; Parnell et al. 1997). Nearly half of the total sediment aggradation in recirculation zones eroded during the 10 months following the experiment and was associated in part with relatively high fluctuating flows of 15,000-20,000 cfs (Hazel et al. 1999).

The morphologic response of eddy-deposited sandbars and associated aquatic backwater habitats between Lees Ferry and RM 258 were also described for the 2008 HFE. Sandbar deposition and reshaping increased the area and volume of backwater habitat when compared from one month before to one month after the HFE. Of 116 locations at 86 sites, total habitat area increased by 30 percent and volume increased by 80 percent HFE (Grams et al., 2010). Scouring of the eddy return-current channels and an increase in the area and elevation of sandbars provided a greater relief of sandbar elevation and a broader range of potential inundation for backwaters.

In the months following the 2008 HFE, erosion of sandbars and deposition in eddy return-current channels caused reductions of backwater area and volume (Grams et al. 2010). However, sandbar relief was still greater in October 2008 such that backwaters were present across a broader range of flows than in February 2008, prior to the HFE. For the six months following the HFE (April to September), dam releases were within normal operations for the season (MLFF). However reworking of the sandbars during diurnal fluctuating flows caused sandbar erosion and a reduction of backwater size and abundance to conditions that were only 5 to 14 percent greater than before the HFE. This erosion may have been slowed by the seasonally adjusted steady flows of about 12,400 cfs during September and October, 2008. These steady flows are released annually from 2008 to 2012 under an experimental release program biological opinion (U.S. Fish and Wildlife Service 2009) to provide stable nearshore habitat for young humpback chub.

Topographic analyses of sandbars and backwaters showed that a greater amount of continuously available backwater habitat was associated with steady flows than with fluctuating flows, which resulted in a greater amount of intermittently available habitat. Except for the period immediately following the HFE, backwater habitat in 2008 was greater for steady flows associated with dam operations of relatively lower monthly volume (about 8,000 cfs) than steady flows associated with higher monthly volume. Similarly, there was greater habitat availability associated with fluctuating flows of lower monthly volume (post-HFE through mid-April 2008) than higher monthly volume (after mid-April 2008)

The HFEs conducted under the proposed action are expected to rebuild and conserve sandbars and backwaters, which are considered to be beneficial to the aquatic ecosystem. However, past post-HFE flows have eroded sandbars to pre-HFE conditions. The steady flows implemented September 1 through October 31 of 2008–2009 under the experimental release program have slowed this erosion process. The manner for slowing erosion of sandbars following an HFE is an important piece of information that can be gathered from future HFEs.

High-flow releases can also affect biological communities within backwaters. The 1996 HFE caused an immediate reduction in benthic invertebrate numbers and fine particulate organic matter (FPOM) in backwaters through scouring (Brouder et al. 1999; Parnell and Bennett 1999). Invertebrates rebounded to pre-test levels by September 1996, but researchers thought that the rate of recolonization was hindered by a lack of FPOM. Still, recovery of key benthic taxa such as chironomids and other Diptera was relatively rapid (3 months), certainly rapid enough for use as food by the following summer's cohort of young-of-year (YOY)

native fish (Brouder et al. 1999). During the 1996 HFE, Parnell and Bennet (1999) also documented burial of autochthonous vegetation during reattachment bar aggradation, which resulted in increased levels of dissolved organic carbon, nitrogen and phosphorus in sandbar ground water and in adjacent backwaters. These nutrients are thus available for uptake by aquatic or emergent vegetation in the backwater.

The biological community of backwaters is not expected to be adversely impacted by one or two HFEs in a calendar or water year. As was observed with the 1996 and 2008 HFEs, invertebrates and other organisms should recover to pre-HFE condition within 2-4 months. However, the impact of multiple consecutive HFEs cannot be predicted. Based on responses by the food base to scouring from multiple artificial floods in the River Spöl in Switzerland, the biological community in backwaters may also transition to a more flood-resistant suite of taxa. In other parts of the Colorado River System (e.g., Green and Upper Colorado Rivers), backwater habitats are annually inundated and yet are among the most productive habitats in the river (Grabowski and Hiebert ; Shiozawa), although these river reaches are seasonally warmed and not subject to cold dam releases.

3.1.9 Vegetation under No Action

Vegetation along the river corridor is distributed along a gradient with the first 60 miles downstream from the dam classified as Upper Sonoran or cold desert plants, gradually shifting downstream to warm desert species typical of Lower Sonoran vegetation (Carothers and Brown 1991). At any one location, the more xerically-adapted species such as four-wing saltbush (*Atriplex canescens*), brittle bush (*Encelia farinosa*), and rubber rabbitbrush (*Chrysothamnus nauseosus*), are found on the terraces away from the river. These upland plants would be largely unaffected by the high-flow releases of the proposed action and are therefore not further considered.

Within the area that would be inundated by high-flow releases of up to 45,000 cfs, vegetation has changed over time in response to changes in the water-levels of the Colorado River, increased soil salinity, increased sand coarseness, climatic changes, and other factors (Carothers and Aitchison 1976; Kearsley et al. 2006; Ralston 2010). If no action were taken, riparian vegetation would continue to reflect the various water elevations from dam releases, including a low water community with marsh plants inhabiting primarily backwaters; a mid-elevation band of water tolerant plants including willows and tamarisk, and a high elevation band with more xeric species.

Stands of emergent marsh vegetation in the riparian zone are dominated by a few species, depending on soil texture and drainage. Cattail (*Typha domingensis*) and common reed (*Phragmities australis*) association grows on fine-grained silty loams while a horseweed (*Conyza canadensis*), knotweed (*Polygonum aviculare*), and Bermuda grass (*Cynodon dactylon*) association grows on loamy sands.

Moving uphill and away from the marsh zone, Bowers et al. (1997) and Webb (1996) have demonstrated that short-lived plants such as longleaf brickellbush (*Brickellia longifola*), brownplume wirelettuce (*Stephanomeria pauciflora*), broom snakeweed (*Gutierrezia*

sarothrae), brittlebush (*Encelia frutescens*), and Emory's baccharis (*Baccharis emoryi*) are actively colonizing the youngest and more disturbed surfaces. Longer-lived species are not as quick to colonize disturbed areas. For example, Mormon tea (*Ephedra* spp.), cactus (*Opuntia* spp.), and catclaw (*Acacia gregii*) are found on surfaces older than seven years and as young as 28 years. The longer-lived species will continue to expand towards the river edge.

Vegetation above the 35,000 cfs river stage tends to be affected more by local precipitation than by dam operations. The effects of hydrologic gradients on species abundance and diversity in riparian areas have been observed in other semi-arid rivers (Shafroth et al. 1998; Stromberg et al. 1996).

3.1.9.1 Noxious Weeds under No Action

Currently, noxious weeds and invasive plants such as tamarisk (*Tamarix ramosissima*), camelthorn (*Alhagi pseudalhagi*), Russian-thistle (*Salsola iberica*), red brome or foxtail brome (*Bromus rubens*), cheatgrass (*Bromus tectorum*), yellow sweet-clover (*Melilotus officinalis*), spiny sow-thistle (*Sonchus asper*), and Bermuda grass (*Cynodon dactylon*) occur throughout the riparian zone. Executive Order 13112 calls on federal agencies to work to prevent and control the introduction and spread of invasive species. Both GCNP and GCRA support ongoing programs under this executive order to control noxious weeds and invasive plants.

Tamarisks are shrubs or shrub-like trees with numerous large basal branches, reaching 13 to 26 feet (4-8 m) in height, but usually less than 20 feet (6 m). Mature tamarisk plants are able to reproduce from adventitious roots, even after the aboveground portion of the plant has been removed. As a facultative phreatophyte and halophyte, tamarisk has a competitive advantage over native, obligate phreatophytes (e.g. cottonwood and willow) in areas where salinities are elevated or water tables depressed, conditions characteristic of disturbed riparian environments. Tamarisk can obtain water at lower plant water potential and has higher water use efficiency than native riparian trees in both mature and postfire communities. Tamarisk can tolerate an extreme range of environmental conditions. The plants accumulate salt in special glands in its leaves, and then excrete it onto the leaf surface. These salts accumulate in the surface layer of soil when plants drop their leaves. As surface soils become more saline over time, particularly along regulated rivers that are no longer subjected to annual flooding and scouring, germination and establishment of many native species become impaired.

Tamarisk plants may flower in their 1st year of life (Warren and Turner 1975), but most begin to reproduce in their 3rd year or later (Stevens 1989). Because tamarisk reproduce sexually throughout most of the growing season, a small plant can produce a substantial seed crop, and a large plant may bear several hundred thousand seeds in a single season. Stevens (1989) reported that mature tamarisk plants are capable of producing 2.5×10^8 seeds per year. Warren and Turner (1975) used seed traps and found that about 100 seeds per square inch ($17/cm^2$) reached the soil surface in a dense tamarisk stand over one growing season; and that more than four seeds per square inch per day (0.64 seeds/cm^2/day) might settle on

the soil surface during the peak of seed production. High stress induced by fire, drought, herbicides, or cutting can increase flowering and seed production in tamarisk.

Tamarisk seeds are readily dispersed by wind and can also be dispersed by water (Stevens 1989). The seeds are short-lived and do not form a persistent seed bank (Warren and Turner 1975). Tamarisk seeds produced during the summer remain viable for up to 45 days under ideal field conditions (ambient humidity and full shade), or for as few as 24 days when exposed to full sunlight and dry conditions. Winter field longevity under ideal conditions is approximately 130 days. Seed mortality is generally due to desiccation (Stevens 1989). If seeds are not germinated during the summer that they are dispersed, almost none germinate the following spring (Warren and Turner 1975). Tamarisk seeds went from 65 percent viability two days after dispersal, to 40 percent viability 14 days after dispersal (Ware 1949).

3.1.10 Vegetation under Proposed Action

Single HFEs spaced one or more years apart are not expected to have measurable impacts on vegetation. There would be short-term scouring of aquatic plants in the river channel and marsh plants in backwaters, but these are expected to recover within about 6 months. An HFE up to 45,000 cfs is not expected to uproot riparian vegetation, but is expected to bury low-lying grasses and shrubs with sediment redeposition; however, the plants would be expected to recover within 6-8 months. Two consecutive HFEs are expected to have a similar impact to single HFEs, given that there would be 4-6 months between events for recovery.

More than two consecutive HFEs are expected to suppress plant reestablishment in the river channel and marsh plant in backwaters. A sequence of HFEs would likely coarsen sand size and reduce overall nutrient levels in sediment, unless the HFE occurred shortly after tributary input and the fines had not been exported from the canyon. This would favor clonal species such as native arrowweed (*Pluchea sericea*), coyote willow (*Salix exigua*), and common reed (*Phragmities australis*). Coarsening of sediment and continued disturbance would be beneficial to restoring a greater proportion of native plant species to the riparian community. Hence, single or multiple HFEs conducted under this protocol are not expected to have adverse impacts on vegetation.

In terms of effects to individual species, an increase in the density of cattails was noted in lower reaches of Grand Canyon following the 1996 HFE as well as increased abundance of woody species in Kwagunt Marsh (Kearsley and Ayers 1996), but this may have been a result of high sustained releases that followed the HFE. Also, total foliar cover was diminished as a result of the 1996 HFE, but no localities showed a significant change in area covered by wetland plants (Kearsley and Ayers 1996). The proposed HFEs would likely result in similar minor impacts: short term burial of seeds and plants on existing sandbars, some scouring of riparian vegetation, and a short-term increase in groundwater and soil nutrient concentrations. Newly exposed sediment may be subject to colonization by exotic plants, particularly on low velocity, low elevation sandbars (Porter 2002), but subsequent establishment in these sites is dependent on long-term operation during the summer growing season. Over time, successional, woody species may occupy these areas.

The proposed HFEs would likely increase the rate at which sediment is deposited at the delta of Lake Mead. However, because of the short duration in flow of each HFE, the extensive area available for sediment deposition in Lake Mead, and the highly fluctuating water levels of Lake Mead, impacts on riparian vegetation would be minor.

3.1.10.1 Noxious Weeds under Proposed Action

The creation of new habitat through the deposition of sediment during flooding is expected to lead to increases in exotic plant species, especially fast-colonizing annuals and tamarisk (Kearsley et al. 2006; Porter 2002). Established tamarisk and camelthorn located on sandbars and along channel margins would be expected to survive a flood, grow through newly deposited sand and resprout and recolonize sandbars, though the extent of the expansion is dependent on subsequent discharge. However, frequent HFEs would likely bury and inundate sandbars and reduce invasion and establishment of exotic plant species.

A principal concern with conducting one or more HFEs is the possibility that the high flow will carry and distribute tamarisk seeds. Tamarisk develop into thick stands of plants with deep roots that become very difficult to remove once established. Tamarisk in Grand Canyon typically produces flowers and seeds from April through September. The timing of the proposed HFEs is outside of the main seed-producing period. A study conducted in 2000 (Porter 2002) for flows of slightly lower magnitude (31,000 cfs) documented an increased germination of nonnative species in exposed areas (e.g. tamarisk). Studies during the 1996 flood did not specifically focus on seedling establishment (Kearsley and Ayers 1999), but expansion of Bermuda grass following the 1996 experimental release was observed by Phillips and Jackson (1996). As noted above, it is the long-term operations following a disturbance that affects riparian vegetation response to a disturbance event (Kearsley et al. 2006; Kearsley and Ayers 1999; Porter 2002).

3.1.11 Terrestrial Invertebrates and Herptofauna under No Action

Carpenter (2006) and Kearsley et al. (2006) found over 27 species of herptofauna (reptiles and amphibians) from the Colorado River up to the xeric terraces in Grand Canyon and the latter suggested that the high density of lizards in the riparian zone may be attributed to abundance of food resources (insects and organic debris left on popular camping beaches). Warren and Schwalbe (1985) reported lizard densities during June at 858/ha in the riparian zone. Common lizards in the riparian zone are the side-blotched lizard (*Uta stansburiana*), Western whiptail (*Cnemidophorus tigris*), desert spiny lizard (*Sceloporus magister*), and tree lizard (*Urosaurus ornatus*). The collared lizard (*Crotaphylus insularis)* and chuckwalla (*Sauromalus obesus)* are less common (Carothers and Brown 1991).

Snakes are common in the higher and drier elevations of the riparian zone and in the more xeric terraces and hillsides. Eight snake species have been documented within the riparian zone; the most common of these are the Grand Canyon rattlesnake (*Crotalus viridis abyssus*), the southwestern speckled rattlesnake (*Crotalus mitchellii Pyrrhus*), and the desert striped whipsnake (*Masticophis taeniatus)*.

Amphibians include frogs, spadefoots, and true toads. Recent surveys have found abundant populations of Woodhouse's toad (*Bufo woodhousii*), red-spotted toad, (*Bufo punctatus*), canyon treefrog (*Hyla arenicolor*), and tiger salamander (*Ambystoma tigrinum*) (Kearsley et al. 2003, 2006).

The northern leopard frog (*Rana pipiens*) has been extirpated from about 70 percent of its range, and it is a candidate species in Arizona. The northern leopard frog in the Glen Canyon reach was monitored before and after the 1996 HFE. The population was very small but was little affected and recovered quickly over time (Spence 1996). However, since 1996 northern leopard frogs have declined dramatically in Glen and Grand canyons and in 2004 only two adults were found in an off-channel pool in Glen Canyon (Drost 2004, 2005). The 2009 Park Profile for Grand Canyon National Park (National Park Service 2009) lists the northern leopard frog as extirpated from GCNP. The finding of a petition to list the northern leopard frog in the western United States as threatened was published in the Federal Register in 2009 (74 FR 31389), and the USFWS is currently undertaking a status review of the species.

The Kanab ambersnail (*Oxyloma haydeni kanabensis*) was listed as endangered in 1992. Kanab ambersnails are found in the riparian vegetation at Vaseys Paradise. The increase in cover, reduction in beach-scouring flows, and introduction of nonnative water-cress (*Nasturtium officinale*) has led to a greater than 40 percent increase in suitable Kanab ambersnail habitat area at Vaseys Paradise from pre-dam conditions (Stevens et al 1997a). Under the no action alternative Kanab ambersnails are expected to maintain their population at Vaseys Paradise.

3.1.12 Terrestrial Invertebrates and Herptofauna under Proposed Action

A single HFE would be expected to displace or kill some terrestrial invertebrates and herptofauna along the river shoreline, but these organisms are expected to recover quickly from individual HFEs. Multiple HFEs could displace greater numbers and prevent or delay recolonization. The impact to populations of terrestrial invertebrates and herptofauna is species-dependent, depending on life history strategies and their locations in the riparian zone. However, floods are natural historic events in Grand Canyon and the populations of terrestrial invertebrates and herptofauna are expected to recover from these events. No recent evidence exists to suggest that northern leopard frogs are present within the Glen Canyon or Grand Canyon reaches of the Colorado River and HFEs would not be expected to impact this species. The proposed action is not expected to adversely impact terrestrial invertebrates or herptofauna.

The high-flow releases would individually result in minor losses of Kanab ambersnails and their habitat at the Vaseys Paradise. If the proposed high-flow protocol is implemented, Reclamation would move approximately 25 percent of affected habitat, including higher quality vegetation and snails within the flood zone, as was done in prior HFEs. Additionally, all vegetation in the potentially flooded zone will be searched for snails and all snails that are found will be temporarily moved with the vegetation. The vegetation and snails would be replaced after the flood waters have receded.

If HFE are conducted frequently under the protocol, the habitat and the population of the Kanab ambersnail are expected to reestablish at a higher elevation. Multiple high-flow events and consequent temporary removal and replacement of snails and habitat would likely impact the snails to a greater degree than a single event. At some point, multiple movements of snails and habitat would become unnecessary. The population will need to be monitored in order to determine when relocation is necessary and when the population has reestablished so as not to be impacted by an HFE. Given the mitigation proposed for the Kanab ambersnail, the proposed action is not expected to adversely impact this endangered species.

3.1.13 Aquatic Food Base under No Action

Construction of Glen Canyon Dam completely changed the river ecosystem and the manner of energy assimilation for much of 300 miles of the Colorado River from the dam to Lake Mead (Blinn and Cole 1991). Cold, clear dam releases, combined with entrainment of large amounts of organic matter in Lake Powell, caused the community of primary and secondary producers to switch from an upstream heterotrophic source of energy to one reliant primarily on local autotrophic photosynthesis in the reaches nearest the dam. Heterotrophic energy sources are materials such as dead plants and animals that wash into the river; where autotrophic energy sources are produced within the stream through photosynthesis. In the upstream reaches, high daily fluctuating releases created an entire new community of algae, diatoms, and aquatic invertebrates based on a varial zone (shoreline habitat that is both inundated and exposed to air by daily flow fluctuations) that was wetted and dried daily and maintained by a large biomass of the green algae (*Cladophora glomerata)* (Blinn et al. 1995, 1998).

Today, large amounts of diatoms, freshwater shrimp (*Gammarus lacustris*), and midges (Chironomidae) rely on these dense mats of algae (Benenati et al. 1998, 2001) and provide large amounts of carbon locally and to downstream sources (Stevens et al. 1997). Further downstream, water clarity and photosynthesis varies with periodic delivery of sediment from tributaries, starting with the Paria River just 15 miles below the dam and the Little Colorado River about 77 miles below the dam (Stevens et al. 1997b). In these downstream reaches, year-round cold water temperatures and low water clarity limit the community of organisms capable of living in these conditions. These changes to the fundamental sources and pathways of energy in the river were dramatic for higher trophic levels, especially the native fish populations.

Recent studies (Rosi-Marshall et al. 2010) indicate that the composition of the benthic assemblage at Lees Ferry is dominated by New Zealand mudsnails (*Potamopyrgus antipodarum),* freshwater shrimp, sludge worms (Tubificidae), earthworms (Lumbricidae), and midges. In cobble habitats, New Zealand mudsnails, sludge worms, and earthworms dominate the assemblage biomass. New Zealand mudsnails and sludge worms also dominate the depositional habitats, although these areas tend to support lower average biomass. Talus slopes and cliff faces are dominated by freshwater shrimp and generally support the lowest biomass of all habitats in the Lees Ferry reach. Blackflies (*Simulium arcticum*) and midges were present at RM 0, but at relatively low abundance and biomass.

Further downstream, near the Little Colorado River, the macroinvertebrate assemblage is dominated by blackflies, sludge worms, and earthworms in cobble habitats and some sludge worms, freshwater shrimp. and midges in the talus and cliff-face habitats (Rosi-Marshall et al. 2010). Biomass of the invertebrate assemblage in this reach is less than one tenth that observed at Lees Ferry. At Diamond Creek, the macroinvertebrate assemblage in cobble habitats is dominated by blackflies and earthworms. In talus and cliff-face habitats, blackflies, sludge worms, and earthworms are present, and New Zealand mudsnails and freshwater shrimp were also present in these habitats in higher biomass than observed near the Little Colorado River.

Archived collections show that the invasive New Zealand mudsnail was present as early as 1995 (Benanati et al. 2002) and has maintained populations through the present day (Kennedy and Gloss 2005). These organisms deplete food supplies by filtering large amounts of nutrients and are thought to represent a trophic "dead end" due to their poor digestibility by trout and other fish (Vinson and Baker 2008; Rosi-Marshall et al. 2010). Because of its small size, lack of an attachment structure, and occurrence in fine unstable sediments, it is highly susceptible to being dislodged by floods.

3.1.14 Aquatic Food Base under Proposed Action

A large portion of the aquatic food base in the Lees Ferry reach would likely be scoured by an HFE of 41,000 to 45,000 cfs. The food base is expected to recover within 1-4 months after a spring HFE, as was observed for the 1996 and 2008 HFEs (Blinn et al. 1999; Rosi-Marshall et al. 2010). Freshwater shrimp, a common food item of fish, will be slower to recover because of their greater susceptibility to become exported by river currents than other invertebrate species. Also, New Zealand mudsnails are expected to be exported in large numbers, which will be a benefit to the food base by making more digestible items available to the fish; the hard shell of mudsnails is not digestible by most fish. Downstream of the Paria River, the effect of scouring from a spring HFE is expected to be less with distance downstream and recovery should be shorter, as was reported for the 2008 HFE (Rosi-Marshall et al. 2010). The effect of an HFE on the food base in backwaters is expected to be short-term, as backwaters would be inundated by the high release and reformed after the event, as was observed for 2008 (Behn et al. 2010).

Time of year is also likely to differently impact the food base. Impacts to the aquatic food base due to a November HFE are an uncertainty that should be evaluated through increased monitoring during such experiments. A November HFE of 41,000 to 45,000 cfs is expected to scour a large portion of the food base, but the recovery period is not known. Benthic sampling was not conducted immediately before and after the November 2004 HFE so effects on these resources cannot be evaluated directly. It is believed that scouring of the food base during this time of year could lead to a protracted recovery period due to reduced solar radiation, which could have short-term implications for health and condition of rainbow trout. The poor condition of the trout population in winter of 2004 and spring of 2005 was partly attributed to the November 2004 HFE, but it is uncertain which other factors may have also been involved, including warm dam release, low dissolved oxygen, and trout suppression flows.

The only information available on effects of a high flow of less than 41,000 cfs is from HMFs of approximately powerplant capacity. It appears that flows of approximately powerplant capacity of 31,500 cfs do not have the large scouring effect on the food base as seen with higher flows. In the Lees Ferry reach, Rogers et al. (2002) documented no short-term reduction in aquatic macrophytes, periphyton, chlorophyll-*a*, or macroinvertebrate densities associated with a 31,000 cfs spike flow in May 2000. Shannon et al. (2002) noted reductions in benthic invertebrate taxa as a result of the September 2000 powerplant flows (31,000 cfs), but these effects were not realized across all reaches and taxa. Comparison of these results to hypothetical effects of an April HFE is also confounded by temporal differences in aquatic food base components, which are known to vary by season (McKinney and Persons 1999; Shannon et al. 2002). Powerplant flows of 31,500 cfs were also released in November 1997, specifically to conserve sediment in the Colorado River under MLFF operations. In the Lees Ferry Reach, Shannon et al. (1998) reported no discernable impact on the benthic community following these flows, and Speas et al. (2004) reported no change in age 1 rainbow trout abundance or condition, as further evidence that the food base has not been impacted by the HMF.

Although effects of repeated HFEs on the food base have not been investigated, the more lasting effects of independent events (1996, 2004, and 2008) likely foretell some of the possible consequences of frequent, consecutive HFEs. Although more information is needed on the effect of a fall HFE on the food base, it is likely that a fall HFE followed by a spring HFE could have a longer-lasting impact on the food base. Only 4-5 months would separate the two events, which would preclude full recovery of most benthic invertebrate assemblages, although some key taxa such as midges may recover within 3 months (Brouder et al. 1999). This effect could be exacerbated if recovery from a fall HFE is delayed until the following spring by reduced winter insolation. A second, spring HFE following a fall HFE could scour the remaining primary producers and susceptible invertebrates and further delay recovery. A spring HFE followed by a fall HFE may not have as great an impact because presumably recovery of the food base (for most taxa) would have occurred by fall.

In order to gain a better understanding of expected impacts of multiple HFEs on the food base in Grand Canyon, it is informative to examine findings from other rivers. For each of the three HFEs in Grand Canyon, nearly 90 percent of instream plants, algae, and diatoms on sediments were uprooted and scoured, along with senescent plant material and detritus (Blinn et al. 1999; Rosi-Marshall et al. 2010). Uehlinger and others (2003) observed a series of 11 artificial floods in the River Spöl of the Swiss Alps over a 3-year period. Like Grand Canyon, the Swiss floods reduced periphyton biomass substantially and transiently shifted ecosystem metabolism towards autotrophy (increased photosynthesis). But after multiple floods, the scouring had less effect and the River Spöl began to look more like a flood prone system with communities adapted to scouring. The floods on the River Spöl, like the HFEs in Grand Canyon, also reduced particulate organic carbon and phosphorus, which resulted in increased production/respiration ratios with each flood (Robinson and Uehlinger, 2008). Multiple sequential floods, such as those on the River Spöl, show that taxa of primary producers will shift toward communities more resistant to flooding, but the effect is not immediate and occurs over a period of years.

An important finding of multiple floods on the River Spöl was that although the first flood reduced macroinvertebrate abundance by about 50 percent, later floods had 30 percent less effect than early floods of similar magnitude, indicating that a new assemblage had established that was more resilient to flood disturbance (Robinson and Uehlinger, 2008). This suggests that more frequent floods in Grand Canyon could cause a shift to more resistant taxa or to new taxa that would colonize the river. However, if these resistant taxa are not present, or if a source of new taxa is not available, the result of frequent floods may be a reduction in macroinvertebrate diversity and possibly abundance, which could result in a reduction in the aquatic food base. Robinson and Uehlinger (2008) suggest that the response of macroinvertebrates to experimental floods occurs over a period of years, rather than months, as species composition adjusts to the new and more variable habitat template.

Reclamation believes that single HFEs within a calendar year or a water year will not adversely impact the aquatic food base. Spring HFEs are expected to recovery within the summer following the event and fall HFEs are expected to delay complete recovery until the following spring; but recovery is expected to occur nevertheless. Reclamation also believes that two consecutive HFEs could have different impacts depending on the seasonal sequence. A spring HFE followed by a fall HFE is not expected to adversely impact the food base because recovery from the spring HFE will have occurred before the fall HFE, and each event will fundamentally have no different impact than independent, single HFEs. However, a fall HFE followed by a spring HFE is expected to have greater impacts because the spring HFE will likely occur before full recovery from the fall HFE, and the effect of scouring will be compounded by the second event.

The impact of more than two consecutive HFEs on the aquatic food base is not known. Possibly, scouring of the food base annually in spring and fall will cause the community to shift toward scour-resistant taxa and decrease the overall abundance and biomass of the food base. In all likelihood, 3-5 consecutive HFEs may be conducted that will began to cause this shift, but the absence of an HFE for one or more seasons will likely allow for restoration of the original food base community. This sequence over 10 years of multiple HFEs followed by periods without HFEs could create instability in the community that may lead to the decline or loss of certain taxa, such as the freshwater amphipod, which is an important food source for fish. This sequence could also substantially reduce the population of the New Zealand mudsnail, which would beneficial impact to the community. Reclamation believes that to avoid adverse impacts to resources, the monitoring program will have to provide a full evaluation and reporting before any additional consecutive HFEs can be conducted.

3.1.15 Fish under No Action

Altogether, 20 species of fish occur in Grand Canyon, including 15 introduced and five native species (Table 10). Only five of the eight fish species native to the Colorado River in Grand Canyon have persisted, including humpback chub, flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and speckled dace (*Rhinichthys osculus*) (Valdez and Carothers 1998). The razorback sucker is extirpated from Grand Canyon, but is found as a small reproducing population downstream of the canyon, in and below the Colorado River inflow to Lake Mead (Albrecht et al. 2008).

Table 10. Nonnative fish species presently found in the Colorado River and lower end of tributaries from Glen Canyon Dam to near Pearce Ferry (Ackmerman and Valdez 2008). 0 = absent, R = rare, L = locally common, N = numerous, A = abundant.

Common Name	Scientific Name	Lees Ferry	Marble Canyon	Grand Canyon
black bullhead	*Ameiurus melas*	0	R	L
brown trout	*Salmo trutta*	R	R	L
largemouth bass	*Micropterus salmoides*	0	0	R
mosquitofish	*Gambusia affinis*	0	0	L
red shiner	*Cyprinella lutrensis*	0	0	L
channel catfish	*Ictalurus punctatus*	0	R	N
common carp	*Cyprinus carpio*	L	N	N
fathead minnow	*Pimephales promelas*	0	0	L
green sunfish	*Lepomus cyanellus*	0	0	R
plains killifish	*Fundulus zebrinus*	0	0	L
rainbow trout	*Oncorhynchus mykiss*	A	A	L
redside shiner	*Richardsonius balteatus*	R	R	R
smallmouth bass	*Micropterus dolomieu*	R	R	R
striped bass	*Morone saxatilis*	R	R	R
walleye	*Sander vitreus*	R	R	R

3.1.15.1 Humpback Chub

The humpback chub is currently listed as "endangered" under the ESA. The humpback chub recovery plan was approved on September 19, 1990 (U.S. Fish and Wildlife Service 1990b), and recovery goals were developed in 2002 (U.S. Fish and Wildlife Service 2002b). Designated critical habitat exists in two reaches near the action area (U.S. Fish and Wildlife Service 1994); the lower 8 miles of the Little Colorado River and 173 miles of the Colorado River and its 100-year floodplain in Marble and Grand Canyons from Nautiloid Canyon (RM 34) to Granite Park (RM 208). One population with nine aggregations is found in Grand Canyon, with most individuals in and near the Little Colorado River (Valdez and Ryel 1995). Water in the mainstem is too cold for spawning and the species spawns primarily in the Little Colorado River, although young have also been found in the Fence Fault Warm Springs at RM 30 (Valdez and Masslich 1999) and further downstream in Middle Granite Gorge. The distribution of juvenile humpback chub downstream of Glen Canyon Dam reveals the locations of most aggregations (Figure 11), but it is uncertain if these fish originated from the Little Colorado River or from local reproduction.

Young and juvenile humpback chub are found primarily in the Little Colorado River and the Colorado River near their confluence, although many are found upstream of the Little Colorado River, presumably from spawning near the Fence Fault Warm Springs (Valdez and Masslich 1999). Humpback chub reproduction occurs annually in spring in the Little Colorado River and the young fish either remain in the Little Colorado River or disperse downstream into the Colorado River. Dispersal of these young fish has been documented as nighttime larval drift during May through July (Robinson et al. 1998), as density dependent

movement during strong year classes (Gorman 1994), and as movement with summer floods caused by monsoonal rain storms during July through September (Valdez and Ryel 1995). Survival of these young fish in the mainstem is thought to be low because of cold mainstem temperatures (Clarkson and Childs 2000; Robinson and Childs 2001), but fish that survive and return to the Little Colorado River contribute to recruitment in this population. Predation by rainbow trout and brown trout in the Little Colorado River confluence area has been identified as an additional source of mortality affecting survival and recruitment of humpback chub (Valdez and Ryel 1995; Marsh and Douglas 1997; Coggins 2008; Yard et al. 2008).

Population estimates using an age-structured, mark-recapture (ASMR) method show that the population has ranged from about 11,000 adults (4 years old and older and capable of reproduction) in 1989 to 5,000 adults in 2001 (Coggins and Walters 2009). The number of adults decreased from 1989 to 2001, but increased by approximately 50 percent between 2001 and 2008 to an estimated 7,650 adults (Figure 12). Inter-relationships between river flow and humpback chub habitat show a close association of juveniles with certain reaches of river having shoreline cover, including large rock talus, debris fans, and vegetation (Converse et al. 1998). Adults also show an affinity for the same river reaches and generally remain in low-velocity pockets within large recirculating eddies (Valdez and Ryel 1995). The principal area occupied by humpback chub is in and around the Little Colorado River, about 77 mi (123 km) downstream of the dam, and although the influence of flow on habitat of juveniles is described (Korman et al. 2003), the long-term effect on the population is not well understood.

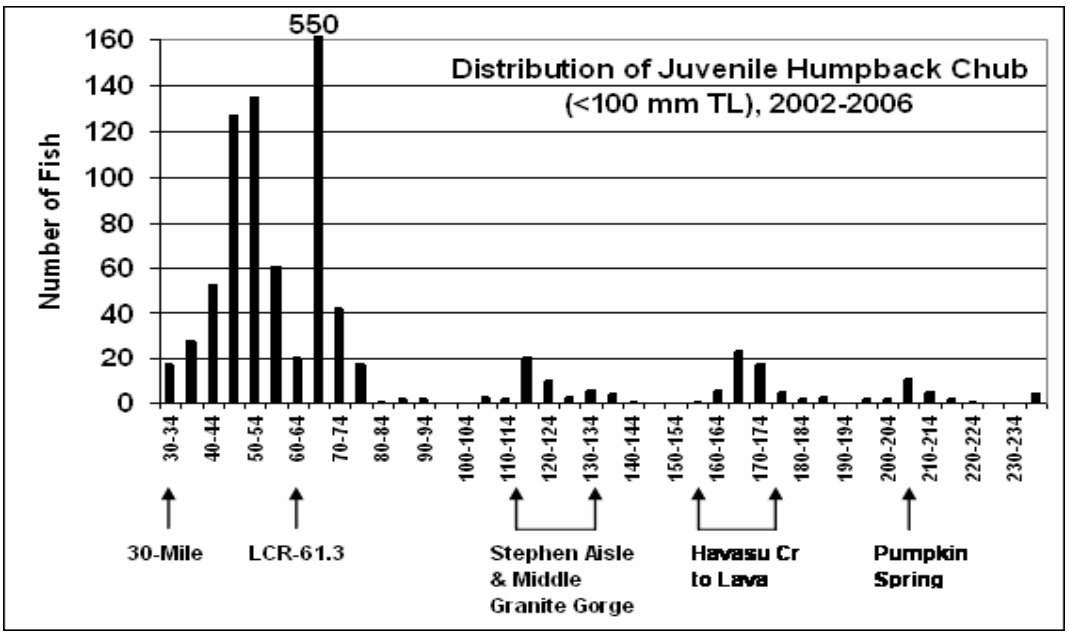

Figure 11. Distribution of juvenile humpback chub <100 mm TL during 2002-2006 by 5-mile increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from Ackerman and Valdez 2008).

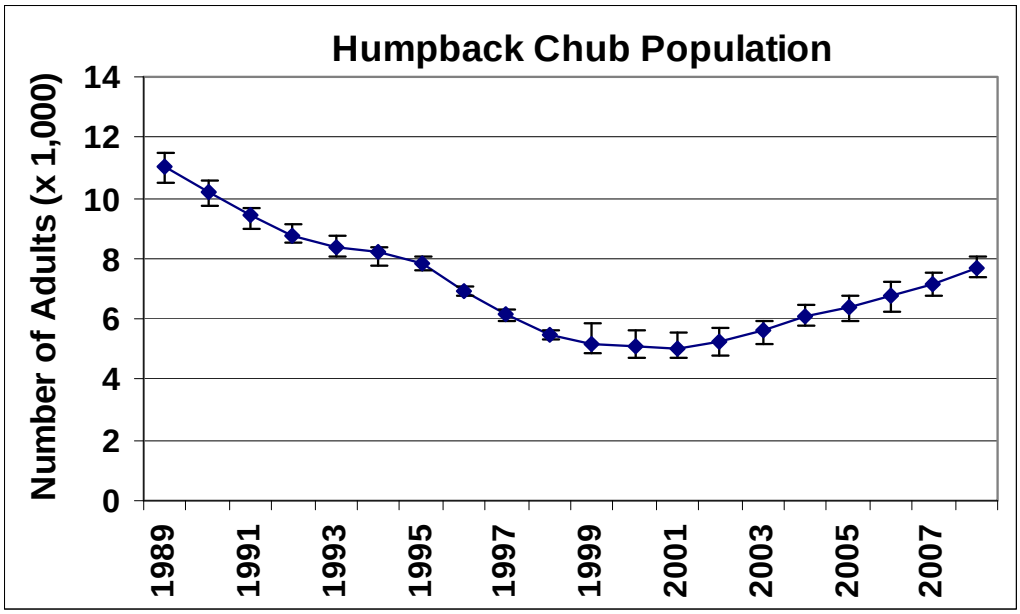

Figure 12. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials. All runs assume the coefficient of variation of the von Bertalanffy $L\infty$ was CV ($L\infty$) = 0.1 and adult mortality was $M\infty$ = 0.13 (Coggins and Walters 2009).

3.1.15.2 Razorback Sucker

The razorback sucker is currently listed as "endangered" under the ESA (56 FR 54957). Designated critical habitat includes the Colorado River and its 100-year floodplain from the confluence with the Paria River (RM 1) downstream to Hoover Dam, a distance of nearly 500 miles, including Lake Mead to the full pool elevation. A recovery plan was approved on December 23, 1998 (U.S. Fish and Wildlife Service 1998) and Recovery Goals were approved on August 1, 2002 (U.S. Fish and Wildlife Service 2002b). Primary threats to razorback sucker populations are streamflow regulation and habitat modification and fragmentation (including cold-water dam releases, habitat loss, and blockage of migration corridors); competition with and predation by nonnative fish species; and pesticides and pollutants (Bestgen 1990; Minckley 1991).

The razorback sucker has not been reported in Grand Canyon since 1990 and only 10 adults were reported between 1944 and 1995 (Valdez 1996; Gloss et al. 2005). Carothers and Minckley (1981) reported four adults from the Paria River in 1978-1979. Maddux et al. (1987) reported one female razorback sucker at Upper Bass Camp (RM 107.5) in 1984, and Minckley (1991) reported five adults in the lower Little Colorado River from 1989-1990. The razorback sucker is probably extirpated from the Colorado River and its tributaries between Glen Canyon Dam and the Lake Mead inflow.

3.1.15.3 Non-Listed Native Fishes

The Colorado River from the dam to the Paria River supports small numbers of bluehead sucker, flannelmouth sucker, and speckled dace. Flannelmouth sucker spawn in this reach and in the Paria River (McIvor and Thieme 2000; McKinney et al. 1999; Thieme 1998). Low to moderate numbers of native bluehead sucker, flannelmouth sucker, humpback chub, and speckled dace occur in the river between the Paria and Little Colorado rivers (Hoffnagle et al. 1999; Trammell et al. 2002; Lauretta and Serrato 2006; Ackerman 2007; Johnstone and Lauretta 2007). Most native fish in the mainstem from the dam to the Little Colorado River are large juveniles and adults. Earlier life stages rely extensively on more protected nearshore habitats, primarily backwaters (Lauretta and Serrato 2006; Trammell et al. 2002). The 174 miles from the Little Colorado River to Bridge Canyon has six major tributaries and supports a diverse fish fauna of cool- to warm-water species to about Havasu Creek, including the three non-listed native species. Non-listed native fish are also well represented in Bright Angel, Shinumo, Tapeats, Kanab, and Havasu creeks (Leibfried et al. 2006; Johnstone and Lauretta 2007), especially during spawning periods. Abundance of flannelmouth suckers, speckled dace, and bluehead suckers in the 45-mile reach of the Colorado River from Bridge Canyon to Pearce Ferry is limited due to lack of spawning habitat and large numbers of predators (Valdez 1994; Valdez et al. 1996). Ackerman et al. (2006) found that flannelmouth sucker comprised no more than 22 percent of the total fish community catch, and composition of bluehead sucker and speckled dace was never more than 3 percent for either species.

Except for reaches below Diamond Creek, the Grand Canyon fish community shifted over the past decade from one dominated by nonnative salmonids to one dominated by native species (Makinster et al. 2010; Ackerman 2007; Johnstone and Lauretta 2007; Lauretta and Serrato 2006; Trammell et al. 2002). Catch rates of flannelmouth and bluehead suckers increased four to six-fold from 2000 through 2008, and speckled dace catch rates were steady but generally higher than historical levels (Makinster et al. 2010b; AGFD 2006; Johnstone and Lauretta 2007; Lauretta and Serrato 2006). It is hypothesized that recent shifts from nonnative to native fish are due in part to warmer than average water temperatures, although decline of coldwater salmonids (due to mechanical removal or temperature increases) has also been implicated (Ackerman 2007; Persons and Rogers 2006; USGS 2006a), although these effects have dissipated and the high abundance of native fish has persisted.

3.1.15.4 Trout

Two species of trout are found in Grand Canyon, the rainbow trout (*Oncorhynchus mykiss*) and the brown trout (*Salmo trutta*). The population of rainbow trout in the 15-mile long Lees Ferry tailwater reach has undergone large changes in abundance since standardized monitoring began in 1991. Recruitment and population size appear to be governed largely by dam operations (Arizona Game and Fish Department, 1996; McKinney et al. 1999, 2001). Rainbow trout are also found fairly consistently in the mainstem Colorado River between the Paria River and the Little Colorado River confluence (Makinster et al. 2010a). Below that point, small numbers are found associated with tributaries, including Bright Angel Creek, Shinumo Creek, Deer Creek, Tapeats Creek, Kanab Creek, and Havasu Creek. Brown trout

are found primarily near and in Bright Angel Creek, where there is a spawning population. Small numbers are found elsewhere in the canyon.

The rainbow trout population in the Lees Ferry reach has been monitored since 1991. From 1993 to 1997, the population increased and remained high until 2001 (Figure 13). McKinney et al (1999; 2001) attributed the dramatic increase from 1991 to 1997 to increased minimum flows and reduced daily discharge fluctuations. After 2001, there was a steady decline in the Lees Ferry population until 2007. A similar decline in rainbow trout abundance below the Paria River was observed during that same time period (Makinster et al. 2010). The 2001–2007 decline is attributed less to increased daily fluctuations during 2003-2005 and more to increased water temperatures (associated with low reservoir elevations) and trout metabolic demands coupled with a static or declining food base, periodic oxygen deficiencies and nuisance aquatic invertebrates (New Zealand mudsnails; Behn et al. 2010). Concurrent with these declines in abundance, however, trout condition (a measure of plumpness or optimal proportionality of weight to fish length) has increased, reflecting a strongly density dependent fish population where growth and condition are inversely related to fish abundance (McKinney and Speas 2001; McKinney et al. 2001).

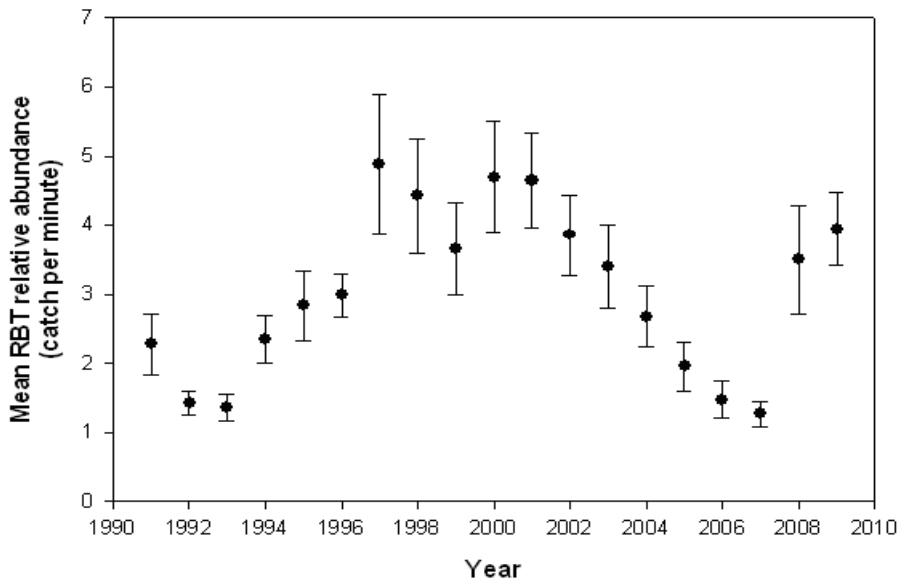

Figure 13. Average annual electrofishing catch rates of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991–2010 (Makinster et al. 2010a).

During 2003-2005, "nonnative fish suppression flows" were released from the dam to evaluate these flows in controlling the trout population in the Lees Ferry reach with high and low flows to reduce survival of eggs and young. In addition, a program of mechanical removal was conducted in the vicinity of the Little Colorado River during 2003–2006 and 2009 to determine if electrofishing could be used to control trout and minimize competition and predation on humpback chub in that reach. The dramatic increase from 2007 to 2008 (Makinster et al. 2010a) is attributed to increased survival and growth of young trout

following the March 2008 HFE (Korman et al. 2010). It is believed that the high-release flushed fine sediment from spawning gravels and stimulated the food base.

3.1.15.5 Other Nonnative Fishes

Fifteen nonnative fish species are currently found in Grand Canyon (Valdez and Carothers 1998; Hilwig et al. 2010). The majority are warm water species; only two are true cold water species—rainbow trout and brown trout. The fish population in Glen Canyon (Lees Ferry) is dominated by rainbow trout, with small numbers of brown trout and local abundances of common carp (Ackerman and Valdez 2008). The fish population in Marble Canyon is dominated by rainbow trout and carp with small numbers of seven other species. In Grand Canyon, dominant species are channel catfish and carp with local abundances of small minnows and sunfishes.

Recently, a few smallmouth bass and striped bass were collected in the vicinity of the Little Colorado River (Hilwig et al. 2010), but no population-level establishment has been documented to date. There are also recent records of green sunfish, black bullhead, yellow bullhead, red shiner, plains killifish and largemouth bass downstream of the Little Colorado River, usually associated with warm springs, tributaries, and backwaters (Johnstone and Lauretta 2007; GCMRC unpublished data). Striped bass are found in relatively low numbers below Lava Falls (Ackerman 2007; Valdez and Leibfried 1999). Common carp are relative common downstream of Bright Angel Creek, although numbers declined from 2000 through 2006 (Makinster et al. 2009a).

Nonnative fish collected below Diamond Creek in 2005 (Ackerman et al. 2006) were comprised primarily of red shiner (28 percent), channel catfish (18 percent), common carp (12 percent), and striped bass (9 percent); smallmouth bass, mosquitofish, *Gambusia affinis*, and fathead minnow were also present in low numbers. Bridge Canyon Rapid impedes upstream movement of most fish species, except for the striped bass, walleye, and channel catfish (Valdez 1994; Valdez et al. 1995; Valdez and Leibfried 1999). Nonnative fish species increased from 11 above to 18 below the rapid (Valdez 1994; Valdez et al. 1995). Above Bridge Canyon Rapid, the red shiner was absent, but below the rapid it comprised 50 percent and 72 percent of all fish captured in tributaries and the mainstream, respectively (Valdez 1994; Valdez et al. 1995). Other common fish species found below Bridge Canyon Rapid include the common carp, fathead minnow, and channel catfish; however, very little fish habitat exists in this reach due to declining elevations of Lake Mead and subsequent downcutting of accumulated deltaic sediments in inflow areas.

3.1.15.6 Fish Habitat

Korman et al. (2004) used a 2-D hydrodynamic model to predict two-dimensional fields of depth and velocity over the range of daily flow fluctuations and monthly volumes in the Colorado River immediately below the LCR. This model was used to evaluate young-of-year fish habitat availability and suitable habitat persistence in Grand Canyon under No Action and the Proposed Action. Transects represented a range of shoreline types typically utilized by young-of-year humpback chub: talus slopes, debris fans, and vegetated shorelines (Converse et al. 1998). The hydrodynamic model was used successfully to predict patterns of

sand deposition following the 1993 flood from the Little Colorado River and during and after the 1996 high flow test (Wiele et al. 1999; Wiele et al. 1996).

It was assumed that habitat availability at 11,500 cfs represents conditions under the No Action alternative. This was the average of 8,000 and 15,000 cfs, which were the elevations evaluated by Korman et al. (2004). Under the No Action alternative, total suitable habitat for native fish on preferred substrates (talus slopes, debris fans and vegetated shorelines) ranged from about 5,000 to 2,700 m^2 (Figure 14). Results for nonnative fish were similar (4,500 to about 2,800 m^2), although less habitat was available over debris fan substrates.

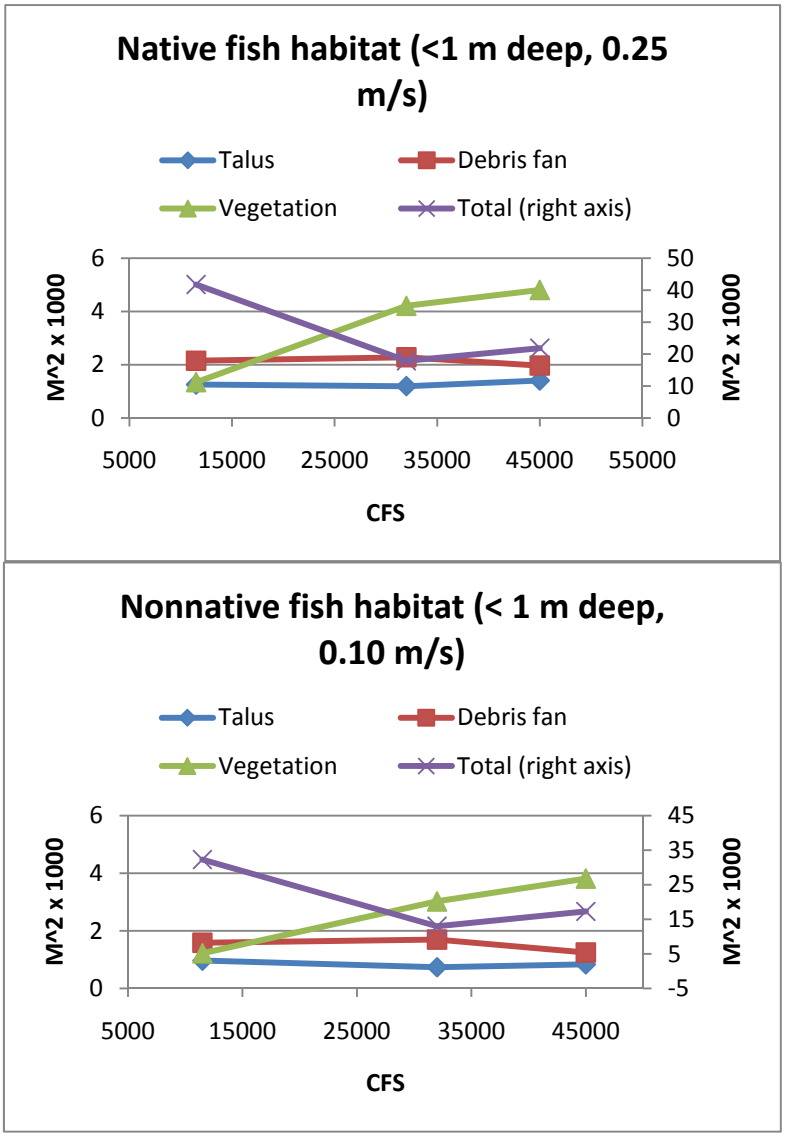

Figure 14. Total suitable habitat (purple line, right axis) and breakdown by shoreline types (left axis) used by native fish (top; approximated by humpback chub parameters) and nonnative fish (bottom). Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transects. Habitat conditions during regular MLFF (No Action) for November and April are approximated by flows of 8,000-15,000 cfs.

The amount of total suitable habitat at a given flow elevation was computed by summing the total wetted area of each reach where velocity was less than or equal to critical values. Two criteria were evaluated for suitable water velocity for humpback chub: < 0.25 m/s and <0.10 m/s. The first criterion was a composite of several field and laboratory studies published previously, including Bulkley and Pimentel (1983), Valdez et al. (1990) and Converse et al. (1998) (Figure 15). We used humpback chub parameters as a surrogate for all native fish found in the Colorado River in Grand Canyon.

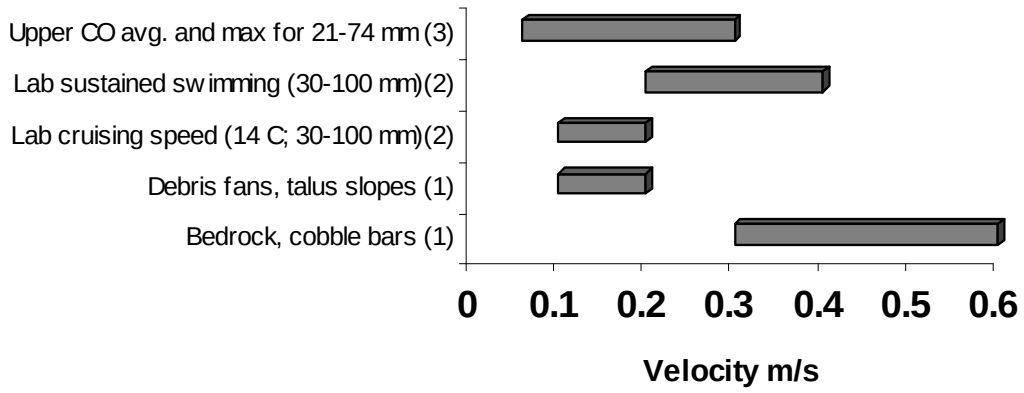

Figure 15. Velocity preference criteria for humpback chub in the Colorado River, Grand Canyon. Sources include (1) Converse et al 1998; (2) Bulkley and Pimentel 1983; and (3) Valdez et al. 1990.

3.1.16 Fish under Proposed Action

3.1.16.1 Humpback Chub

Assessment of the proposed action relies on the best and most recent scientific information regarding the status and population trend of the endangered humpback chub. This includes recognition that improvement in the humpback chub population began between 1994 and 1999—before any of the recent suite of specific actions to benefit the species were undertaken (Coggins and Walters 2009)—and that greater numbers of young humpback chub have been found in the mainstem Colorado River during 2002 through 2006, including above the Little Colorado River (Ackerman 2007). These improvements were seen during implementation of MLFF as adopted in the 1996 ROD. Subsequent to the improvement in humpback chub status, but before the improvement was detected by scientists, a number of management actions were implemented, including the 1996 HFE, 2000 steady summer flows and associated HMFs, 2004 HFE, 2003–2005 trout suppression flows, and 2003-2006 nonnative fish mechanical removal.

A Biological Assessment of impacts to humpback chub due to the proposed action is included in Appendix C (presently in preparation). Reclamation's conclusion is that the proposed action will likely adversely affect humpback chub and adversely modify critical habitat. Humpback chub will be adversely affected through incidental take caused by repeated physical displacement by high flows conducted as part of the proposed action. Critical habitat of humpback chub will be adversely modified under the proposed action due to (1) impairment of the food supply from sequential HFEs; and (2) possible increased predation by and competition with rainbow trout due to HFEs conducted in March or April. Fate of displaced fish is unknown because neither the river reaches they are likely to arrive at nor habitat conditions therein are known. The extent of impacts due to predation are unknown because of uncertainties in the repeatability of results from the 2008 HFE on rainbow trout and trout immigration rates into the Little Colorado River reach.

To some extent, though, these impacts will be outweighed by two factors: (1) Reclamation is committed to implementing efforts to minimize impacts of rainbow trout on humpback chub under the 2008 Biological Opinion and is currently consulting with the USFWS on development and implementation of future nonnative fish control actions; and (2) due to the high likelihood of repeated HFEs to conserve sediment at in Grand Canyon, the likelihood of creation and stabilization of nearshore and backwater rearing habitats is also relatively high. Thus, by reducing threats of nonnative fish and creation and maintenance of rearing habitat, we believe the propose action will ultimately benefit the species over the proposed action's 10-year timeframe.

3.1.16.2 Razorback Sucker

The nearest population is found at Las Vegas Bay, Echo Bay, and the Muddy River/Virgin River in Lake Mead, about 400 miles downstream from Glen Canyon Dam (Albrecht et al. 2008). Because the razorback sucker is not presently found in the action area, the proposed action is not expected to impact the species.

3.1.16.3 Non-listed Native Fishes

Effects of an April HFE on non-listed native fish are not expected to be adverse. Population-level effects on flannelmouth and bluehead sucker were not observed during the 1996 HFE (Hoffnagle et al. 1999). Shifts in habitat use were observed for speckled dace during the 1996 HFE but species relative abundance did not change following the 1996 HFE (Hoffnagle et al. 1999). Abundance of flannelmouth and bluehead sucker and speckled dace in backwaters increased during the months following the 2008 HFE (Grams et al. 2010), although these could be considered normal seasonal occurrences.

We do not expect non-listed native fish to be adversely impacted by a November HFE. Sampling was not conducted downstream of the Lees Ferry reach immediately before and after the 2004 HFE so effects on non-listed native fish cannot be evaluated directly. However, several studies (Lauretta and Serrato 2006; Ackerman 2008; Makinster et al. 2010a) showed that numbers of flannelmouth and bluehead sucker and speckled dace remained stable or increased from 2004 to 2005, indicating negligible effects on these fish at the population level.

3.1.16.4 Trout

All available information suggests that an April HFE would have few effects on juvenile and adult rainbow trout. Survival of larval and age-0 fish could be enhanced, although this effect is not expected to be as pronounced as it was in 2008. This population is strongly influenced by dam releases, and understanding the effect of the March 2008 HFE on reproductive success, early life stage survival, and downstream movement is important for maintaining a quality recreational fishery in balance with its food base and with downstream native fish populations. Changes in trout catch rate were seen in the year following the spring 1996 HFE (increase of 66 percent) and the fall 2004 HFE (decrease of 25 percent), but the mechanisms behind these changes were not determined and it was unclear if part or all of these responses were attributable to the HFEs.

Although evidence exists for downstream displacement of juvenile rainbow trout from the Lees Ferry fishery due to the 1996 HFE (McKinney et al. 1999), the 2008 HFE appeared to have little overall affect on the movement/displacement of rainbow trout downstream (Makinster et al. 2009a, 2009b). Of 94 rainbow trout of various sizes equipped with acoustic tags by Hilwig and Makinster (2010), the majority of tagged trout were not displaced downstream of Lees Ferry during the HFE or over the 95-d lifespan of the acoustic tags. Only 3 of 94 tagged fish were detected by a remote receiver located 6 mi downstream of Lees Ferry. The greatest documented movements by tagged trout were 18.1 mi downstream and 6.4 mi upstream, both of which occurred prior to the HFE.

Rainbow trout relative condition did not change during the period of the 1996 HFE (McKinney et al. 1999). These results contrast with those observed during the 2008 HFE, which appeared to cause a decline in overall trout relative condition (Makinster et al. 2010a). This is likely a result of increased metabolism and/or subsequent scour of the aquatic food base during the experiment. Concerns about a potential loss of the 2008 cohort due to food limitations were alleviated since relative condition returned to levels observed in previous years during summer and fall sampling. Aquatic food base analysis pre- and post-HFE suggested New Zealand mudsnails were negatively impacted by the experiment, which may have led to increased food availability, especially for young fish, immediately following the experiment.

Multiple lines of evidence indicate that the March 2008 HFE resulted in a large increase in early survival rates of age-0 trout because of an improvement in habitat conditions (Korman et al. 2010a). A stock-recruitment analysis demonstrated that age-0 abundance in July 2008 was more than fourfold higher than expected, given the number of viable eggs that produced these fish. A hatch-date analysis showed that early survival rates were much higher for cohorts that hatched about 1 month after the 2008 HFE (about April 15, 2008) relative to those fish that hatched before this date. A substantial fraction of the cohort originating from the peak spawn period (Feb 21-Mar 27) was thus fertilized after the 2008 HFE and would have emerged into a benthic invertebrate community that had recovered and was possibly enhanced by the HFE. Inter-annual differences in growth of age-0 trout, determined on the basis of otolith microstructure, support this hypothesis. Korman et al. (2010) speculate that the 60-hour-long 2008 HFE increased interstitial spaces in the gravel bed substrate and food

availability or quality, leading to higher early survival of recently emerged trout and better growth of these fish through summer and fall.

There may be a risk of increased predation pressure on native and endangered fish due to enhanced young-of-year rainbow trout survival resulting from HFEs conducted in March, but the magnitude of such a risk from an April HFE is unknown due to two factors. First, the date of peak rainbow trout spawning from 2004-2009 ranged from February 21 to March 27 and the average peak spawning date was March 6. The 2008 HFE was conducted on March 5-9, which coincided almost perfectly with peak spawning activity; thus, a substantial fraction of the rainbow trout eggs deposited in spring 2008 were fertilized after the HFE and, after emergence a month or two later, benefited from cleaner gravel substrate and perhaps enhanced food availability. Under the proposed action, spring HFE's would take place in April, approximately one month or more after the peak spawning period, which means that a larger fraction of that year's eggs would be fertilized prior to the HFE. Korman et al. (2010) speculate that if the bulk of fertilization were to take place prior to an HFE, survival of the resulting fry would be much lower than that observed in 2008. Most of these fish would still be in the gravel when the HFE occurs and would be vulnerable to scour or burial, or would be vulnerable to displacement and mortality because of increased water velocity (Heggenes and Traaen, 1988; Einum and Nislow, 2005).

Inferences on the effect of Glen Canyon Dam HFEs during late winter to early spring on early survival and growth rates from this analysis are limited by the fact that only one treatment has been conducted and studied using the above methods. The 1996 HFE consisted of a high-flow releases that lasted more than twice the duration of the 2008 HFE, but the rainbow trout monitoring methods used during the 2008 study had not yet been applied to the Lees Ferry reach. Korman et al. (2010) recommended that survival rates of gravel-stage and older age-0 rainbow trout be repeated if future HFEs were conducted to determine if the trout responses are similar to those observed during the 2008 HFE.

Secondly, downstream dispersal rate of rainbow trout from upstream reaches into areas populated by humpback chub (i.e., near the LCR at RM 61.5) have not been quantified and are hypothesized to range from 50 to 300 fish per month (Hilwig et al. 2010). It is also hypothesized that this rate might vary with trout density in upstream reaches, so effects of enhanced survival of rainbow trout due to HFEs in April are an uncertainty within any given year and needs to be evaluated.

We do not expect a November HFE to adversely impact rainbow trout. It appears that the late fall 2004 HFE exported large numbers of young trout downstream from the Lees Ferry reach but did not apparently affect the larger fish. Korman (2009) observed a threefold decrease in numbers of very young trout following the HFE. The fate of these fish was not directly measured and it was assumed that they were displaced downstream or did not survive. Electrofishing catch rates for all sizes of trout before (2.82 fish/min) and after (3.09 fish/min) the November 2004 HFE were not significantly different, however, indicating that mortality and downstream displacement did not affect on the population (Makinster et al. 2007). Trout condition declined slightly from 2004 to 2005, but the effect was size-specific and condition rebounded sharply by 2006 (Makinster et al. 2007, 2009). Sampling was not

conducted downstream of Lees Ferry immediately before and after the 2004 so downstream dispersal of trout as an effect of high flows could not be evaluated directly.

3.1.16.5 Other Nonnative Fishes

Effects of an April HFE are likely species-species specific and expected to be comparable to those from other experimental flow tests during March-April 1996 and March 2008 (Hoffnagle et al. 1999; Makinster et al. 2007; McKinney et al. 1999; Valdez and Hoffnagle 1999; Korman et al 2010).

It is likely that nonnative fish will experience some short-term negative impacts of the high flow tests, perhaps more so than humpback chub due to their preferences for lower water velocities (Table 11). Whereas average preferred velocity for juvenile humpback chub is 0.25 m/s (Korman et al. 2004; Converse et al 1998; Bulkley and Pimentel 1983; Valdez et al. 1990), nonnative fish preferences average about 0.10 m/s. Hoffnagle et al. (1999) noted that the 1996 test had few discernable effects on native fish, but reduced numbers of fathead minnow and plains killifish, presumably by downstream displacement. Abundance of fathead minnow in backwaters increased during the months following the 2008 HFE (Grams et al. 2010), but this could be considered normal seasonal trends in abundance. These effects were believed to be temporary and resulted in no long term decline in fish abundance.

Trammell et al. (2002) found evidence that fathead minnow were displaced downstream during the September 2000 HMF of 31,000 cfs , but despite declines in relative abundance of native fish (flannelmouth and bluehead sucker, speckled dace) remained significantly higher than previous years. This suggested a disproportionate effect of powerplant (ca. 31,5000 cfs) flows on small-bodied nonnative fish. Trammell et al. (2002) did not report adverse effects of the powerplant flows on humpback chub, and Speas et al. (2002) did not document any effects of the powerplant flow on age-1 nonnative rainbow trout.

We do not expect nonnative fish to be adversely impacted by a November HFE. Sampling was not conducted downstream of the Lees Ferry reach immediately before and after the 2004 HFE so effects on non-listed native fish cannot be evaluated directly. However, several studies (Lauretta and Serrato 2006; Ackerman 2008; Makinster et al. 2009) showed that numbers of common carp, channel catfish, black bullhead, brown trout, were low (compared to native fish) and remained stable or declined slightly from 2004 to 2005, indicating negligible effects on these fish.

Table 11. Preferred water velocities (m/s) for nonnative fish found in the vicinity of the Little Colorado River.

Species	Velocity	Source
Rainbow trout	0.13	Moyle and Baltz 1985
Rainbow trout	0.07	Korman et al. 2005
Rainbow trout	0.1	Baltz et al. 1991
Brown trout	0.03	Heggenes et al. 1990
Common carp	0.11	Aadland 1993
Golden shiner	0.04	Aadland 1993
Green sunfish	0.05	Aadland 1993
Smallmouth bass	0.12	Aadland 1993
Black bullhead	0	Aadland 1993
Channel catfish	0.25	Aadland 1993
Smallmouth bass	0.1	Leonard and Orth 1988
Fathead minnow	0.15	Kolok and Oris 1995
Red shiner	0.15	Shyi-Liang and Peters 2002
Red shiner	0.09	Edwards 1997
Average NNF velocity	0.10	

3.1.16.6 Fish Habitat

Other than creation of backwater habitats, we do not expect other major fish habitat types (talus, debris fans, and vegetated shorelines) to be adversely impacted by HFEs conducted during time period or at any magnitude or duration. Habitat impacts due to changes in depth and velocity will be restricted to the magnitude and duration necessary to conserve sediment. While shifts in use by fish are certainly expected (Hoffnagle et al. 1999), these changes are short-term and the fish and habitats are expected to return to pre-HFE conditions following the high flow.

A temporary decrease in total fish habitat of 57 percent is expected as flows move from 11,500 cfs (an approximation of MLFF flows under No Action) to about 31,500 cfs, and 48 percent between 15,000 cfs and 45,000 cfs (Figure 14, top). These decreases are due mainly to reductions in available habitat in cobble, bedrock and sandbar habitats. However, available habitat over more commonly utilized habitats such as talus and debris fan substrates is not expected to change during high flows as compared to No Action releases and area of vegetated shorelines would actually be near its maximum predicted values. The available habitat is expected to return to pre-HFE conditions following the high flow.

Results are similar for nonnative fish if we assume depth preferences of less than 1 meter and velocities of 0.1 meter per second. We expect total habitat availability to temporarily decrease by about 60 percent as flows move from 11,500 cfs (an approximation of MLFF flows under No Action) to about 31,500 cfs, and by 47 percent between 15,000 cfs and 45,000 cfs (Figure 14, bottom).

3.1.17 Birds under No Action

More than 30 species of birds have been recorded breeding in the riparian zone along the Colorado River in Grand Canyon (Brown 1988). Most birds in the action area nest and forage for insects within the riparian zone and the adjacent uplands. Of the 15 most common riparian breeding bird species, 10 are neotropical migrants that breed in the study area but winter primarily south of the United States-Mexico border. The rest of the breeding birds that use the canyon are year-round residents or short-distance migrants that primarily winter in the region or in nearby southern Arizona (Brown et al. 1987; Brown 1989).

Eleven of the breeding bird species in Glen and Grand Canyons are considered obligate riparian species due to their complete dependence on the riparian zone. Obligate riparian birds nesting within the riparian zone include the neotropical migrants Lucy's warbler (*Vermivora luciae*) and Bell's vireo (*Vireo bellii*), two species identified as "high priority" under regional Partners-in-Flight bird plans and area state bird plans. The remaining riparian obligates include common yellowthroat (*Geothlypis trichas*), yellow warbler (*Dendroica petechia*), yellow-breasted chat (*Icteria virens*), black-chinned hummingbird (*Archilochus alexandri*), the endangered Southwestern willow flycatcher (*Empidonax trailii extimus*), and Bewick's wren (*Thryomanes bewickii*), a sometimes permanent resident of Grand Canyon (Spence 2004). Black Phoebe (*Sayornis nigricans*) is a common permanent resident of the canyon with a close association to water (Spence 2004). Winter songbirds associated with the riparian area include ruby-crowned kinglet (*Regulus calendula*), white-crowned sparrow (*Zonotrichia leucophrys*), dark-eyed junco (*Junco hyemalis*), and song sparrow (Spence 2004). Spence (2004) found that winter species diversity increased below RM 205. Breeding and wintering songbirds are not expected to be impacted by no action.

The aquatic bird community is almost exclusively made up of winter residents (Spence 2004, Yard and Blake 2004). Thirty-four species of wintering waterfowl along with loons, cormorants, grebes, herons, rails, and sandpipers use the river corridor. Increases in abundance and species richness have been attributed to the increased river clarity and productivity associated with the presence of Glen Canyon Dam (Spence 2004; Stevens et al. 1997b). The majority of waterfowl tend to concentrate above the LCR due to the greater primary productivity that benefits dabbling ducks and greater clarity for diving, piscivorous ducks. 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*), and ring-necked duck (*A. collaris*). Other than great blue heron (*Ardea herodias*) and spotted sandpiper (*Actitis macularia*), which are fairly common winter and summer residents along the river, other shorebirds are rare in this area (Spence 2004, Yard and Blake 2004).

The bald eagle (*Haliaeetus leucocephalus*) is no longer a federally listed species in the action area. It was listed as endangered under the ESA in 1967, down-listed to threatened in 1995, and delisted on July 9, 2007 (U.S. Fish and Wildlife Service 2007). It was listed as endangered under the California Endangered Species Act in 1971, and is a species of special concern in Arizona.

A wintering concentration of bald eagles was first observed in Grand Canyon in the early 1980s and numbers have increased dramatically since 1985 (Brown 1992; Brown and Stevens 1991, 1992; Brown et al. 1989). Territorial behavior, but no breeding activity, has been observed. This wintering population has been monitored since 1988 and it occurs throughout the upper half of the Grand Canyon, in Marble Canyon. Density of the Grand Canyon bald eagles during the winter peak (late February and early March) ranged from 13 to 24 birds between Glen Canyon Dam and the Little Colorado River confluence from 1993 to 1995 (Sogge et al. 1995b). A concentration of wintering bald eagles often occurred in late February at the mouth of Nankoweap Creek, where large numbers of rainbow trout congregated to spawn (Gloss et al. 2005). However a flash flood recently destroyed the trout spawning habitat and the eagles no longer congregate at that tributary. Under no action, bald eagles are expected to benefit from current conditions and no changes are expected to numbers using the canyon or to local populations.

The American peregrine falcon (*Falco peregrinus*) was listed as endangered on June 2, 1970. Following restrictions on organochlorine pesticides in the United States and Canada, and implementation of various management actions, including the release of approximately 6,000 captive-reared falcons, recovery goals were substantially exceeded in some areas, and on August 25, 1999, the American peregrine falcon was removed from the List of Endangered and Threatened Wildlife and Plants (64 FR 46541). Although peregrine falcons are uncommon year-round residents in the action area, the population has gradually increased since the 1970s (Brown 1991). In recent years, as many as twelve active eyries have been found in the canyon. Nest sites are usually associated with water. In Grand Canyon, common prey items in summer include the white-throated swift (*Aeronautes saxatalis*), swallows, other song birds and bats (Brown 1991), many of which feed on invertebrate species (especially Diptera) that emerge out of the Colorado River (Stevens et al. 1997b). In winter, a common prey item is waterfowl. Under no action, peregrine falcons are expected to benefit from current conditions and no changes are expected to numbers using the canyon or to local populations.

3.1.17.1 Southwestern Willow Flycatcher

The southwestern willow flycatcher was designated by the USFWS as endangered in 1995. Critical habitat for SWFL was redesignated in October of 2005 and no longer includes habitat within the action area (U.S. Fish and Wildlife Service 2005). The SWFL is an insectivorous riparian obligate. It breeds and forages in dense, multistoried riparian vegetation near surface water or moist soil (Whitmore 1977) along low gradient streams (Sogge 1995). Resident birds arrive in Grand Canyon in May. Nesting occurs in nonnative tamarisk 13 to 23 feet tall with dense foliage 0 to 13 feet from the ground, and the birds forage in tamarisk stands on sandbars, around backwaters, and at the water's edge (Tibbetts and Johnson 1999). Proximity to water is necessary and correlated with food supplies.

In recent years, SWFL have consistently nested along the river corridor in the Grand Canyon as new riparian habitat, primarily tamarisk, has developed in response to altered river flow regimes (Gloss et al, 2005). This expansion of riparian vegetation may have provided additional habitat for the flycatcher, but populations in the upper river corridor persist at a

very low level at only one or two sites. Resident birds have been documented in a limited stretch of Marble Canyon and the lower Canyon near the inflow to Lake Mead (Sogge et. al. 1995a, Tibbets and Johnson 1999, 2000; Unitt 1987). Population numbers have fluctuated between five breeding pairs and three territorial, but non-breeding, pairs in 1995 to one single breeding pair in more recent years. The year 2004 marked the sixth consecutive year in which surveys located a single breeding pair at the upper sites, the lowest population level since surveys began in 1982. In 2006 two nests were detected during the breeding season at the inflow area to Lake Mead (Koronkiewicz et al. 2006), but no flycatchers were found in Marble Canyon in either 2006 or 2007. During surveys for SWFL in 2010 six individual birds were detected in the river corridor between Lees Ferry and Pearce Ferry (Ward et al. 2010). Breeding pairs were not detected (NPS 2010 draft report). All of the birds were found in dense stands of tamarisk and willow. Due to extreme drops in water levels in Lake Mead that started in 2000, much of the occupied habitat of the 1990s is now dead or dying. More recently, new stands of vegetation have been developing in areas exposed by receding water and this vegetation is now developing into suitable flycatcher habitat.

3.1.18 Birds under Proposed Action

Many birds using the Colorado River below Glen Canyon Dam depend on the aquatic food chain associated with green alga (*Cladophora glomerata*). No long-term adverse impacts to *Cladophora* and associated organisms are expected to result from the proposed high-flow release protocol for a single HFE because none were observed during the 1996 experiment (Shannon et al. 2001; Blinn et al. 1999; McKinney et al. 1999). Although other algae and submerged plants use sand or silt as substrate and may be temporarily lost, they are expected to recover relatively quickly if there is no additional disturbance.

A March/April high flow would probably have no negative effect on the bald eagle because wintering and migrant bald eagles have largely left the Grand Canyon region by this time (Sogge et al. 1995b). Birds were unaffected by prior high flows so no effects are expected from the proposed action. Most wintering waterfowl have left the canyons by the time of the flood and would not be affected by it. However, mallard, mergansers, late migrating gadwall, and American widgeon may be present (Spence 2004). These birds are ground nesters and a spring flood might impact them, although adequate waterfowl nest cover exists at higher elevations. Furthermore, the timing of the high flow test is prior to the primary nesting period for all these species. Under the proposed action, no adverse effects are expected to the bird community in Glen and Grand canyons.

The three prior HFEs (1996, 2004, and 2008) all occurred outside of the nesting time of southwestern willow flycatchers and did not impact the species. Nesting usually occurs in May–June, so the HFEs did not interfere with nesting or feeding by adults near nest sites. Reclamation's conclusion is that the proposed action is not likely to adversely affect the southwest willow flycatcher. The SWFL are not found in the action area during the proposed high-flow test so no effects are expected.

3.1.19 Mammals under No Action

Within GCNP 34 species of mammals have been found (Carothers and Aitchison 1976; Frey 2003, Kearsley et al. 2003, 2006; Warren and Schwable 1985). Of these mammals only three are obligate aquatic mammals—beaver (*Castor canadensis*), muskrat (*Ondatra canadensis*), and river otter (*Lutra canadensis*). Despite occasional reported sightings of river otters in Grand Canyon, no reliable documentation exists since the 1970s (Kearsley et al. 2006). River otters are classified as extirpated and muskrats are considered extremely rare.

An increase in the population size and distribution of beaver in Glen and Grand Canyons has occurred since the construction of the dam, likely due to the increase in riparian vegetation and relatively stable flows (Kearsley et al. 2006). Beavers cut willows, cottonwoods, and shrubs for food and can substantially affect riparian vegetation. Beaver in Grand Canyon excavate lodges in the banks of the river with the entrance located underwater and a tunnel leading up under the bank to a living chamber. Beaver are affected by fluctuating water levels in the Grand Canyon since their lodges can become flooded by increases in water levels or the entrances can be exposed by falling water levels. Both situations can expose beaver to increased predation since they are forced to abandon the lodge if flooded or predators can enter the den if the opening is exposed.

Muskrats in Grand Canyon also construct and use bank dens or old beaver dens (Perry 1982) and can be affected by fluctuating water levels. Impacts to muskrats under current flow fluctuations from Glen Canyon Dam are unknown but likely result in increased stress and exposure to predation similar to beaver.

Bats in the Grand Canyon typically roost in desert uplands, but forage on abundant insects along the Colorado River and its tributaries. Bats would continue to forage on the insects present in the riparian corridor.

3.1.20 Mammals under Proposed Action

Beaver typically mate from January through March and the kits are born in March to June (Hill 1982). Young-of-year beaver occupy the lodge with the parents until their second year, when they leave their natal range and search for unoccupied habitat to colonize. Because the proposed action includes a relatively high flow that beaver do not experience on a regular basis, it is likely that the high flow would temporarily disperse sub-adult and adult beaver. Kits born prior to the high-flow-test would likely be killed due to drowning because they would be unable to disperse from the lodge. High flows during March or April in subsequent years could severely affect the beaver population since several year classes could be eliminated. High flows in October or November would likely have little long-term affect on beaver.

Muskrats in Grand Canyon would similarly be dispersed from their bank dens by high flows during March. However, muskrats rarely give birth before May (Perry 1982), and they are polyestrous and capable of producing multiple litters within the year. Muskrats would not likely be affected by an HFE in March/April or October/November.

Bats could be indirectly affected by the proposed action. Insect production from an HFE could be altered, which might have an impact on foraging by bats. However, any change in insect abundance is not expected to have long-term consequences and will likely be minor. Reclamation's conclusion is that the proposed action is not likely to adversely affect bats.

3.2 Cultural Resources under No Action

The Grand Canyon of the Colorado is significant for its human history and its ongoing role in the lives and traditions of American Indians of the Colorado Plateau. Cultural resources include historic properties which are defined as districts, sites, buildings, structures, and objects that are eligible for listing on the National Register of Historic Places. Cultural resources also include Indian sacred sites as defined by Executive Order 13007.

Under No Action, there are at least 151 eligible historic properties or contributing elements to an historic district located with the area of potential effects (Bureau of Reclamation, unpublished data).

Five federally-recognized Indian tribes consider the Grand Canyon a sacred site, as defined under Executive Order 13007.

3.3 Cultural Resources under Proposed Action

3.3.1 Historic Properties

Consultation on the proposed action with the Arizona State Historic Preservation Officer and the Navajo and Hualapai Tribal Historic Preservation Officers has been initiated, but is not yet completed. The area of potential effects (APE) for this undertaking is defined in lineal distance as following the Colorado River from Glen Canyon Dam down to the inflow area of Lake Mead. The lateral extent is defined by a 97,000 cfs stage elevation model prepared by the U.S. Geological Survey. Within this area of potential effect, the area of direct effect would be from the surface of the Colorado River up to the 45,000 cfs stage elevation or flow line and the area of indirect effect would be from 45,000 up to 97,000 cfs.

Within this APE, there are at least 151 eligible properties or contributing elements that could be altered, either directly or indirectly, as a result of one or more HFEs. Application of the criteria of effect at 36 CFR 800.6 indicates that multiple HFEs could change the character or use of these properties, particularly those within the 45,000 cfs inundation area and that the integrity of the properties could be diminished. In other words, at this time, Reclamation anticipates the undertaking will result in an adverse effect determination for the section 106 compliance process.

3.3.2 Sacred Sites

At least five federally-recognized tribes recognize the Colorado River and Grand Canyon as a sacred site. Following EO 13007, the HFEs would alter access to the river corridor during the events. Thus, there would be short-term, minor effects on Indian sacred sites from

the proposed action. In the long-term, the effects on the Indian sacred sites could prove beneficial and not adverse, but the final determination of effects will be reached through the tribal consultation process. *(Editor's note tribal consultation to be initiated prior to EA publication).*

3.4 Socioeconomic Resources

Social and economic conditions were examined to determine whether the proposed action would affect them. The indicators reviewed include environmental justice (E.O. 13175), Indian trust assets, population growth and housing, public health (focusing on flood risk), recreation, the regional economy (focusing on economic cost associated with altering hydropower produced), and traffic and transportation.

3.4.1 Hydropower under No Action

One of the purposes of Glen Canyon Dam, as stated in the CRSPA (43 U.S.C. § 620), is the generation of hydroelectric power. Glen Canyon Dam and the powerplant are part of the Colorado River Storage Project (CRSP), a federal project from which Western markets power. The CRSPA directs that Glen Canyon Dam be *"operated in conjunction with other Federal powerplants … so as to produce the greatest practicable amount of power and energy that can be sold at firm power and energy rates."*

Glen Canyon Dam does not operate, and is not marketed, as an isolated entity. Instead it is one component of a larger hydropower system, and it is packaged along with other power plants for marketing purposes. Capacity and energy from the CRSP, which includes Glen Canyon Dam, the Dolores Project, the Collbran Project, and the Rio Grande Project, are bundled and marketed by Western as the Salt Lake City Area Integrated Projects (SLCA/IP) to end-use consumers across Arizona, Colorado, Nebraska, New Mexico, Nevada, Utah, and Wyoming (Figure 16). The combined installed capacity of the 11 SLCA/IP power plants is 1,819 MW, and they serve cities and towns in mostly rural areas, rural electric cooperatives, agricultural irrigation districts, Indian Tribes, and Federal and state agencies. Western's SLCA/IP annually markets more than 4.3 billion kilowatt-hours (kWhr) from the Glen Canyon Dam powerplant, which represents about 3 percent of the summer capacity in this seven-state region (Harpman 1999).

The marketing of SLCA/IP, including the Glen Canyon component, is under the auspices of Western's CRSP Management Center (MC) headquartered in Salt Lake City, Utah. Western's principal marketing program is the sale of long-term, firm (LTF) capacity and energy at LTF rates. Reclamation has responsibilities for the construction, operation, and maintenance of dams and power plants and for water sales.

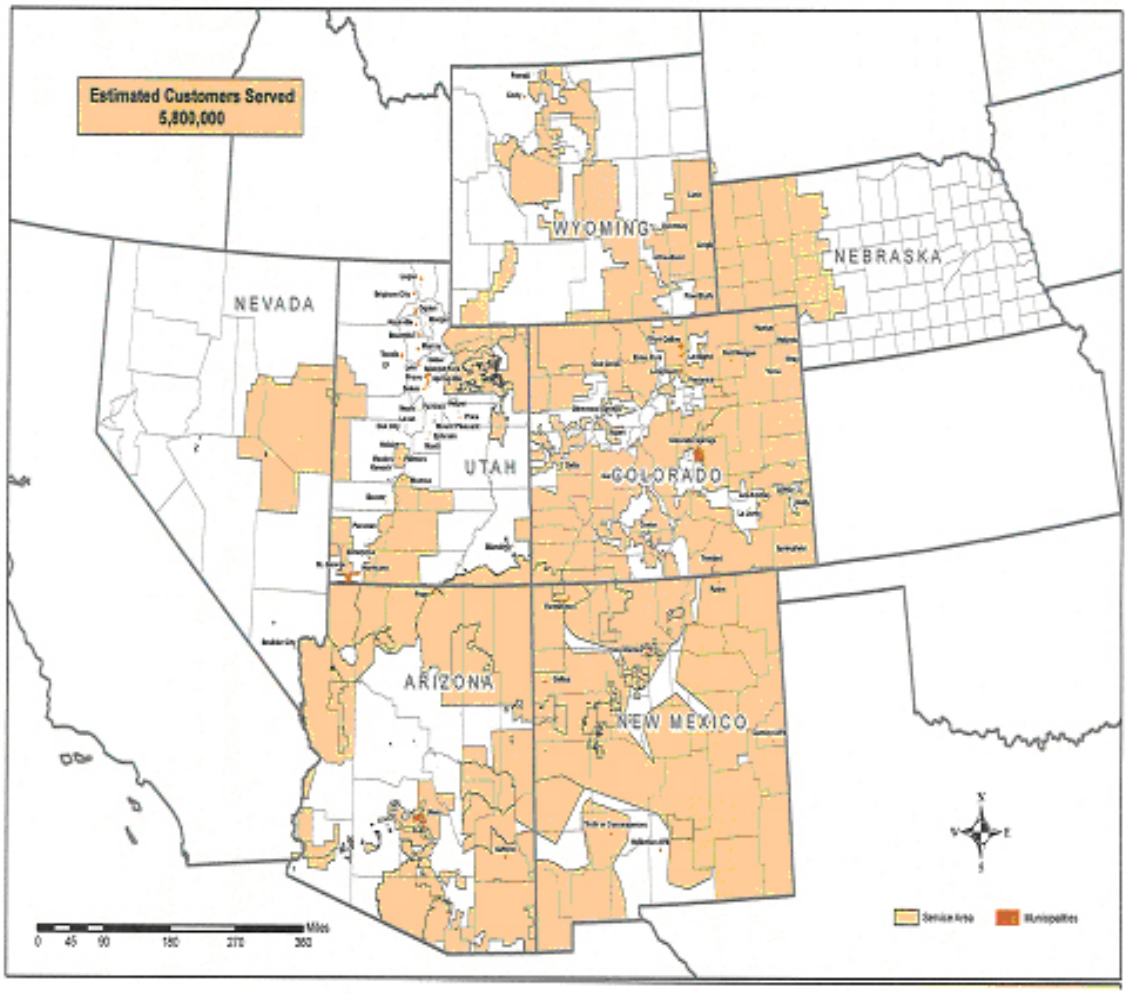

Figure 16. Colorado River Storage Project management center service territory. Map courtesy of Western Area Power Administration.

Demand for electric energy is known as "load." Load varies on a monthly, weekly, daily, and hourly basis, with the highest demand for electricity in the winter and summer when heating and cooling needs, respectively, are greatest. Load is less in the spring and fall (Harpman 1999). The period when demand is highest is called "on peak." In the Glen Canyon Dam service area, the on peak period is from 7:00 a.m. to 11:00 p.m., Monday through Saturday, Mountain Standard Time (MST). All other hours are off peak. During normal operations at Glen Canyon Dam, water releases fluctuate from a low base flow during off peak hours to a high flow that corresponds to the largest electrical demand, subject to the limitations established in the 1996 Record of Decision.

The maximum amount of electric energy than can be produced by a powerplant at a single moment in time is its "capacity," measured in megawatts (MW). Electrical energy or generation is the capacity in MW over a period of time or megawatt-hours (MWh). The rate at which a powerplant can change from one generation level to another is called a "ramp rate," measured in change as cubic feet per second over a one-hour period.

Methods, models, and the amount of hydropower expected to be generated through 2012 are described in Reclamation (2007a:4-251-4-278). The description of the preferred alternative in that EIS serves as the description of hydropower under no action in this environmental assessment. If Reclamation takes no action, 4,481 gigawatt-hours (GWh; 1 GWh = 1,000 MWh) would be produced in 2008. During the period of the proposed action, additional power must be purchased to meet firm power contract provisions; in 2008 about 4,440 GWh would be produced and this additional purchase power cost is projected to be $43.5 million (Western Area Power Administration 2008). To preserve the liquidity of the Basin Fund, increases in the firm power rate charged to power customers may need to be increased, particularly during periods of below average annual dam releases. Such a rate adjustment process is currently underway (Western Area Power Administration 2008). This establishes a baseline against which effects of the proposed action may be compared.

3.4.2 Hydropower under Proposed Action

The economic effect of past experiments has been measured in "avoided costs," essentially the opportunity cost of the experiment. The avoided cost is the difference between the cost of satisfying the demand for electric energy with and without operating the hydropower plant (Harpman 1999). During high-flow releases, the ability to fluctuate water releases to match electrical demand ceases. This means that during periods of low electrical demand, power must be sold at a reduced price and during high electrical demand power, must be bought at an increased price on the spot market to meet customer contracts. When the volume of water released from the dam is greater than the capacity of the powerplant (as with an HFE), the outlet works (bypass tubes) must be used to release flows. The powerplant is bypassed and water is "spilled" through the outlet works where it is unavailable to produce electric energy. During an HFE, power must be purchased from other sources to replace that lost from bypass and the absence of fluctuating releases. This replacement power is generally purchased from coal or gas-fired powerplants, which result in greater carbon emissions (see section 3.1.6). During high flows, more power may be generated than would have been the case without the experiment, depending on the circumstances of the release.

For the March 2008 HFE, based on additional purchases by Western required to meet the SLAC/IP contractual requirements, the projected total cost of the high flow test for water year 2008 was $4.1 million, or a 9.4 percent increase in the purchase power requirement for 2008. This included the effect of moving water from the summer months that have large electrical demand and high prices to “shoulder” months where electrical demand and prices are lower.

The information included in this economic analysis is the effect on the regional economy from a change in Glen Canyon Dam operations. This requires an analysis that estimates the change in value of a resource. The estimates for the value of electrical power and energy included here were taken from a study prepared by Western and Reclamation for the Grand Canyon Monitoring and Research Center (GCMRC) in 2006. GCMRC and the AMP proposed some dam operational regimes to be included in a long-term experiment (LTEP). The proposed options included HFEs.

Western calculated the economic impact of each type of HFE option proposed in the LTEP. These power impacts were included in GCMRC's report. The following is an explanation of how the economic impacts of the 2006 report were modified for this EA. Since the economic impact of HFEs in this EA are derived from the estimate of the impact of a BHBF described in the 2006 LTEP report, the same assumptions used for the LTEP report are embedded in this analysis. This includes, among other things, that the redistribution of water among the months in any given year in order to release an HFE is the same redistribution of water assumed for the LTEP report. Even though the redistribution of water for a future HFE would likely to be different than what redistribution of water has occurred in the past, it is likely that the relative differences among the HFEs as to their impact on electrical power production would not be significantly different.

The following steps were taken to calculate power costs:

1. Identify the economic impact calculated for the 2006 LTEP options report for a BHBF that occurs in the fall.
2. Adjust estimated impact (in annual 2006 dollars) to 2011 market prices.
3. Resulting figure was then "scaled" up or down to reflect the proposed HFE (1 through 13). For example, the BHBF described in the 2006 LTEP report was to have a 60-hour duration at the peak discharge of 45,000 cfs. In this EA, HFE 1 is a 96-hour duration HFE at 45,000 cfs. Therefore the dollar impact estimated for the Fall in the LTEP report was "scaled up" accordingly. Prices used for adjusting economic costs for this EA before the "scaling" were futures prices as received by Western on September 30, 2010.
4. Each of the November HFEs described in this EA (1 through 13) were scaled appropriately to reflect the difference in the number of hours at peak and the variation in the peak flow.
5. The same method is then used to arrive at estimated economic impact for April HFEs (1 through 13) beginning with the Spring BHBFs described in the LTEP report.

The estimated economic impact of each of the 13 types of HFEs for the months of April and November are provided in Table 12. Since the duration and velocity of each HFE is reduced as one reads down the list of HFEs (1 through 13), the economic impact is smaller for each HFE. These numbers are reported for just one HFE and do not include the compounding of economic loss resulting from multiple HFEs in a given year.

Table 12. Estimated economic impact[1] of HFEs on electrical power production.

			April HFE	November HFE
HFE No.	cfs	Duration (hours)	millions of 2011 $	millions of 2011 $
1	45,000	96	$2.85	$3.34
2	45,000	72	$2.14	$2.50
3	45,000	60	$1.78	$2.09
4	45,000	48	$1.43	$1.67
5	45,000	36	$1.07	$1.25
6	45,000	24	$0.71	$0.83
7	45,000	12	$0.36	$0.42
8	45,000	1	$0.03	$0.03
9	41,500	1	$0.03	$0.03
10	39,000	1	$0.03	$0.03
11	36,500	1	$0.02	$0.03
12	34,000	1	$0.02	$0.03
13	31,500	1	$0.02	$0.02

[1]Prices used for adjusting economic costs for this EA before the "scaling" were futures prices as received by Western on September 30, 2010.

3.4.3 Recreation under No Action

Recreational resources of concern include trout fishing and boating from Glen Canyon Dam to Lees Ferry, whitewater boating through Grand Canyon, and the Hualapai Indian tribe's boating enterprise at the western end of Grand Canyon and into Lake Mead.

3.4.3.1 Fishing under No Action

The Colorado River from the dam to Lees Ferry is a blue ribbon rainbow trout fishery that attracts local, national, and international anglers. Most angling is done from boats or is facilitated by boat access, often provided by guide services. Some anglers also fish by wading in the area of Lees Ferry.

The month with the highest number of user days for 2006 and 2009 was April (Figure 17). Angler use remains high from March through October, and months of lowest use are December through February.

The angler use declined from approximately 20,000 anglers in 2000 to less than 6,000 in 2003 (Loomis et al. 2005). It increased in 2006 to approximately 13,000 user days (Henson 2007), but in 2009 a 25 percent decline occurred to approximately 9,800 user days (Anderson 2010).

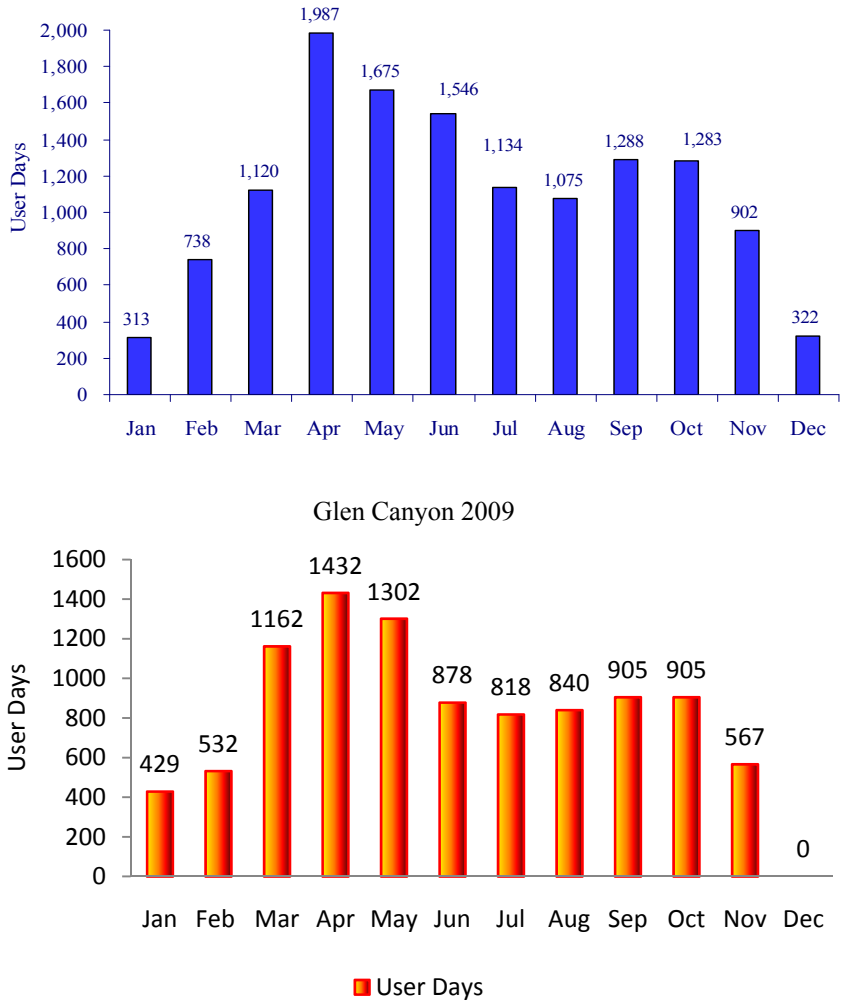

Figure 17. Fishing user days by month in the Lees Ferry reach for 2006 (top) and 2009 (bottom).

3.4.3.2 Whitewater Boating under No Action

Whitewater boating (kayaking, rafting, canoeing, etc.) in the reach below Lees Ferry and through the Grand Canyon is internationally renowned. Use is regulated by the NPS under the Colorado River Management Plan (CRMP) and it is not uncommon for private parties to wait 10-12 years for the opportunity to float the Grand Canyon of the Colorado River.

For river management purposes, the Colorado River is divided into two reaches. The upper reach extends from Lees Ferry (river mile (RM) 0) to Diamond Creek (RM 226). The lower reach starts at Diamond Creek (RM 226) on the Hualapai Reservation and extends to Lake Mead (RM 277).

The CRMP for whitewater boating through Grand Canyon National Park (National Park Service 2005 a, 2005 b, 2005 c and 2006 b) governs use in both the Lees Ferry reach and the

reach from Diamond Creek down to Lake Mead. Annual use in the Lees Ferry Reach is expected to be 115,500 commercial user-days and approximately 113,500 noncommercial (private) user-days (National Park Service 2006). Highest use months for commercial operations extend from May through September, but are relatively consistent through the year for noncommercial boating (Figure 18).

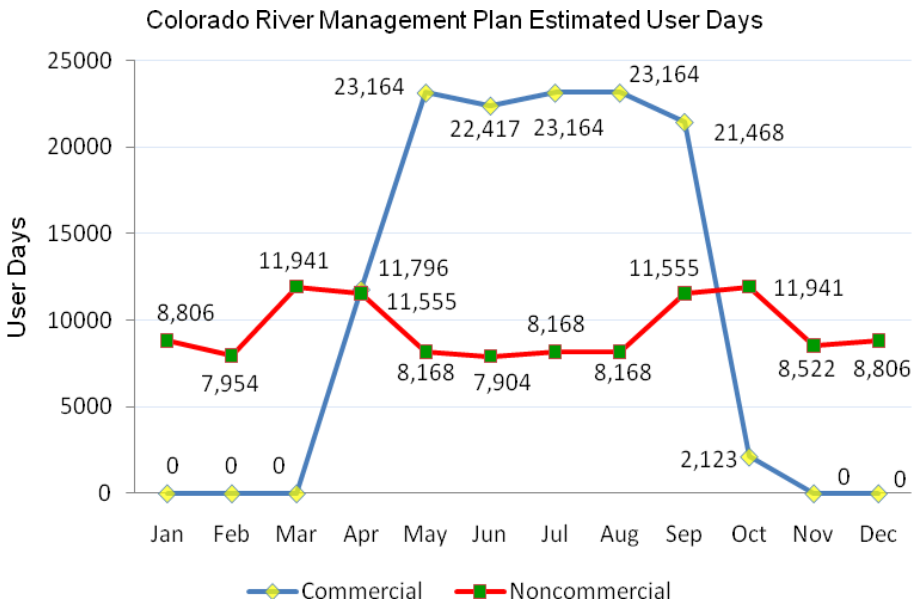

Figure 18. Whitewater boating in the Grand Canyon, annual use by month (Grand Canyon National Park 2007).

The CRMP allows up to 1,100 total yearly launches (598 commercial trips and 504 noncommercial trips). Up to 24,567 river runners could be accommodated annually if all trips were taken and all were filled to capacity. Actual experience has shown that all noncommercial trips that are available are not taken and not all available trips are filled to capacity.

Commercial and recreational whitewater boating also takes place downstream of Diamond Creek. Diamond Creek is at about mile 227, or about 243 miles downstream from Glen Canyon Dam, and is an end point for many boating trips that begin at Lees Ferry. It is also the starting point for those commercial and noncommercial trips that originate on the Hualapai Indian Reservation. Private parties launching at this site pay launch and user fees to the Hualapai Tribe. The river running season for the boating operations (Grand Canyon West) opens on March 15 and runs until October 31st. Commercial day and overnight trips run by Hualapai River Runners (HRR) begin at Diamond Creek and end at Quartermaster or at Lake Mead (South Cove). The overnight trips make use of campsites (beaches) along the southern bank of the river. There is also a concession pontoon boat operation that offers 20 minute river rides that launch and return to a boat dock at Quartermaster. Damage to Hualapai boat docks have occurred in the past at 45,000 cfs flows.

Recreational use below Diamond Creek is managed in accordance with the CRMP (National Park Service 2005 a, 2005 b, 2005 c and 2006 b). Figure 19 illustrates the maximum whitewater boating use below Diamond Creek by the HRR as allowed by the CRMP. Months of highest allowable use are June through September, with moderate use from March through May and in October. There is no allowable use from November through February.

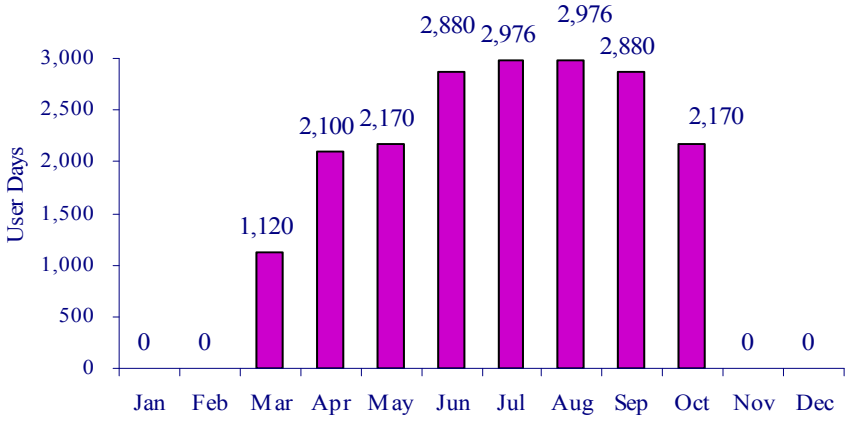

Figure 19. Recreation use below Diamond Creek (HRR maximum possible).

The section of the Colorado River between Diamond Creek and Lake Mead is less demanding than the river above Diamond Creek, and is less visited by noncommercial river runners. From 2007 to 2009, the total number of user days for trips launching at Diamond Creek ranged from 6,805 to 4,788 (Figure 20). A comparable number of user days were recorded for trips launching before Diamond Creek and continuing past Diamond Creek.

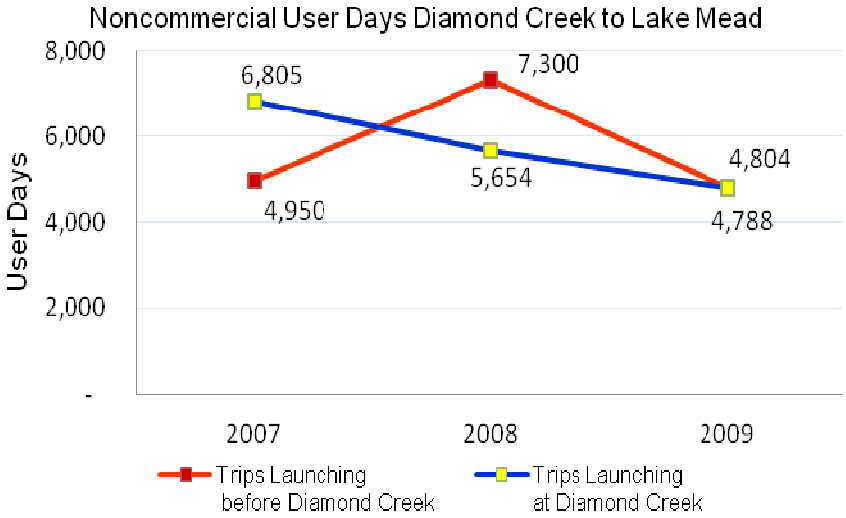

Figure 20. Noncommercial user days – Diamond Creek to Lake Mead (National Park Service 2009).

The pontoon boat operation between Quartermaster and Pearce Ferry has a daily limit of 480 passengers and is limited to having five boats with passengers in the water at any one time. Approximately 175,200 passengers are expected annually, with a monthly range of 13,440 to 14,880.

3.4.3.3 Net Economic Use Value of Recreation under No Action

Net economic use value is a measure of the value over and above the costs of participating in a recreation activity. The total net economic value is related to the number of recreationists who participate in each activity, the time of year in which they participate, and the value of each trip taken.

Regional economic activity refers to expenditures and their impacts within the study area. River-based recreational users, such as anglers and white-water boaters, spend large sums of money in the region. While these expenditures do not represent a benefit measure, they nonetheless are important because they support local businesses and provide employment for local residents.

The annual regional economic activity that results from nonresident anglers, whitewater boaters, and day rafters who visit Glen and Grand canyons was estimated (Bureau of Reclamation 1995a) at approximately $25.7 million in 1995. Glen Canyon and Grand Canyon recreational use in the region comprised of Coconino and Mojave Counties supported approximately 585 jobs (Douglas and Harpman 1995). By 2003, jobs had decreased to approximately 394 jobs (Hjerpe and Kim 2003). This decline has continued mostly as a result of a declining national economy.

Non-use refers to individuals that may never visit or otherwise use these resources. An economic expression of their preferences regarding the status of the natural environment is termed “nonuse” or “passive use” value (King and Mazzotta 2007). The Bureau of Reclamation conducted an analysis of total economic value for the 1995 Glen Canyon EIS. The estimated average nonuse value for U.S. households was $18.74 (in 2008 dollars) for the moderate fluctuating flow alternative. When expanded by the pertinent population, this yields an aggregate estimate of $3,159.21 million per year (in 2008 dollars) for the national sample.

The findings of this study illustrate the significance of Grand Canyon resources and the value placed upon them by members of the public. The results of the nonuse value study are summarized as Attachment 3 in the Record of Decision (U.S. Department of the Interior 1996).

3.4.4 Recreation under Proposed Action

3.4.4.1 Fishing under Proposed Action

Most anglers elected not to fish from Glen Canyon Dam to Lees Ferry during previous HFEs and the same behavior would be expected under the proposed action. Fisherman

reported reduced success in the Lees Ferry area during and after the past HFEs.

Effects of HFEs to the fishery will be dependent on the season, duration, and volume of the water released. AGFD data indicated the March 26, 1996 HFE of 45,000 cfs for 7 days had no effect on catch rate or condition indices of trout (McKinney et al. 1999). Shannon (2001) showed that high flows resulted in benthic scouring and entrainment of both primary and secondary producers, but macroinvertebrates and filamentous algae recovered within 3 months, depending on the taxa. The 1996 test flow removed suspended particles from the water column and increased water clarity, which also enhanced benthic recovery (Shannon et al. 2001) and benefited the trout fishery.

Wading anglers who elect to fish during the event, will experience rapid increases in river stage that may place them at risk if they are unaware and unprepared. Advance public notice, onsite warnings provided by management agencies, and the timing, magnitude, and duration of the flow would allow anglers to make personal assessments of risk during this period.

3.4.4.2 Whitewater Boating under Proposed Action

A commercial operation (Colorado River Discovery) hikes people down to the base of the dam and offers a boat ride to Lees Ferry. During previous high flow tests, boats not were allowed to launch immediately below the dam. The concessionaire on the Lees Ferry to Glen Canyon Dam reach cannot operate under HFEs of 40,000 cfs to 45,000 cfs. The 20-boat pontoon fleet must be taken in and out of the water which takes several days. Day use rafting trips was not restricted from Lees Ferry and boats could move upstream under Whitewater Boating Safety Rules.

The effects of high flows above powerplant capacity on navigability is not well documented in the peer-reviewed literature, but anecdotal information and several in-house NPS studies (Jalbert, 1996; Jalbert, 2001) suggest that higher flows improve the navigability of most rapids by covering rocks that would otherwise be exposed and by creating more channels for boaters to chose from as they navigate downstream. Also, Webb et al. (1999) showed that BHBFs can clear channels of rock debris accumulations, which generally creates easier passage for boats after flows diminish. The NPS studies found a slight increase in flipped row boats and inadvertent swimmers under experimental high flows in the 45,000 cfs range, but the difference in numbers of these incidents under high and lower flows was not statistically significant (Jalbert 1996.)

Several in-house studies have been undertaken by the NPS that evaluated the effects of high flows at or above powerplant capacity on safety (e.g., Brown and Hahn 1988; Jalbert 1996.) The results of these studies are somewhat difficult to evaluate because the studies were relatively short term, the sampling strategy was not random, the studies did not take into account nonflow factors such as boater experience. In addition, various studies have evaluated boaters' perceptions of risk at high flows (e.g., Bishop et al., 1987; Shelby et al. 1992; Stewart et al. 2000), but the findings from these studies have not been independently evaluated through actual monitoring of safety incidents during non-experimental flow events. Based on a comparison of data from 1987, when flows in the low 30,000 cfs range were

common, with incident data collected during the 1996 BHBF, it was concluded that more accidents were likely to occur under flows of 31,500–33,000 cfs than at 45,000 cfs (Jalbert 1996). The 1996 NPS study concluded that despite observing a slight increase in boat flips and unintentional swims at a couple of rapids during the 1996 BFBH, the overall numbers of incidents at 45,000 cfs were not significantly different from those reported during non-experimental flow conditions (Jalbert 1996.) Studies specifically designed to evaluate safety issues at a variety of different flows are needed to substantiate these conclusions.

Sandbars form the camping beaches used by river runners in the Grand Canyon. Total camping area above the 25,000 cfs stage elevation has decreased since 1998 (Kaplinski et al. 2005, 2009). Usable camping beach area above the high water line (currently 25,000 cfs) is limited in narrow reaches of the canyon. High flows during an HFE and large fluctuations in river stage may limit the usable beaches by inundating some and reducing usable area of others. Boaters on the water during high flow tests need to be cautious in selecting campsites, but the duration of the experiment relative to the length of a typical non-motorized trip (18 days), suggests effects on boaters would be limited.

Wilderness characteristics of whitewater boating trips may be influenced by fluctuating river stages and by the conditions of beaches, vegetation, and other features of the riparian zone (Bishop et al., 1987; Shelby et al., 1992; Welsh, et al., 1995). Whitewater boating visitation use has been unaffected by river flows.

Comments received from the Grand Canyon River Guides, Grand Canyon River Runners Association, and many individual guides and commercial rafting companies have supported previous HFEs because of the potential to improve camping beaches and overall conditions in the river corridor.

3.4.4.3 Net Economic Use Value of Recreation under Proposed Action

The net effect of the proposed HFEs on regional economic activity is expected to have a short-term negative impact due to the temporary loss of angling and boating user days in the Lees Ferry reach and consequent income to local businesses (Figure 21). These include Vermillion Cliffs, Marble Canyon, Lees Ferry and Navajo vendors. The HFEs are perceived by some in the local community to be the reason for the overall economic hardship. The anglers, fishing guides, and business people believe that the HFEs have had a negative effect on their business because the public perceives the trout fishery is impacted and negative publicity deters the anglers from fishing at Lees Ferry for extended periods of time.

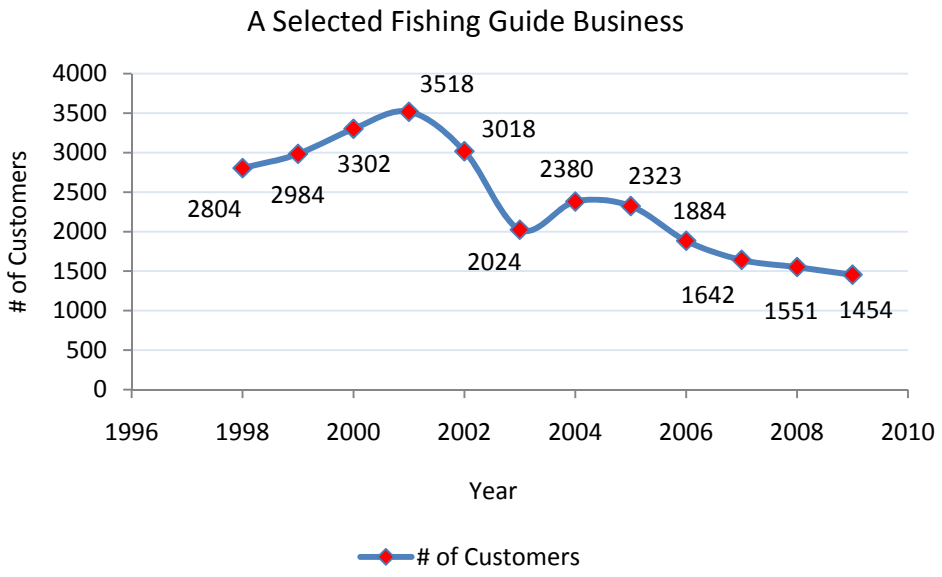

Figure 21. Numbers of anglers served by one fishing guide business.

Table 13. Summary of impacts on resources from a single, independent high-flow experiment (HFE). The October/November and March/April time periods represent the most probable times for a suitable sediment supply to meet the Purpose and Need of the Action. The release magnitude of 31,500–33,200 cfs represents the powerplant capacity range not currently authorized, and 41,000–45,000 cfs represents the maximum release with all eight units of the powerplant (31,500 cfs) and the four bypass tubes. There is a knowledge gap between 31,500 and 41,000 cfs; experimental releases can shed some light on effects to resources.

HFE Attribute	**October/November**			**March/April**		
Magnitude	31,500–33,200 cfs	41,000–45,000 cfs		31,500–33,200 cfs	41,000–45,000 cfs	
Duration	0–8 hrs	0–48 hrs	60–96 hrs	0–8 hrs	0–48 hrs	60–96 hrs
Resource						
Water Delivery	No impact to annual delivery or monthly volumes.	No impact to annual delivery. Monthly patterns will change only as necessary for HFE reallocation.	No impact to annual delivery. Monthly patterns will change only as necessary for HFE reallocation.	No impact to annual delivery or monthly volumes.	No impact to annual delivery. Monthly patterns will change only as necessary for HFE reallocation.	No impact to annual delivery. Monthly patterns will change only as necessary for HFE reallocation.
Water Quality	Minor impacts except during times of low dissolved oxygen in Lake Powell.	Minor impacts except during times of low dissolved oxygen in Lake Powell. Temporary turbidity increase from scouring.	Minor impacts except during times of low dissolved oxygen in Lake Powell. Temporary turbidity increase from scouring.	Minor impacts except during times of low dissolved oxygen in Lake Powell.	Minor impacts except during times of low dissolved oxygen in Lake Powell. Temporary turbidity increase from scouring.	Minor impacts except during times of low dissolved oxygen in Lake Powell. Temporary turbidity increase from scouring.
Air Quality	No measureable impact.	Addition of up to 32,000 metric tons of CO_2	Addition of 39,000 to 63,000 metric tons of CO_2	No measureable impact.	Addition of up to 32,000 metric tons of CO_2	Addition of 39,000 to 63,000 metric tons of CO_2
Sediment	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 33,000 cfs stage.	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage.	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage. Potential for better balancing sediment delivery between upstream and downstream reaches.	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 33,000 cfs stage.	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage.	Effect dependent on antecedent conditions and ensuing flows. Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage. Potential for better balancing sediment delivery between

HFE Attribute	October/November			March/April		
Magnitude	31,500–33,200 cfs	41,000–45,000 cfs		31,500–33,200 cfs	41,000–45,000 cfs	
Duration	0–8 hrs	0–48 hrs	60–96 hrs	0–8 hrs	0–48 hrs	60–96 hrs
						upstream and downstream reaches.
Riparian Vegetation	Minor impact: some inundation of low elevation plants; minor scouring of wetland vegetation in backwaters; multiple HFEs could eliminate wetland vegetation in backwaters.	Moderate impact: inundation and burial of plants in flood zone; scouring of wetland vegetation in backwaters; multiple HFEs could eliminate wetland vegetation in backwaters.	Moderate impact: inundation and burial of plants in flood zone; scouring of wetland vegetation in backwaters; multiple HFEs could eliminate wetland vegetation in backwaters.	Minor impact: some inundation of low elevation plants; minor scouring of wetland vegetation in backwaters; multiple HFEs could eliminate wetland vegetation in backwaters.	Moderate impact: inundation and burial of plants in flood zone; scouring of wetland vegetation in backwaters; multiple HFEs could eliminate wetland vegetation in backwaters.	Could create habitat for more riparian and wetland vegetation and remove habitat and vegetation
Noxious Weeds	Flood would be outside main seed-producing period, could have increased dispersal	Flood would be outside main seed-producing period, could have increased dispersal	Flood would be outside main seed-producing period, could have increased dispersal	Flood would be outside main seed-producing period, could have increased dispersal	Flood would be outside main seed-producing period, could have increased dispersal	Flood would be outside main seed-producing period, could have increased dispersal
Terrestrial Vertebrates and Herptofauna	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved	Kanab Ambersnail will be displaced, minor loss of habitat, best habitat will be temporarily moved
Aquatic Food Base	Minimal impact, although some scouring could occur	Scouring of algae and plant material likely; recovery may take long time	Scouring of algae and plant material likely; recovery may take long time	Minimal impact, although some scouring could occur	Scouring of algae and plant material likely; recovery may take long time	Scouring of algae and plant material likely; recovery may take long time
Humpback Chub	Minimal impact; some creation of backwater habitat	Short-term displacement; creation of backwater habitat; short-term reduction in food supply		Minimal impact; some creation of backwater habitat; increased predation due to increased trout survival	Creation of backwater habitat; increased predation due to increased trout survival	

HFE Attribute	October/November			March/April		
Magnitude	31,500–33,200 cfs	41,000–45,000 cfs		31,500–33,200 cfs	41,000–45,000 cfs	
Duration	0–8 hrs	0–48 hrs	60–96 hrs	0–8 hrs	0–48 hrs	60–96 hrs
Razorback sucker	No impacts (does not occur in action area)					
Non-Listed Native Fish	Limited displacement of small-bodied fish from backwaters	N/A	Temporary habitat shifts including displacement of small-bodied fish from backwaters; no lasting population effects expected.	Limited displacement of small-bodied fish from backwaters	N/A	Temporary habitat shifts including displacement of small-bodied fish from backwaters; no lasting population effects expected.
Trout	Minimal impact	Displacement of YOY, minor decline in condition, possible decline in survival; short term reduction in food supply	Displacement of YOY, minor decline in condition, possible decline in survival; short term reduction in food supply	Minimal impact	Increased YOY survival from compensatory response; temporary decline (ca. 3-4 mo.) in condition; downstream displacement of small fish	Increased YOY survival from compensatory response; temporary decline (ca. 3-4 mo.) in condition; downstream displacement of small fish
Other Nonnative Fish	No lasting impacts; displacement of small-bodied fish from backwaters, short-term population reduction	No lasting impacts; displacement of small-bodied fish from backwaters, short-term population reduction	No lasting impacts; displacement of small-bodied fish from backwaters, short-term population reduction	No lasting impacts; displacement of small bodied fish from backwaters	No lasting impacts; displacement of small bodied fish	No lasting impacts; displacement of small bodied fish
Fish Habitat	Temporary decline in total habitat by about 57-60 percent during HFE	Temporary decline in total habitat by about 47-48 percent during HFE		Temporary decline in total habitat by about 57-60 percent during HFE	Temporary decline in total habitat by about 47-48 percent during HFE	
Birds	Minor impacts to waterfowl related to food availability, no impact to	Minor impacts to waterfowl related to food	Minor impacts to waterfowl related to food availability, no impact to SWFL since flood	Minor impacts to waterfowl related to food availability, no	Minor impacts to waterfowl related to food availability, no	Minor impacts to waterfowl related to food availability, no

HFE Attribute	October/November			March/April		
Magnitude	31,500–33,200 cfs	41,000–45,000 cfs		31,500–33,200 cfs	41,000–45,000 cfs	
Duration	0–8 hrs	0–48 hrs	60–96 hrs	0–8 hrs	0–48 hrs	60–96 hrs
	SWFL since flood is outside of occupancy period	availability, no impact to SWFL since flood is outside of occupancy period	is outside of occupancy period	impact to SWFL since flood is outside of occupancy period	impact to SWFL since flood is outside of occupancy period	impact to SWFL since flood is outside of occupancy period
Mammals	Minor impacts to aquatic mammals which would temporarily move	Minor impacts to aquatic mammals which would temporarily move	Minor impacts to aquatic mammals which would temporarily move	Young-of-year beaver would likely be killed, adult mammals would be temporarily displaced	Young-of-year beaver would likely be killed, adult mammals would be temporarily displaced	Young-of-year beaver would likely be killed, adult mammals would be temporarily displaced
Historic Properties	Adverse	Adverse	Adverse	Adverse	Adverse	Adverse
Sacred Sites	Access altered	Access altered	Access altered	Access altered	Access altered	Access altered
Hydropowe r			Small negative effect from loss of hydropower and ability to peak power; mitigated with purchase of alternative power			Small negative effect from loss of hydropower and ability to peak power; mitigated with purchase of alternative power
Recreation	Minimal or negligible impact to boating, rafting, angling	Minimal effect due to short duration unless trout fishery is harmed	Adverse affect due to long duration and relatively higher flows	Minimal effect due to short duration and smaller volume	Minimal effect due to short duration unless trout fishery is harmed	Adverse affect due to long duration and relatively higher flows
Conclusion						

Table 14. Summary of impacts on resources from multiple high-flow experiments (HFEs).

	High Occurrence Probability, Low Resource Risk		Moderate Occurrence Probability, Moderate Resource Risk		Low Occurrence Probability, High Resource Risk	
Resource	One April HFE in a Year; at Least One Intervening Year with No HFE	One November HFE in a Year; at Least One Intervening Year with No HFE	One April HFE Every Year for 10 Years	One April HFE in a Year; at Least One Intervening Year with No HFE	One November HFE in a Year; at Least One Intervening Year with No HFE	One April HFE Every Year for 10 Years
Native Fish	Backwaters may provide some habitat. Release prior to May should not affect young HBC, FMS, BHS, SPD.	Backwaters may provide some habitat. Young HBC, FMS, BHS, SPD should be large enough to not be affected.	Backwaters may provide some habitat. Release prior to May should not affect young HBC, FMS, BHS, SPD.	Backwaters may provide some habitat. Young HBC, FMS, BHS, SPD should be large enough to not be affected. Little impact expected except through food base.	Backwaters may provide some habitat. Young HBC, FMS, BHS, SPD should be large enough to not be affected. Little impact expected except through food base.	Backwaters may provide some habitat. Little impact expected except through food base.
Lees Ferry Trout	March release would stimulate age-0 survival, growth and increase population; April release could reduce survival, growth of age-0 and reduce population.	November release could decrease overwinter health and condition and lead to reduced spawning success in following spring.	Spring release could stimulate or reduce trout production, but effect of annual release unknown.	November release could decrease overwinter health and condition and lead to reduced long-term spawning success.	Could lead to long-term population reduction.	Spring release could stimulate or reduce trout production; fall release could reduce spawning success in following spring.

	High Occurrence Probability, Low Resource Risk		Moderate Occurrence Probability, Moderate Resource Risk		Low Occurrence Probability, High Resource Risk	
Other Nonnative Fish	Little impact to large-bodied fish except from food base effect; small-bodied fish would be displaced from backwaters with 1-2 year population effect.	Little impact to large-bodied fish except from food base effect; YOY and small-bodied fish would be displaced with 1-2 year population effect.	Annual releases could displace small nonnative fish and reduce populations of certain species long-term.	Annual releases could displace small nonnative fish and reduce populations of certain species long-term.	Two annual releases could displace small nonnative fish and suppress populations of certain species long-term.	Two releases per year could displace small nonnative fish and reduce populations of certain species.
Aquatic Food Base	Spring release would flush sediment, scour food base and stimulate Lees Ferry food production with short-term recovery.	November release would flush sediment, scour food base and could damage overwinter Lees Ferry food production because low solar radiation would inhibit recovery until spring.	Spring release would flush sediment, scour food base and stimulate Lees Ferry food production with short-term recovery, but effect of annual release unknown.	November release would flush sediment, scour food base and could damage overwinter Lees Ferry food production; effect of annual release unknown.	November release could damage food base which could be further depleted by spring release.	Spring release would flush sediment, scour food base and stimulate Lees Ferry food production with most recovery by fall; November release could damage food base.
	Spring release would flush sediment, invertebrates from downstream backwaters with short-term recovery.	November release would flush sediment, invertebrates from downstream backwaters with slowed recovery.	Spring release would flush sediment, invertebrates with short-term recovery, but effect of annual release unknown.	Downstream food base likely to recovery faster than at Lees Ferry.	Downstream food base likely to recovery faster than at Lees Ferry.	Spring release would flush sediment, invertebrates from downstream backwaters with short-term recovery; November release would be slower recovery.
Endangered and Other Special Status Species	Will inundate KAS habitat at Vasey's Paradise; relocation possible.	Will inundate KAS habitat at Vasey's Paradise; relocation possible.	Will inundate KAS habitat at Vasey's Paradise; frequent relocation may impact population.	Will inundate KAS habitat at Vasey's Paradise; frequent relocation may impact population.	Will inundate KAS habitat at Vasey's Paradise; frequent relocation may impact population.	Will inundate KAS habitat at Vasey's Paradise; relocation possible.

Table 15. Summary of impacts on resources from the proposed action.

Resource	Impact Determination	Unavoidable Adverse Impacts	Uncertainties or Unknowns	Mitigation
NATURAL RESOURCES				
Water Operations	No adverse impact	None	Protocol is based on water availability	Release volume would be distributed over other months
Water Quality	No adverse impact	None	Frequent HFEs may degrade water quality in Lees Ferry; reduced reservoir elevation may warm releases, cause oxygen depletions	Water chemistry monitoring of Lake Powell and Lees Ferry reach should continue
Sediment	No adverse impact	None	HFEs expected to benefit sediment conservation; erosion of sandbars likely to take place with post-HFE MLFF flows	Investigate methods for reducing post-HFE erosion of sandbars
Aquatic Food Base	No adverse impact	None	Scouring expected, but recovery of fall HFEs uncertain; HFEs not expected to affect downstream food base	Monitoring will be necessary to ensure against detrimental effects from consecutive HFEs
Vegetation	No adverse impact	None	Multiple HFEs could coarsen sand, reduce nutrients, and favor clonal native plants	Investigate effects of sand coarsening, nutrient depletion on riparian vegetation
Terrestrial Invertebrates and Herptofauna	No adverse impact	None	Individuals may become exported; frequent HFEs may establish new elevation for communities	Investigate effects to riparian communities from frequent HFEs
Federally Listed Species				

Resource	Impact Determination	Unavoidable Adverse Impacts	Uncertainties or Unknowns	Mitigation
• Humpback Chub	No adverse impact	None	HFEs not expected to export young from shorelines; young in inundated backwaters will be displaced but not likely exported	Nearshore ecology studies should address use of shorelines and backwaters and effects of HFEs on population
• Razorback Sucker	No adverse impact	None	Species does not appear to be present in action area	None
• Kanab Ambersnail	Adverse impact of some habitat and take of individuals; not likely to adversely affect overall population	High flows will inundate occupied habitat and export and destroy individuals	Frequent HFEs may cause population to reestablish at higher elevation, as in pre-dam period	Habitat and individuals will be monitored and relocated, as necessary; relocation may not be necessary as habitat and population reestablish at a higher elevation; an Incidental Take Statement covers losses of individuals
• Western Willow Flycatcher	No adverse impact	None	Nesting occurs primarily in tamarisk which may be stabilized or reduced with sand coarsening; not expected to impact birds	None
Fish				
• Trout	No adverse impact	None	Spring HFEs could stimulate population increase and downstream migration of trout to habitat occupied by humpback chub; Fall HFEs could damage food base and degrade trout condition	Timing of HFEs will be investigated to determine how dam operations can be used to manage trout population size and health
• Native Fishes	No adverse impact	None	HFEs not expected to export young from shorelines; young	Nearshore ecology studies should address use of

Resource	Impact Determination	Unavoidable Adverse Impacts	Uncertainties or Unknowns	Mitigation
			in inundated backwaters will be displaced but not likely exported; HFEs not expected to affect downstream food base	shorelines and backwaters and effects of HFEs on populations
• Nonnative Fishes	No adverse impact	None	HFEs expected to export small-bodied fish from shorelines and inundated backwaters	Nearshore ecology studies should address use of shorelines and backwaters and effects of HFEs on populations
Birds	No adverse impact	None	HFEs in spring and fall may reduce quiet habitat for migratory waterfowl	HFEs expected to have short duration (<90 hr) that should not affect birds
Mammals	No adverse impact	None	Individuals may become exported; frequent HFEs may establish new elevation for communities	Investigate effects to riparian communities from frequent HFEs
CULTURAL RESOURCES				
Historic Properties	No adverse impact	Restricted access, short-term effect	HFEs are expected to conserve sand that surrounds and protects sites from damage by erosion	Sites will continue to be monitored
Sacred Sites	No adverse impact	Restricted access, short-term effect	N/A	None possible if HFE held
SOCIOECONOMIC RESOURCES				
Hydropower	No adverse impact	None	There will be short-term loss of hydropower if by-pass valves are used	Other sources of power will need to be purchased
Recreation	Minor short-term impact; long-term impact not likely	Minor adverse impact on Colorado River Discovery Tours; no impact to	High release may increase difficulty of some rapids, reduce access to certain	Advance notice will be given to anglers and rafters

Resource	Impact Determination	Unavoidable Adverse Impacts	Uncertainties or Unknowns	Mitigation
		commercial boaters	fishing areas in Lees Ferry	
Indian Trust Assets	No adverse impact	None	None	None
Wild and Scenic Status	No adverse impact	None	HFEs expected to enhance ecosystem diversity and enhance wilderness values	None

Table 16. Expected resource impact from single and consecutive HFEs with a magnitude of 41,000 cfs to 45,000 cfs. '+', '--', '0', or '?' indicate positive impact, negative impact, no impact, and unknown impact, respectively. Green, yellow, and red denote increasing uncertainty in the predicted response. We assume that flows less than 41,000 cfs create less impact.

Resource	Single HFE	Spring Followed by Fall	Fall Followed by Spring	More than Two Consecutive HFEs
NATURAL RESOURCES				
Water Operations	0	0	0	0
Water Quality	0	0	0	?
Sediment	+	+	+	+
Aquatic Food Base	+	0	--	?
Vegetation	+	+	+	?
Terrestrial Invertebrates and Herptofauna	0	0	0	0
Federally Listed Species				
• Humpback Chub	0	0	0	?
• Razorback Sucker	0	0	0	0
• Kanab Ambersnail	--	--	--	?
• Western Willow Flycatcher	0	0	0	0
Fish				
• Trout	+	+	--	?
• Native Fishes	0	0	0	?
• Nonnative Fishes	--	--	--	?
Birds	0	0	0	0
Mammals	0	0	0	0
CULTURAL RESOURCES				
Historic Properties	0	0	0	?
Sacred Sites	0	0	0	?
SOCIOECONOMIC RESOURCES				
Hydropower	--	--	--	--
Recreation	--	--	--	--
Indian Trust Assets	0	0	0	0
Wild and Scenic Status	0	0	0	0

3.5 Indian Trust Assets

Indian trust assets are legal interests in property held in trust by the US government for Indian tribes or individuals. Examples of such resources are lands, minerals, or water rights. The action area is bounded on the east by the Navajo Indian Reservation and on the south by the Hualapai Indian Reservation. Reclamation has ongoing consultation with these tribes regarding potential effects of the proposed action on their trust assets and reserved rights. High-flow releases will inundate shoreline areas historically affected by seasonal floods, and effects to resources show that the proposed action is not likely to impact lands, minerals, or water rights.

3.6 Environmental Justice Implications

Environmental justice refers to those issues resulting from a proposed action that disproportionately affect minority or low-income populations. To implement Executive Order 12898, *Environmental Justice in Minority Populations and Low Income Populations*, the Council on Environmental Quality (1997) instructs agencies to determine whether minority or low-income populations or Indian tribes 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 affected area is bounded by the Navajo Indian Reservation and the Hualapai Indian Reservation. Hydropower and financial impacts to the Hualapai Tribe's recreational boating operations on the Colorado River were identified as potential environmental justice issues in this environmental assessment.

Hydropower impacts are a potential issue because electricity generated by Glen Canyon Dam or CRSP power is marketed to non-profit municipalities and Indian tribes, which are generally rural and small communities. Over 50 Indian tribes now receive the benefits of CRSP power, and a number of households receive federal energy assistance. However, disproportionately high and adverse costs to minority or low-income groups are not expected from the HFEs, given that the principal months for a high-release are during low to moderate power demand and alternative sources of energy are available, as needed.

3.7 Wild and Scenic Rivers or Wilderness

The issue of wild and scenic rivers was not brought up in scoping, but will be added as an issue per 16 USC 1271 and 40 CFR 1508.27(b)(3). The Wild and Scenic Rivers Act of 1969 calls for preservation and protection of free-flowing rivers. Pursuant to §5(d) of the Wild and Scenic Rivers Act, the NPS maintains a nationwide inventory of river segments that potentially qualify as wild, scenic, or recreational rivers. Within the action area, overlapping study segments have been proposed: (1) from the Paria Riffle (RM 1) to 237-Mile Rapid in Grand Canyon, and (2) from Glen Canyon Dam (RM -15) to Lake Mead. Grand Canyon National Park (NPS 1995, 2005b:18) acknowledges that the Colorado River meets the criteria for designation under the Wild and Scenic Rivers Act as part of the nationwide

system; however, formal study and designation has not been completed.

3.8 Other NEPA Considerations

Reclamation manages Glen Canyon Dam and Powerplant which are located in Coconino County, Arizona. This EA is tiered from several environmental impact statements related to Glen Canyon Dam operations including Reclamation's *Operation of Glen Canyon Dam Final Environmental Impact Statement* (Reclamation 1995) and Reclamation's *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Reclamation 2007a). Coordinated operations of Lakes Powell and Mead under the 2007 EIS and 2007 Record of Decision govern the annual release from Lake Powell, while the 1996 Record of Decision for the 1995 EIS governs releases from Lake Powell at shorter time increments. Additionally, a program of experimental releases is ongoing from 2008 through 2012 through an Environmental Assessment and Finding of No Significant Impact (Bureau of Reclamation 2008).

Reclamation is also concurrently developing an Environmental Assessment to control nonnative fish in the Colorado River downstream of Glen Canyon Dam in an effort to minimize competition and predation and help conserve the endangered humpback chub. The action described in this Environmental Assessment on high-flow releases may affect some of the treatments that are part of the action to control nonnative fish, and *vice versa*. For example, the timing of a high-flow release (spring vs fall) may benefit or damage the trout population, as was observed in the prior three HFEs, and this may affect the need for one or more of the nonnative fish control treatments. The activities associated with high-flow releases and releases designed for nonnative fish control will need to be coordinated.

4.0 Consultation and Coordination

The 1995 EIS and 1996 Record of Decision called for an adaptive management approach to the management of the dam and powerplant. Since then, monitoring and research has substantially increased knowledge of the effects of dam operations on resources downstream in GCNP and GCRA, including knowledge of sediment transport rates and geomorphological processes along the Colorado River. Pursuant to the Grand Canyon Protection Act, the Colorado River Storage Project Act, and the other federal laws and regulations, this new EA should add to this knowledge and understanding.

4.1 Consultation

Tribal consultation on a government-to-government basis will have been initiated before publication of this EA.

4.2 Public Scoping Activities

In compliance with NEPA and the Council on Environmental Quality's implementing regulations (40 CFR 1501.7), "scoping" was conducted on this proposed action as an early and open process by which Reclamation solicited input from the public to determine the nature and extent of issues to be addressed in this EA. The “scope” of a NEPA analysis refers to the extent of the action, the range of alternatives, and the types of impacts to be evaluated (40 CFR 1508.25). A scoping report was developed by Reclamation (2010) for the Glen Canyon Dam high-flow protocol EA. The report describes issues that were analyzed in detail in this EA and those issues eliminated from detailed study due to their insignificance as related to the action or their thorough analysis in prior environmental reviews.

The high flow protocol was presented to the public and other agencies for comment beginning with an announcement from Secretary Salazar on December 10, 2009. This announcement was followed with a *Federal Register* notice on December 31, 2009 and subsequently with a public meeting of the Glen Canyon Dam Adaptive Management Program (AMP) in Phoenix, Arizona. As part of information gathering during the formulation of the proposed action, Reclamation also conducted a meeting with fishing guides and business owners, including Navajo Nation vendors in the Marble Canyon area. Their concerns were primarily socioeconomic and associated with public perception of impacts to fishing success in the Lees Ferry reach. Scoping from prior high flow experiments was also included and used to discover alternatives, identify issues that need to be analyzed in the EA, and to help develop mitigation measures for potentially adverse environmental impacts.

A Scoping Report was produced by Reclamation and issued to the Cooperating Agencies in September 2010 (Bureau of Reclamation 2010). Reclamation considered all comments or

issues brought forward after that date, but the Scoping Report was not updated to tabulate these comments; rather, additional scoping information was integrated into the EA.

The Scoping Report described the following 10 issues identified by the public during scoping with the indicated numbers of times the issue was identified. This scoping indicates that the issues of greatest concern were socioeconomics and recreation. All 10 issues identified in scoping are addressed in the impact analysis of in this EA.

- Air quality (as related to having to switch from hydropower to use of polluting energy sources), n=1.
- Aquatic and riparian communities and ecosystem (includes wildlife and invasive plants), n=4.
- Cultural resources including American Indian Tribes traditional cultural properties, n=5.
- Hydropower, n=6.
- Listed species including the endangered humpback chub and Kanab ambersnail, n=4.
- Recreation including boating and fishing, n=19.
- Safety of wading anglers and boaters, n=2.
- Sediment including camping beaches and habitat for aquatic species, n=4.
- Socioeconomics, including costs of the experiment including lost incomes, effects on local families and businesses and costs of replacement power for hydropower losses, n=18.
- Water resources or water supply and dam operations, n=2.

A synthesis of prior experimentation with the dam is currently in preparation by the U.S. Geological Survey, Grand Canyon Monitoring and Research Center (Schmidt et al. in preparation). To benefit from preliminary findings from this synthesis, a workshop was held in Salt Lake City on July 15-16, 2010. The results of this workshop and ongoing communications with the researchers involved in the synthesis have been incorporated into Reclamation scoping report, along with comments from the public, other agencies, and tribes.

4.2.1 Agency Cooperation

Multiple federal and state agencies were invited to become cooperating agencies in the preparation of this EA. Coconino County also stated its interest in participating as a cooperating agency. Scoping comments were submitted by three of the cooperating agencies. As of September 3, 2010, the following are the cooperating federal and state agencies and tribes for this EA.

Federal:

- National Park Service, Intermountain Region
- U.S. Bureau of Indian Affairs
- U.S. Fish and Wildlife Service

- U.S. Geological Survey, Grand Canyon Monitoring and Research Center
- Western Area Power Administration

State:

- Arizona Game and Fish Commission
- Upper Colorado River Commission

Tribes:

These three tribes are serving as NEPA review:

- Hopi Tribe
- Hualapai Tribe
- Pueblo of Zuni

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Appendix A: Federal Register Notice

Failure to appear at an ASC for a required ASC appointment will result in denial of your case due to abandonment unless you submit an address change notification (see instructions below) or a rescheduling request prior to your appointment.

What if My Address Changes after I File My Re-Registration Application?

If your address changes after you file your application for re-registration, you must complete and submit Form AR–11 by mail or electronically. The mailing address is: U.S. Citizenship and Immigration Services, Change of Address, P.O. Box 7134, London, KY 40742–7134.

Form AR–11 can also be filed electronically by following the directions on the USCIS Web site at: *http://www.uscis.gov.* To facilitate processing your address change on your TPS application, you may call the USCIS National Customer Service Center at 1–800–375–5283 (TTY 1–800–767–1833) to request that your address be updated on your application. Please note that calling the USCIS National Customer Service Center does *not* relieve you of your burden to properly file a Form AR–11 with USCIS.

Will My Current EAD that is Set To Expire on May 2, 2010, Automatically Be Extended for Six Months?

No. This Notice does not automatically extend previously-issued EADs. DHS has announced the extension of the TPS designation of Sudan and established the re-registration period at an early date to allow sufficient time for DHS to process EAD requests prior to the May 2, 2010, expiration date. You must apply during the 60-day re-registration period. Failure to apply during the re-registration period without good cause will result in a withdrawal of your TPS benefits. DHS *strongly* encourages you to file as early as possible within the re-registration period.

May I Request an Interim EAD at My Local District Office?

No. USCIS will not issue interim EADs to TPS applicants and re-registrants at district offices.

What Documents May a Qualified Individual Show to His or Her Employer as Proof of Employment Authorization and Identity When Completing Form I–9?

After May 2, 2010, a TPS beneficiary under TPS for Sudan who has timely re-registered with USCIS as directed under this Notice and obtained a new EAD valid through November 2, 2011, may present his or her new valid EAD to an employer as proof of employment authorization and identity. Employers may not accept previously issued EADs that are no longer valid.

Individuals also may present any other legally acceptable document or combination of documents listed on the Form I–9 as proof of identity and employment eligibility.

Note to Employers

Employers are reminded that the laws requiring employment eligibility verification and prohibiting unfair immigration-related employment practices remain in full force. This Notice does not supersede or in any way limit applicable employment verification rules and policy guidance, including those rules setting forth re-verification requirements. For questions, employers may call the USCIS Customer Assistance Office at 1–800–357–2099. Employers may also call the U.S. Department of Justice Office of Special Counsel for Immigration Related Unfair Employment Practices (OSC) Employer Hotline at 1–800–255–8155. Employees or applicants may call the OSC Employee Hotline at 1–800–255–7688 for information regarding the automatic extension. Additional information is available on the OSC Web site at *http://www.usdoj.gov/crt/osc/index.html.*

[FR Doc. E9–30831 Filed 12–30–09; 8:45 am]

BILLING CODE 9111–97–P

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

[Docket No. FR–5280–N–51]

Federal Property Suitable as Facilities To Assist the Homeless

AGENCY: Office of the Assistant Secretary for Community Planning and Development, HUD.

ACTION: Notice.

SUMMARY: This Notice identifies unutilized, underutilized, excess, and surplus Federal property reviewed by HUD for suitability for possible use to assist the homeless.

DATES: *Effective Date: December 31, 2009.*

FOR FURTHER INFORMATION CONTACT: Kathy Ezzell, Department of Housing and Urban Development, 451 Seventh Street, SW., Room 7262, Washington, DC 20410; telephone (202) 708–1234; TTY number for the hearing- and speech-impaired (202) 708–2565, (these telephone numbers are not toll-free), or call the toll-free Title V information line at 800–927–7588.

SUPPLEMENTARY INFORMATION: In accordance with the December 12, 1988 court order in *National Coalition for the Homeless* v. *Veterans Administration,* No. 88–2503–OG (D.D.C.), HUD publishes a Notice, on a weekly basis, identifying unutilized, underutilized, excess and surplus Federal buildings and real property that HUD has reviewed for suitability for use to assist the homeless. Today's Notice is for the purpose of announcing that no additional properties have been determined suitable or unsuitable this week.

Dated: December 22, 2009.

Mark R. Johnston,

Deputy Assistant Secretary for Special Needs.

[FR Doc. E9–30714 Filed 12–30–09; 8:45 am]

BILLING CODE 4210–67–P

DEPARTMENT OF THE INTERIOR

Bureau of Reclamation

Glen Canyon Dam Adaptive Management Program

AGENCY: Bureau of Reclamation, Interior.

ACTION: Notice of Development of Experimental Protocol for High-Flow Releases from Glen Canyon Dam under the Authority of the Secretary of the Interior (Secretary), Development of Environmental Assessment, and Notice of Public Meeting.

SUMMARY: On December 10, 2009, Secretary of the Interior Ken Salazar announced that the Department of the Interior (Department) would initiate development of a High-Flow Experimental Protocol (Protocol) for releases from Glen Canyon Dam as part of the ongoing implementation of the Glen Canyon Dam Adaptive Management Program (AMP). High-flow experimental releases have been undertaken in the past and will be further analyzed and implemented pursuant to the direction of the Secretary to assess the ability of such releases to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. As part of the AMP, the Department's effort to develop the Protocol is a component of its efforts to comply with the requirements and obligations established by the Grand Canyon Protection Act of 1992 (Pub. L. 102–575) (GCPA).

The AMP was established by, and has been implemented pursuant to the Secretary of the Interior's 1996 Record of Decision on the Operation of Glen

Canyon Dam, in order to comply with monitoring and consultation requirements of the GCPA. The AMP includes a Federal advisory committee known as the Adaptive Management Work Group (AMWG), a technical work group, a scientific monitoring and research center, and independent review panels. The AMWG makes recommendations to the Secretary of the Interior concerning Glen Canyon Dam operations and other management actions to protect resources downstream of Glen Canyon Dam consistent with the GCPA.

This **Federal Register** notice provides the public with initial information regarding the anticipated development and purpose of the High-Flow Experimental Protocol, notice of the Department's commitment to analyze the Protocol pursuant to the National Environmental Policy Act (NEPA), as well as information regarding an upcoming AMWG public meeting that will address, in part, the development of the Protocol. Additional information regarding the dates and times for the upcoming AMWG public meeting and the development of the Protocol will be provided in a future **Federal Register** notice, as well as through other methods of public involvement as the NEPA process is undertaken and the Protocol is developed and analyzed.

FOR FURTHER INFORMATION CONTACT: Mr. Tom Ryan, Bureau of Reclamation, telephone (801) 524–3732; facsimile (801) 524–5499; e-mail at *protocol@usbr.gov.*

SUPPLEMENTARY INFORMATION: On December 10, 2009, Secretary of the Interior Ken Salazar directed the development of a protocol for conducting additional high-flow experiments from Glen Canyon Dam as part of the ongoing implementation of the Glen Canyon Dam AMP. The text of the Secretary's statement and further information on his direction can be found at *http://www.doi.gov.*

High-Flow Experimental Protocol and Sediment Resources

Sandbars are a primary component of the Colorado River ecosystem, and determining how sand conservation can be achieved in areas within Grand Canyon National Park downstream of Glen Canyon Dam is a high priority of the AMP and the Department of the Interior. Previous high-flow experiments from Glen Canyon Dam were conducted in 1996, 2004, and 2008. Experimental high flows mobilize sand stored in the main channel of the Colorado River to rebuild sandbars, beaches, and associated backwater habitats along shorelines. Sandbars provide key wildlife habitat, protect archeological sites and vegetation structure, and provide camping opportunities in Grand Canyon.

Each experimental release has added to the understanding of the river ecosystem below the dam and the impacts of high-flow releases. Following the initial test in 1996, experimental approaches linking high-flow releases from Glen Canyon Dam to downstream tributary sand inputs to Grand Canyon were developed by scientists working in collaboration with the AMP. *See e.g.*, 66 FR 7772, 7778 (January 25, 2001) (Riverflow Issues). One of the best tools available for rebuilding sandbars using dam operations is to release short-duration high flows after tributary floods deposit new sand into the main channel of the Colorado River. Development and implementation of the Protocol builds on information developed in the previous three high-flow experiments, and will be designed to further evaluate the hypothesis that repeated high-flow releases conducted under conditions of sand enrichment in Grand Canyon may result in cumulative increases in sandbar area and volume. The Protocol constitutes the next logical step in adaptive management with respect to high flow testing.

Anticipated Approach Regarding Development of High-Flow Experimental Protocol

The Department intends to develop the High-Flow Experimental Protocol through a public process pursuant to NEPA, through the development of an Environmental Assessment (EA). The Protocol is anticipated to be a multi-year, multi-experiment approach and will be based on the best available scientific information developed through the AMP as well as other sources of relevant information. For example, in early 2010, it is anticipated that the U.S. Geological Survey will publish detailed information that provides a full and thorough analysis of the results of the most recent high-flow experimental release conducted in March 2008. It is anticipated that the Protocol will address such factors as the appropriate number of experiments, the appropriate sand input "triggering" for conducting future experiments, the timing and duration of high-flow releases to optimize sand conservation, the appropriate interval between high-flow releases, as well as the anticipated approach to monitoring the results and effectiveness of the experimental actions, among other resource issues.

The Department is currently developing a tribal consultation policy for matters related to the Glen Canyon Dam AMP. The Department will continue to consult with local affected tribes, including through the tribal consultation policy, to ensure the AMP and the Protocol take into account the United States' trust responsibility to the tribes and their natural resources. There will be a consistent and ongoing effort to consult with the tribes in development of the Protocol, and in implementation of any subsequent related decisions.

Consistent with the provisions of 43 CFR 46.305 (public involvement in the environmental assessment process), the Department "must, to the extent practicable, provide for public notification and public involvement when an environmental assessment is being prepared." This **Federal Register** notice is the first of many steps that the Department intends to take to ensure public input in the development of the Protocol and the NEPA process. The Department will next provide additional information on the Protocol and the EA process at a public AMWG meeting in Phoenix, Arizona, on February 3–4, 2010. Additional information regarding this upcoming AMWG meeting (including times, location, and agenda items) will be provided to the public in an upcoming **Federal Register** notice. The AMWG meeting is intended to provide scoping information for the EA process. Although scoping is not required for the preparation of an EA (CEQ regulations at 40 CFR 1501.7 specifically reference the preparation of an environmental impact statement), the Department recognizes and encourages the use of scoping where appropriate as it does represent a form of public involvement. *See* 43 CFR 46.305(a)(2), 73 FR 61292, 61306 (Oct. 15, 2008).

Further information regarding the development of the High-Flow Experimental Protocol, the EA process, and other relevant information will also be made available to the public through the AMP's Web site which may be accessed at *http://www.usbr.gov/uc/rm/amp/.*

Dated: December 22, 2009.

Anne Castle,

Assistant Secretary—Water & Science.

[FR Doc. E9–31050 Filed 12–30–09; 8:45 am]

BILLING CODE 4310–MN–P

Appendix B: Science Plan (under development)

This initial plan was developed by the Grand Canyon Monitoring and Research Center, U.S. Geological Survey, and was extracted from the FY 2011 and FY 2012 Work Plans of the Glen Canyon Dam Adaptive Management Program.

Monitoring and Research Plan for Potential High Flow Experimental Protocol

PLAN 12.P6.11-12

Start Date

October 2010

End Date

Ongoing (as defined in the HFE protocol Environmental Assessment)

Principal Investigator(s)

Helen Fairley, Paul Grams, Kara Hilwig, Theodore Kennedy, Bill Persons, Barbara Ralston, David Topping, and Bill Vernieu: U.S. Geological Survey, Grand Canyon Monitoring and Research Center

Geographic Scope

The Colorado River from Glen Canyon Dam to the upper end of Lake Mead

Project Goals

The goal of this experimental project is to test the hypothesis that a series of sand-enriched high flows will be an effective strategy for rebuilding and maintaining sandbars using dam operations (Topping and others, 2006). Testing this hypothesis requires that high flows occur each time the sand input triggering criteria are met. The details of high flow triggering criteria are currently being developed in the context of an Environmental Assessment for a High Flow Protocol (see below).

The second goal will be to evaluate the effects of implementation of the High Flow Protocol on a variety of other priority AMP resources including aquatic food base, native fish, Lees' Ferry trout and angler satisfaction, riparian vegetation, and archaeological sites.

Need for Project

Previous high flow experiments from Glen Canyon Dam were conducted in 1996, 2004, and 2008. These experiments generally concluded that one of the best tools available for rebuilding sand bars using dam operations is to release short duration high flows after tributary floods deposit new sand into the main channel of the Colorado River. On December 31, 2009, a Federal Register Notice was issued for development of an experimental protocol for high flow releases from Glen Canyon Dam (FR vol 74, no 250 p 69361). As described in the Federal Register, the high flow protocol will be designed to further evaluate the hypothesis that repeated high flow releases conducted under conditions of sand enrichment may result in cumulative increases in sand bar area and volume. Currently, the details of the high flow protocol are being developed in an Environmental Assessment (EA) process pursuant to NEPA. However the Federal Register Notices indicates the Protocol is anticipated to be a multi-year experimental that will address such factors as the appropriate number of experiments, the appropriate sand input triggering criteria, the timing and duration of high flow releases to optimize sand conservation, the interval between high flows releases as well as the anticipated approach to monitoring results and the effectiveness of the experiment. The purpose of this work plan is to outline how current monitoring projects will address the evaluation of the effectiveness of the HFE protocol. Some changes to this work plan may be needed once the Protocol is finalized pursuant to the EA process. Additional revisions may be required to address additional experimental activities that may be identified in the Long Term Experimental and Management Plan EIS.

The proposed approach will rely on existing quality of water, sediment, and other resource monitoring projects to assess the effects of the HFE protocol. No new studies would be added, however, some existing monitoring efforts will be expanded.

In the Methods and Tasks Section below, high flow monitoring associated with each GCDAMP project is summarized with references to the section in the work plan where the details of the respective monitoring program are contained. Budget implications are discussed where appropriate.

Strategic Science Questions

The science activities conducted to evaluate the HFE protocol will address the following strategic science question(s) and associated HFE protocol science questions (listed within the task descriptions). The HFE protocol science questions are considered preliminary and subject to revision in the course of the planning process.

> **SSQ 4-1.** Is there a "Flow Only" operation (that is, a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal timescales?

Methods and Tasks

Tasks related to high flow monitoring are summarized below. Please refer to the individual project descriptions in the work plan for more detailed descriptions. The budget figures provided in the task descriptions and the summary table are in gross dollars and reflect a differential cost to the respective project, not a total project cost. The budget figures assume that the respective annual work plan projects are funded at the level indicated in this work plan. Changes to budgets in the work plan would require revising the cost estimates, below.

Task 1. Monitoring In-Channel Sediment Storage—SedTrend

Information Needs

> **HFE protocol science question 1:** Will multiple high flows conducted over a period of several years result in net increases in sandbar area and volume (time domain to be addressed in the

course of HFE protocol development)? *This question is related to CMIN 8.2.1. -- Track, as appropriate, the biennial or annual sandbar area, volume, and grain-size changes within and outside of eddies between 5,000 and 25,000 cfs stage, by reach; CMIN 8.5.1. -- Track, as appropriate, the biennial sandbar area, volume, and grain-size changes above 25,000 cfs stage, by reach; CMIN 8.1.1. -- Determine and track the biennial sandbar area and fine-sediment volume and grain-size changes within eddies below 5,000 cfs stage, by reach; and CMIN 9.3.1. -- Determine and track the size, quality, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons.*

HFE protocol science question 2: With the available sand supply (i.e. tributary inputs) is the approach of using repeated floods to build sandbars sustainable? *This question is related to all of the CMIN's listed for question 1 and the following: CMIN 7.4.2. -- Determine and track flow releases from Glen Canyon Dam, under all operating conditions, particularly related to flow duration, upramp, and downramp conditions; CMIN 8.1.3. -- Track, as appropriate, the monthly sand and silt/clay volumes and grain-size characteristics, by reach, as measured or estimated at the Paria and LCR stations, other major tributaries like Kanab and Havasu Creeks, and "lesser" tributaries; and CMIN 8.1.2. -- What are the monthly sand and silt/clay export volumes and grain-size characteristics, by reach, as measured or estimated at Lees Ferry, Lower Marble Canyon, Grand Canyon, and Diamond Creek Stations?*

Project Description

This project addresses the HFE protocol science question 1 by tracking net changes in the area and volume of sandbars at stages above and below 8,000 cfs. This project also address HFE protocol science question 2 by tracking changes in sand storage for the study period. The SedTrend channel mapping project is designed to monitor the cumulative results of multiple high flows over a 5 to 10 year period. The results from previous high flow monitoring demonstrate that high flows build sandbars and that the magnitude of bar building is greatest when sand concentrations are highest. The question that is unresolved, which this program seeks to address, is whether repeated high flows and intervening dam operations can result in maintenance or increase in sandbars over longer periods of time. This objective of the project is described in detail in the goal 8 project description (PHY 8.M2). In summary, these monitoring data will allow us to determine at the end of the experimental period whether the continued use of high flows is likely to be a sustainable approach to building and maintaining sandbars or whether more sand than the tributaries supply is required to avoid progressive sand export and erosion. Because the objective is to monitor sandbars and the channel in a "typical" condition, the channel mapping should occur 6 months or more following a high flow. To simplify the scheduling, the channel mapping is currently scheduled to occur only in years that do not have high flows. Deferment of channel mapping in these years makes available about $110,000 in logistical and other expenses. Personnel are retained to continue with data processing and reporting.

Task 2. Monitor High-Elevation Sandbar Study Sites

Information Needs

HFE protocol science question 1: Will multiple high flows conducted over a period of several years result in net increases in sandbar area and volume? (see above for CMINs)

Project Description

This project addresses HFE protocol science question 1 by tracking changes in sandbar area and volume at the long-term sandbar monitoring sites above the stage of 8,000 cfs. See the goal 8 project

description for a summary of the methods and the Goal 9 project description for a summary of the campsite monitoring component. In the absence of high flows, the repeat surveys of these sites have documented that the sandbars gradually erode. For this reason, the monitoring is scheduled to occur every two years unless a high flow occurs. Similarly, the surveys done immediately before and after high flows have repeatedly documented deposition. While continued quantification of the precise magnitude of deposition associated with each high flow would be beneficial, it is not critical monitoring. Instead, we propose to perform a survey approximately 6 months following each flood and use that as the benchmark monitoring record. This monitoring would be accomplished by the regular biennial sandbar survey unless the high flow occurs in an off year. In that case, an additional monitoring trip would be required at an added cost to Goal 8 of about $50,000. A sandbar monitoring trip is currently planned for FY 2011, so FY 2012 is the first year that this need could occur. Monitoring of the immediate response of future high flows would be limited to information gained by daily photographs taken by remote cameras. The photographic data would allow comparison of the degree of sandbar building between past and future high flows. Currently 18 sandbar monitoring sites are instrumented with remote cameras. We propose installing cameras at an additional 20 sites before the next high flow. This would require a one-time cost (prior to the next high flow) of about $50,000.

Task 3. Monitor Campable Area at High-Elevation Sandbar Study Sites

Information Needs

> **HFE protocol science question 3:** Will multiple high flows conducted over a period of several years result in net increases in campable area within the Colorado River ecosystem (time domain to be addressed in the course of HFE protocol development)? *This question is related to CMIN 9.3.1. --Determine and track the size, quality, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons (top-ranked goal 9 CMIN); EIN 9.3.1. -- How do the size, quality and distribution of camping beaches change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?; and SSQ 3-9. -- How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?*

Project Description

Monitoring the high-elevation campsite study sites (a subset of the NAU sandbar time series) is necessary to maintain continuity in the campable area monitoring record. Monitoring is currently scheduled to occur every two years unless a high flow occurs (see the goal 9 project description under REC 9.R1.11-12 for a summary of the planned campsite monitoring component.) In the absence of high flows, repeat surveys of the campable area at these sites have documented that the lower elevation portions of the sandbars erode while vegetation encroaches on the higher elevation open sand areas that form the major component of campable area in the CRE. While continued quantification of the precise magnitude of deposition and erosion associated with each high flow would be beneficial, it is not critical; instead, we propose to perform a campable area survey approximately 6 months following each high flow in conjunction with the proposed sand bar monitoring program following each HFE and will use that as the benchmark monitoring record. This monitoring would be accomplished by the regular biennial sandbar survey unless the high flow occurs in an off year. In that case, an additional monitoring trip would be required at an added cost (to Goal 8) of about $58,745. A sandbar monitoring trip is currently planned for FY 2011, so FY 2012 is the first year that this need for supplementary funding could occur.

Task 4. Repeat Systemwide Inventory of High-Elevation Sand Deposits

Information Needs

HFE protocol science question 1: Will multiple high flows conducted over a period of several years result in net increases in sandbar area and volume? (See above for CMINs)

Project Description

This project addresses HFE protocol science question 1 by tracking changes in sandbar area throughout the CRE between Lees Ferry and the upper end of Lake Mead above the stage of 8,000 cfs. Remote sensing can provide a systemwide quantitative measure of the area of sand exposed above the water surface at the time of imagery collection (usually about 8,000 cfs). Collection and processing of these data will provide the long-term monitoring of the area of exposed sand to evaluate the cumulative result of multiple high flows and intervening operations over the experimental period. These data will also be used to quantify changes in vegetation distribution that may result in increases or decreases in the area of exposed sand. See Goal 8 (PHY 8.M2) and goal 12 (DASA 12.D9) for more detailed project descriptions. This is part of the regular monitoring program that addresses high flows and does not require additional funding when high flows occur.

Task 5. Monitor Archaeological Site Condition and Stability in Response to Repeated HFEs at a Sample of Sites in the CRE

Information Needs

HFE protocol science question 4: Will multiple high flows conducted over a period of several years improve archaeological site condition as reflected in increased sand deposition, increased site stability, and reduction in rates of erosion (time domain to be addressed in the course of HFE protocol development)? *This question is related to CMIN 11.1.1 -- Determine the condition and integrity of prehistoric and historic sites in the CRE through tracking rates of erosion, visitor impacts, and other relevant variables; EIN 11.1 -- Determine the efficacy of treatments (e.g., alternative flows) for mitigation of adverse effects to historic properties; SSQ 2-1. -- Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites in the CRE, and if so, how?; and SSQ 2-4. -- How effective are various treatments (e.g., repeated high flow events) in slowing rates of erosion at archaeological sites over the long term?*

Project Description

The monitoring protocols being developed and piloted by GCMRC as part of project CUL 11.R1.11-12 are specifically designed to be applicable for evaluating physical changes at archaeological sites tied to changes in sediment supply under a variety of dam operations. The planned monitoring program, which will be piloted starting in FY11, will allow GCMRC and AMP stakeholders to objectively determine whether changes in sand bar area and volume resulting from repeated high flows translate into measurable changes in the amount and rates of sediment being deposited at or eroded from a sample of archaeological sites distributed throughout the CRE. In the current work plan, baseline measurements will be collected in FY11 at approximately 30 sites selected from a stratified population of cultural sites in the CRE; this stratified random sample will serve as the initial sample population for evaluating system-wide changes at archaeological sites due to dam operations, including changes resulting from any high flows conducted as part of the HF protocol or any subsequent alternative flow experiments. Completing a robust evaluation of high flow effects on archaeological sites requires implementation of the cultural monitoring project (CUL11.R1.11-12) as currently planned; no additional monitoring beyond what is already described in project CUL

11.R1.11-12 is anticipated to be needed to evaluate the effects of an HF protocol experiment at archaeological sites.

Task 6. Monitoring Sediment Flux

Information Needs

HFE protocol science question 2: With the available sand supply (i.e. tributary inputs) is the approach of using repeated floods to build sandbars sustainable? (see above for CMINs)

Project Description

This project addresses HFE protocol science question 2 by tracking sand inputs and export, by reach. Monitoring of sediment (sand and finer) flux during future high flows will be conducted as part of the regular goal 7 downstream integrated quality of water program. The methods, monitoring sites, and planned products are described in the goal 7 (PHY 7.M1) project description. This task does require added work during a high flow to maintain the monitoring record because the instrumentation is vulnerable to high dam releases and additional samples are required to maintain instrument calibration. This added work requires about $110,000 in addition to the regular Goal 7 budget.

Task 7. Monitoring the Aquatic Food Base

Information Needs

SSQ 3-5. How is invertebrate flux affected by water quality (for example, temperature, nutrient concentrations, turbidity) and dam operations?

Project Description

The aquatic food base project has been working since 2006 to establish a monitoring protocol that accurately captures key metrics that are relevant to other resources in the Colorado River, especially rainbow trout and humpback chub. Based on their work to date the aquatic food base research scientists have determined that monthly monitoring of benthic organisms and Lees Ferry and at Diamond Creek, and monthly monitoring of drifting organisms is critically important information that supports assessment of all Glen Canyon Dam release regimes, whether modified low fluctuating flows, an experimental high flow, or other flows. Therefore, the aquatic food base project presented in this FY 11-12 work plan (BIO 1.1M.11) includes the sampling strategies described above. Collecting these data in years without a high flow provides important baseline information, including assessment of seasonal variability. Collecting these data in years when a high flow release occurs allows the scientists to assess the amount of change, if any, which occurs as a result of the high flow.

Task 8. Lees Ferry Fish Monitoring

Information Needs

RIN 4.2.7. What dam release patterns most effectively maintain the Lees Ferry rainbow trout trophy fishery while limiting rainbow trout survival below the Paria River?

Project Description

Monitoring of the adult rainbow trout population in the Lees Ferry reach has been conducted regularly since the closure of Glen Canyon Dam in 1963. In 2010, in response to the 2009 Protocol Evaluation Panel for Monitoring Grand Canyon Fishes, GCMRC and cooperating agencies, but especially the Arizona Game and Fish Department, made some adjustments to the protocols for monitoring fish between Glen Canyon Dam and Lees Ferry. Monitoring of stratified random sites

continues to be conducted as a tool to monitor adult rainbow trout, but now also collects data that help monitor other native and nonnative fishes. A monitoring trip to specifically look for nonnative fishes is now also conducted. The monitoring of rainbow trout redds (nests) and age-0 abundance, conducted in the 2000s as a research project, has now been added to the Lees Ferry fish monitoring, specifically because of the utility of this monitoring in assessing impacts of dam flows on young life stages of rainbow trout. A new research project proposed in this budget adds additional fish monitoring below Lees Ferry. Continuing to conduct all of this monitoring is important to understanding the existing variability of the fish community in the Lees Ferry reach; when a high flow is conducted, this monitoring should still be conducted to allow for assessment of changes that may occur in this fish community. This additional work is intended to evaluate the timing and age structuring of rainbow trout movement, when it occurs. The new work below Lees Ferry, conducted from the mouth of the Paria River to Badger Rapid, is also intended to begin establishing the relationship, if any, between the size and condition of the Lees Ferry rainbow trout population to downstream movement, as might occur in response to a high flow. The new monitoring between the Paria and Badger Rapid would be a precursor to any new removal efforts, including potentially removing rainbow trout alive. Please see projects BIO 2.18R.11 and BIO 4.1M.10 for more details.

Task 9. Evaluate Lees Ferry Recreation Experience Quality

Information Needs

HFE protocol science question 5: How will multiple high flows conducted over a period of several years affect recreational experience quality in the Colorado River corridor (time domain to be addressed in the course of HFE protocol development)? *This task is related to CMIN 9.1.1 -- Determine and track the changes attributable to dam operations in recreational quality, opportunities and use, impacts, serious incidents, and perceptions of users, including the level of satisfaction in the Colorado River Ecosystem; EIN 9.1.1 -- How do recreational use trends, impacts, and perceptions change in response to an experiment performed under the Record of Decision, unanticipated events, or other management action?; SSQ 3-6. -- What Glen Canyon Dam operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?; SSQ 3-7. -- How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE?; and SSQ 3-8. -- What are the drivers for recreational experiences in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?*

Project Description

In FY2011-2012, GCMRC proposes to initiate a recreation experience valuation study for the Glen Canyon reach of the CRE. This study will evaluate the value and relative importance of a suite of biophysical attributes that are affected by dam releases and which anglers and other visitors determine to be important to maintaining a high quality recreation experience in the uppermost reach of the CRE. This study will also update monetary values associated with current recreational activities in the Glen Canyon reach. The intent of this study is to provide a foundation for evaluating how different dam operations, including future high flow experiments, affect the biophysical attributes of the Glen Canyon reach that visitors value and consider to be important for maintaining a high quality recreation experience in the Glen Canyon reach. See project REC 9.R4 for specific details of the proposed study approach.

Task 10. Mainstem Fish Monitoring

Information Needs

RIN 2.2.8. What combination of dam release patterns and nonnative fish control facilitates successful spawning and recruitment of humpback chub in the Colorado River ecosystem?

Project Description

Monitoring of the Colorado River mainstem fish community has been conducted by various researchers on an irregular schedule since the 1940s. More consistent, systematic monitoring began with BOR's Grand Canyon Environmental Studies that began in the 1990s. Since 1996 mainstem monitoring has been conducted by GCMRC and cooperating agencies, especially the Arizona Game and Fish Department. The principal long-term, full river monitoring has been 2 river-wide electroshocking trips, usually conducted in the spring. For many of the years in the decade of the 2000s this regular pair of trips was accompanied by intensive monitoring collected as a component of the mechanical removal project conducted between river miles 55 and 75. Together these data provide a picture of the distribution and relative abundance of the most common large bodied fish species in the mainstem. Backwater seining trips, conducted during the mid 1990s and from 2003 to present, have provided a picture of the relative abundance, distribution, and species composition of small-bodied fishes (juveniles and adults) in backwater habitats. Together these efforts have provided the currently available Grand Canyon fish data, and have also shown where additional data are needed. The existing fish data show where larger concentrations of the more common species are most likely to be found and how those populations have fluctuated over time. The constraints and challenges of sampling widely in a large, turbid river are also highlighted in these data because the methods show that only some gear types are effective in the Colorado River, making some aquatic habitat types difficult, if not impossible, to sample. However, GCMRC and cooperators, primarily the University of Florida, have established an intensive habitat-specific monitoring program, the Near Shore Ecology project, to help define small-bodied fish distributions and responses to flow changes in the mainstem just below the mouth of the Little Colorado River. The NSE project will be conducting field studies in 2011 and this intensive effort has the best potential for detecting any localized effects on small-bodied fishes in the mainstem. Analyses of all fish community monitoring data are continuing, but some relative abundance, population size, and distributional trends are evident. These monitoring programs should continue and be expanded as recommended by the 2009 Protocol Evaluation Panel to help assess any changes that result from a high flow released from Glen Canyon Dam. This 2011-12 work plan includes expanding monitoring of humpback chub aggregations and testing other gear types. The springtime mainstem monitoring is planned for years when a large-scale mechanical removal trip is not conducted because a mechanical removal effort will require the people, time, and equipment that would otherwise be available for the spring mainstem monitoring. All of these mainstem sampling efforts are proposed for implementation in all years to help assess fish responses with and without a high flow release. See BIO 2.4M.10 for more details.

Task 11. Riparian Vegetation

Information Needs

RIN 12.9.1 What is the impact on downstream resources of short-term increases to maximum flow, daily fluctuations, and downramp limits?

Together with cooperators, GCMRC has been monitoring the riparian vegetation community in the 2000s. Because of the distribution and extent of the vegetation community, GCMRC has been developing methods that use remotely sensed overflight imagery to assess vegetation changes. Part of this development has included identification of the limitations of the overflight data. An important limitation is that understory plants and herbaceous species, are difficult if not impossible to detect

from aerial data. Therefore, the GCMRC monitoring program includes a field component that monitors vegetation at established vegetation transects on a biennial schedule. Repeated sampling at established vegetation transects allows for the establishment of natural variability versus changes associated with a large-scale disturbance, like a controlled flood. Vegetation monitoring using transects is scheduled to take place in 2011 and odd-numbered years thereafter. Supplemental monitoring of vegetation in 2012 would be needed if a controlled flood occurred in 2012. Monitoring vegetation in years with a high flow release allows for assessment of high flow impacts to riparian vegetation. The current budget for this work plan allows covers the cost of field transect monitoring in 2011. See BIO 6.1M.10 for details. A monitoring trip in 2012 if a controlled flood occurred would cost $50,000 and would cover the cost of a field crew and single trip taking place in the fall following the flood event.

Task 12. KAS Monitoring

Information Needs

RIN 5.1.9. How can incidental take for Kanab ambersnail at Vasey's Paradise be minimized?

RIN 5.2.2. How does the size and quality of the habitat used by Kanab ambersnail change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Project Description

In prior experimental high flows the low-elevation habitat for Kanab ambersnail has been temporarily moved during the experiment, then replaced so as to maintain this habitat. This conservation effort has proved successful in previous experiments and so is planned for future experiments.

Task 13. Lake Powell

Information Needs

Existing monitoring of Lake Powell water quality provides an important baseline. Leading up to a high flow release this standard monitoring is particularly important for establishing antecedent conditions, which vary from year to year. Immediately following a high flow release, additional water quality monitoring is needed to assess changes in water quality that may occur. Changes to the released water quality, especially dissolved oxygen, were observed in previous high flow releases.

Project Description

Monitoring of the water quality in Lake Powell, the reservoir impounded by Glen Canyon Dam, provides an important piece of information in the assessment of any high-flow release impacts to the reservoir itself or to downstream resources that rely on the water released from the dam. Data from the Lake Powell monitoring program provides a basis from which the effects of a high-flow release can be evaluated. As part of the GCDAMP work plan, regular water-quality monitoring of the Lake Powell forebay is conducted on a monthly basis. The entire reservoir is sampled at multiple locations on a quarterly basis. This monitoring will be conducted in years without a high flow release to support continued characterization of the reservoir and effects to its water quality. See BIO 7.1M.10 for details.

In years with a high flow release, some additional monitoring will be conducted so that high flow impacts to the water-quality of the reservoir and dam releases can be assessed. This includes: 1)

additional reservoir monitoring shortly after the high-flow release to assess the short-term effect of high-flow releases on the water quality of the reservoir; 2) the establishment of additional monitoring sites in the Glen Canyon Dam tailwater during the high-flow release to assess changes in combined releases between the dam and Lees Ferry; and 3) further study to resolve temperature anomalies that were observed in the 2008 HFE monitoring of river outlet works releases. Anticipated costs associated with additional monitoring for high-flow releases are estimated at $9,300.

Task 14. Evaluate Effects to Hydropower from Repeated HFEs

Information Needs

CMIN 10.1. Determine and track the marketable capacity and energy produced through dam operations in relation to various release scenarios.

SSQ 3-4. What are the projected hydropower costs associated with the various alternative flow regimes being discussed for future experimental science (as defined in the next phase experimental design)?

Project Description

In FY2011-2012, GCMRC proposes to undertake an evaluation of WAPA's GTMax model and explore the utility of this model and potentially other existing models for assessing economic costs associated with alternative operating scenarios at Glen Canyon Dam. Depending on the outcome of this assessment, the GTMax model or an alternative model may be used to assess potential costs and benefits to hydropower from implementing a series of HFEs, as well as for evaluating other alternative experimental operational scenarios in the future. See project: HYD 10.R1 for specifics about the proposed study.

Products/Reports

Primary reporting of monitoring activities and results will be performed in the context of annual reporting and publications as described in the work plans associated with each individual monitoring project (see individual project descriptions). A summary of monitoring results and relevant findings specific to each individual HFE will be provided in USGS Open-file Reports and/or Fact Sheets in the following fiscal year. A thorough analysis and synthesis of results of the multi-year experiment will be provided at the conclusion of the HFE protocol experiment.

Budget

The monitoring projects described above are funded primarily through the annual work plan. Some projects are supplemented with experimental funds and there are some differences in how these funds are used in years with high flows (Table 10).

Table 11 Use of Experimental Funds to support monitoring for high flow experimental protocol

Task	No HFE	With HFE
Task 1 – SedTrend	$250,000	$140,000
Task 2 – Sandbar monitoring	50,000	50,000
Task 3 – Campable area monitoring	*	*
Task 4 – Remote sensing	*	*
Task 5 – Archeological site monitoring	*	*
Task 6 – Sediment flux	*	110,000
Task 7 – Aquatic food base	100,000	100,000
Task 8 – Lees Ferry fish	22,709	22,709
Task 9 – Lees Ferry recreation experience	25,000	25,000
Task 10 – Mainstem fish monitoring	*	*
Task 11 – Riparian vegetation	*	*
Task 12 – Kanab ambersnail	*	*
Task 13 – Lake Powell	*	*
Task 14 – Hydropower	*	*
Total	$447,709	$447,709

Appendix C: Biological Assessment (under development)

Appendix D: Hydrology Input to Sediment Model

Glen Canyon Dam High Flow Protocol Hydrologic Trace Selection and Disaggregation to Hourly Flows

Katrina Grantz and Heather Patno, Bureau of Reclamation, Upper Colorado Region

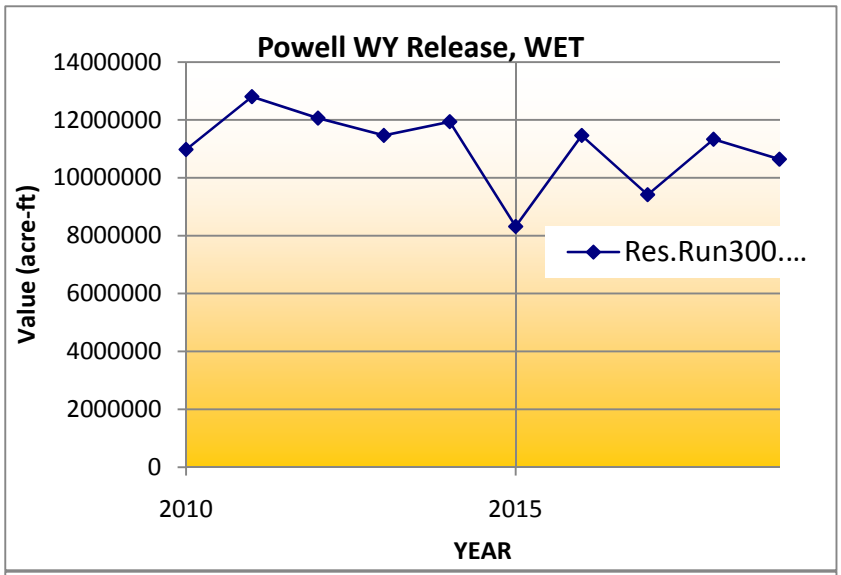
March 25, 2010

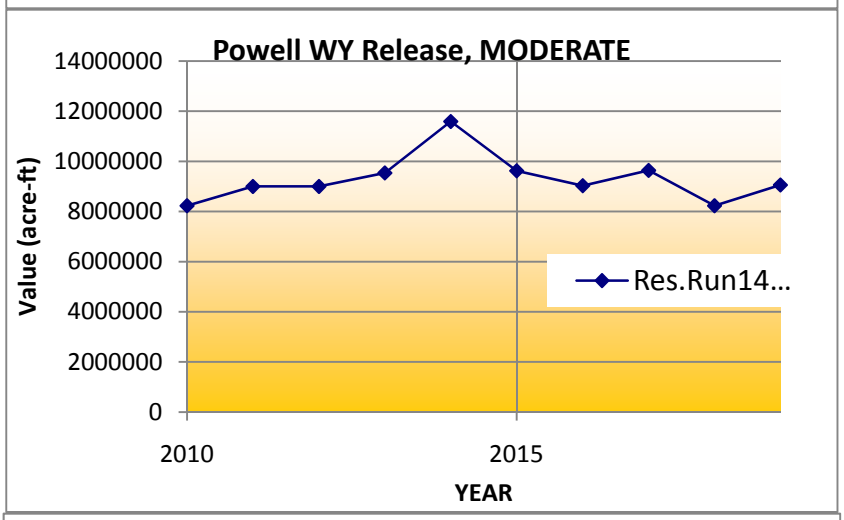
Hydrologic Trace Selection

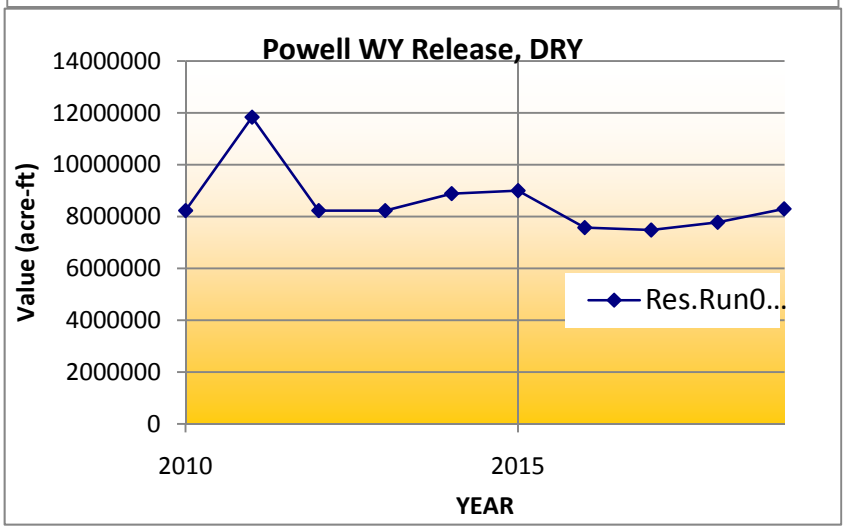
CRSS was run with the nonparametric paleo-conditioned (NPC) inflow hydrology for the period 2010 to 2060, resulting in 500 simulations. CRSS was initialized to January 1, 2010 observed reservoir elevations. Upper Basin depletions come from the new (2007) UCRC depletion schedule. The new ICS assumptions used in the bi-national modeling effort and in the official January 2010 CRSS run were also used.

Outside of CRSS, statistical analysis was performed on the NPC natural flow hydrology for the Colorado River at Lees Ferry. For all 500 inflow traces, the first ten years of the annual volumes were averaged then ranked. Based on the ranking, five wet, five moderate, and five dry traces were selected as candidate inflow hydrology scenarios. Wet traces were those closest to the 90th percentile (9.6 percent exceedance to 10.4 percent exceedance probability), moderate traces the 50th percentile and dry traces, the 10th percentile.

The 15 corresponding traces were pulled from CRSS output to gather the Lake Powell outflow for the years 2010 to 2019. Each of the wet ten-year outflow time series was plotted and the time series were evaluated against each other to select the best for the sediment analysis. Time series were evaluated by visual inspection to eliminate traces with step-functions and to select the time series with the least amount of trend and the greatest amount of variability. The process was repeated the select the best moderate trace and best dry trace. The final three time series are shown below. In addition, each set of 10 water year release values (10 each for wet, moderate, and dry) are plotted on top of the cumulative distribution of all Powell water year release values (see below).


Powell WY Release, WET
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
Value (acre-ft)
2010
2015
YEAR
Res.Run300....


Powell WY Release, MODERATE
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
Value (acre-ft)
2010
2015
YEAR
Res.Run14...


Powell WY Release, DRY
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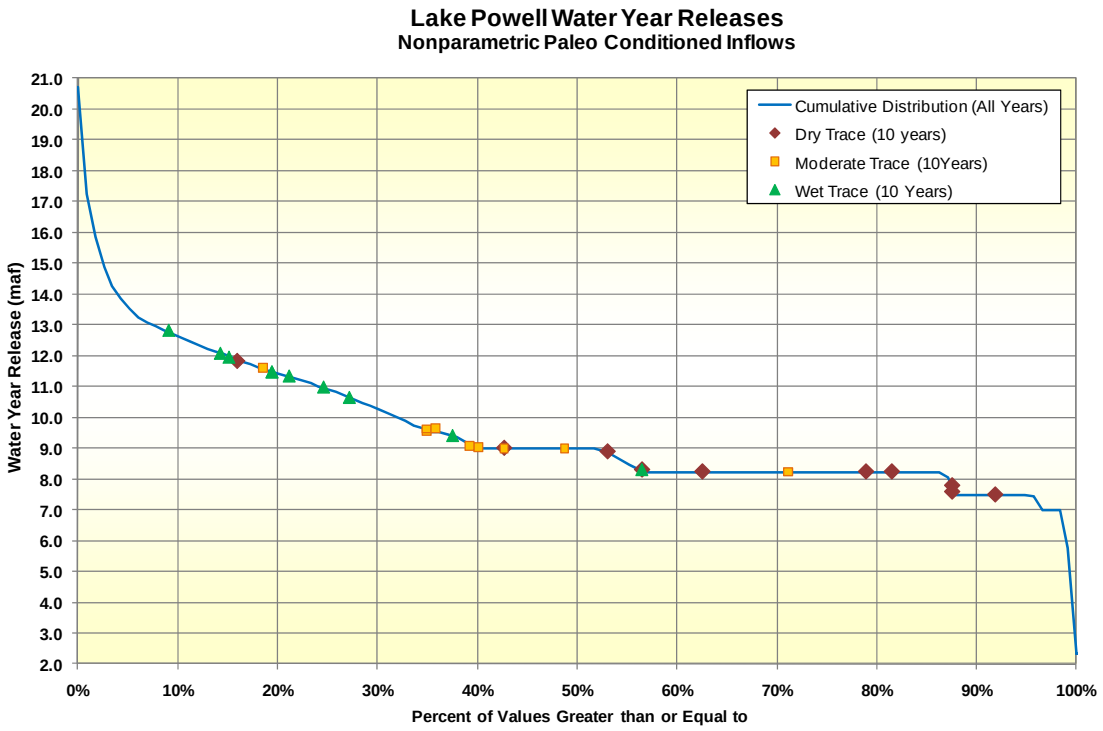
10000000
8000000
6000000
4000000
2000000
0
Value (acre-ft)
2010
2015
YEAR
Res.Run0...



As a side note, the above process was also done with the historic record natural flow (index sequential method). Results were similar between the paleo-conditioned and the historic record natural inflows. However, the pale-conditioned flows provided a slightly wider range of flows at Lees Ferry for the 10-year window.

Disaggregation to Hourly Flows

- Methodology for disaggregation from monthly to hourly releases in order to assess sediment input and erosion in the Grand Canyon downstream of Glen Canyon Dam was agreed upon during the LTEP process in 2006. This same methodology was utilized in the current analysis.
- Disaggregation of monthly to hourly flows for Glen Canyon Dam releases have specific operational constraints that must be addressed. These operational constraints are as follows:
- Maximum daily change in cubic feet per second (cfs) per day for various monthly release volumes in thousands of acre-feet (KAF)
- Maximum release of 25,000 cfs
- Minimum release of 8,000/5,000 cfs
- Turbine release capacity at different hydraulic head
- Seasonal differences in electrical demand

Monthly Release Volume (KAF)	Daily Change Limit (cfs/day)
< 600	5,000
>= 600 and < 800	6,000
>= 800	8,000

Western Area Power Administration (Western) utilizes GTMax, optimization software developed by Argonne National Laboratories (Argonne) to generate hourly release schedules for the Colorado River Storage Program system based on water availability, historic electrical demand, environmental and operational constraints. The GTMax model output received from Western/Argonne contained 33 runs created around a matrix. There were 11 runs at three different elevations (3,700, 3,600 and 3,489 feet) to account for release based on hydraulic head. At each elevation level there were hourly patterns for an entire calendar year at specific monthly volumes that transitioned the MLFF restrictions (i.e., in January there was a monthly release of both 799 and 800 KAF release to transition between 6,000 cfs and 8,000 cfs daily release restrictions).

The monthly release volumes discussed in the hydrologic trace selection above were compared against the GTMax matrix. The hourly GTMax output was scaled and interpolated based on percent difference between the monthly volumes in the hydrologic trace selection. There are some instances where the daily change is approximately 100 cfs greater than the allowable daily change, but the scaled pattern was decreased such that it was unrealistic release pattern. During wet releases, the scaled hourly pattern would exceed the 25,000 cfs maximum release, and in those instances releases are assumed to be steady at the scaled monthly volume. While this is an unrealistic release pattern, it is assumed to be adequate for this analysis.

TABLE C-1. GTMax matrix output.

			Monthly Release (TAF)											
Output Folder	Run	Reservoir Elevation (ft)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Run11	11	3,700.00	2,152	1,944	2,152	2,083	2,635	4,710	3,100	2,152	2,083	2,152	2,083	2,152
Run10	10	3,700.00	1,537	1,388	1,537	1,488	1,537	1,488	1,537	1,537	1,488	1,537	1,488	1,537
Run9	9	3,700.00	1,055	1,000	1,000	1,000	1,000	1,000	1200	1,000	1,000	1,000	1,000	1,260
Run8	8	3,700.00	850	900	900	900	900	900	1,000	900	850	900	900	900
Run7	7	3,700.00	800	800	800	800	800	800	850	880	800	800	800	800
Run6	6	3,700.00	799	799	799	799	799	799	799	799	799	799	799	799
Run5	5	3,700.00	650	650	650	640	650	650	650	745	620	660	660	660
Run4	4	3,700.00	600	600	600	600	600	600	600	600	600	600	600	600
Run3	3	3,700.00	599	599	599	599	599	599	599	599	599	599	599	599
Run2	2	3,700.00	550	550	550	500	550	560	560	550	560	480	480	480
Run1	1	3,700.00	434	392	434	420	434	420	434	434	420	434	420	434
Run22	22	3,600.00	2,152	1,944	2,152	2,083	2,635	4,710	3,100	2,152	2,083	2,152	2,083	2,152
Run21	21	3,600.00	1,537	1,388	1,537	1,488	1,537	1,488	1,537	1,537	1,488	1,537	1,488	1,537
Run20	20	3,600.00	1,055	1,000	1,000	1,000	1,000	1,000	1,200	1,000	1,000	1,000	1,000	1,260
Run19	19	3,600.00	850	900	900	900	900	900	1,000	900	850	900	900	900
Run18	18	3,600.00	800	800	800	800	800	800	850	880	800	800	800	800
Run17	17	3,600.00	799	799	799	799	799	799	799	799	799	799	799	799
Run16	16	3,600.00	650	650	650	640	650	650	650	745	620	660	660	660
Run15	15	3,600.00	600	600	600	600	600	600	600	600	600	600	600	600
Run14	14	3,600.00	599	599	599	599	599	599	599	599	599	599	599	599
Run13	13	3,600.00	550	550	550	500	550	560	560	550	560	480	480	480
Run12	12	3,600.00	434	392	434	420	434	420	434	434	420	434	420	434
Run33	33	3,489.90	2152	1944	2152	2083	2635	4710	3100	2152	2082.63	2152	2083	2152
Run32	32	3,489.90	1537	1388	1537	1488	1537	1488	1537	1537	1487.59	1537	1488	1537
Run31	31	3,489.90	1055	1000	1000	1000	1000	1000	1200	1000	1000	1000	1000	1260
Run30	30	3,489.90	850	900	900	900	900	900	1000	900	850	900	900	900
Run29	29	3,489.90	800	800	800	800	800	800	850	880	800	800	800	800
Run28	28	3,489.90	799	799	799	799	799	799	799	799	799	799	799	799
Run27	27	3,489.90	650	650	650	640	650	650	650	745	620	660	660	660
Run26	26	3,489.90	600	600	600	600	600	600	600	600	600	600	600	600
Run25	25	3,489.90	599	599	599	599	599	599	599	599	599	599	599	599
Run24	24	3,489.90	550	550	550	500	550	560	560	550	560	480	480	480
Run23	23	3,489.90	434	392	434	420	434	420	434	434	420	434	420	434

Appendix E: Integration of Hydrology Output into Sediment Budget Model

DRAFT Methodology for Estimating the Frequency, Magnitude, and Duration of High Flow Experiments

Kendra Russell, Denver Technical Services Center, Bureau of Reclamation

Objectives

The purpose of this analysis is to estimate the frequency, magnitude, and duration of high flows that can be implemented to maximize potential for sandbar building with the available sand supply. Specific questions are:

1. How many HFEs might occur in the next 10 years?
2. What is the expected magnitude and duration of high flows?

Methodology

A sand budget numerical model that tracks the storage and transport of sand in the Colorado River below Glen Canyon Dam has recently been developed by U.S. Geological Survey (Wright et. al. 2010). The model uses empirically based rating curves for specific particle sizes. It includes three reaches where sand is tracked: 1) from Lees Ferry/Paria River (RM 0) to RM 30, 2) from RM 30 to Little Colorado River (RM61), and from Little Colorado River to RM 87. Several output data are provided to the user including mass balance of sand in each of the three reaches over time, thickness of the bed and D_{50} of the bed material in each reach, and the suspended sediment D_{50} and concentration in each reach.

For the Environmental Assessment (EA), the sand budget model was modified to help determine how many HFEs could hypothetically occur in the next 10 years given a list of criteria. Modifications were needed to have a modified sand budget model that could be simulated for ten years. In addition, the model needed to keep track of the sand mass balance in reaches 1 and 2 over the accumulation periods There are two accounting periods in the model: July 1st to November 30th and December 1st to June 30th. The model determined which HFE could be implemented and produces a positive sand balance based on the beginning of the accounting period. Finally a reallocation of flow was calculated for the remainder of a month if an HFE was selected. The table below shows the input parameters used for the model simulations.

Data	Description
Hydrology	Use hourly traces produced in Grantz and Patno, 2010. Three hydrology traces are available: dry (10% non-exceedance), moderate (50%) and wet (90%) for 10 years each. These traces include equalization criteria.
Tributary Input	Use the sand-load gage record for the Paria River (09382000) to create low (10%), medium (50%), and high (90%) 10-year traces using a stochastic method. Use the previously developed particle-size distribution (Wright et al., 2010).
Antecedent Conditions	Use the previously developed March 2009 initial conditions for sand thickness and bed-material size gradation (Wright et al., 2010).
Geometry	Use previously developed geometry (Wiele et al., 2007) for flow routing and sand budget model.

Colorado River Flow, Stage, and Sediment (CRFSS) was run to route three hydrology traces to downstream locations of interest to generate input for the modified sand budget model. The modified sand budget model was used to simulate nine combinations of hydrology and tributary sediment traces (see table below).

Hydrology input	Tributary input
10% hydrology trace	10% tributary sand supply 50% tributary sand supply 90% tributary sand supply
50% hydrology trace	10% tributary sand supply 50% tributary sand supply 90% tributary sand supply
90% hydrology trace	10% tributary sand supply 50% tributary sand supply 90% tributary sand supply

Assumptions were made in each of the model runs. These include:

- Flow from the Paria River is ignored; only the sand loads are used.
- Sand from Paria River is input as monthly loads.
- The sand transport at the upstream boundary (Glen Canyon Dam) is zero.
- No sediment inputs from the Little Colorado River were considered.
- HFE's tested in the sand budget model included thirteen options ranging from a peak discharge of 45,000 cfs with peak duration of 96 hours to an instantaneous peak discharge of 31,500 cfs.
- The HFE may occur in either October/November or March/April of a given water year.
- The magnitude and duration of a HFE will be determined from the sand storage mass available on October 1st and March 1st of each water year.

- For the purpose of the simulation, the water volume used by each HFE is accommodated by adjustment to the releases for the remainder of the implementation month; in practice, the volume would be accommodated by adjustment to the monthly release volumes for the remainder of the water year.

Decision Criteria

Key criteria that determined the model decision making include:

- Sandbar building potential is greatest by generating the greatest possible sand concentrations and largest possible areas of inundation, both of which are maximized by increasing flow magnitude.
- Sandbar building occurs as long as elevated sand concentrations are maintained; thus high flows should be of as long a duration as can be maintained with available sand.
- For each November and April HFE implementation month, the maximum HFE that can be conducted with the available sand supply is calculated iteratively by determining the highest ranking HFE that will not result in a negative sand balance for the accounting period.

Output

The model outputs include the number of HFEs that would occur during each simulation of 10-years based on sediment storage as well as what HFE peak flow and duration were selected. The amount of flow to be reallocated based on the HFE peak and duration is also calculated.

References

Grantz, K. and Patno, H., 2010, Glen Canyon Dam High Flow Protocol Hydrologic Trace Selection and Disaggregation to Hourly Flows.

Wiele, S.M., Wilcock, P.R., and Grams, P.E., 2007. Reach-averaged sediment routing model of a canyon river, *Water Resources Research*, Vol. 43, W02425, doi:10.1029/2005WR004824.

Wright, S.A., and Grams, P.E., 2010, Evaluation of Water Year 2011 Glen Canyon Dam flow release scenarios on downstream sand storage along the Colorado River in Arizona: U.S. Geological Survey Open-File Report 2010-1133, 19 p.