RECLAMATION

*Managing Water in the West*

# Draft Environmental Assessment

## 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

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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

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 to better determine whether and how sand conservation can be improved in the Colorado River corridor within Grand Canyon National Park. This protocol will evaluate short-duration, high volume dam releases during sediment-enriched conditions for a 10-year period of experimentation, 2011–2020, to determine how multiple events can be used to better build sandbars and conserve sand over a long time period. Under the concept of HFEs, sand stored in the river channel is suspended by these dam releases and a portion of the sand is redeposited downstream as sandbars and beaches, while another portion are transported downstream by river flows. These sand features and associated backwater habitats can provide key wildlife habitat, potentially reduce erosion of archaeological sites, enhance riparian vegetation, maintain or increase camping opportunities, and improve the wilderness experience along the Colorado River in Grand Canyon National Park. Additional attention would be given to ensure that other resources would not be unduly or unacceptably impacted or that any such impacts could be sufficiently mitigated.

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 parameters of high flow releases 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 of up to 45,000 cfs 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.

This protocol for high-flow experimental releases is part of the ongoing implementation of the Glen Canyon Dam Adaptive Management Program (GCDAMP), and is a component of Interior's compliance with the Grand Canyon Protection Act of 1992 (Public Law 102-575, GCPA). Annual release volumes (the volume of water released in a water year[1]) would follow the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (2007 Colorado River Interim Guidelines; (Reclamation 2007a); in addition, releases would also follow the Modified Low Fluctuating Flow (MLFF) preferred alternative as described in the 1996 Record of Decision for the Operation of Glen Canyon Dam, with the added refinement of steady flows as identified in the

[1] A water year is the 12-month period from October through September. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. For example, the year ending September 30, 2007 is called the "2007 water year."

2008 Biological Opinion and the 2009 Supplemental Biological Opinion. The timing of high-flow releases would be March-April and October-November, and the magnitude may range from 31,500 cfs to 45,000 cfs, and the duration may range from one hour to 96 hours.

The proposed HFE protocol is a decision-making process that consists of three components: (1) planning and budgeting, (2) modeling, and (3) decision and implementation. First, planning will occur such that an HFE can be conducted if conditions are appropriate. An important aspect of planning is the development and implementation of research and monitoring activities appropriate to monitor the effects of the HFEs and as described in a HFE science plan. Second, a hydrology model and sand budget model will be used to evaluate the available volume of water for release from the dam and the sand availability, as delivered primarily by the Paria River, at the onset of each release window. Finally, the decision to conduct an HFE would be based on a determination by scientists and federal managers of the suitability of the hydrology, sediment, and other resource conditions, and a recommendation to Interior.

Impacts of the proposed action were identified and evaluated in comparison to an environmental baseline for four resource categories including physical, biological, cultural, and socio-economic. The impacts were assessed relative to the timing, magnitude, duration and frequency of HFEs. The predicted impacts of the high flow experimental release protocol on these resources are summarized as follows:

***Water Resources.***—The pattern of monthly releases from Glen Canyon Dam would differ slightly from no action, depending on the frequency of high-flow releases, but water year releases would comply with Glen Canyon Dam Operating Criteria (Federal Register, Volume 62, No. 41, March 3, 1997), the Record of Decision – Glen Canyon Dam Final Environmental Impact Statement (October 1996) and the Record of Decision – Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (December 2007). An HFE would only be conducted if it would not alter annual water deliveries or the operational tiers or elevations that would have otherwise been dictated by the 2007 Interim Guidelines in the absence of an HFE.

***Water Quality.***—HFEs are expected to have minor short-term impacts on water quality of Lake Powell and the Colorado River below Glen Canyon Dam. Dam releases will cause a slight reduction in downstream temperature and a slight increase in salinity, as well as a temporary turbidity increase from scouring. Because effects of an HFE on water quality are short-lived, impacts to water quality from two or more HFEs are not expected to be greater than single HFEs. The impact of HFEs on the water quality of Lake Powell will depend on reservoir elevation, but are not expected to affect the long-term water quality of the reservoir.

***Air Quality.***—Energy generated from coal or gas-fired powerplants will need to make up the amount of hydropower lost from releasing water through the bypass tubes. 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, of regional emissions. Two HFEs within the same year would result in an amount of $CO_2$ emissions from these alternative sources estimated to be about 0.05 percent of regional emissions. The long-term impact depends on the number of consecutive HFEs and the total number over the 10-year experimental period, but the long-term impact is not expected to be substantial because the effects to air quality would be expected to dissipate quickly between HFEs.

***Sediment.***—Single HFEs are expected to suspend and redeposit sediment on sandbars and beaches up to the magnitude of the HFE, but that material is expected to erode with ensuing flows. Two consecutive HFEs are expected to have a beneficial impact from the additional sediment stored in sandbars and beaches that may better balance the sediment budget. Effects of more than two consecutive HFEs are uncertain, but they may have a long-term beneficial impact if there is additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage. More than two successive HFEs would have the potential for better balancing sediment delivery between upstream and downstream reaches and for long-term conservation of sediment to offset ongoing transport and erosion; however, successive HFEs or intervening periods of degradation without HFEs could offset this positive effect if they negatively impact the sand mass balance. Furthermore, this degradation, if extreme, could impact other resources and it is advisable to ensure that the net amount of sand in the river channel is not overly depleted so as to compromise other ecosystem components.

***Vegetation.***—Some riparian vegetation would be lost through scouring or burial by sediment transported during a high-flow release. Both emergent marsh and woody vegetation would recover quickly in the months and years, respectively, following the release and return to no action conditions. If high-flow releases are held frequently, recovery of plants may be slower.

***Terrestrial Invertebrates and Herpetofauna.***—Some habitat and individual animals will likely be scoured and exported, but these are expected to recover quickly with no population level impacts. Frequent HFEs would likely cause animals to relocate further upslope.

***Kanab Ambersnail.***—The endangered Kanab ambersnail would likely sustain short-term population and habitat impacts at Vasey's Paradise, although the allowable incidental take would not be exceeded

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***Aquatic Foodbase.***—The proposed action would likely result in a temporary reduction in aquatic foodbase production following HFEs,particularly for the mudsnail *Potamopyrgus antipodarum* and the amphipod *Gammarus lacustris*, in the Glen Canyon reach, with increased drift downstream due to increased tractive forces from higher volume releases. Spring releases would likely stimulate aquatic foodbase production with short-term recovery of less than 4 months. Fall releases would also scour the foodbase, but recovery could take longer because of the reduced photosynthesis that would occur in the reduced photoperiod and sun angle during the winter following the HFE. Research will need to be gathered on the impacts of seasonal short-term high flows on the aquatic foodbase. Multiple, consecutive HFEs could reduce forms susceptible to high flows and favor flood-resistant forms, possibly resulting in reduced species diversity.

***Humpback Chub.***—Adult humpback chub are not likely to be impacted by HFEs. Some young-of-year and juveniles could be displaced by experimental high flows from mainstem nursery habitats near the Little Colorado River into less desirable downstream habitat. These young fish may also experience higher rates of predation and competition from increased numbers of trout as an unintended consequence of the HFEs. These impacts are not expected to affect the overall population of humpback chub in Grand Canyon, although the uncertainty of effect increases with the frequency of HFEs. Periodic HFEs are likely to benefit the humpback chub by reshaping and maintaining habitats, stimulating foodbase production, and reducing numbers of flood-susceptible non-native fish. Effects of HFEs will be assessed through research and monitoring contained in the science plan accompanying this environmental assessment. Potential effects of trout predation on humpback chub are discussed separately.

***Razorback Sucker.***—Razorback suckers have been found spawning in the Colorado River inflow within 10 miles of Pearce Ferry, with a total of 40 larvae caught between Pearce Ferry and Iceberg Canyon in 2000, 2001, and 2010. HFEs could displace larvae in spring, but could also create new productive nursery habitats and delivery large amounts of food for all sizes of fish. The proposed action is not expected to have population-level impacts to the razorback sucker.

***Non-native Fish.***—Non-native fish life cycles would be temporarily disrupted. Backwaters would be reformed and subsequently available for use by native and non-native fish after the high-flow. Research data would be obtained on the relationships between flow duration and magnitude and backwater formation.

***Trout.***—Based on information learned during prior high flow releases, high-releases in spring (March to April) would likely increase survival and recruitment of rainbow trout in the Lees Ferry reach because of the cleansing effect on spawning/incubating gravels and stimulated production of higher quality food sources, such as midges (Chironomidae) and black flies (Simuliidae). Increased density of trout could result in dispersal of young trout to downstream areas where these fish could subsequently prey on and compete with the endangered humpback chub. A parallel environmental assessment, the Non-native Fish Control environmental assessment, is being developed by Reclamation to identify actions proposed to mitigate or counteract the effects of increased numbers of trout dispersing from the Lees Ferry reach. It is likely that some trout eggs, fry, and young would be destroyed or lost downstream. This temporary loss could reduce total trout numbers and help to stabilize the size and age structure of the population. There is some short-term risk that the aquatic foodbase would be reduced, subsequently affecting adult trout for a period following a high-flow release. The impact of a fall HFE on the trout population is uncertain due to a lack of data on trout response to the one fall HFE conducted in November 2004.

***Birds.***—The proposed action is not likely to adversely impact any bird species, including the endangered southwestern willow flycatcher and California condor.

***Mammals.***—Wildlife use riparian vegetation as habitat, and some habitat would be temporarily lost during a high-flow release. Patches of bare sand created by the release would add diversity to the new high water zone habitats. Habitat conditions would return to no action levels as riparian vegetation returns to no action conditions. Some loss of young beaver may occur due to flooding of dens during spring HFEs.

***Cultural Resources.***—Reclamation has determined that historic properties would be adversely affected per 36 CFR 800.6; consultation with SHPOs and THPOs is in progress. Access to sacred sites would be temporarily restricted during high flows and this constitutes an adverse effect. A resolution of effect for the overall undertaking will be reached by all consulting parties.

***Hydropower.—***No change to operating criteria for Glen Canyon Dam or 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead for reservoir operations would occur except during the high-flow release. Many of the HFEs require bypassing the power generating facilities at Glen Canyon to produce the high flows and replacement power must be purchased as a result. Estimated differences between no action and the proposed action in total cost, including energy cost and capacity cost, ranged from $8.1 to $122.1 million for 10-year periods based on modeling of nine different combinations of hydrology and sand input from the Paria River.

***Recreation.***—HFEs are expected to increase the area and volume of beaches and sand bars used by river runners for camping. All river-based recreation activities would be affected to some degree by the high-flow release, although little or no impact outside of the flow period is expected. There is some risk of longer-term adverse impacts on trout fishing if high-flow releases are conducted too frequently. A warning system would need to be developed to advise anglers, boaters, and rafters of a planned HFE, particularly if the HFE occurred during the time of a tributary flood as described in the rapid response approach. The Hualapai Tribe has informed Reclamation of potential adverse effects to its commercial operations on the Colorado River. Appropriate monitoring and mitigation measures will be determined as part of the ongoing tribal consultation process.

# 1 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 from Glen Canyon Dam including areas within Grand Canyon National Park. 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 can provide key fish and wildlife habitat, potentially reduce erosion of archaeological sites, restore and enhance riparian vegetation, and provide camping opportunities and enhance wilderness values along the Colorado River in Grand Canyon National Park.

The *Federal Register* (74 FR 69361; see Appendix A), provided the public with initial information regarding the anticipated development and purpose of the High-flow Experimental Protocol (HFE Protocol). The Department is developing the HFE Protocol through a public process pursuant to NEPA, and assessing the impacts of this proposed action with this Environmental Assessment (EA). The HFE Protocol is a multi-year, multi- experiment approach and will be based on the best available scientific information developed through the GCDAMP as well as other sources of relevant information. The HFE Protocol is a component of the Department's effort to comply with the requirements and obligations established by the Grand Canyon Protection Act of 1992 (Public Law 102-575, GCPA).

The focus of the proposed action is to improve conditions downstream from the Paria River, the first major sediment-producing tributary below Glen Canyon Dam. Glen Canyon Dam impounds the Colorado River about 16 miles upstream of Lees Ferry, Coconino County, Arizona and the confluence of the Paria River. 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). It includes Glen Canyon National Recreation Area (GCNRA) 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.

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

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

The 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. 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.

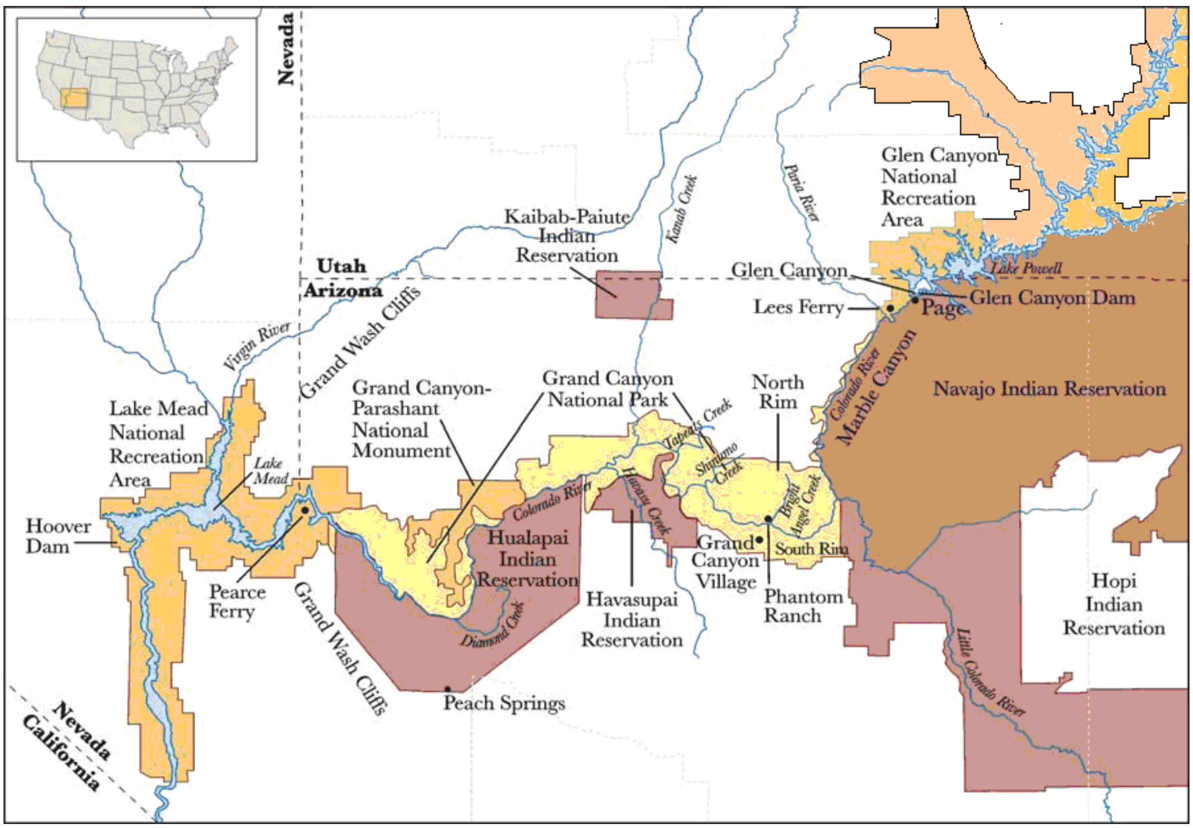


**Figure 1. Geographic scope of the proposed action, showing places referenced in the text. Map courtesy of U.S. Geological Survey.**

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; Reclamation 1982), 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 proposed uprate and rewind and existing 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 (Reclamation 1988). These studies also brought forth concerns about the effects of dam operations on the resources of GCNP and GCNRA 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). The GCPA was enacted by Congress because of the detrimental effects of dam operations on downstream resources. Section 1802(a) of the GCPA provided 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."

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."

Section 1806 of GCPA further stipulates that:

"Nothing in this title [GCPA] is intended to affect in any way—
(1) The allocations of water secured to the Colorado Basin States by any compact, law, or decree; or
(2) Any Federal environmental law, including the Endangered Species Act (16 U.S.C. 1531 et seq.)."

The GCPA also acknowledges the importance of natural and cultural resources in Grand Canyon. Section 1802(c) directs that:

"Nothing in this title alters the purposes for which the Grand Canyon National Park or the Glen Canyon National Recreation Area were established or affects the authority and responsibility of the Secretary with respect to the management and administration of the Grand Canyon National Park or the Glen Canyon National Recreation Area, including natural and cultural resources and visitor use, under laws applicable to those areas, including, but not limited to, the Act of August 25, 1916 (39 Stat. 535) as amended and supplemented."

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 (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 (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 final EIS hypothesized that high flows were important for restoring ecological integrity, and identified these as beach-habitat building flows and habitat maintenance flows. Additionally, the 1995 Biological Opinion (U.S. Fish and Wildlife Service [USFWS] 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 and were 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 (USFWS 2008), which was subsequently supplemented in 2009 (USFWS 2009). A more complete history of high-flow releases is provided in section 1.5 of this EA.

Section 1805 of the GCPA also requires the Secretary to undertake research and monitoring to determine if 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 (GCDAMP; www.gcdamp.gov). The GCDAMP 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 GCDAMP 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 and other natural and cultural resources below the dam.

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 (Reclamation 2007a), which was followed by an Interior Record of Decision on the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (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. All HFEs will be conducted in conformance with these authorities.

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 sandbar building and sand conservation can best be achieved in the Colorado River corridor in GCNP and the impacts that would result from these high-flow releases. The proposed action in this EA would occur in the same timeframe and in the same geographic area as a corollary proposal to control non-native fish in the Colorado River below Glen Canyon Dam.

## 1.2 Relationship between EAs for Non-native Fish Control and High-flow Experimental Protocol

Reclamation is in the process of concurrently preparing two EAs related to the ongoing implementation of the Glen Canyon Dam Adaptive Management Program. In addition to this EA that addresses the HFE Protocol, the other EA addresses Non-native Fish Control. Both efforts are designed to include important research components, with the expectation that the undertakings will improve resource conditions, and thereby provide important additional information for future decision-making within the GCDAMP. Although both EAs relate to and are part of the overall GCDAMP, Reclamation has considered the content of both efforts and believes that it is appropriate to maintain separate NEPA processes because each activity under consideration serves a different and independent purpose, has independent utility, and includes very different on the ground activities and actions (rate, duration and timing of water releases as compared with non-native fish research, management and control actions).

The HFE Protocol EA is designed to assess the effects of development and implementation of a multi-year, multi-experiment protocol for high-flow experimental releases from Glen Canyon

Dam to better determine whether and how sandbar and beach building and sand conservation can be improved in the Colorado River corridor downstream from Glen Canyon Dam including areas within Grand Canyon National Park.

The Non-native Fish Control EA is designed to control non-native fish, particularly rainbow and brown trout, in the Colorado River downstream from Glen Canyon Dam in an effort to help conserve native fish. The purpose of the action is to minimize the negative impacts of competition and predation on an endangered fish, the humpback chub (*Gila cypha*) in Grand Canyon, while addressing concerns for taking of life within a place that is sacred to American Indian tribes and fundamental in several creation beliefs.

During the first round of public review and comment on the High Flow and Non-Native control EAs, several comments from the public suggested that these high-flow dam release and fish control activities are "connected actions" or "similar actions" for NEPA purposes and therefore must be combined into a single NEPA document. The primary basis for this concern appears to be that, notwithstanding the differing nature of the experimental actions, based on a previous high-flow release, there is a concern that high-flow events during certain times of the year have the potential to increase the number of non-native trout that have been documented to upon native, endangered humpback chub.

Reclamation reviewed and considered these comments and has added this discussion to this updated Draft EA in order to provide the public with additional information with respect to the basis for the NEPA processes that are being utilized for the development of these two actions.

As an initial matter, the high flow release protocol and the non-native removal efforts are not portions of a single action. The release protocol will address multiple projected experimental operations (i.e., variable, high-flow water releases) from Glen Canyon Dam that would link high-volume releases to sediment availability in reaches downstream of Glen Canyon Dam. The high-flow releases would be conducted over a period of years and on multiple occasions to assess the ability to reduce the erosion of beach habitat in the Grand Canyon and potentially to enhance and retain beach habitat over multiple years.

Separately, the non-native research and control efforts are designed to enhance understanding of the life-cycle, movement and impacts of non-native fish on the native species in areas of the Colorado River downstream of Glen Canyon Dam. The non-native control actions are likely to address methods to reduce the population of predatory nonnative trout in areas where young-of-year native fish are located. Predation by non-native fish (both warm water and cold water species) has been identified as a primary threat to native fish in the Colorado River Basin.

Reclamation has considered the most appropriate approach to NEPA compliance for these actions and has reached a conclusion at this stage of analysis that it is not necessary to combine the EAs into a single NEPA document under the applicable NEPA regulations. Under NEPA's implementing regulations, the question of whether the two actions must be analyzed in a single compliance document turns on whether the two actions are considered "connected actions," "cumulative actions," or "similar actions." Pursuant to 40 C.F.R. § 1508.25(a)(1), connected actions are "closely related and therefore should be discussed in the same impact statement." The regulations go on to provide that: "Actions are connected if they: (i) Automatically trigger other actions which may require environmental impact statements. (ii) Cannot or will not proceed unless other actions are taken previously or simultaneously. (iii) Are interdependent parts of a larger action and depend on the larger action for their justification." 40 C.F.R. § 1508.25(a)(1).

The EAs do not meet the regulatory standard for connected actions. Neither activity under consideration will automatically trigger other actions which may require environmental impact statements as part of the Glen Canyon Adaptive Management Program. Implementation of both the high flow and non-native control actions are designed and expected to advance scientific knowledge and inform future GCDAMP decision-making, and may lead to adjustments in release patterns and/or strategies to control the size and location of predatory non-native fish. However, Reclamation cannot conclude at this time that such information will automatically trigger other actions which may require EISs. Secondly, the non-native control process is not dependent on other actions being taken previously or simultaneously. Rather, the timing and manner of nonnative control will depend, in part, upon the results of monitoring efforts determining the number of trout, their location and movement, etc. While the implementation of spring high-flows has been raised as a issue, given the post-2008 monitoring results, it is clear that both warm and cold-water non-native control actions will be necessary regardless of high flow implementation. There are no other actions that are conditions precedent to the efforts proceeding, and neither action depends on a larger action for their justification.

There are some obvious relationships and linkages between the two proposed actions, but those similarities do not rise to the standard of requiring preparation of a single NEPA document as "connected actions" for NEPA purposes. Both actions are part of the overall Glen Canyon Dam Adaptive Management Program, and they share a common overall geographic area (primarily focused on the mainstem of the Colorado River below Glen Canyon Dam). In addition, there are some overlapping impact analysis issues that are discussed herein, as it is possible that certain high-flow releases may impact the size and distribution of nonnative fish that have been identified as species that prey on native fish. However, each action has independent methods (dam releases vs. fish monitoring, tracking, and potential removal actions), an independent focus (protection and enhancement of riparian habitat vs. non-native fish research, monitoring and control), and each action has independent utility whether or not the other action proceeds. Moreover, where the two proposed actions are projected to involve overlapping environmental effects (*i.e.*, potential effects on predatory non-native species), the relevant analysis of these common environmental effects is included in both EAs.

Another regulatory basis for NEPA documents to be combined is if the activities in question are "similar actions." Pursuant to 40 C.F.R. § 1508.25(a)(3), similar actions "have similarities that provide a basis for evaluating their environmental consequences together, such as common timing or geography." While the two efforts address areas downstream of Glen Canyon Dam (and thus share a common geography, as well as timing), there are unique areas that will be the focus of each NEPA effort. The primary action of the high flow protocol is the timing, rate and duration of releases of water from Glen Canyon Dam. In terms of downstream research and monitoring, the high-flow protocol has a particular focus on sediment transport and geomorphological processes, and will include research and monitoring focused on the number, size and distribution of sandbars throughout Marble and Grand Canyons. In contrast, the non-native control effort is focused on biological processes and is expected to focus its analysis on particular areas that are important to both native and non-native fish species near the confluences of the Paria River and Little Colorado River with the Colorado River.

Even where two actions are deemed to be "similar actions" under the regulations, the applicable NEPA regulations go on to provide that, "[a]n agency *may wish* to analyze these actions in the same impact statement . . . when the *best way* to assess adequately the combined impacts of similar actions or reasonable alternatives to such actions is to treat them in a single impact statement." *Id*. This regulatory provision leaves the agency decisionmakers with sufficient discretion to determine the "best way" to assess impacts of similar actions. Given the differences between the two efforts, and based on the analysis of the differing scientific focus of each experimental effort, Reclamation, based on the best available information that is available at this stage of analysis, has considered this issue and determined that the best way to analyze each action is to continue to analyze the high flow protocol and the non-native control strategy through separate and independent NEPA processes, recognizing that resource analyses that are relevant to both EAs have been documented and included in both EAs, where appropriate (e.g., potential high flow impacts on population and distribution of predatory non-native species). Reclamation is also ensuring that both EAs contain up-to-date information on resource status and impacts and has been carefully coordinating the preparation schedules of the two EAs to ensure consistency of content.

Finally, both actions do not constitute "cumulative actions" necessitating review in a single NEPA document. Nonetheless, Reclamation does address the cumulative effects from both actions in the affected environment section of each EA, under the topical discussion for each resource (*see appropriate sections, Chapter 3*). Reclamation has properly considered the cumulative effects from these two actions, and other relevant related actions, in both NEPA documents. Consistent with these analyses, at this point in the NEPA process Reclamation has not concluded that the actions have "cumulatively significant impacts" which pursuant to 40 C.F.R. § 1508.25(a)(2) would indicate that the actions "should therefore be discussed in the same impact statement."

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 will be issued;

2. A notice of intent to prepare 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.

## 1.3 Relationship between this EA and the Long-Term Experimental and Management Plan

As discussed herein, there are a number of ongoing activities of the GCDAMP that complement the actions and research anticipated under the HFE Protocol EA. In addition, the Department is embarking on the first major, comprehensive analysis of the GCDAMP since 1996 with the initiation of the Glen Canyon Dam Adaptive Management Program Long Term Experimental and Management Plan (LTEMP). The Department has determined that it is appropriate and timely to undertake a new environmental impact statement (EIS) that reviews and analyzes a broad scope of Glen Canyon Dam operations and other related activities. Given that it has been 15 years since completion of the 1996 ROD on the operation of Glen Canyon Dam, the Department will study new information developed through the GCDAMP, including information on climate change, so as to more fully inform future decisions regarding the operation of Glen Canyon Dam and other management and experimental actions. The LTEMP is a component of the Department's efforts to continue to comply with the ongoing requirements and obligations established by the Grand Canyon Protection Act of 1992 (Pub. L. No. 102-575). The Department has determined that the LTEMP EIS will be co-led by the Bureau of Reclamation and the National Park Service. Reclamation and the NPS will co-lead this effort because Reclamation has primary responsibility for operation of Glen Canyon Dam and the NPS has primary responsibility for Grand Canyon National Park and Glen Canyon National Recreation Area. A formal notice of intent to prepare an EIS is anticipated during the summer of 2011, which will be followed by a thorough scoping process.

The purpose of the proposed LTEMP is to utilize current, and develop additional, scientific information to better inform Departmental decisions and to operate the dam in such a manner as to improve and protect important downstream resources while maintaining compliance with relevant laws, including the GCPA, the Law of the River, and the Endangered Species Act (ESA). Information developed through this EA and through the monitoring and implementation of the HFE Protocol will be further reviewed and analyzed as part of the LTEMP process. That is, while this EA is designed to analyze and adopt an approach to high-flow experimental releases, the effectiveness of such actions will also be further analyzed, integrated and potentially refined and/or modified as part of the LTEMP NEPA process. Scientific and resource information developed through this EA, and the implementation of the HFE Protocol are essential to ensuring that fully informed decisions are made as part of the LTEMP process. Accordingly, Reclamation has determined that it is essential and appropriate to move forward with this EA because it will provide important information related to multi-year, multi-experiment high-flow releases from Glen Canyon Dam. This information is important for independent reasons described throughout this EA, and it will also aid in future decisions associated with the LTEMP process. Continuing with the EA to learn more information about Glen Canyon Dam operations is consistent with the principles of adaptive management, which have guided decision making since the 1996 Record of Decision.

## 1.4 Purpose of and Need for Action

The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and ongoing dam releases further deplete sediment delivered to the main channel by periodic tributary floods. High dam releases mobilize sand stored in the river channel and redeposit it as sandbars and beaches that form associated backwater and riparian habitats. These sand formations are further reworked to varying degrees by wind (aeolian) forces (Draut et al. 2010). Sandbars and beaches can provide key fish and 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. Conservation of fine sediment and building of sandbars and beaches has not occurred to the degree anticipated in the 1996 Record of Decision. Further research is needed to determine whether multiple HFEs during sediment-enriched periods can better achieve this goal.

The goal of the proposed action is directed at improving sediment conservation downstream from the Paria River, because sediment inputs are very limited upstream of that tributary. In the 2011 USGS Report on the Effects of Three High-Flow Experiments on the Colorado River Ecosystem (Melis et al. 2011), USGS concluded the three high flow experiments that occurred in 1996, 2004 and 2008 showed that individual HFEs are effective at building sandbars, particularly if conducted soon after Colorado River tributaries have deposited sediment inputs in the main channel bed. However, sandbars tend to erode in the weeks and months following HFEs. The goal of the HFE Protocol is to maintain and increase sandbars and beaches through a long-term, sustainable strategy of conducting more frequent HFEs when conditions are favorable.

Reclamation is proposing to develop and implement a protocol for 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[2]-enriched conditions in the channel of the Colorado River downstream from the dam.

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 parameters of high-flow releases in conserving sediment to benefit downstream resources in Glen, Marble, and Grand Canyons.

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[2] 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 (Webster's Unabridged Dictionary). In this case, sediment consists of a mixture of varying coarseness of clay, silt, and 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. In practicality, the sediment that is transported during an HFE will contain lower percentages of particles finer than sand as the time since it was received from the tributary and deposited in the river channel increases. Therefore, HFEs conducted during (rapid response) or soon after tributary inputs will contain higher percentages of fine organic matter, silts and clays than HFEs that occur after these finer particles have been transported downstream.

The need for the proposed action is to take advantage of future sediment-enriched conditions in the Colorado River by implementing experimental high flow tests to improve the understanding of the relationships between high dam releases of up to 45,000 cfs and sediment conservation for the benefit of resources downstream of Glen Canyon Dam. 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.

During the life of the proposed action, Interior will monitor and analyze the effectiveness of experimental high flow releases in achieving specific resource goals downstream of Glen Canyon Dam. Information obtained from this monitoring and analysis will be collected in annual progress reports and incorporated into the decision making component of the HFE Protocol *(see Section on decision making)* to better inform future decision making regarding dam operations and other related management actions. Interior does not propose through this proposed action to undertake any experimental high flow tests in the absence of scientific monitoring and analysis, the results of which will be integrated into the ongoing implementation of the HFE Protocol.

In proposing this HFE Protocol, Interior is not modifying, in any manner, the current long-term management approach to implementation of "beach-habitat building flows" (BHBFs) as described in section 3 of the Operating Criteria for Glen Canyon Dam, published at 62 Fed. Reg. 9447 (Mar. 3, 1997). As provided in section 3 of the Operating Criteria, in adopting the management approach for "beach-habitat building flows" the Secretary found that releases pursuant to such an approach "are consistent with the 1956 Colorado River Storage Project Act, the 1968 Colorado River Basin Project Act, and the 1992 Grand Canyon Protection Act." Id. While no modification is proposed or anticipated at this time, any future potential modification of the 1996 ROD or 1997 Glen Canyon Dam Operating Criteria would only occur after public review, comment and consultation, as well as any required environmental compliance efforts.

Interior recognizes that differences exist with respect to interpretations of certain provisions contained in the "Law of the River" related to the implementation of high flow releases in excess of power plant capacity and the proper application and interpretation of those provisions of law. In proposing the HFE Protocol, Interior does not intend to revisit or modify, in any manner, the determinations or considerations that led to the adoption of the management approach for BHBFs contained in Section 3 of the 1997 Glen Canyon Dam Operating Criteria or the 1996 ROD. Nor does Interior intend that implementation of this HFE Protocol will constitute a formal determination regarding the multiple and complex issues that would need to be considered in the event that a decision were made to revisit the BHBF management strategy contained in Section 3 of the Glen Canyon Operating Criteria. Accordingly, Interior recognizes that positions and rights concerning the issues related to BHBF management strategies as compared to experimental releases of water from Lake Powell are reserved, and that implementation of the proposed action shall not prejudice the position or interests of any stakeholder. Furthermore, the Secretary, through this proposed action, makes no determination with respect to the correctness of any interpretation or position of the individual Colorado River Basin states or any other stakeholder. Implementation of the proposed action shall not represent a formal interpretation of existing law by the Secretary, nor predetermine in any manner, the means of operation of Glen Canyon Dam that the Secretary may adopt in the future following implementation of the proposed action, nor the design and implementation of future experimental actions.

## 1.5 Related Actions, Projects, Plans and Documents

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

### 1.5.1 Bureau of Reclamation Actions

The action proposed in this EA is tiered from two environmental impact statements—Reclamation's 1995 EIS on the operation of Glen Canyon Dam (Reclamation 1995) and the associated 1996 Record of Decision (Interior 1996); and Reclamation's 2007 EIS on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead (Reclamation 2007a) and the associated 2007 Interior Record of Decision (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 water year releases from Lake Powell in coordination with Lake Mead.

A past NEPA analysis that overlaps with the first year of this proposed action is the "Final Environmental Assessment and Finding of No Significant Impact for Experimental Releases from Glen Canyon Dam, Arizona, 2008 through 2012" (Reclamation 2008). Effects of this action are included in the resource analyses for this EA.

There are no other Reclamation EAs with FONSIs. However, Reclamation is developing an EA for non-native fish control downstream from Glen Canyon Dam concurrent with this EA. These EAs are related because they occur in the same geographic area during the same time period and because the actions proposed in these EAs may affect each other. The present EA proposes to develop and implement a protocol of experimental high-flow releases that is likely to increase the numbers of rainbow trout in the Lees Ferry reach and may also cause greater downstream dispersal of trout into reaches of the Colorado River that are occupied by humpback chub (Korman et al. 2011, Yard et al. 2011). One of the purposes of the non-native fish control EA will be to assess this effect and provide mitigation for increased predation and competition by the trout on humpback chub. This can be attempted through several means, as recently identified by Runge et al. (2011), including removal using electrofishing, modifying dam operations, electric barrier curtain, and sediment augmentation to increase turbidity. The effect of HFEs is not the only reason for the non-native fish control EA; which is required by previous biological opinions on the operation of Glen Canyon Dam. There is pre-existing information that has identified predation by rainbow trout and brown trout on young humpback chub in the vicinity of the Little Colorado River (Marsh and Douglas 1997; Valdez and Ryel 1995). Part of the reason for upstream interdiction being considered in the non-native fish control EA is to address concerns of American Indian tribes.

The non-native fish control effort arises from a conservation measure commitment made by Reclamation and contained in biological opinions issued by the USFWS in 2007 and 2008. There are several other conservation measures, all of which are intended to offset or mitigate the effects the operation of Glen Canyon Dam. Those conservation measures are identified and described in the Biological Assessment (see Appendix C) that accompanies this EA. Progress on those conservation measures is identified in the 2010 BA (Reclamation 2010a).

### 1.5.2 National Park Service Actions

The following documents list and describe 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.

GCNRA General Management Plan (GMP): The recreation area's 1979 GMP set an objective to manage the Lees Ferry and Colorado River corridor below the Glen Canyon Dam to "give primary emphasis to historical interpretation and access to recreational pursuits on the Colorado River" (NPS 1979).

GCNP General Management Plan (GMP): The 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).

GCNP Resource Management Plan (RMP): 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).

GCNP Backcountry Management Plan: This plan describes provisions for resource and wilderness management, including backcountry use, within Grand Canyon National Park. The plan is being updated in 2011.

GCNP Colorado River Management Plan (CRMP): The CRMP management objectives emphasize managing river recreation to minimize impacts to resources while providing a quality river visitor experience (NPS 2006). 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 and monitoring program, what impacts are occurring, how these impacts alter resource condition, and how adverse impacts can be effectively mitigated. The NPS will develop and implement a detailed plan that includes individual and integrated resource-monitoring components.

GCNP/GCNRA Draft Native Fish Management Plan (in preparation), including:

Translocation of humpback chub to Shinumo Creek and Havasu Creek: juvenile humpback chub were translocated from the Little Colorado River to Shinumo Creek in 2009 and 2010. Plans are in place to make a translocation to Shinumo Creek and Havasu Creek in 2011. This translocation action is part of a conservation measure contained in the 2008 BO and 2009 Supplemental BO.

Mechanical removal of non-native fish, primarily 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. This action is part of a conservation measure related to the 2008 BO and 2009 Supplemental BO.

GCNP 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.

GCNRA 2010 Tamarisk Leaf Beetle Action Plan.

GCNRA 2008 Colorado River Riparian Revegetation Plan, including implementation of the 2009 Hidden Slough Environmental Assessment.

### 1.5.3 Arizona Game and Fish Department Actions

The Arizona Game and Fish Department (AGFD) is also a cooperating agency in this EA through the Arizona Game and Fish Commission. The following are related actions identified by the agency.

Proposed changes to bag limits: The Arizona Game and Fish Commission modified its size and bag limits for trout below Glen Canyon Dam. Regulation changes were in effect beginning January 1, 2011. This modification is designed to better manage abundance and size of trout in the blue ribbon trout fishery at Lees Ferry and to reduce the numbers of trout immigrating downstream to habitat occupied by humpback chub, where they prey upon and compete with this endangered fish species.

Stocking of sport fish in the State of Arizona by the state wildlife agency and by USFWS, Southwest Region, is undergoing Intra-Service consultation. Of particular interest to this action is the proposed stocking of salmonids (trout species) in Colorado River tributaries.

## 1.6 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.

### 1.6.1 Department of the Interior

**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 GCDAMP, 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.

**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."

**National Park Service**

The NPS protects and 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 GCNRA 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). 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.

**U.S. Fish and Wildlife Service**

The USFWS provides Endangered Species Act (ESA) conservation and associated consultation and recovery leadership with various stakeholders primarily to benefit five ESA-listed species in Grand Canyon: humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), southwestern willow flycatcher (*Empidonax trailii extimus*), Kanab ambersnail (*Oxyloma haydeni kanabensis*), and California condor (*Gymnogyps californianus*).

The USFWS provides Fish and Wildlife Coordination Act (FWCA) planning assistance and recommendations to support conservation of important fish and wildlife resources. Of special concern to the USFWS is the opportunity provided under the FWCA for collaborative development of recommendations to conserve non-listed native species such that the need for listing in the future under the ESA is unnecessary.

A FWCA report (June 28, 1994) provided recommendations that included timing for flows, protection of juvenile humpback chub and other native fish, and trout management, in support of preparation of the 1995 EIS. This information was provided to support conservation of fish and wildlife, including endangered species, in GCNP and GCNRA.

**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 GCNRA. The GCMRC provides independent, policy- neutral scientific information to the GCDAMP 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.

### 1.6.2 Department of Energy

**Western Area Power Administration**

Western Area Power Administration (Western) mission is to market and deliver clean, renewable, reliable, cost-based federal hydroelectric power and related services. Western's CRSP-Management Center markets power from the CRSP and its participating projects (Dolores and Seedskadee and Collbran and Rio Grande projects). These resources are provided by eleven power plants in Arizona, Colorado, New Mexico, Utah and Wyoming and are marketed together as the Salt Lake City Integrated Projects. CRSP staff also market power from the Provo River Project in Utah and the Amistad-Falcon Project in Texas.

Transmission service is provided on transmission facilities in Arizona, Colorado, Nevada, New Mexico, Texas, Utah and Wyoming. 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.

## 1.7 Previous High-Flow Experiments

Beginning in 1996, Reclamation and its collaborators within the GCDAMP initiated the first of several experimental high-flow releases from Glen Canyon Dam (Reclamation 1996) that have helped to inform the design of the proposed HFE Protocol described in this EA. High releases in spring and summer of 1983-1985 were not experimental in nature, but were intended to balance dam releases with inflow from high spring runoff. The terminology for experimental releases has varied, and includes beach/habitat building flows (BHBFs), habitat maintenance flows (HMFs), high-flow experiments (HFEs), as well as high-flow tests.

Starting with the 1995 EIS (Reclamation 1995), high-flow releases were described as BHBFs and HMFs. A BHBF was a scheduled high release of short duration intended to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system. In the EIS, a BHBF was defined as: (1) scheduled only in years when the projected storage in Lake Powell on January 1 was less than 19 million acre-feet (maf) (low reservoir condition) to avoid the risk of unscheduled releases greater than power plant capacity during high reservoir conditions, and (2) a release of water from Glen Canyon that is at least 10,000 cfs greater than the allowable peak discharge (25,000 cfs) but not greater than 45,000 cfs. In the 1996 ROD, a BHBF was changed to occur in years in which Lake Powell storage was high on January 1, to be accomplished by utilizing reservoir releases in excess of power plant capacity required for dam safety purposes. In the EIS, 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. An HFE was a scheduled experimental high-flow release that could occur at reservoir elevations outside the range of BHBFs when sediment and hydrology conditions were suitable and could range from 41,000 cfs to 45,000 cfs.

The history of scheduled experimental high-flow releases is as follows:

- 1996 BHBF, 45,000 cfs for 7 days, March 26-April 2, 1996.
- 1997 HMF, 31,000 cfs for 72 hours, November 5-7, 1997.
- 2000 HMF, 31,000 cfs for 72 hours, May 2-4, 2000.
- 2000 HMF, 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 BHBF was held March 26 to April 8, 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 BHBF on physical, biological, cultural, and socio-economic resources was documented by Webb et al. (1999). The 1996 experiment was conducted when the Colorado River was relatively sand depleted, especially in Marble Canyon, and, as a result, the primary sources of sand for building high-elevation sandbars were the low-elevation parts of the upstream sandbars and not the channel bed (Andrews 1991; Schmidt et al. 1999; Hazel et al. 1999). During the 1996 experiment, the erosion of low-elevation sandbars actually resulted in a net reduction in overall sandbar size. Sandbars that eroded during the 1996 experiment did not recover their former sand volume during the late 1990s, in spite of above-average sand supplies and the implementation of ROD operations. These results indicated that high-flow releases conducted under sand-depleted conditions, such as those that existed in 1996, will not successfully sustain sandbar area and volume. Scientists and managers used this information to focus their efforts on the need to strategically time high-flow releases to better take advantage of episodic tributary floods that supply new sand, particularly sand input by the Paria River, to the Colorado River downstream from Glen Canyon Dam.

The findings of the 1996 BHBF led to the decision to conduct the next HFE when a sediment-enriched condition existed (Reclamation 2002). This experiment was held November 21–23, 2004, and included a 60-hour release of 41,000 cfs (Reclamation 2004). 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 in the upper portion of Marble Canyon 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 scheduled high release 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 fish, particularly humpback chub, and riparian wildlife and campsites for Grand Canyon recreationists. The 2008 HFE was preceded by accumulated sediment that was greater than prior to 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 (Draut et al. 2010; Grams et al. 2010; Hilwig and Makinster 2010; 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. Another HMF was scheduled in the 2002 EA (Reclamation 2002, page 21) as a release that would coincide with a high Paria River inflow, but the conditions for conducting this HMF were never met. 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 released in association with 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 non-native fish, and evaluate ponding of tributary inflows. With respect to sediment, all flows export more sediment than they place into storage and past powerplant capacity flows have been less efficient at this than HFEs (Hazel et al. 2006).

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, a high-flow release 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.

## 1.8 **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. 2011; 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.

Relevant resources considered in this EA are similar to those evaluated in other Reclamation EAs and considered by Ralston et al. (1998) as part of resource criteria for beach/habitat building flows. Downstream resources were categorized as physical, biological, cultural, and socio-economic, and included those identified by managers and stakeholders as resources that should be considered when making recommendations concerning operations of Glen Canyon Dam. Additional development of resource evaluations will occur during the planning and implementation phases of future HFEs if the decision is made to proceed with the HFE Protocol.

### 1.8.1 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 the governments of American Indian Tribes. Any field work within the boundaries of GCNP or GCNRA would require permits from the NPS. Permits from the Hualapai Tribe or Navajo Nation would be needed for any field work within reservation boundaries. The Bureau of Indian Affairs (BIA) has informed Reclamation that if field work entails cultural resource/archeological work then permits from the BIA will be required as well. Researchers working with threatened or endangered species would have to obtain a permit from the USFWS. Researchers working with resident fish or wildlife species could need an Arizona Game and Fish Department permit. No other permits are known to be required at this time.

**Table 1. List of resources and issues evaluated.**

| | |
|---|---|
| PHYSICAL RESOURCES | CULTURAL RESOURCES |
| Water Resources | Historic Properties |
| Water Quality | Sacred Sites |
| Air Quality | SOCIO-ECONOMIC RESOURCES |
| Sediment | Hydropower |
| BIOLOGICAL RESOURCES | Recreation (including Public Safety) |
| Vegetation | Non-Use Values |
| Terrestrial Invertebrates and Herptofauna | |
| Aquatic Foodbase | |
| Fish | |
| • Humpback Chub | |
| • Razorback Sucker | |
| • Non-Listed Native Fishes | |
| • Trout | |
| • Other Non-native Fishes | |
| • Fish Habitat | |
| Birds | |
| Mammals | |

### 1.8.2 Potential Limitations to Conducting an HFE

**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. The combined release of these eight units, when all are available and operating at full capacity, is currently 31,500 cfs. Unit 6 has been "derated," however, 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). Thus, the present powerplant release capability is 31,000 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 unit annuals. The turbine runners on all 8 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 eight- year period. Four of the eight runners have now been replaced. Unit 7, the fourth of eight, was completed in February 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 also could occur in completing the final four runner replacements.

Reclamation has a five-year maintenance schedule for the Glen Canyon Powerplant. There are scheduled outages for maintenance during the months of March/April and October/November from the present through November 2015 (Table 2). At least one unit will be unavailable during November and April through April of 2014. The five-year schedule currently shows no major maintenance beyond the spring of 2014. However, several major powerplant maintenance activities are being planned for the next 10 years, including replacement of the generator transformers and generator rewinds for 4 of the 8 units. These are major activities, which render the unit unavailable for extended periods of time (a month or more for a transformer replacement, and a year or more for a generator rewind). Additionally, mechanical or electrical failures can result in unplanned "forced outages." In 2008, for instance, Unit 6 experienced a significant failure in the generator winding resulting in a forced outage. Unit 6 was unavailable for a period of 2 years while the generator was repaired and the turbine runner replaced.

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

| Unit Number | Oct – Nov 2011 | Mar – Apr 2012 | Oct – Nov 2012 | Mar – Apr 2013 | Oct – Nov 2013 | Mar – Apr 2014 | Oct – Nov 2014 | Mar – Apr 2015 | Oct – Nov 2015 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | | | |
| 4 | | | | | | | | | |
| 5 | | | | | | | | | |
| 6 (limited) | | | | | | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| Units Available | 5 to 7 | 5 to 7 | 5 to 7 | 6 to 7 | 5 to 7 | 6 to 7 | 6 to 8 | 6 to 8 | 6 to 8 |
| Powerplant Capacity | 20 to 27 Kcfs | 20 to 27 Kcfs | 20 to 27 Kcfs | 23 to 27 Kcfs | 20 to 27 Kcfs | 23 to 27 Kcfs | 24 to 31 Kcfs | 23 to 31 Kcfs | 24 to 31 Kcfs |
| Powerplant plus River Bypass Capacity | 35 to 42 Kcfs | 35 to 42 Kcfs | 35 to 42 Kcfs | 38 to 42 Kcfs | 35 to 42 Kcfs | 38 to 42 Kcfs | 39 to 45 Kcfs | 38 to 45 Kcfs | 39 to 45 Kcfs |

Given the age of the powerplant (nearly 50 years), and scheduled and unplanned maintenance at the Glen Canyon Powerplant, it is reasonable to expect that in the 10-year period the HFE Protocol is in place, at least one unit would be unavailable in the months of March/April and October/November, with a powerplant capacity release not likely to be greater than 27,500 cfs and a combined powerplant and river bypass tube release capacity not likely to be greater than 42,500 cfs. High flows proposed and analyzed in this EA utilize the maximum available release from the powerplant combined with up to 15,000 cfs from the bypass tubes. Releases greater than the combined capacity of the powerplant and river bypass tubes, which would require using spillways, are not anticipated during the period of this protocol and are not covered by the compliance in this environmental assessment.

Maintenance on the river bypass tubes and associated hollow jet valves will also be needed at some point in the future. Relining of the coating on the inside of the bypass tubes would likely be part of this maintenance as would a rebuild of the hollow jet valves. Such an activity has not been scheduled, but such a maintenance activity would render the river bypass tubes unavailable for a period of a year or more (personal communication, Lonnie Gourley, Manager, Glen Canyon Field Division).

**Sediment and Flow Limitations**

The principal driving variables of this HFE Protocol are sediment and flow. In order for an HFE to be conducted without creating a negative sediment mass balance, a minimum amount of sediment must be available in the river channel. A certain amount of water also 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; however some transfer of water across months is possible to meet this need. 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.

**Condition of Resources**

The condition of both physical and biological resources must be taken into account by Interior 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. Reclamation recognizes the need to ensure that implementation of the HFE Protocol does not result in significant impacts to GCDAMP resources such as endangered humpback chub and will closely monitor both trout and chub populations to ensure that potential changes are detected as rapidly as possible. Reclamation will take a conservative approach and will re-evaluate, and suspend if necessary, the protocol, if it anticipates that significant impacts could occur that cannot be mitigated. If a specific key resource is identified in decline, it is reasonable to expect that this will be detected through core monitoring and appropriately considered in the HFE decision-making process.

**Other Possible Limitations**

There may be additional limitations to conducting an HFE other than those described above. Because the HFE Protocol includes a decision strategy that takes 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 the development of a proposed action through a non-native fish control EA for managing the numbers of trout in Grand Canyon to reduce the effects of predation and competition on the endangered humpback chub (see section 1.3 Related Actions). 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 could be necessary to manage trout numbers.

The proposed action regarding trout control will be important in two ways. First, the trout control 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 increases in trout numbers will be conducted through the nonnative fish EA. As each EA proceeds, the pertinent analyses will draw from one another.

# 2 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 (Interior 1996), and the 2007 Record of Decision for Interim Guidelines for Lower Basin Shortages and the Coordinated Reservoir Operations (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 (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 that occurred on March 4, 2008, and (2) steady flows in September and October of each year, 2008 through 2012.

The MLFF flow regime was the selected alternative of the 1996 ROD because it reduces daily flow fluctuations to 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 the fall to stabilize habitat for juvenile humpback chub.

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 and from November 1 to December 31 (except for 60-hour HFE in March 2008). Steady flows, adjusted to available water volume, would be released for all 5 years in September and October through 2012. After October 2012, releases would follow the provisions of MLFF as defined in the 1996 ROD and the 2007 ROD.

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 (USFWS 2008). The 2008 Opinion was supplemented in a Supplemental Opinion (USFWS 2009) that affirmed the 2008 Opinion as a result of a Court Order of May 26, 2009. The Court remanded the incidental take statement back to the Service, and a revised Incidental Take Statement was issued in 2010 (USFWS 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). The Court upheld the revised incidental take statement on March 30, 2011.

**Table 3. Summary of No Action and Modified Low Fluctuating Flow Preferred Alternative Criteria for the 1996 Record of Decision.**

| Flow Parameter or Element | Unrestricted Fluctuating Flows | Restricted Fluctuating Flows |
|---|---|---|
| | No Action | Moderate Low Fluctuating |
| Minimum releases (cfs)[1] | 1,000 Labor Day–Easter<br>[2]3,000 Easter–Labor Day | 8,000 between 7 a.m. and 7 p.m.<br>5,000 at night |
| Maximum releases (cfs)[3] | 31,500 | 25,000 (exceeded during habitat maintenance flows) |
| Allowable daily flow fluctuations (cfs/24 hours) | 30,500 Labor Day–Easter<br>28,500 Easter–Labor Day | [4]5,000; 6,000; or 8,000 |
| Ramp rates (cfs/hour) | Unrestricted | 4,000 up; 1,500 down |
| Common elements | | Adaptive management (including long-term monitoring and research)<br>Monitoring and protecting cultural resources<br>Flood frequency reduction measures<br>Beach-habitat building flows<br>New population of humpback chub<br>Further study of selective withdrawal<br>Emergency exception criteria |

[1] In high volume release months, the allowable daily change would require higher 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] Maximums represent normal or routine limits and may necessarily be exceeded during high water years.
[4] 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.

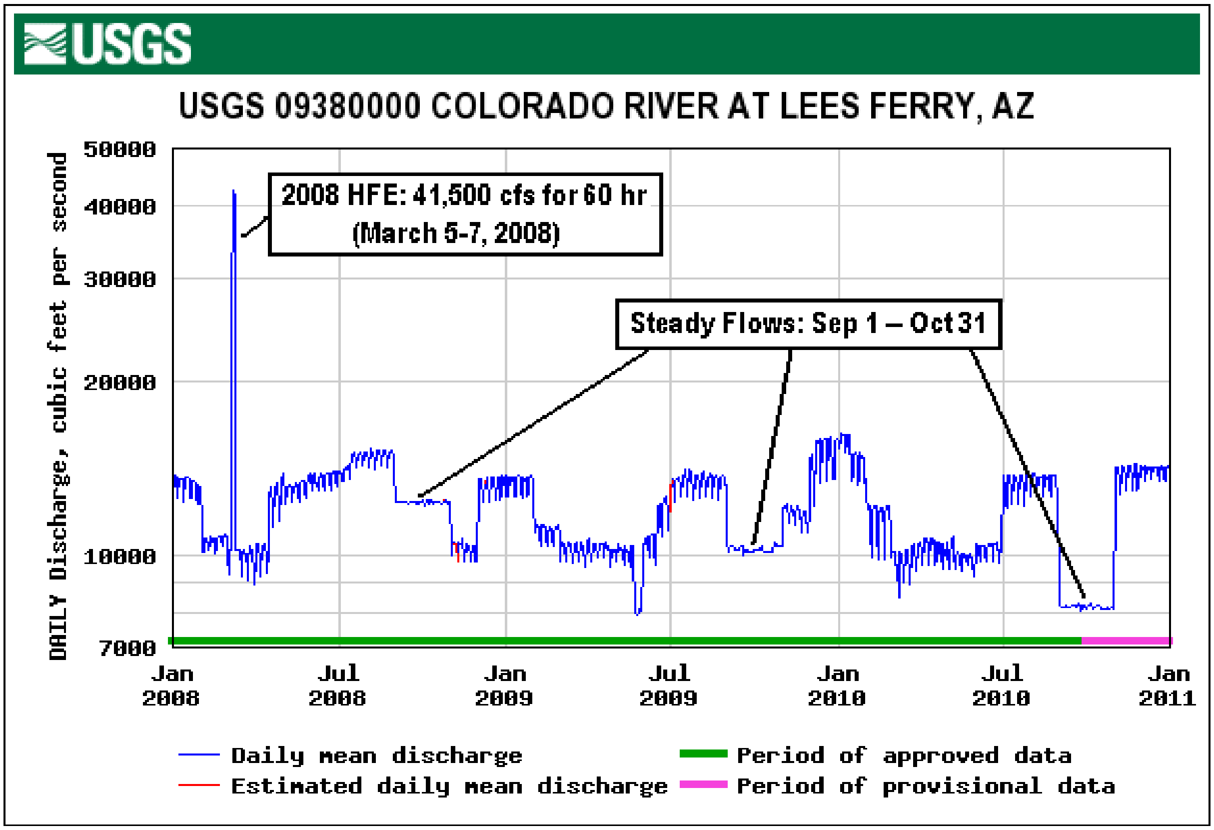



**Figure 2. Mean daily discharge of the Colorado River at Lees Ferry from January 1, 2008 to December 31, 2010, showing the 2008 HFE, the September-October steady flows, and the intervening releases under modified low fluctuating flows (MLFF).**

## 2.2 Proposed Action: Protocol for High-Flow Experimental Releases

### 2.2.1 Overview 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. Water year releases would follow the MLFF preferred alternative as described in the 1996 ROD with the added refinement of steady flows through 2012 as identified in the 2008 Biological Opinion and the 2009 Supplemental Biological Opinion. For the remainder of the proposed action period, through 2020, dam releases would follow the provisions of MLFF as defined in the 1996 ROD and the 2007 ROD unless required as an outcome of future ESA consultation. 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. Frequency of HFEs would be determined by tributary sediment inputs, resource conditions, and a decision process carried out by Interior.

Developing this HFE Protocol is important 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 a variety of single-event high-flow experiments and the benefit to sandbar and beach maintenance has been temporary. One purpose for this HFE Protocol is to assess whether multiple, potentially sequential, predictable HFEs conducted under consistent criteria can better conserve sediment resources while not negatively impacting other resources The 10-year experimental window provides opportunities for multiple HFEs to be conducted and analyzed and the protocol to be modified as appropriate. Since necessary sediment and hydrology conditions may not occur every year, the 10-year window assures that multiple events can be conducted. It also allows for the flexibility needed to respond to sediment thresholds as they occur without delays for additional compliance. The HFE Protocol will incorporate annual reviews to ensure that unacceptable impacts do not occur. Interior will conduct a comprehensive review of the protocol after multiple events (at least 3) have occurred.

A protocol in science, 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 was a primary component of the historic pre-dam Colorado River ecosystem, and determining how sediment conservation can be achieved in areas within GCNP downstream from Glen Canyon Dam is a high priority of the GCDAMP 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.

This HFE Protocol is intended to be experimental in nature, and is designed to learn how to incorporate high releases into future dam operations in a manner that effectively conserves sediment and sediment-dependent resources in the long term. A number of hypotheses may be tested through this experimental protocol. These hypotheses could be directed at varying the timing, magnitude, duration, and frequency of HFEs to determine the effectiveness on sandbar building and sand conservation. Two approaches have been put forward with respect to timing of a high release in response to the delivery of sediment into the river channel. The “store and release” approach was developed by USGS and was first introduced as the basis for the HFE Protocol in a June 2010 modeling workshop. The “rapid response” approach was proposed later in September by Western Area Power Administration, and is intended to test whether the desired sediment conservation can be achieved with dam releases at the time of the tributary sediment input using a powerplant capacity release of 31,500 cfs to 33,200 cfs.

The store and release approach relies on accumulation of sand during periods of above-average sediment input from tributaries to achieve sediment-enriched conditions called for in the development of the HFE Protocol (74 FR 69361). It is directed at sand, rather than sand and finer particle sizes, as is the rapid response approach, since finer particles largely are transported downstream during the sand storage period. Sand budget models used to estimate the magnitude and duration of HFEs that would maintain a positive sand budget also are not calibrated to estimate retention or transport of finer particle sizes. An approach similar to store and release was used for the 2004 and 2008 HFEs and these were effective at redepositing sand. Sand is accumulated over a period of several months at which time a recommendation is made to release or not release a high flow from the dam. In contrast, the rapid response approach relies on real-time measurements of flood events by stream gages in the tributary supplying the sediment (i.e., Paria River), which is a combination of clays, silts, sand and organic matter. This information must be transmitted to dam operators in sufficient time so they can release water from the dam to coincide with the flood input from the tributary. The success of the rapid response approach requires coupling of tributary floods and dam releases to transport sediment-enriched water downstream. The decision process for rapid response must occur within a matter of hours. The rapid response authors identify several potential positive effects on various resources downstream from Glen Canyon Dam:

- The potential to build and maintain ecologically important sandbar complexes with greater efficiency than the storage and release approach for HFEs.
- An advantage in delivering high suspended sediment concentrations downstream, which has been shown to exert primary control on the building of sandbar complexes in previous HFEs.
- The combined Paria River flood and dam release flow magnitude is slightly lower than the previous HFEs, but evidence from previous HFEs suggests that sand deposition at high elevations zones is achievable.
- 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.
- A greater storage and deposition of fine, cohesive sediments (silts and clays) along with organic material that can help stabilize sandbars as well as enhance productivity in backwater habitats.

The rapid response approach has certain elements that exhibit promise and merit further testing. There are, however, several issues, concerns, and information needs that must be addressed prior to testing of this approach, including:

- It relies on the flow of the Paria River as the trigger for the HFE. The rapid response decision framework requires short-term decisions that must be based on the progression of floods in the Paria River. These floods are highly variable and of short duration, often 24 hours or less. This presents a major challenge in the coinciding of a dam release with a flood event. If a dam release misses the flood event, the high flow would scour sediment that is being accumulated in the river channel and could negatively impact the opportunity for future HFEs.
- The models used to develop and implement an HFE under store and release are not capable of evaluating the retention of sediment and organic matter finer than sand. These models could be developed with further refinement of the existing sand budget model.

- The rapid response proposal identifies that a high dam release coupled with a flood event from the Paria River would have to be made 'at a moment's notice.' Such a rapid response, which would have to occur in a matter of a few hours, could produce negative impacts on private property, recreation and safety, and dam operations. Prior to the initiation of a rapid response HFE, an appropriate warning system would need to be developed. An effective warning system will require coordination with dam operators and notices to anglers, boaters, rafters, and recreationists to ensure public safety.
- Average monthly sand load from the Paria River is greatest in August and September. Therefore, rapid response would most often be triggered in these months, which are outside the release windows for the store and release approach (March-April and October-November).
- The proposed action is intended to take advantage of sediment-enriched conditions to more efficiently conserve sediment. A large input from the Paria River during a time of low sediment storage might not meet these conditions.

It is expected that the above issues and concerns can be addressed sufficiently during the early stages of the implementation of the HFE Protocol to test a rapid response HFE within the same release windows identified for the store and release HFE and Reclamation intends to test the rapid response method as soon as practicable. Initiation of this process would occur in 2011 and begin with a reevaluation of the habitat maintenance flow identified as the fourth hydrological scenario identified in the 2002 EA (Reclamation 2002). During the period of development for the rapid response approach, a science plan would need to be developed; models would have to be updated; safety warning systems would need to be developed; communication systems and dam operations protocols would need to be put in place; and real-time sediment input gages would have to be established. Additional compliance would be needed to evaluate the impacts of a rapid release HFE outside the October-November and March-April windows. If a decision is made to proceed with the proposed action, all necessary steps would be completed to allow a rapid response HFE in 2013 if that is the outcome of the HFE Protocol process.

**Models to Assist in Development and Implementation of HFE Protocol**

Mathematical models are used for two purposes for the HFE Protocol. The first is to estimate the magnitude, duration, and frequency of HFEs that could occur under the store and release approach using historic sediment and hydrologic data as inputs to maximize the potential for sandbar building with the available sand supply. The second is to make recommendations for future HFEs using contemporary sediment data and forecasted hydrologic data to determine whether suitable sediment and hydrology conditions exist for a high-flow experimental release.

**Development of Data Input to Estimate Types of HFEs**

The two basic inputs for the modeling are the water input or hydrology, which is taken from the Colorado River Simulation System (CRSS) (Reclamation 1988, 2007b) and the sediment, which in this case is restricted to inputs from the Paria River. A flow routing model (Wiele and Smith 1996) was used to simulate water passing downstream. A 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.

The hydrology model was used to develop dam release scenarios for 10-year periods under dry, moderate, and wet conditions (Grantz and Patno 2010, see Appendix D). The three hydrology time series were then used in conjunction with historical sediment input data (low, moderate, high) from the Paria River to create nine different sediment/hydrology combinations for input into the sediment budget model (Russell and Huang 2010, see Appendix E). The sediment budget model uses the sediment inputs and estimates the 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 (RM 61), and (3) from Little Colorado River to RM 87. For the purposes of this EA, only the first two reaches were used because results from the third reach would be confounded by Little Colorado River inputs. The major purpose of the sediment budget model is to estimate the maximum possible magnitude and duration of an HFE that will not create a negative sand mass balance.

**Data Inputs to Implement the HFE Protocol**

The same mathematical models, with different data inputs, will be used to implement the modeling component of the HFE Protocol and to help make decisions whether or not to conduct an HFE under the storage and release approach. Whereas the hydrology data for the protocol development were drawn from historic records, hydrologic data for implementation would be based on forecasted monthly inflow volumes from the National Weather Service's Colorado Basin River Forecast Center (CBRFC) and Reclamation's 24-month study projected storage conditions. The 24-month study computer model projects future reservoir conditions and potential dam operations for the system reservoirs given existing reservoir conditions; inflow forecasts and projections; and a variety of operational policies and guidelines. Monthly volumes would be apportioned to daily dam releases by Western. Sediment data would be real-time accumulated inputs from the Paria River gages. 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 projections will need to be considered in the decision-making process (Grantz and Patno 2010).

### 2.2.2 Modeled Estimates of Types and Occurrences of HFEs

Thirteen HFEs having a range of magnitudes and durations of previously tested HFEs (Table 4) were used with the sediment/hydrology model to project the potential frequency of HFEs under the store and release approach. High releases of 41,000–45,000 cfs at durations of 60-168 hours were conducted in 1996, 2004, and 2008, and three releases of 31,000 cfs for 72 hours were conducted in 1997 and 2000. HFEs of less than 60 hours duration and magnitudes between 31,000 and 41,000 cfs have not been conducted.

Model runs were done using 10-year series of dry, moderate, and wet hydrology coupled with 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 from the Paria River (Russell and Huang 2010; see Appendix E). Each run was evaluated against 13 described HFEs to determine their possible occurrence in the months of March-April or October-November. The magnitude and duration of a HFE was determined from the sand storage mass available on October 1st and

March 1st of each water year and the forecasted hydrology (Grantz and Patno 2010). 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.

**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 | | | |

If enough sediment is available to achieve a positive sand mass balance in Marble Canyon, that magnitude and duration of HFE can be implemented. A positive mass balance is defined as a condition in which the amount of sediment being delivered by tributaries into the system exceeds the amount being exported from the system by ongoing dam operations and HFEs. If the model run does not conclude that enough sediment is available to achieve a positive mass balance, the next lower magnitude or duration HFE 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.

It is assumed that the highest magnitude and duration HFE possible without creating a negative sand mass balance is desirable, because larger HFEs will place sand at higher elevations and create larger beaches and sand bars without impacting the mass balance. Increase in area and volume of beaches and sandbars is a desired outcome of the HFE Protocol and previous powerplant capacity releases did little to improve sandbars and beaches relative to the higher releases conducted in 1996, 2004, and 2008. There is also an assumption that water is not limiting because reallocation of water from other months can be used to ensure that sufficient water is available for the HFE without violating any laws or compacts to deliver water to the lower Colorado River basin.

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, an HFE of 45,000 cfs 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. It is important to recognize that all HFEs do not have an equal opportunity to occur because the model starts considering HFEs from the top of the list (45,000 cfs for 96 hours) and works down the list. This is done to ensure that the most effective HFEs, based on previous research, have the greatest probability of occurring.

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 two or more, 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 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 because it is highly unlikely that the same sediment/hydrology condition will persist for the full 10-year period. It also is unlikely that each sediment/hydrology condition will be equally represented. However, this table provides an insight into the potential frequency, magnitude, and duration of spring and fall HFEs.

**Table 5. Type of HFE by month for each of the nine traces of sediment (Low, Moderate, and High) and hydrology (Dry, Moderate, Wet). See Table 4 for descriptions of HFEs (Russell and Huang 2010).**

| Month/Year | Low, Dry | Low, Mod. | Low, Wet | Mod, Dry | Mod., Mod. | Mod., Wet | High, Dry | High, Mod. | High, Wet |
|---|---|---|---|---|---|---|---|---|---|
| Mar-Apr Yr 1 | 5 | 5 | | | | | 7 | 7 | |
| Oct-Nov Yr 1 | 2 | 2 | | 6 | 6 | | 6 | 6 | |
| Mar-Apr Yr 2 | | | | | | | | | |
| Oct-Nov Yr 2 | | 7 | | | | | | | |
| Mar-Apr Yr 3 | 6 | 12 | | 1 | 2 | 1 | 8 | | |
| Oct-Nov Yr 3 | 3 | 8 | 4 | 1 | 2 | 1 | 1 | 1 | 1 |
| Mar-Apr Yr 4 | 10 | | | 1 | 1 | 1 | 2 | 8 | 3 |
| Oct-Nov Yr 4 | 1 | 1 | 7 | 8 | 8 | | 6 | 8 | |
| Mar-Apr Yr 5 | | | | | | | 2 | 7 | 1 |
| Oct-Nov Yr 5 | 1 | | 4 | 8 | | | | | |
| Mar-Apr Yr 6 | 11 | 8 | 8 | 5 | 1 | 1 | | 12 | 9 |
| Oct-Nov Yr 6 | | | 8 | | | | 1 | 1 | 1 |
| Mar-Apr Yr 7 | 8 | 8 | | | 8 | | 9 | 10 | |
| Oct-Nov Yr 7 | 7 | 7 | | | | | 1 | 1 | 1 |
| Mar-Apr Yr 8 | | | 7 | 8 | | 4 | 4 | 9 | 1 |
| Oct-Nov Yr 8 | 4 | 3 | 3 | 1 | 1 | 1 | 6 | 7 | 8 |
| Mar-Apr Yr 9 | | | | | | | | | |
| Oct-Nov Yr 9 | 9 | 7 | | 1 | 1 | 1 | | | |
| Mar-Apr Yr 10 | 1 | 1 | 2 | | | | | | |
| Oct-Nov Yr 10 | 2 | 2 | 1 | 5 | 6 | 2 | 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 low sediment/dry hydrology conditions, followed by a tie among low sediment/moderate hydrology, high sediment/dry hydrology, and high sediment/moderate hydrology. 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.

The monthly water allocations for dam releases were generated through the CRSS model. Those allocations had to be adjusted to provide water necessary for HFEs of varying magnitude and duration. The amounts that were reallocated for the different HFE scenarios ranged from about 23,000 to 344,000 acre-feet (Table 6). The model assumed that all water necessary for an HFE could be provided in the month of the HFE and did not restrict that volume to follow MLFF. In reality, the reallocated amounts would first be drawn from the HFE month subject to MLFF minimum flows, then from other months based on hydropower production priorities (see section 2.2.6).

**Table 6. Projected volume of water (acre-feet) to be reallocated as a result of the selected HFE. See Table 4 for type of HFE (Russell and Huang 2010).**

| Month of Potential HFE | Low, Dry | Low, Mod. | Low, Wet | Mod, Dry | Mod., Mod. | Mod., Wet | High, Dry | High, Mod. | High, Wet |
|---|---|---|---|---|---|---|---|---|---|
| Mar-Apr Yr 1 | 154,673 | 154,673 | | | | | 84,733 | 84,733 | |
| Oct-Nov Yr 1 | 256,536 | 256,536 | | 118,024 | 118,024 | | 118,024 | 118,024 | |
| Mar-Apr Yr 2 | | | | | | | | | |
| Oct-Nov Yr 2 | | 83,395 | | | | | | | |
| Mar-Apr Yr 3 | 118,024 | 23,010 | | 325,792 | 256,536 | 325,792 | 48,767 | | |
| Oct-Nov Yr 3 | 221,938 | 48,767 | 187,279 | 325,792 | 256,536 | 325,792 | 325,792 | 325,792 | 325,792 |
| Mar-Apr Yr 4 | 32,693 | | | 325,792 | 237,854 | 276,934 | 256,536 | 25,272 | 186,506 |
| Oct-Nov Yr 4 | 325,792 | 325,792 | 83,395 | 48,767 | 48,767 | | 118,024 | 48,767 | |
| Mar-Apr Yr 5 | | | | | | | 268,375 | 53,922 | 278,784 |
| Oct-Nov Yr 5 | 325,792 | | 187,279 | 48,767 | | | | | |
| Mar-Apr Yr 6 | 28,363 | 48,796 | 49,742 | 154,629 | 325,901 | 329,441 | | 23,030 | 40,258 |
| Oct-Nov Yr 6 | | | 48,767 | | | | 325,792 | 325,792 | 325,792 |
| Mar-Apr Yr 7 | 57,680 | 45,376 | | | 45,376 | | 47,515 | 29,882 | |
| Oct-Nov Yr 7 | 89,923 | 83,395 | | | | | 343,986 | 325,792 | 308,939 |
| Mar-Apr Yr 8 | | | 84,286 | 53,628 | | 188,851 | 198,808 | 20,184 | 328,272 |
| Oct-Nov Yr 8 | 187,279 | 221,938 | 221,938 | 325,792 | 325,792 | 325,792 | 118,024 | 83,395 | 48,767 |
| Mar-Apr Yr 9 | | | | | | | | | |
| Oct-Nov Yr 9 | 39,366 | 83,395 | | 325,792 | 325,792 | 325,792 | | | |
| Mar-Apr Yr 10 | 334,188 | 317,046 | 256,600 | | | | | | |
| Oct-Nov Yr 10 | 256,536 | 256,536 | 308,078 | 152,652 | 118,024 | 242,068 | 118,024 | 83,395 | 308,078 |

### 2.2.3 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.

**Planning and Budgeting Component**

The first component of the HFE Protocol is planning and budgeting (Figure 3). 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 would evaluate the information on the status and trends of key resources. This information would be provided to Interior to assist with the decision and implementation component of this protocol. Funding for HFEs is provided through the GCDAMP in a biennial budget process. Reclamation would be prepared to conduct an HFE if funding is provided, resource conditions are suitable, and there is sufficient sediment input to trigger an HFE.

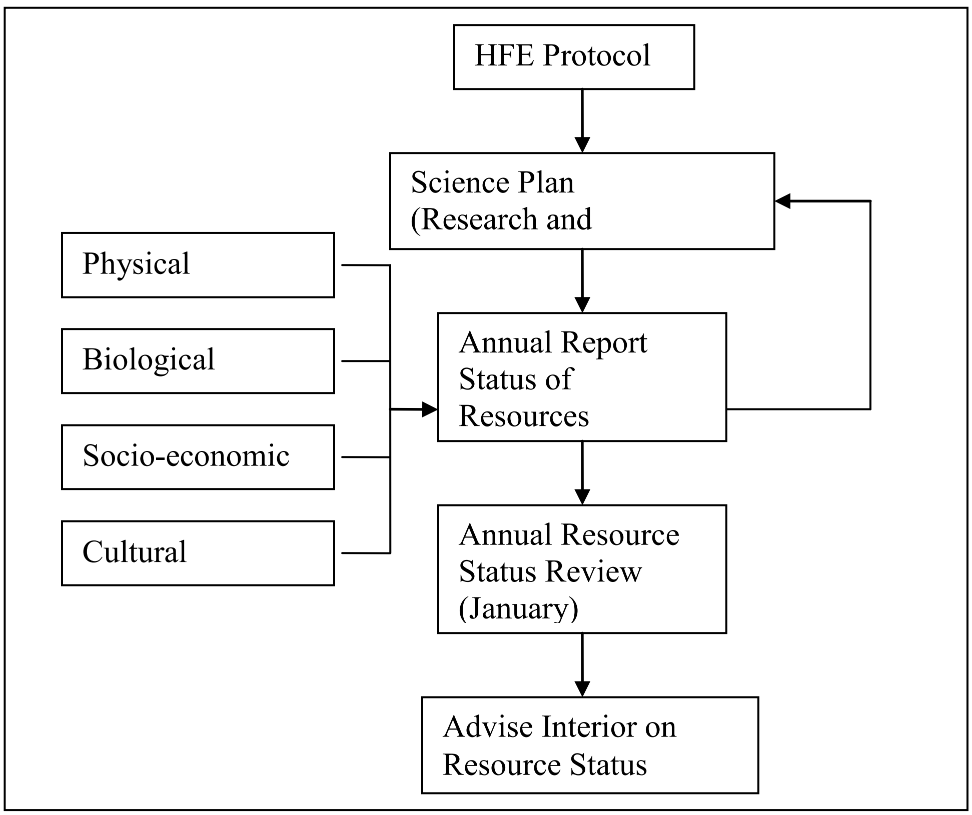



**Figure 3. Planning and budgeting component for the HFE protocol.**

The details of this implementation process have not been finalized, but it likely would be based on resource criteria and a decision process for beach/habitat building flows, as initiated by Ralston et al. (1998) (Table 7). Additional key resources would be drawn from those being monitored under the HFE Protocol science plan. In this way, the HFE Protocol would be evaluated annually for the effects of its implementation on resources. Resources that would be evaluated for determining whether or not an HFE would take place could include (but may not be not limited to): in-channel sediment storage, high-elevation sandbar, sandbar campable area, high-elevation sand deposits, archaeological site condition and stability, sediment flux, aquatic food base, Lees Ferry fish monitoring, Lees Ferry recreation experience quality, fish abundance and species composition in the mainstem and Little Colorado River (including abundance of humpback chub), riparian vegetation, Kanab ambersnail, Lake Powell and Lees Ferry water quality, and hydropower production and marketable capacity.

The results of the annual status of resources report and review would be used to help determine if future HFEs will take place. If monitoring shows that there are unacceptable impacts, such as a significant decline in humpback chub numbers, Reclamation would suspend implementation for that cycle and re-evaluate the HFE Protocol. In a separate EA process, Reclamation has developed a proposed action to control non-native fish. Because humpback chub are a key GCDAMP resource that could be adversely affected by HFEs through increases in trout numbers, a trigger of adult humpback chub declining to less than 7,000 individuals would cause resumption of mechanical removal of non-native fish in the LCR reach of the Colorado River. Removal of non-native fish in the LCR reach would only take place if the number of adult humpback chub, as measured using the Age-Structured Mark Recapture Model (ASMR; Coggins and Walters 2009) indicates that adult abundance has dropped below 7,000 adult humpback chub.

**Table 7. Resource indicators for important resources potentially affected by BHBFs (Ralston et al. 1998).**

| |
|---|
| Sediment Resources (Sandbars, beaches and backwaters) |
| Total number of sandbars above 20,000 cfs, by reach and stage.<br>Average area of sandbars above 20,000 cfs, by reach and stage<br>Number of suitable backwater habitats by reach at specific river stages between 8,000 cfs and 45,000 cfs<br>Estimated quantity of river-stored sediment available for redistribution by reach |
| Terrestrial and Riparian Resources |
| Kanab ambersnail (as compared to 1996 pre-flood conditions) |
| Number of known populations of KAS in Arizona<br>Populated KAS habitat (total area) outside impact zone<br>Estimated total KAS population outside impact zone<br>Analysis: Probable BHBF effects on long-term sustainability of known populations (e.g., recruitment, genetic integrity, sustainability of pre-dam habitats) |
| Southwestern willow flycatcher |
| Number of SWWF territories expected to be significantly affected by BHBF (describe effect)<br>Number of breeding pairs expected to be displaced by BHBF<br>Analysis: Probable effects of BIHBF on recruitment (reproduction, nest parasitism, survival of young, etc.) |
| Aquatic Resources |
| Aquatic foodbase |
| Foodbase species composition, population structure, density, and distribution in Glen and Grand Canyon reaches.<br>Analysis: Probable effects of BHBF on composition, recovery rates of algal, macroinvertebrates and effects on organic drift. |
| Humpback chub, Razorback sucker, Flannelmouth sucker, other native fish, Rainbow trout |
| Number of successfully reproducing populations (including single trout population in Lees Ferry reach).<br>Estimated number of successfully reproducing adult fish (creel catch rate; electrofishing catch rate by size class as an index of population size)<br>Survival of juveniles and subadults<br>Recruitment<br>Growth rate<br>Relative condition (length/weight relationship) |

**Modeling Component**

The sand budget is the net amount of sand in metric tons that has accrued in the river channel over some period of time. In the Paria River, the two primary sand input periods are July through October and January through March (Figure 4). During these two periods, sand is being accumulated at a higher rate than in the remaining months. This progressive accumulation of sand is the fundamental basis of the store and release approach. If this inquiry was just about optimizing sand conservation, the release months would be November and April; however to accommodate the decision process that follows the modeling and to address other resource needs or concerns, the HFE windows were broadened to October-November and March-April. As this decision process is refined and made more efficient with the experience of conducting HFEs, it is likely that the time necessary to make HFE decisions can be decreased, when it is advantageous to do so.

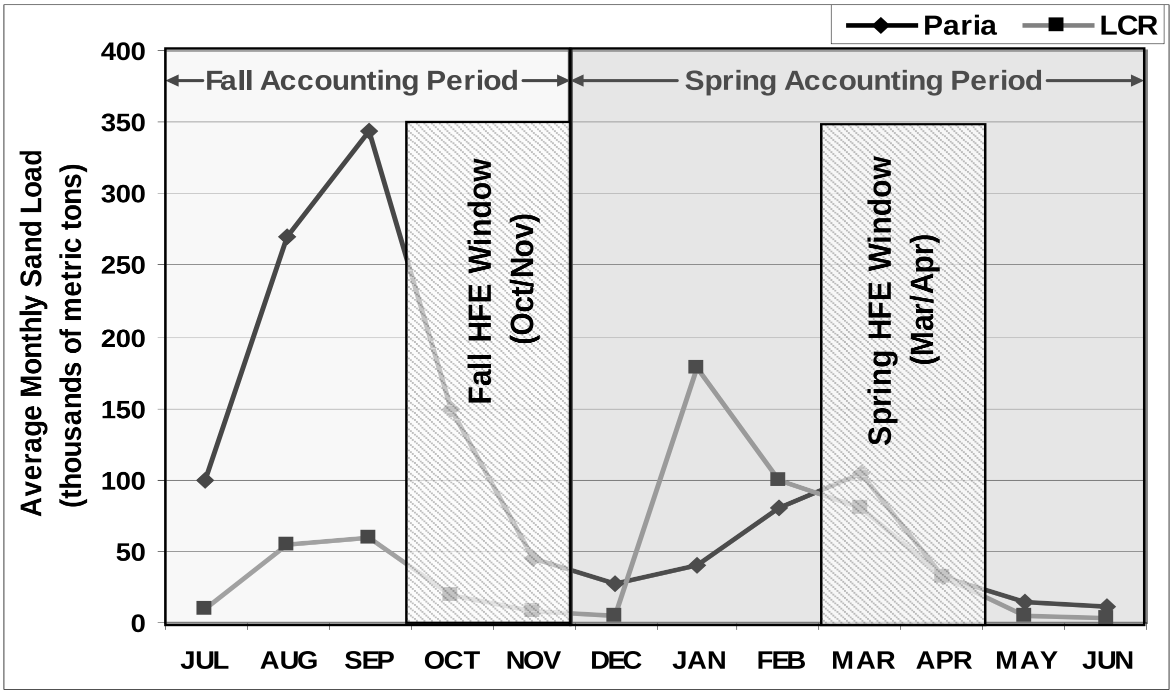



**Figure 4. The two sand accounting periods and the two high-release periods with average monthly sand loads for the Paria River and the Little Colorado River (adopted from Scott Wright, U.S. Geological Survey, personal communication).**

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. The Little Colorado River input cycle largely follows the same accrual periods as the Paria River; however, only sand inputs from the Paria River would be used in HFE modeling recommendations.

The modeling component is based on four key analysis phases associated with the two sand budget accounting periods and the two HFE windows.

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

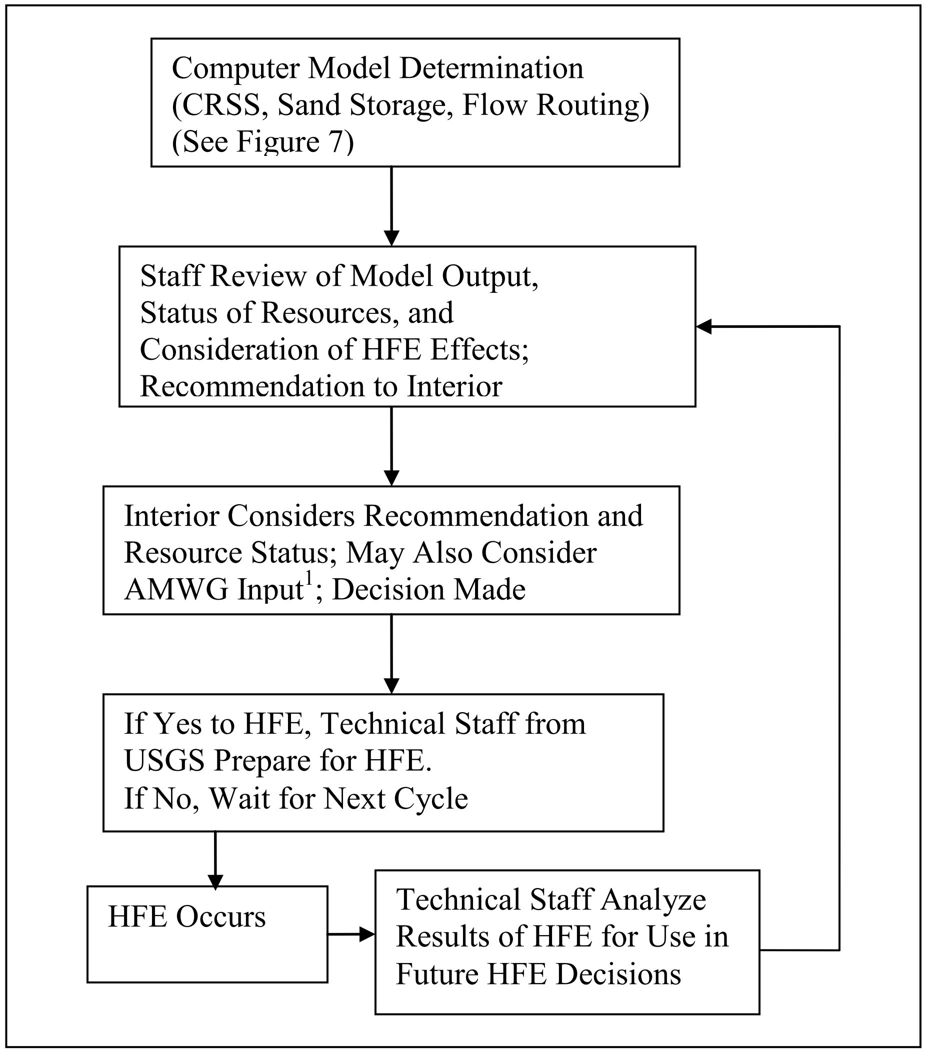
**Phase 2** – October-November HFE window. Beginning October 1, sand storage and forecast hydrology are evaluated using the sediment budget model to determine whether conditions are suitable for an HFE. The model determines what magnitude and duration of the HFE, if any, will produce a positive sand balance at the end of the accounting period. If the model produces a positive result, the largest HFE that will result in a positive mass balance is forwarded to the decision and implementation component (see section 2.2.4.3), which also allows for other factors (biological, economic, societal) to be considered in the planning process. During the decision process, sediment input would continue to be measured, the model would continue to be run and results or output would be forwarded to decision-makers to allow for refinement of the previously recommended magnitude and duration of the HFE. If the model produces a negative result, the model will be rerun using more recent sediment input to determine whether a positive mass balance will be reached in time to have an HFE in the release window.

**Phase 3** – Spring accounting period. The spring accounting period is December 1 to June 30. 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, whether or not an HFE has occurred.

**Phase 4** – March-April HFE window. The evaluation in this phase is the same as for the October-November HFE window (see Phase 2) with the model output being forwarded to the decision and implementation component. The model output would be used in the same way as for the October-November determination. 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. Whether or not an HFE is scheduled, sediment inputs would continue to be monitored through the end of the spring accounting period for use in the next accounting period.

**Decision and Implementation Component**

The third component of the HFE Protocol is decision and implementation component for conducting an HFE (Figure 5). This component could span a portion or most of the HFE window, depending on when conditions are deemed suitable for an HFE. The output from the model runs described above is used to determine if sediment and hydrology conditions are suitable for an HFE of a given magnitude and duration. If the scenario that is identified by the model cannot be implemented because of facility limitation to 42,000 cfs or less (see section 1.10.1), the range of magnitude and duration identified in this assessment would need to be modified. The loss of 45,000 cfs HFEs would result in a reduction from 13 to 5 scenarios as modeled (see Table 4) and not include HFEs of greater than 41,500 cfs for 1 hour. It would likely be necessary to redefine the magnitude and duration so that the full range of HFEs could be adequately tested. Because this assessment has considered the effects of 45,000 cfs HFEs for 1 to 96 hours, it also serves to assess the effects of HFEs at lower magnitudes and equivalent durations.




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

**Figure 5. Decision and implementation component of HFE protocol.**

Because the model only considers water and sediment, an added 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 managers. Managers 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 in cooperation with other agencies. If not, the process would be repeated during the next accounting window. For each HFE, technical staff would analyze results and integrate information from other HFEs for use in future HFE decisions.

The decision process could result in an HFE being considered whether or not a positive sand balance is projected. Caution would need to be exercised, however, because the sand mass balance only accounts for the difference between inputs and outputs, and does not adequately portray the degradation of sand already resident in the river channel. Successive HFEs or intervening periods of degradation without HFEs could negatively impact the ability of future HFEs to form sandbars and beaches. Furthermore, this degradation could impact other resources and it is advisable to ensure that the net amount of sand in the river channel is not depleted so as to compromise other ecosystem components. The output of the model would be integrated with an assessment of the status and trend of other resources, as an acknowledgement that the decision cannot be focused solely on the condition of the sediment to ensure that the decision fully encompasses the impacts on all important resources.

**Operation in Accordance with the 2007 Interim Guidelines**

The decision making process would be in conformance with Reclamation's obligations to deliver water under existing law including under the December 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). Reclamation will not implement an HFE that is inconsistent with the 2007 Interim Guidelines. The 2007 Interim Guidelines provide that the Secretary may consult with the Basin States as appropriate; Reclamation will consult with the Basin States prior to undertaking an HFE. Reclamation will utilize the most current information available in the Colorado River Annual Operating Plan 24-month Study to ensure that an HFE will not alter annual water deliveries under the 2007 Interim Guidelines. An HFE would only be conducted if it would not alter annual water deliveries or the operational tiers or elevations that would have otherwise been dictated by the 2007 Interim Guidelines in the absence of an HFE.

### 2.2.4 Operation of Glen Canyon Dam to Achieve HFE Protocol

The scenarios considered below describe how Reclamation would modify the operation of Glen Canyon Dam to reallocate monthly volumes when necessary to achieve high flow events as called for by the HFE Protocol. Implementation of the protocol for HFEs from Glen Canyon Dam will be done in concert with coordinated river operations. 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 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a) for lower basin shortages and the coordinated reservoir operations (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 (USFWS 2007a). Based on the conditions and criteria of the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a), projected monthly Glen Canyon Dam release volumes for the period 2009–2012 are provided in Table 8 for dry, medium, and wet conditions.

**Table 8. No Action Glen Canyon Dam releases under dry (7.48 maf), median (8.23 maf), and wet (12.3 maf) conditions, 2009-2012 (Interior 2007).**

| | 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 |

Reclamation operates Glen Canyon Dam pursuant to the December 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead (Interim Guidelines) and consistent with other laws and guidance including the 1996 Record of Decision (ROD) on the Operation of Glen Canyon Dam, the Operating Criteria for Glen Canyon Dam, the Final Environmental Assessment: Experimental Releases from Glen Canyon Dam, Arizona, 2008 through 2012 (Reclamation 2008). Pursuant to the 2007 Colorado River Interim Guidelines, the annual release volume from Lake Powell is projected and updated each month in response to the monthly 24-Month Study model run. This projected annual release volume is allocated to produce projected monthly release volumes and becomes the basis for scheduled monthly releases from Glen Canyon Dam. It is important to note that, regardless of the timing of releases, implementation of the HFE Protocol would not affect annual release volumes.

The HFE Protocol is anticipated to call for high flow events during a fall HFE implementation period (October and November) and a spring HFE implementation period (March and April). High flow events under the HFE Protocol could require more water than what is scheduled for release through the coordinated operating process described above. In order to perform these high flow events called for by the HFE Protocol, reallocation of monthly releases from Glen Canyon Dam may be necessary. Monthly reallocations for an HFE would not affect annual release volumes.

**Potential Operation of Glen Canyon Dam during the Fall HFE Implementation Period**
When releases during October are not scheduled to be steady and consistent with September releases, pursuant to the 2008 Experimental Releases EA, Reclamation would reduce release volumes during October to conserve water for potential high flow events. If the annual release volume was projected to be 8.23 maf or less, the monthly release volume for October could be scheduled at 500,000 acre-feet (500 kaf) in order to conserve water for potential high flow events. If the annual release volume was projected to be greater than 8.23 maf, the monthly release volume for October could be scheduled at 500 kaf or greater without impacting potential high flow events.

Reclamation would attempt to achieve fall high flow events by lowering the remaining shoulder days within the fall HFE period to the degree practicable up to as low as allowed under the Operating Criteria for Glen Canyon Dam and 1996 Record of Decision in order to release the projected October and November volume in the 24-Month Study. Reclamation would conduct high flow events as soon as practicable within the fall HFE implementation period. If the fall high flow event could be achieved within the release volume projected for October and November in the 24-Month Study, no reallocation of the monthly volumes from other months would need to be performed.

If Reclamation determined that it would not be possible to achieve the high flow event within the monthly release volume projected for October and November, Reclamation would reduce the projected monthly release volumes as necessary for the following December through March period. For these months, the projected monthly release volumes would be reduced to the minimum MLFF thresholds of 600 kaf and 800 kaf as practicable and reductions would be reallocated to October and November. This process would be performed in reverse order where practicable from March to December (i.e., where March would first be lowered to 600 kaf, then February to 600 kaf, then January to 800 kaf and finally December to 800 kaf). Reallocation would only be conducted up to the amount necessary to result in the projected monthly volume for October and November being sufficient to conduct the high flow event. If additional reallocation of the monthly volumes is required to achieve the high flow event, Reclamation would approach this with the intent of protecting the release volume for December and January to be at least 800 kaf.

**Potential Operation of Glen Canyon Dam during the Spring HFE Implementation Period**
Reclamation would attempt to achieve spring high flow events by lowering the remaining shoulder days within the spring HFE implementation period to the degree practicable up to as low as allowed under the Operating Criteria for Glen Canyon Dam and 1996 Record of Decision to release the volume projected for March and April in the 24-Month Study. Reclamation would conduct high flow events as soon as practicable within the spring HFE implementation period. If the spring high flow event could be achieved within the release volume projected for March and April in the 24-Month Study no reallocation of the monthly volumes from other months would need to be performed.

If Reclamation determined that it would not be possible to achieve the high flow event within the monthly release volume projected for March and April, Reclamation would reduce the projected monthly release volumes as necessary for the following May through August period. For these months, the projected monthly release volumes would be reduced to the minimum MLFF thresholds of 600 kaf and 800 kaf as practicable and reductions would be reallocated to March and April. This process would be performed in order where practicable from May to August (i.e., May would first be lowered to 600 kaf, then June to 600 kaf, then July to 800 kaf and finally August to 800 kaf). This reallocation process would only be conducted up to the amount necessary to result in the projected monthly volume for March and April being sufficient to conduct the high flow event. If additional reallocation of the monthly volumes is required to achieve the high flow event, Reclamation would approach this with the intent of protecting the release volume for July and August to be at least 800 kaf.

### 2.2.5 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 (GCDAMP). The GCDAMP is administered through a designated senior Department of the Interior official who chairs the Adaptive Management Work Group (AMWG). Pursuant to the Grand Canyon Protection Act, the AMWG provides advice and recommendations to the Secretary of the Interior relative to the operation of Glen Canyon Dam. Implementation procedures will follow guidelines issued by Interior for incorporation of adaptive management into NEPA compliance (Interior 2003) and take into account recommendations issued by the NEPA Task Force to the Council on Environmental Quality (2003). These procedures provide guidance on addressing uncertainty, monitoring, public participation, communication and permitting or other regulatory requirements.

**Adaptive Management Science through the GCDAMP**
The details of the HFE 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 Interior. 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 HFE Protocol and the

adaptive management process. The 10-year high-flow protocol lays the foundation for a process of "learning by doing," which is another fundamental principle of adaptive management.

A draft HFE science plan, prepared by GCMRC, 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 GCDAMP. This plan was drawn from the FY 2011 and FY 2012 Work Plans of the GCDAMP. Similar science plans were developed for the experimental flow treatments and mechanical removal activities in water years 2002-2004 (USGS 2003) and for the 2008 HFE (USGS 2007a). In addition, a Strategic Science Plan has been developed to support the GCDAMP (USGS 2009).

Continuing 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. 2006) and 2007 (USGS 2007a). Highly qualified scientists with expertise in fields of science relevant to Grand Canyon issues would ensure that the most accurate and up-to-date information is used in developing the final HFE 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 HFE 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. 2006). 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 variables (i.e., sediment and water temperature) was relatively certain to uncertain. However, the assessment also concluded that response directions for the aquatic foodbase and fish were uncertain or highly uncertain. This knowledge assessment has not been reevaluated since 2005, but the process for conducting the next assessment is underway and will be completed in 2012 through the GCDAMP. 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 on beaches and sandbars but will have less certain effects on biotic resources (see Kennedy and Ralston 2011).

A corollary process being conducted through the GCDAMP is the development of desired future conditions for resources of high importance to the program. A set of desired future conditions has been drafted and is presently moving through a process for recommendation to the Secretary of the Interior. Priorities associated with the desired future conditions include protection and recovery of humpback chub; sediment in the Grand Canyon and its importance to so many other resources; non-native fish control, and the recreational rainbow trout fishery at Lees Ferry. When adopted, very likely during the duration of this proposed action, they will serve as a basis for determining through resource monitoring whether these desired conditions are being achieved by the GCDAMP.

Reclamation has conducted three high flow tests in 1996, 2004, and 2008. These tests have shown valuable findings about resource responses, but they have also revealed unknowns and uncertainties that need to be addressed as part of this HFE Protocol. Uncertainty of outcome is an inherent aspect of experimentation conducted under adaptive management. Uncertainty can be expressed as testable models, however, and can be addressed through a monitoring system established to ensure that outcomes are detected before they negatively impact resources of concern. The research and monitoring identified in the accompanying draft HFE science plan, coupled with a workshop of scientists and managers to refine the plan, are important components of addressing the uncertainty. The following two over-arching questions relate to sand conservation and impacts to other resources and are a main focus of the science plan:

- Over-arching Question #1: Is there a "Flow Only" operation (that is, a strategy for dam releases, including managing tributary inputs with HFEs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal timescales? (USGS 2007a, 2009)
- Over-arching Question #2: Can an HFE Protocol be implemented without causing significant impacts to other resources?

Key research questions will be tiered from the over-arching questions and addressed in greater detail in the final HFE science plan. These research questions include, but may not be limited to the following:

- Research Question #1a: 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?
- Research Question #1b: Are there optimal times to conduct high flows in regard to sediment building, humpback chub survivability, and ecosystem response?

Summary: 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: What is the effect of HFEs on humpback chub and native fish populations located downstream from Glen Canyon Dam?

Summary: Ongoing research and monitoring of humpback chub and native fish populations downstream from 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 non-native predators and competitors. The humpback chub population declined from about 11,000 adults in 1989 to about 5,050 adults in 2001, and subsequently stabilized and increased to 7,650 adults in 2008 (Coggins and Walters 2009). Focused investigations are needed to better understand how aspects of an HFE (timing, magnitude, duration, frequency) affect these native fish populations, including nearshore habitat, dispersal of young from the Little Colorado River, foodbase, and predation and competition by non-native fish species.

- Research Question #3: Is sediment conservation more effective following a sediment enrichment period in the context of multi-year, multi-event experiments?

Summary: 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 releases are made under an established HFE Protocol during sediment-enriched conditions.

- Research Question #4: Is sediment conservation more effective when an HFE is held in rapid response to sediment input from the Paria River?

Summary: 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, from coarse sand and fine organic matter, that will help to build sandbars and beaches and provide nutrients for riparian plants and backwaters. A rapid response HFE will require real-time monitoring of the Paria River to accurately determine the sediment load, protocols for timely responses by dam operators to Paria River inputs, and public notices to ensure safety for recreational users and property owners. At this time, these requirements have not been met.

- Research Question #5: How can erosion of sandbars after an HFE be minimized or offset?

Summary: 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 #6: What is the effect of a fall HFE on the foodbase at Lees Ferry?

Summary: Monitoring of the spring 1996 and 2008 HFEs showed scouring of a large portion of the foodbase 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 foodbase at a time when photoperiodicity and hence, photosynthesis are reduced, and recovery of the foodbase would be delayed until the following spring.

- Research Question #7: What is the effect of a fall HFE on the trout population at Lees Ferry?

Summary: 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, downstream mechanical removal of trout). Fall HFEs should be tested for their effects on the rainbow trout population.

- Research Question #8: What effect would consecutive HFEs (spring followed by fall, or fall followed by spring) have on the foodbase and trout population at Lees Ferry?

Summary: Consecutive HFEs at intervals of a year or less 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 foodbase and trout population and needs to be tested.

- Research Question #9: What is the relationship of high-release magnitude and duration on the extent of foodbase scouring in the Lees Ferry reach?

Summary: High-flow releases of 41,000 to 45,000 cfs were shown to scour about 90 percent of the foodbase on sediments and much of the foodbase 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 foodbase.

- Research Question #10: Is it possible to manage the Lees Ferry trout population with a spring HFE held at slightly different times than previous spring HFEs?

Summary: The peak of rainbow trout spawning in Lees Ferry is early March. High-flow releases 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 potentially negatively 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 the trout population. A healthy trout population in the Lees Ferry reach is a desirable resource. Conditions that encourage emigration downstream and rainbow trout population increase at the mouth of the Little Colorado River are not desirable, because rainbow trout are documented predators of the endangered humpback chub and other native fish.

**Public Involvement**

As part of the adaptive management process, Reclamation has conducted three HFEs (1996, 2004, and 2008) and three HMFs (1997 and two in 2000). 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 HFE Protocol. The effects of each HFE have been documented to provide this information to the scientific community and to the public, including the 1996 HFE (Webb et al. 1999), and the 2004 and 2008 HFEs (Gloss et al. 2005; Korman et al. 2011; Makinster et al. 2010a, 2010b; Ralston 2010; Rosi-Marshall et al. 2010, Melis 2011). 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 HFE 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 published in the *Federal Register* on December 31, 2009 (74 FR 69361) to develop an experimental high flow 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 and in December 2010, where comments on the proposed action were received (Reclamation 2010b).

In addition to scoping, Reclamation also used available information from an assimilation and synthesis of information by the U.S. Geological Survey on the three HFEs in Grand Canyon (Melis 2011). 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.

# 3 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 physical, biological, cultural, and socio-economic. Each of these categories is further divided into specific resources for the impact analysis, as described in Table 1 (see section 1.8). In addition to addressing resource-specific impacts, this EA also addresses ten issues identified in public scoping (see section 4.2), as required by federal regulations 40 CFR 1501.7 and 40 CFR 1508.25. This document assesses whether this HFE Protocol could be accomplished during 2011 through 2020 without significant adverse impacts to nine key resources under the four categories. Resource analysis includes a consideration of direct, indirect, and cumulative impacts in accordance with CEQ and Interior regulations, and are summarized for single and multiple HFEs in Tables 18 and 19. A biological assessment was also conducted to address the effects of the proposed action on five threatened and endangered species (see Appendix C).

In order to better define the proposed action for 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 time for the high dam release from the start of up-ramp to the end of down-ramp; 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) is also included in the analysis of more than one HFE. 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 of different timing, magnitude and duration, and an even larger number of combinations of sequential HFEs that could be triggered through the decision-making process of the proposed HFE Protocol (see Tables 4 and 5). 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 these impacts increases with the number of consecutive HFEs, particularly if HFEs are of a magnitude and duration not previously tested.

The assessment for single HFEs evaluates impacts for the October-November and March-April periods, each at magnitudes of 31,500–33,200 cfs (for 1-8 hours) and 41,000–45,000 cfs (for 1-48 and 60-96 hours). The release magnitude of 31,500–33,200 cfs is the theoretical powerplant capacity range, and 41,000–45,000 cfs represents the maximum release available from the eight units of the powerplant and the four bypass tubes, which have a capacity of 15,000 cfs. Prior HFEs have been conducted at 31,000 cfs, 41,000 cfs, 41,500, and 45,000 cfs, and there is a knowledge gap for HFEs between 31,000 cfs and 41,000 cfs.

The assessment for two or more HFEs evaluates impacts for a spring (March-April) HFE followed by a fall (October-November) HFE, and for a fall HFE followed by a spring HFE, as well as more than two consecutive HFEs, each with a magnitude of 41,000-45,000 cfs. Larger magnitude and longer duration HFEs are assessed with the assumption that they have greater impacts than lower magnitude and shorter duration HFEs, and we presume that the impacts of lesser HFEs are adequately evaluated in the assessment of the larger magnitude and longer duration HFEs. This presumption is based on results of studies done on previous high flow release experiments (Table 9).

The six HFEs that have been conducted in Grand Canyon have been independent single events. The impacts of these were evaluated, documented, and used to provide baseline information for the impact analysis of this EA (Table 9). Study results of HFEs varied and were more complete for some events and resources than others, and it was difficult to determine if the HFEs had achieved their desired effects.

The spring 1996 HFE was a 7-day release of 45,000 cfs preceded and followed by 4 days at 8,000 cfs. The decision to undertake the first HFE was inspired by a need to show that short duration high flows had the potential to improve the condition of many desired resources, including sandbars and beaches (Schmidt et al. 1999). The experiment was considered a success in terms of the amount that was learned from the high-flow release, although monitoring of the rebuilt sandbars and beaches over the ensuing months showed ongoing erosion and export of sediment. This HFE revealed that sediment redistribution could be accomplished in less than 7 days, but that post-HFE flows were likely to continue to erode sandbars and beaches. The 2004 and 2008 HFEs were each 60 hours long and 41,000 cfs to 41,500 cfs with moderately enriched and enriched sediment concentrations, respectively. Sand storage and sandbar volume was greater following the 2008 HFE.

The November 1997 HFE was a 3-day release of 31,000 cfs designed to conserve sediment and maintain habitats, as described in the 1995 EIS. This high flow test was conducted during a period of high releases (maximum daily flows for October to December exceeded 19,000 cfs) in which there was high sediment transport that reduced the amount of available sediment and did not noticeably increase sandbar volume.

The May and September HFEs of 2000 were each 3-day releases of 31,000 cfs that took place before and after the low-steady summer flow release of 8,000 cfs from June 1 to September 4, 2000. The two high releases were habitat maintenance flows (HMFs) designed to conserve sediment and maintain habitats. The May HMF resulted in a small increase in sandbar volume and impounding of the Paria River and Little Colorado River inflows to provide a warm environment for newly-hatched native fish escaping from these tributaries. The September HMF resulted in a notable increase in sandbar volume and reduced densities of small-bodied non-native fish in the short-term.

**Table 9. 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 Section 3.**

| Parameter | 1996 HFE | 1997 HFE | 2000 HFE | 2000 HFE | 2004 HFE | 2008 HFE |
|---|---|---|---|---|---|---|
| Timing | Mar-Apr | Nov | May | Sep | Nov | Mar |
| Magnitude | 45,000 cfs | 31,000 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 |
| Sediment | Successful redistribution of sediment onto sandbars and beaches, but effect was short-term (months). | Occurred during high flow months; no notable increase in sandbar volume. | Small increase in sandbar volume; impounding of tributary inflows but little thermal mixing. | Notable increase in sandbar volume; short-term decrease in small-bodied non-native fish. | Moderately enriched sediment concentrations in upper Marble Canyon produced sandbars larger than 1996 HFE, but downstream from RM 42 only 18 percent of sandbars were larger. | Sand storage in Marble and Grand canyon's was substantially greater than preceding 2004 HFE; large increase in sandbar volume. |
| Aquatic foodbase | 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 of some taxa, enhanced production of others, recovery after 16 mo; improved fish food quality[20]. |
| Kanab ambersnail | Estimated 17 percent of vegetation and snails scoured; recovered in 2.5 years. | Not studied. | Not studied. | Not studied. | Plots of vegetation moved and replaced; recovered in 6 months.[22] | Plots of vegetation moved and replaced; recovered in 6 months. |
| 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] |

| Parameter | 1996 HFE | 1997 HFE | 2000 HFE | 2000 HFE | 2004 HFE | 2008 HFE |
|---|---|---|---|---|---|---|
| Timing | Mar-Apr | Nov | May | Sep | Nov | Mar |
| Magnitude | 45,000 cfs | 31,000 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 |
| Endangered fish | No population effects detected[5]; Creation of backwater habitat [6,7,8] | 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 habitat[6,8]; 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 non-native 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. 2011
7 Andrews 1991
8 Brouder et al. 1999
9 Speas et al. 2004
10 Shannon et al. 1998
11 Speas et al. 2002
12 Persons et al. 2003
13 Shannon et al. 2002
14 Trammell et al. 2002
15 Lauretta and Serrato 2006
16 Ackerman 2007
17 Makinster et al. 2010a
18 GCMRC, unpublished data
19 Grams et al. 2010
20 Rosi-Marshall et al. 2010
21 Cross et al. in press
22 Sorenson 2005

## 3.1 Physical Resources

Physical resources are those natural resources that are the inorganic components of the ecosystem, including water, air, and sediment. Effects of the no action alternative are identified in previous EISs (Reclamation 1995, 2007) and/or BOs (USFWS 1995, 2008, 2009) and are incorporated herein by reference.

### 3.1.1 Dam Releases under No Action

Under no action, monthly, daily, and hourly releases from Glen Canyon Dam would continue to be made consistent with the MLFF of the 1996 ROD (Interior 1996) and annual releases would be made in compliance with the 2007 ROD (Interior 2007) on 2007 Colorado River Interim Guidelines (Reclamation 2010) for lower basin shortages and coordinated operations. The ongoing program of experimental releases with steady flows from September 1 through October 31 would be in effect for the period 2008 through 2012 (Reclamation 2008). Details of annual and monthly projected dam operations are provided in the cited documents. Table 8 presents the most probable future values for monthly releases if no action is taken.

Reclamation's conclusion is that the no action alternative is not likely to affect dam releases including annual volumes delivered from Lake Powell.

### 3.1.2 Dam Releases under Proposed Action

The HFE Protocol will call for high flow events during a fall HFE implementation period (October-November) and spring HFE implementation period (March-April). High flow events under the HFE Protocol could potentially require more water than what is scheduled for release through the coordinated operating process. In order to perform these high flow events as prescribed by the HFE Protocol, reallocation of monthly releases from Glen Canyon Dam may be necessary. If Reclamation determines that it is not possible to achieve the high flow event within the monthly release volume projected for October-November or March-April, Reclamation will adjust the projected monthly release volumes as necessary for the following December through March period or May through August period, respectively.

The timing, magnitude, and duration of HFEs will not affect annual water year volumes because Reclamation plans to reallocate water within or among months to achieve the necessary volume. The frequency of HFEs is not currently known, but modeling indicates that more than one HFE per year and more than two consecutive HFEs are likely. Given that Reclamation plans to reallocate water within or among months to achieve the necessary volume, dam operations will not be adversely impacted over the 10-year period of the HFE Protocol.

### 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 of the reservoir, or hypolimnion, and ranges from about 9ºC to 12ºC. During 2004 and 2005, lowered reservoir levels caused the withdrawal of 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 about 9–12ºC.

A suite of water quality parameters is measured as part of monitoring 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.

Reclamation's conclusion is that the no action alternative is not likely to change water quality from what has been observed under previous MLFF operations.

### 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 river 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 would increase slightly.

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. The initial increased flow volume not the duration of the flow produced the scour (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.

Reclamation's conclusion is that the range of timing, magnitude, and duration of HFEs considered in this assessment will have minor short-term impacts on water quality of Lake Powell and the Colorado River below Glen Canyon Dam. The minor impact will be due to a slight reduction in downstream temperature and a slight increase in salinity, as well as a temporary increase in turbidity from scouring. The frequency of HFEs is not currently known, but modeling indicates that more than one HFE per year and two or more consecutive HFEs are likely. Because effects of an HFE on water quality are short-lived, impacts to water quality from more than two HFEs are not expected to be greater than single HFEs.The impact of HFEs on the water quality of Lake Powell will depend on reservoir elevation. At moderate to high reservoir levels, withdrawal of water for HFEs is not expected to negatively affect water quality in the reservoir. Releases in March-April would occur during the spring recirculation period of the reservoir, and releases in October-November would occur at the end of the thermal stratification period when surface temperatures are the warmest (Vernieu 2010). At low reservoir levels, such as during 2005, water released for an HFE could draw from the warm top layer of the reservoir, especially in October-November and result in warm dam releases, but would not likely affect the overall reservoir temperature or water quality.

### 3.1.5 Air Quality and Climate under No Action

The Clean Air Act, as amended (42 USC 7401) established Prevention of Significant Deterioration (PSD) provisions to help protect the nation's air quality and visibility. Under the PSD provisions, Grand Canyon National Park is a Class I Area, with the most stringent requirements for air quality, while Glen Canyon NRA is a Class II area. The counties encompassing the park are in attainment status for National Ambient Air Quality Standards (NAAQS). Currently, air pollution in Coconino and Mohave counties comes from four principle sources: dust and other local particulates, prescribed burns, regional haze, and coal-fired power plants.

The EPA's Air Quality System and National Emission Inventory databases show good air quality in the Grand Canyon region (http://www.epa.gov/ttn/airs/airsaqs). 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 from Glen Canyon Dam) 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. An additional primary source of particulates to the air is automobile emissions.

Reclamation's conclusion is that under no action, air quality in the Grand Canyon region is expected to remain high, but subject to other sources of pollution external to the canyon.

### 3.1.6 Air Quality and Climate Change 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 and contributions of emissions from these plants of greenhouse gases, which have the potential to affect climate. The assessment done here presumes that all replacement hydropower or energy (due to water being bypassed and not passed through the turbines) comes from coal-fired generation, but the replacement power is likely to come from a mix of energy sources 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 10 illustrates the estimated additional $CO_2$ inputs from high flows of 45,000 cfs, based on an average emission rate in the United States from coal-fired generation of 2,249 lbs/MWh of carbon dioxide, 13 lbs/MWh of sulfur dioxide, and 6 lbs/MWh of nitrogen oxides (Environmental Protection Agency 2010).

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, of regional emissions. HFEs of duration greater than 36 hours could result in $CO_2$ emissions greater than the 25,000 metric tons of $CO_2$ that requires Clean Air Act reporting. 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. These emissions would be reported by fossil fuel generating facilities, of which there are many in the area receiving energy from Glen Canyon Dam, and would not be specifically quantifiable to a particular source.

The proposed HFEs with the attendant requirement for replacement power are expected to have minor short-term impacts on air quality and climate change, and the long-term impact is not expected to be substantial because the effects to air quality would be expected to dissipate between HFEs.

Reclamations concludes that the effects on air quality and climate change from the proposed action would be minor and temporary.

**Table 10. Megawatt hours of lost electrical generation and subsequent additions of $CO_2$ are emitted for every MWh produced (Environmental Protection Agency 2010). 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

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 (Topping et al. 2007, 2010). 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.

Geomorphologists believe that Grand Canyon sandbars will continue to degrade due to the existence and operation of the dam, and it is hypothesized that dam operations, particularly high flows, may be used to rebuild, conserve, or enhance sandbars, particularly when combined with significant tributary sediment inputs (Schmidt et al. 1999; 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 operation (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).

Reclamation's conclusion is that under no action, without any HFEs, uninterrupted sediment erosion would continue and beaches and sandbars would decrease in area and volume as in the periods between HFEs in Figure 6.

### 3.1.8 Sediment under Proposed Action

The HFE Protocol evaluated in this EA is designed to provide experiments that will determine how best to restore and improve sandbars and beaches as a means of conserving sand and sediment in Grand Canyon. A hypothesis to be tested with this action is that multiple HFEs under sediment enriched conditions will rebuild, conserve, and better maintain sandbars, 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) provided insight into the possible effect of an HFE on sand storage in each of four reaches of the Colorado River (Table 11; 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 (Topping et al. 2010).

**Table 11. 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 |

Reclamation believes that these high-flow experimental releases are critical in determining the potential for creating and sustaining high elevation beaches and sand bars in Grand Canyon, while not sacrificing the long term sustainability of the sediment supply. 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 from 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 a 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. With respect to the retention of sandbars thus created, Figure 6 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.

- 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.
- In contrast to the declining trend in total sediment storage prior to 1996, the HFEs of 1996, 1997, 2000, and 2004 each increased the amount of sand storage, for both mid-elevation and high elevation deposits.
- Initial increases in sand storage declined 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.

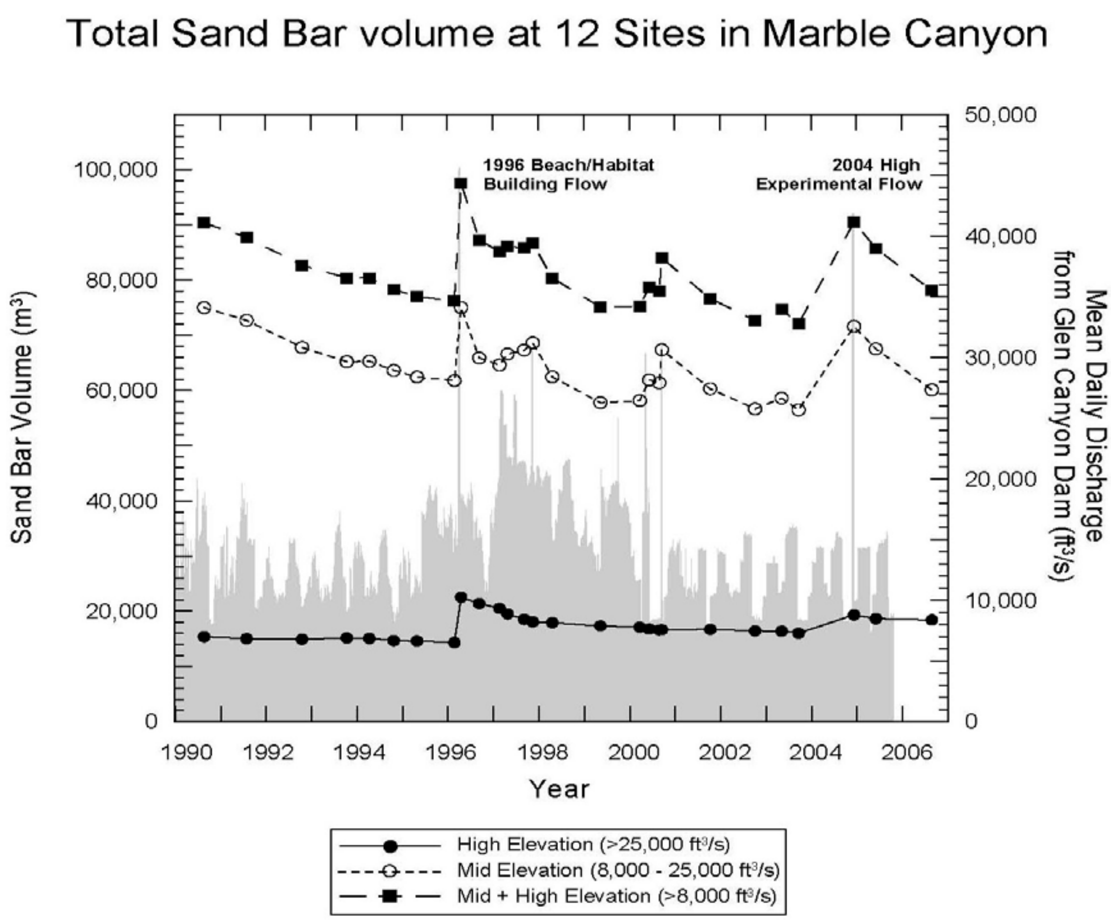



**Figure 6. Total sandbar volume at 12 sites in Marble Canyon.** ***Source:*** **J. Hazel, preliminary data courtesy of Northern Arizona University.**

High-volume MLFF releases from Glen Canyon Dam 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 remainder of the water year and exceeded 20,000 cfs for much of water year 1997. Following the 2004 HFE, high fluctuating winter releases designed to limit non-native trout spawning reached a daily maximum of 20,000 cfs for the January through March 2005 period (Reclamation 2008). 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 that reduced the amount of sediment transported downstream, allowing sediment accumulation in the Colorado River mainstem above RM 30 and the Little Colorado River confluence (USGS 2007b).

While it is generally expected that positive sandbar building will occur during a high flow test, it is difficult to predict the locations where sandbar building will occur, how long those effects 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 if there is a more sediment-enhanced 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 Canyon's was substantially greater than that preceding the 2004 HFE (Topping et al. 2010). As of August 2007, about 1.75 mmt (million metric tons) of fine sediment relative to October 2006 was still stored in the channel above the confluence of the Little Colorado River, with about 1.5 mmt above RM 30 (USGS 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 and longer lasting effects.

Under the HFE 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 7 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 produces less downstream transport and a greater amount of in-channel sediment accumulation. A wet hydrology condition means higher volume releases that transport more sediment on a daily basis and deplete the sediment in the channel. It should be noted that the numbers, frequency, magnitude, and duration of HFEs shown in Figure 7 are not likely to occur because a consistent condition of sediment and hydrology is unlikely over a 10-year period. Nevertheless, these illustrate the range of possibilities for the magnitude and duration of single as well as multiple HFEs.

An HFE of 31,500-33,200 cfs is expected to have a short-term beneficial impact from additional sediment stored in sandbars, beaches, and eddies up to the 33,200 cfs stage. An HFE of 41,000-45,000 cfs would also have a short-term beneficial impact from additional sediment stored in sandbars, beaches, and eddies up to the 45,000 cfs stage, with a temporary increase in number and area of backwaters expected. A high magnitude HFE of longer duration has the potential for better balancing sediment delivery between upstream and downstream reaches. No differences in sediment conservation are expected between spring and fall HFEs.

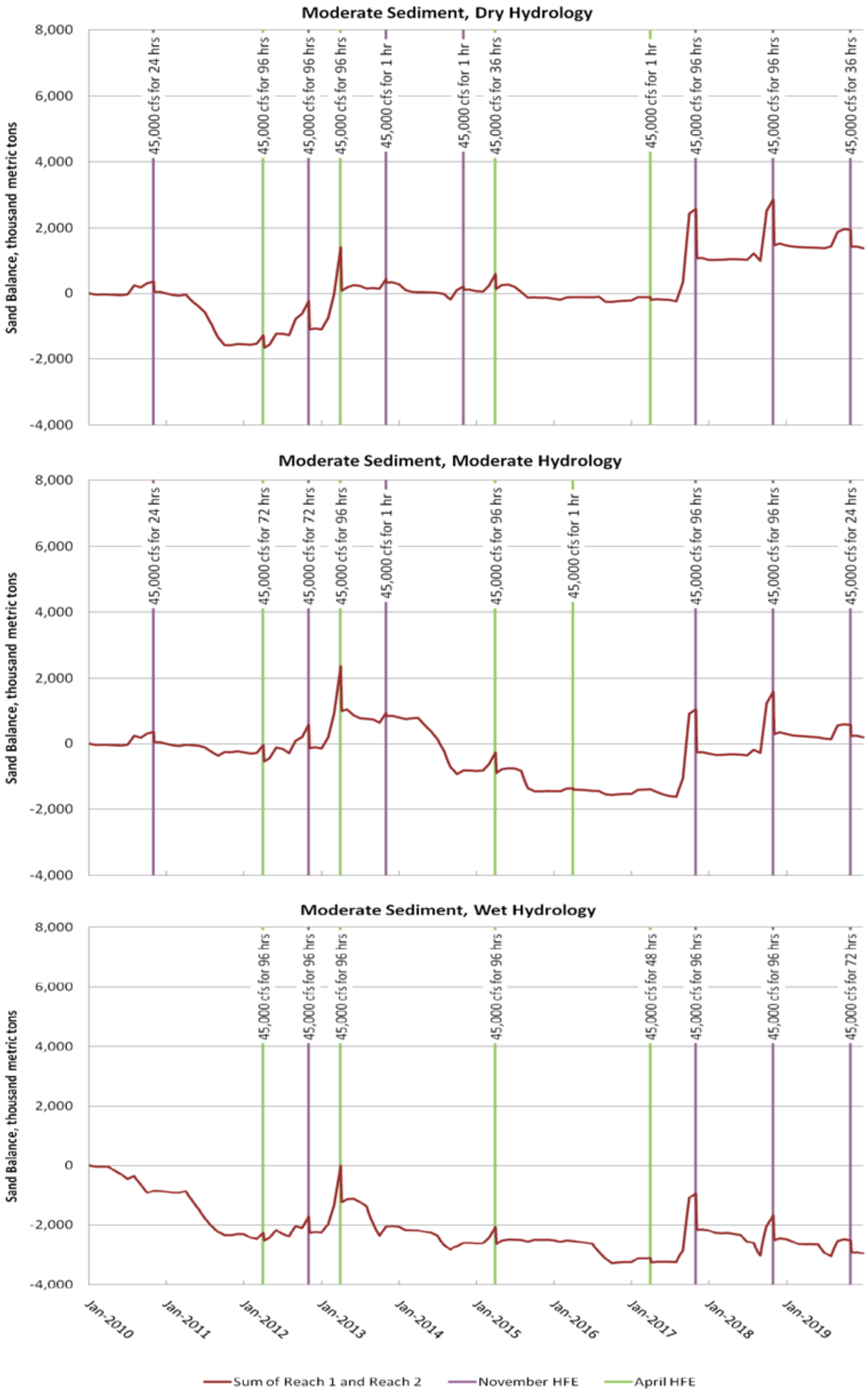



**Figure 7. Occurrence of described HFEs from model runs for moderate sediment with dry, moderate, and wet hydrology in reaches 1 and 2 (Russell and Huang 2010).**

Reclamation concludes that single or up to two consecutive HFEs (fall followed by spring, or spring followed by fall) are expected to have a beneficial impact from the additional sediment stored in sandbars, beaches, and eddies that may better balance the sediment budget. More than two consecutive HFEs are expected to have a long-term beneficial impact from the additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage if a positive sand mass balance is maintained. The effect of additional consecutive HFEs is more uncertain and more dependent on adherence to the commitment for a positive sand mass balance. Multiple consecutive HFEs have the potential for better balancing sediment delivery between upstream and downstream reaches and for long-term conservation of sediment to offset ongoing transport and erosion if a positive mass sand balance is maintained.

### 3.1.9 Effects of No Action on Backwaters

Backwaters can be an important rearing habitat for most native fish due to lower water velocity, warmer water, and higher levels of biological productivity than the main river channel (AGFD 1996), particularly under steady flows (Behn et al. 2010). The importance of backwaters in Grand Canyon with respect to the endangered humpback chub is uncertain. A key question associated with the proposed action is how HFEs function to form and maintain backwaters and how much the native and endangered 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 still water surrounded on three sides by sand deposits and open to the main channel environment on the fourth side. Reattachment sandbars are the primary physiographic 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). Their numbers also are river stage-dependent and dependent on preceding dam releases. 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.

As originally proposed in the 1995 EIS, restoration of backwaters has not been realized under the strategy of MLFF and hydrologically triggered experimental high flows (Lovich and Melis 2005). In the absence of high-flow releases under no action, backwaters would probably continue to fill with sediment and eventually transition to marsh-like habitats (Stevens et al. 1995; Lovich and Melis 2005).

### 3.1.10 Effects of Proposed Action on Backwaters

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 equalization flows, and then 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, equalization flows (over 13,000 cfs) and MLFF caused 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 being released annually from 2008 to 2012 under an experimental release program biological opinion (USFWS 2008, 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 related to river stage and dam operations, i.e. 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, unless sand storage is depleted by multiple HFEs. However, past post-HFE flows have eroded sandbars to pre-HFE conditions in as little as several weeks (Brouder et al. 1999). 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 Bennett (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 two or more consecutive HFEs is uncertain. Based on responses by the foodbase to scouring from multiple artificial floods in the River Spöl in Switzerland (Uehlinger et al. 2003; Robinson and Uehlinger 2008), 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 by high spring flows and yet are among the most productive habitats in the river (Grabowski and Hiebert 1989; Mabey and Shiozawa 1993), although these river reaches are seasonally warmed and not subject to cold dam releases.

Reclamation concludes that HFEs conducted under the proposed action are expected to rebuild and conserve sandbars and backwaters, which are considered to be a beneficial to the aquatic ecosystem and native fish. The persistence of these habitats is highly dependent upon the hydrology following the HFE.

## 3.2 Biological Resources

Biological resources covered in this section are those natural resources that are the organic components of the ecosystem, other than those addressed above under backwaters, including vegetation, terrestrial invertebrates and herptofauna, aquatic foodbase, fish, birds, and mammals.

Effects of the no action alternative are identified in previous EISs (Reclamation 1995, 2007) and/or BOs (USFWS 1995, 2008, 2009) and are incorporated herein by reference.

### 3.2.1 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).

Stands of emergent marsh vegetation in the riparian zone are dominated by a few species, depending on soil texture and drainage. A 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 that have not been disturbed for 7-28 years. These longer-lived species are expected to 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). NPS management policies require management of native species, including areas where disturbance has occurred. GCNP, Lake Mead National Recreation Area, and GCNRA have programs to manage for native vegetation within the park units.

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 GCNRA support ongoing programs under this executive order to control noxious weeds and invasive plants.

The most prominent of these invasive plants is tamarisk. Tamarisk grows as 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, has higher water use efficiency than native riparian trees in both mature and post-fire communities, and can tolerate an extreme range of environmental conditions. The plants accumulates salt in special glands in its leaves, and then excretes 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 first year of life (Warren and Turner 1975), but most begin to reproduce in their third year or later (Stevens 1989). Because tamarisk reproduce 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 $2.5 \times 10^8$ 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 and Penfound 1949).

Tamarisk leaf beetles (*Diorhabda* spp.) have been introduced to the Colorado River Basin and were discovered at Lees Ferry in 2009. By late 2010, they had colonized much of the riparian corridor of the Colorado River in Grand Canyon (Minard 2011). The effect of these beetles on the tamarisk population in Grand Canyon is not certain, but it is likely that they will defoliate and eventually kill many of the exotic trees. Loss of tamarisk could result in additional erosion of the riparian zone, temporary diminishment of avian, beaver and other riparian wildlife habitats, and a large increase in beetle biomass, at least in the short term, which could provide a food supply for insectivorous species.

Reclamation concludes that 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 successional backwaters; a mid-elevation band of water tolerant plants including willows and tamarisk, and a high elevation band with more xeric species (Ralston 2010). No action will allow noxious weeds and invasive plants, particularly tamarisk to proliferate throughout the riparian zone, but the tamarisk beetle is expected to exert considerable control on this species. Both GCNP and GCNRA will continue to support programs to control noxious weeds and invasive plants.

### 3.2.2 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, as was observed for the 1996, 2004, and 2008 HFEs. 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 would be expected to suppress plant reestablishment in the river channel and backwater marsh communities. 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. Coarsening of sand would favor clonal species such as arrowweed (*Pluchea sericea*), coyote willow (*Salix exigua*), and common reed (*Phragmities australis*). Sand coarsening and continued disturbance would be beneficial to restoring a greater proportion of clonal plant species to the riparian community. Hence, single or multiple HFEs conducted under this protocol are not expected to have adverse impacts on desirable vegetation, and may have beneficial effects by resetting successional stages of marsh development. Floods are resetting agents for marsh and wetland habitats and enhance species diversity and prevent monocultures. Periodic flooding and drying of wetland vegetation is beneficial to diversity and productivity (Stevens et al. 1995). Seed banks and fluctuating water levels interact in complicated ways to produce vegetation communities in riparian wetlands. Generally, seed germination is maximized with damp soil or shallow water conditions, after which many perennials can reproduce vegetatively into deeper water. Species composition, density, and biomass are all affected by flooding and drying, but as a rule, periodic flooding tends to benefit riparian wetlands and maintain their structure and function (Mitsch and Gosselink 2000).

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 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.

A principal concern with conducting one or more HFEs is the possibility that the high flow will carry and distribute tamarisk seeds. Tamarisk develops 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. Thus, the timing of the proposed HFEs largely is outside of the main seed-producing period. Seeds may not yet be present in March, however an April HFE could contribute to the spread of tamarisk. Porter (2002) found that flows of slightly lower magnitude (31,000 cfs) preceded an increased germination of non-native 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 (MLFF) operations following a disturbance that affects riparian vegetation response to a disturbance event (Kearsley and Ayers 1999; Porter 2002; Kearsley et al. 2006).

Defoliation and loss of tamarisk to tamarisk leaf beetles could greatly change the abundance, distribution, and population dynamics of this exotic plant in Grand Canyon. Regeneration of this plant likely will be greatly curtailed and distribution likely will be considerably diminished. If this is the case, concerns for HFEs contributing to the spread of this exotic species are expected to subside.

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.

Reclamation concludes that 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 through increased seed dispersal, 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. Frequent HFEs depositing large amounts of sand would likely bury and inundate sandbars, however, and reduce invasion and establishment of exotic plant species.

### 3.2.3 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 (dry) 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)* were 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. 2006). Of 27 sites in Glen Canyon and Grand Canyon where northern leopard frogs were previously found, USGS surveys indicate they are now extirpated, or probably extirpated, from 18 (Drost et al. 2008). This includes previously known sites in Grand Canyon National Park (downstream from Lees Ferry) and the majority of sites in Glen Canyon (including Horseshoe Bend). 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 2003-2004 only two adults were found in an off-channel pool in Glen Canyon (Drost 2004, 2005). Surveys since that time have not detected any leopard frogs. The 2009 Park Profile for Grand Canyon National Park (National Park Service 2009a) also lists the northern leopard frog as extirpated from GCNP.

The northern leopard frog (*Rana pipiens*) has been extirpated from about 70 percent of its range (Rorabaugh 2011) and in 2006 the USFWS was petitioned to list the frog in 18 western states. In 2009, the USFWS published a positive 90-day finding and is currently conducting a 12-month status review to determine if listing the species under the Endangered Species Act is warranted. Northern leopard frogs are currently listed as a species of conservation concern by several state and Federal agencies, including Arizona Game and Fish Department ("Species of Concern"), the State of Colorado ("Special Concern Species"), the U.S. Forest Service ("Sensitive)" Regions 2 and 3 (Colorado, New Mexico and Arizona), and the Navajo Nation ("Threatened").

The Kanab ambersnail (*Oxyloma haydeni kanabensis*) was listed as endangered in 1992. Recent evidence from anatomical and molecular genetics studies indicate that this is a geographically widespread taxon whose listing in 1992 may have been incorrect (Littlefield 2007). A five-year status review was initiated in 2006 by USFWS (USFWS 2006). Kanab ambersnails are found in the riparian vegetation at Vasey's Paradise, and at another spring-fed site that harbors a translocated population, Elves Chasm. The Elves Chasm population is above the elevation affected by river flows. The increase in cover, reduction in beach-scouring flows, and introduction of non-native water-cress (*Nasturtium officinale*) has led to a greater than 40 percent increase in suitable Kanab ambersnail habitat area at Vasey's Paradise from pre-dam conditions (Stevens et al. 1997a).

Under the no action alternative Reclamation concludes that terrestrial invertebrates and heptofauna will continue at their current status as will the endangered Kanab ambersnail populations at Vasey's Paradise and at Elves Chasm.

### 3.2.4 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. Two or more HFEs could displace greater numbers and prevent or delay recolonization. The impact to populations of terrestrial invertebrates and herptofauna is species-specific, depending on life history strategies and the locations of animals 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 therefore 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 Vasey's Paradise. Meretsky and Wegner (2000) noted that even at flows from 20,000 to 25,000 cfs (MLFF allows flows up to 25,000 cfs), only one patch of snail habitat is much affected (Patch 12), and a second patch to a lesser extent at flows above 23,000 cfs (Patch 11). Very few Kanab ambersnails have been found in patches 11 and 12 historically, and habitat in these patches is of low quality (J. Sorensen, AGFD, pers. comm., 2009). Maximum impact to Kanab ambersnail habitat at Vasey's Paradise would be to scour and displace about 17 percent of habitat at 45,000 cfs. HFEs of a lower magnitude would have less impact.

If the proposed HFE HFE Protocol is implemented, Reclamation would remove mats of ambersnail habitat in the anticipated inundation zone and relocate the habitat after the high flow subsides, as was done for the 2004 and 2008 HFEs. Additionally, all vegetation in the potentially flooded zone will be searched for snails and all snails that are found would be temporarily moved with the vegetation. Reclamation would conduct this relocation of habitat and snails for HFEs in excess of 33,200 cfs.

Based on estimates calculated in August 2004, a flow of 45,000 cfs would scour approximately 1,285 $ft^2$ of habitat, approximately 17 percent of available habitat. During the 2004 HFE, AGFD and GCMRC removed mats of ambersnail habitat in the potential inundation zone prior to the flood and later replaced these habitat pieces after flooding subsided. The conservation measure was deemed successful, as these lower habitat areas had recovered completely in 6 months (Sorensen 2005). As with the 2004 test, this conservation measure worked well, and six months after the high flow test, the habitat had fully recovered and was occupied by snails (J. Sorensen, AGFD, pers. comm., 2009). Recovery of this habitat from previous high flow tests that did not include habitat mitigation efforts (i.e. the 1996 high flow test) required 2.5 years for ambersnail habitat to recover completely from scouring (Sorensen 2005).

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. Two or more 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 if frequent HFEs are conducted, multiple movements of snails and habitat would become unproductive as recovery from previous events would not occur prior to the next HFE. 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.

Reclamation concludes that under the proposed action alternative most terrestrial invertebrates and herptofauna are not likely to be negatively impacted. Floods are natural historic events in Grand Canyon and the populations of terrestrial invertebrates and herptofauna are expected to recover quickly from individual HFEs. Kanab ambersnail and its habitat at Vaseys Paradise will be negatively impacted by one or more HFEs. The extent of the impact and its persistence will be related to the magnitude and frequency of HFEs. Two or more HFEs could displace greater numbers and prevent or delay recolonization. Mitigation for Kanab amberstail would reduce the impact to levels that would not exceed the allowable incidental take.

### 3.2.5 Aquatic Foodbase under No Action

Construction of Glen Canyon Dam transformed 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 near 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 dominated by a large biomass of the green algae (*Cladophora glomerata)* (Blinn et al. 1995, 1998).

Today, large numbers of diatoms, freshwater amphipods(*Gammarus lacustris*), and midges (Chironomidae) rely on these dense mats of algae (Benenati et al. 1998, 2001) that are periodically dislodged and provide large amounts of carbon locally and to downstream sources (Stevens et al. 1997b). 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 amphipods, 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 amphipods and generally support the lowest biomass of all habitats in the Lees Ferry reach. Blackflies (*Simulium arcticum*) and midges were present in the Lees Ferry reach, but in relatively low abundance and biomass.

Further downstream, near the Little Colorado River, the macroinvertebrate assemblage in cobble habitats is dominated by blackflies, sludge worms, and earthworms. Talus and cliff-face habitats support some sludge worms, freshwater amphipods, and midges (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 amphipods 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 (Rosi-Marshall et al. 2010). Because of its small size, lack of an attachment structure, and occurrence in fine unstable sediments, the mudsnail is highly susceptible to being dislodged by floods.

Reclamations concludes that under the no action alternative the present composition, abundance and distribution of foodbase taxa would persist. Lack of high dam releases could lead to senescence of algal communities, particularly diatoms, which would decrease the availability of high energy food resources utilized by both invertebrates and fish, but variation in annual volumes due to changing reservoir storage and equalization would limit this impact.

### 3.2.6 Aquatic Foodbase under Proposed Action

A large portion of the aquatic foodbase in the Lees Ferry reach would likely be scoured by an HFE of 41,000 to 45,000 cfs regardless of the time of year. The initial hydrostatic wave produces the scouring effect and the duration of the flow is more important in transporting the material downstream (Rosi-Marshall et al. 2010). The foodbase is expected to recover within 1-4 months after a spring HFE, as was observed for the spring 1996 and 2008 HFEs (Blinn et al. 1999; Rosi-Marshall et al. 2010), and a post-flood increase in production and drift of midges and black flies is expected following spring HFEs (Cross et al. in press). The freshwater amphipod, a common food item for fish, is expected to be slower to recover because of its greater susceptibility to being exported by river currents than most other invertebrate species. New Zealand mudsnails are also expected to be exported in large numbers, which will be a benefit to the foodbase by making more digestible items available to fish; the hard shell of mudsnails is not digestible by most fish. Downstream from 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 foodbase 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 likely to differentially affect the recovery of the foodbase. Benthic sampling was not conducted immediately before and after the November 2004 HFE, however a release of 41,000 to 45,000cfs is expected to scour a large portion of the food base at any time of the year. Scouring of the foodbase in fall could lead to an extended recovery period due to reduced solar radiation, which could reduce the foodbase and 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 whether other factors also were involved, including warm dam releases, low dissolved oxygen, and trout suppression flows (Korman et al. 2004b; Korman et al. 2011). Impacts to the aquatic foodbase due to a November HFE are uncertain and would be evaluated through increased monitoring during such experiments.

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 31,500 cfs do not have the large scouring effect on the foodbase as seen with higher flows. In the Lees Ferry reach, Persons et al. (2003) 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 foodbase 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 abundance or condition of age 1 rainbow trout, as further evidence that the foodbase was not been impacted by the HMF.

Although effects of repeated HFEs on the foodbase 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 foodbase, it is likely that a fall HFE followed by a spring HFE could have a longer-lasting impact on the foodbase. Only 4-5 months could separate the two events, which would preclude full recovery of most benthic invertebrate assemblages; however, some key taxa, such as midges, may recover within 3 months (Brouder et al. 1999). This effect could be exacerbated by reduced winter insolation and photoperiod if recovery from a fall HFE is delayed until the following spring. A 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 foodbase (for most taxa) would have occurred by fall.

To gain a better understanding of expected impacts of more than two HFEs on the foodbase in Grand Canyon, it is informative to examine findings from other rivers. For each of the three large 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 et al. (2003) observed a series of 11 artificial floods in the River Spöl of the Swiss Alps over a 3-year period. As in 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. Which species would form such a community in Grand Canyon is uncertain.

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 foodbase. 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.

The impact of more than two consecutive HFEs on the aquatic foodbase is uncertain. Scouring of the foodbase annually in spring and fall could cause the community to shift toward scour-resistant taxa and decrease the overall abundance and biomass of the foodbase. Three to five consecutive HFEs might be necessary to cause this shift, however, and the absence of an HFE for one or more seasons might allow for recovery of the original foodbase community. This sequence over 10 years of multiple HFEs followed by periods without HFEs could create instability in the community that may lead to a decline or loss of certain taxa, such as the freshwater amphipod *Gammarus*, which is an important food source for fish. This sequence could also substantially reduce the population of the New Zealand mudsnail, which could be a beneficial impact to the community.

Reclamations conclusion is that there will be short-term scouring of the aquatic food base that will occur and increase with the magnitude of HFEs. Some taxa will be affected more than others, and there is the potential for some improvement of foodbase quality due to the differential effect. The impacts have the potential to be more pronounced and longer lasting in October-November than the March-April HFEs because of the reduced photoperiod during ensuing winter months. Two or more successive HFEs can have cumulative effects if they occur in sufficiently close proximity that recovery from the first event is truncated by ensuing HFEs. In the extreme there may be changes in community composition due to selection for flood resistant taxa as evidenced in other rivers (Robinson and Uehlinger 2008), but the likely composition of the flood-resistant community is uncertain.

### 3.2.7 Fish under No Action

Altogether, 21 species of fish likely occur in Grand Canyon, including 16 introduced and five native species (razorback sucker may be extirpated) (Table 12). Only five of the original eight fish species native to the Colorado River in Grand Canyon definitely 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 may be extirpated from Grand Canyon, but is found as a small reproducing population downstream from the canyon in and below the Colorado River inflow to Lake Mead (Albrecht et al. 2008, 2010).

**Table 12. Non-native and native fish species presently found in the Colorado River and lower end of tributaries from Glen Canyon Dam to near Pearce Ferry (Valdez 2008). X=absent , P=present in small numbers, C = common, , A = abundant.**

| Common Name | Scientific Name | Lees Ferry | Marble Canyon | Grand Canyon |
|---|---|---|---|---|
| Nonnative species | | | | |
| black bullhead | Ameiurus melas | X | P | P |
| brown trout | Salmo trutta | P | P | C |
| largemouth bass | Micropterus salmoides | X | X | X |
| mosquitofish | Gambusia affinis | X | X | X |
| guppies | Poecilia reticulata | X | X | P[1] |
| red shiner | Cyprinella lutrensis | X | P | C |
| channel catfish | Ictalurus punctatus | X | X | P |
| common carp | Cyprinus carpio | P | NC | NC |
| fathead minnow | Pimephales promelas | P | C | C |
| green sunfish | Lepomus cyanellus | X | X | P |
| plains killifish | Fundulus zebrinus | X | X | P |
| rainbow trout | Oncorhynchus mykiss | A | A | C |
| redside shiner | Richardsonius balteatus | A | A | P |
| smallmouth bass | Micropterus dolomieu | A | P | P |
| striped bass | Morone saxatilis | X | X | P |
| walleye | Sander vitreus | X | P | P |
| Native species | | | | |
| speckled dace | Rhinichthys osculus | P | C | C |
| humpback chub | Gila cypha | A | C | C |
| flannelmouth sucker | Catostomus latipinnis | C | C | C |
| bluehead sucker | Catostoumus discobolus | P | C | C |
| razorback sucker | Xyruachen texanus | X | X | P |

[1]Present in a spring in Havasu Canyon (Stevens and Ayers 2002)

### 3.2.8 Humpback Chub Under No Action

The humpback chub is a federally endangered fish species that is distributed in the Colorado River through the Grand Canyon as nine aggregations (Valdez and Ryel 1995). The largest aggregation inhabits the lower 8 miles of the Little Colorado River and the mainstem Colorado River in the area of their confluence. Water in the mainstem is generally too cold for spawning. The fish spawns primarily in the Little Colorado River (Clarkson and Childs 2000; Robinson and Childs 2001), although spawning and possibly occasional recruitment does occur in the mainstem (Anderson et al. 2010). Known mainstem spawning is restricted to select reaches where warm springs emerge, such as the Fence Fault Warm Springs at RM 30 (31 miles upstream of the LCR; Valdez and Masslich 1999; Andersen et al. 2010)

Young humpback chub hatched in the Little Colorado River move to the mainstem via active and passive drift as larvae and post-larvae beginning in early summer (May-July; Robinson et al. 1998), during overcrowding from strong year classes (Gorman 1994), and with summer floods caused by monsoonal rain storms during July through September (Valdez and Ryel 1995). Survival of the younger fish is thought to be low because of cold mainstem water temperatures (Clarkson and Childs 2000). Valdez and Ryel (1995) found that there was little survival of young humpback chub less than 53 mm in length when they entered the mainstem. The distribution of juvenile humpback chub downstream from Glen Canyon Dam reveals the locations of most aggregations (Figure 8), but it is uncertain if these fish originated from the Little Colorado River or from local reproduction.

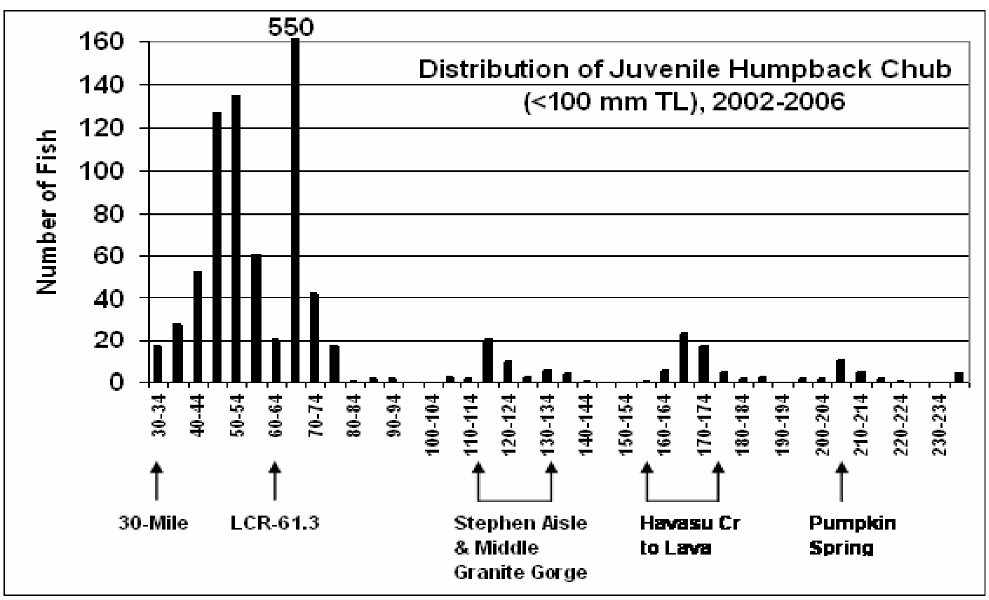



**Figure 8. Distribution of juvenile humpback chub < 100 mm TL during 2002-2006 by 5-mile increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from SWCA 2008).**

Young humpback chub that escape from the Little Colorado River take up residence along the shoreline of the Colorado River in the vicinity of their confluence. Predation by rainbow trout and brown trout in the confluence area has been identified as a principal source of mortality for the young fish (Valdez and Ryel 1995; Marsh and Douglas 1997; Coggins 2008; Yard et al. 2011), however estimates for other sources of mortality are lacking. It is hypothesized that the majority of rainbow trout in this area originate as downstream dispersal from the Lees Ferry reach (Coggins et al. 2011), and the majority of brown trout originate from the area of Bright Angel Creek (Valdez and Ryel 1995). In the 2010 Biological Opinion, the USFWS anticipated that between 1,000 and 24,000, with a mean estimate of 10,817, young-of-year or juvenile humpback chub (50-125 mm total length), would be lost to predation by trout with suspension of mechanical removal of non-native fish during a 13-month period. Yard et al. (2011) estimated that 9326 humpback chub and more than 24,000 other fish were consumed by rainbow and brown trout in the vicinity of the confluence of the Little Colorado River during 2003 and 2004. Concurrent estimates of the numbers of young humpback chub present were not made, so the population effect of this loss is unknown.

Humpback chub in their first and second years of life inhabit complex shoreline habitats and then move offshore to deeper water in large recirculation eddies (Valdez and Ryel 1995). During their occupation of near-shore habitats, those young humpback chub can be displaced downstream by high velocity, cold water releases from Glen Canyon Dam. The numbers of young humpback chub that are displaced downstream are not known, nor is their disposition following displacement. Small numbers of fish marked in the Little Colorado River area have been captured in downstream aggregations and show that some of these fish survive to take up residence further downstream. Others likely starve or are eaten by predators. The condition under which this dispersal occurs is not known. In the past, the USFWS has issued biological opinions expressing concern over dispersal caused by high flows. Concerning the November 2004 HFE, USFWS expressed concern for displacement, but also concluded that mortality of young humpback chub attributable to the HFE likely was not discernable from other mortality factors in the mainstream, including cold water temperatures, predation or loss of habitat (USFWS 2004). A 5-year program of experimental flows (2008-2012) provides for steady flows during the months of September and October to provide stable habitat for young humpback chub. Ongoing studies of the near-shore ecology of humpback chub are expected to provide valuable information on the question of dispersal and displacement with respect to high-flow releases.

Population estimates using an age-structured, mark-recapture (ASMR) method show that the Little Colorado River population ranged from about 11,000 adults (4 years old and older and capable of reproduction) in 1989 to 5,000 adults in 2001 (Figure 9; Coggins and Walters 2009). Between 2001 and 2008, the population increased approximately 50 percent to an estimated 7,650 adults. 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 from the dam, and although the influence of flow on habitat of juveniles has been modeled (Korman et al. 2004), the long-term effect on the population is not well understood.

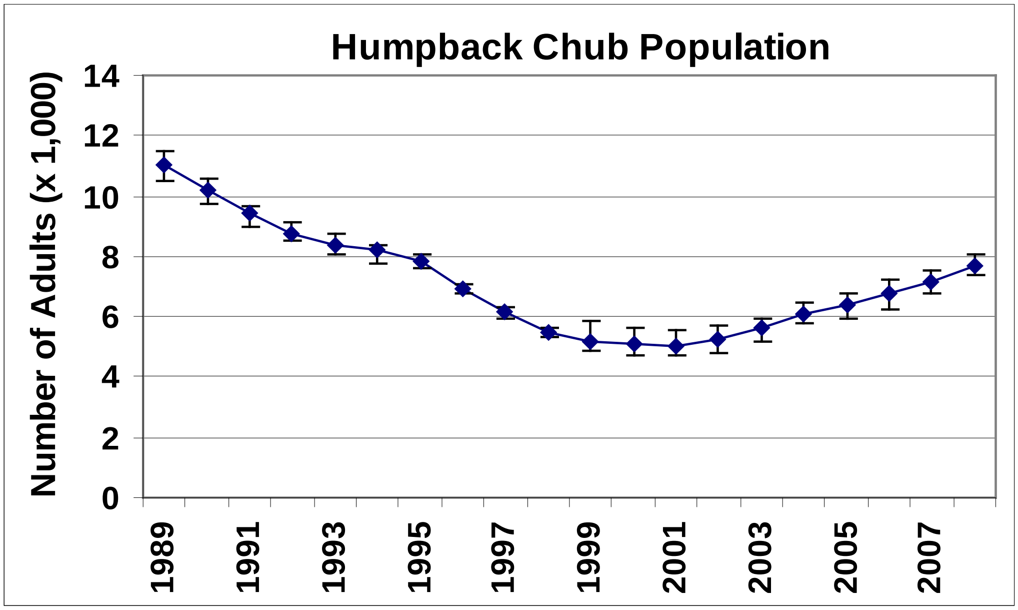



**Figure 9. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials. 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).**

Reclamation concludes that the no action alternative, in combination with fulfillment of the ongoing conservation measures through 2012, would not negatively impact humpback chub. This presumes that the commitment for nonnative fish control will be implemented through the nonnative fish control EA.

### 3.2.9 Razorback Sucker Under No Action

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 (USFWS 1998) and Recovery Goals were approved on August 1, 2002 (USFWS 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 non-native fish species; and pesticides and pollutants (Bestgen 1990; Minckley 1991).

Adult razorback suckers have 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 likely extirpated from the Colorado River and its tributaries between Glen Canyon Dam and the Lake Mead inflow.

The largest populations of the razorback sucker are currently found in Lake Mohave and Lake Mead. The population in Lake Mead consists of approximately 500 adults and is the only known naturally recruiting population of razorback sucker (Holden et al. 2000; Abate et al. 2002; Albrecht and Holden 2005).

From 1990 through 1996, 61 razorback suckers were collected, 34 from the Blackbird Point area of Las Vegas Bay and 27 from Echo Bay in the Overton Arm (Holden et al. 1997). From 1996 to 2008, nearly 500 unique individuals were captured in those areas (Kegerries et al. 2009). Subadults and larvae captured in Echo Bay and Las Vegas Bay indicate that the razorback sucker is reproducing and recruiting in these areas, which are located about 50 miles down-lake from Pearce Ferry.

Adult and larval razorback suckers have also been found recently in the Lake Mead inflow near the lower end of the action area. In 2000 and 2001, 11 and 22 larvae, respectively, were captured in the Colorado River inflow between Iceberg Canyon and Grand Wash Bay, about 8 miles downstream from Pearce Ferry (Albrecht et al. 2008). During the 2002 and 2003 spawning periods, no larval razorback suckers were captured in this area. This spawning site was either not used in 2002–2003, or spawning took place outside of the sampling area. Alteration of spawning sites resulting from lake elevation changes may be responsible for the apparent inconsistent use of spawning sites in the Colorado River inflow region, as in other sites on Lake Mead described above.

In spring of 2010, seven larval razorback sucker were captured in the Colorado River inflow area (i.e., Gregg Basin region of Lake Mead), as well as one larval flannelmouth sucker (*Catostomus latipinnis*) and four larval fish thought to be either flannelmouth sucker or hybrid flannelmouth x razorback sucker (Albrecht et al. 2010). Although catch rate was low, the identification of larval razorback sucker in the Colorado River inflow documented successful spawning in 2010. Spawning is believed to have occurred on rock and gravel points between North Bay and Devil's Cove, in the lake interface about 10 miles downstream of Pearce Ferry. Moreover, Albrecht et al. (2010) reported that trammel netting in the inflow area yielded three wild razorback suckers, four hybrids of razorback and flannelmouth sucker , and 52 flannelmouth suckers. All three razorback suckers were males expressing milt, which helped confirm spawning activities. Two of these individuals were 6 years old and one was 11 years old. Sonic-tagged razorback sucker released near the Colorado River inflow in 2010 used the riverine habitat and inflow region as far upstream as the mouth of Devil's Cove, about 8 miles downstream of Pearce Ferry. Razorback suckers have not been caught recently upstream of Pearce Ferry or in lower Grand Canyon. Reclamation has provided funding for a science panel to evaluate the potential for razorback sucker habitat in lower Grand Canyon and the Lake Mead inflow, as well as the potential for reintroduction of fish into the area.

Kegerries et al. (2009) hypothesized that lake-level fluctuation, which promotes growth and inundation of shoreline vegetation, is largely responsible for the recruitment observed in the Lake Mead razorback sucker population. The inundated vegetation likely serves as protective cover that, along with turbidity, allows young razorback sucker to avoid predation by non-native fishes. Recent non-native introductions, such as quagga mussels (*Dreissena rostriformis bugensis*) and gizzard shad (*Dorosoma cepedianum*), could also affect the foodbase of the razorback sucker in Lake Mead, but the nature and severity of these effects remains unknown.

Reclamation concludes that under no action razorback sucker would continue to be rare in occurrence and geographically restricted to the lower end of Grand Canyon with occasional forays by individuals from Lake Mead upstream to the inflow of the Colorado River. Ongoing limited reproduction and recruitment in Lake Mead is not expected to be affected under no action. Under no action Reclamation would continue to fulfill conservation measures contained in the 2007 and 2008 biological opinions.

### 3.2.10 Non-Listed Native Fishes Under No Action

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 (Thieme 1998; McKinney et al. 1999; McIvor and Thieme 1999) but their reproductive success is low due to predation by large numbers of rainbow trout. 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 (Trammell et al. 2002; Lauretta and Serrato 2006). 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 and Carothers 1998). Ackerman (2007) 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 has shifted over the past decade from one dominated by non-native salmonids to one dominated by native species (Tramell et al. 2002; Lauretta and Serrato 2006; Ackerman 2007; Johnstone and Lauretta 2007; Makinster et al. 2010b). 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 (Lauretta and Serrato 2006; Johnstone and Lauretta 2007; Makinster et al. 2010b). Recent shifts from non-native to native fish likely are due in part to warmer than average water temperatures in releases from Glen Canyon Dam, although decline of coldwater salmonids (due to mechanical removal or temperature increases) has also been implicated (Paukert and Rogers 2004; Ackerman 2007).

Predation on HBC as illustrated above also occurs for the remaining native fish. During the mechanical removal period of 2003-2004 over 19,000 speckled dace, flannel mouth sucker and bluehead sucker were preyed upon by rainbow and brown trout. The total number of native fish was 85% of all fish recorded from the guts of these two predators (Yard et al. 2011).

Reclamation concludes that recent improvements in abundance of native fish under no action MLFF dam releases will be maintained with the continuation of conservation measures including the resumption of nonnative fish control under the nonnative fish control EA. Under no action there would be no HFEs and no additional stimulation of rainbow trout production.

### 3.2.11 Trout Under No Action

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 and condition. Recruitment and population size appear to be governed largely by dam operations (Maddux et al. 1987; AGFD 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 (Valdez and Ryel 1995). Small numbers are found elsewhere in the canyon (Maddux et al. 1987).

The rainbow trout population in the Lees Ferry reach has been monitored under the Glen Canyon Environmental Studies from 1983-1990 and since 1991 under the GCDAMP. From 1993 to 1997, the population increased and remained high until 2001 (Figure 10). 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. 2010a). The 2001–2007 decline was 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 foodbase, 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).

During 2003-2005, "non-native fish suppression flows" were released from the dam to evaluate effectiveness of these highly fluctuating flows in controlling the trout population in the Lees Ferry reach by reducing survival of eggs and young (Korman et al. 2004b). 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 rainbow trout increase in 2008-2009 (Makinster et al. 2010a; Kennedy and Ralston 2011) was attributed to increased survival and growth of young trout following the March 2008 HFE due to improved spawning habitat and quality of food (Korman et al. 2011) and the cessation of mechanical removal during 2007-2008, although the efficacy of this control has been questioned (Coggins et al. 2011). See Section XXX in the Environmental Assessment of Nonnative Fish Control Downstream of Glen Canyon Dam, for additional discussion of trout removal.

Under the no action alternative dam releases would follow the MLFF preferred alternative and no HFEs would occur. Reclamation concludes that trout numbers would likely experience cyclical changes similar to those illustrated in Figure 10 and portrayed similarly by Kennedy and Ralston (2011). Strong rainbow trout population increases such as those seen in 1997 and 2008-2009 following spring HFEs would not likely occur, although high volume, relatively steady equalization releases, such as those being experienced in 2011, may have some stimulatory effect. Control measures undertaken through the non-native fish control EA would offset at least part of the effects of any increased reproduction, recruitment and dispersal downstream.

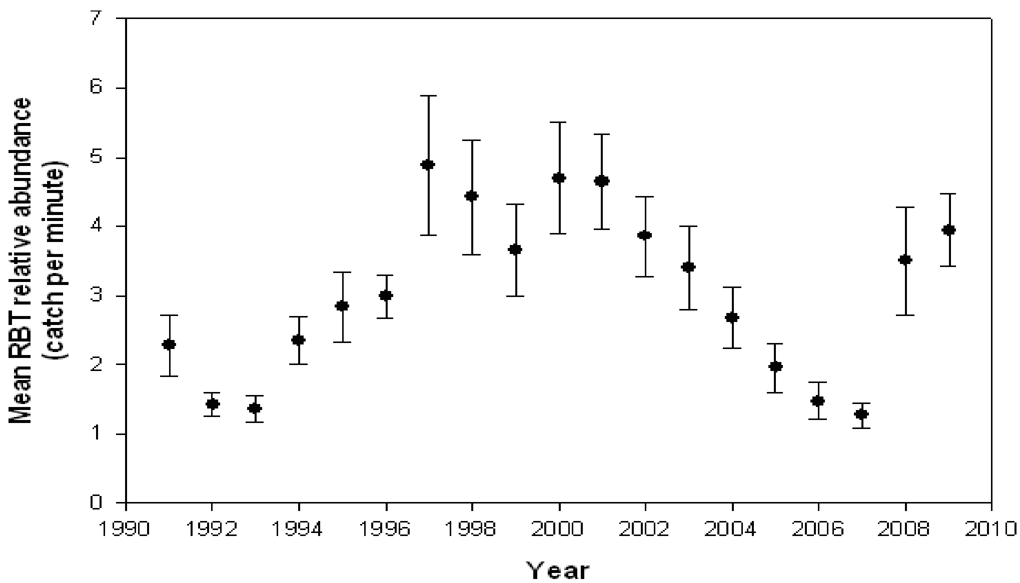



**Figure 10. Average annual electrofishing catch rate of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991-2010 (Makinster et al. 2010a).**

### 3.2.12 Other Non-native Fishes Under No Action

Sixteen non-native fish species are currently found in Grand Canyon (Valdez and Carothers 1998; Hilwig et al. 2010; Stevens and Ayers 2002). The majority are warm water species; only two—rainbow trout and brown trout—are true cold water species. 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 (SWCA 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 from 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 from Bright Angel Creek, although numbers declined from 2000 through 2006 (Makinster et al. 2010b).

Non-native fish collected below Diamond Creek in 2005 (Ackerman 2007) 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). Non-native fish species increased from 11 above to 18 below the rapid. 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. Other common fish species found below Bridge Canyon Rapid include the common carp, fathead minnow, and channel catfish; however, poor fish habitat exists in this reach due to declining elevations of Lake Mead and subsequent downcutting of accumulated deltaic sediments in inflow areas.

Under the no action alternative dam releases would follow the MLFF preferred alternative and no HFEs would occur. Reclamation concludes that non-native fish, other than trout, distribution and abundance would likely experience cyclical changes similar to those observed over the last 10 years.

### 3.2.13 Fish Habitat Under No Action

Korman et al. (2004a) 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 a range of releases from Glen Canyon Dam. 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. 1996, 1999).

It was assumed that habitat availability at 11,500 cfs represents conditions under MLFF, the no action alternative. This was the average of 8,000 and 15,000 cfs, which were the elevations evaluated by Korman et al. (2004a). 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 11). Results for non-native fish were similar (4,500 to about 2,800 $m^2$), although less habitat was available over debris fan substrates.

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 12). We used humpback chub parameters as a surrogate for all native fish found in the Colorado River in Grand Canyon. We recognize that the HBC is not totally representative of the other native fish, however it is likely among the most sensitive to environmental conditions as evidenced by its endangered status. Also, this species has been extensively studied and its habitat needs are well documented.

Results of this analysis show that under the no action alternative fish habitat in the Colorado River below Glen Dam will remain within the limits observed under MLFF dam releases as prescribed in the 1996 Record of Decision. No significant change in distribution and abundance of these fishes from change in habitat availability or quality is therefore expected.

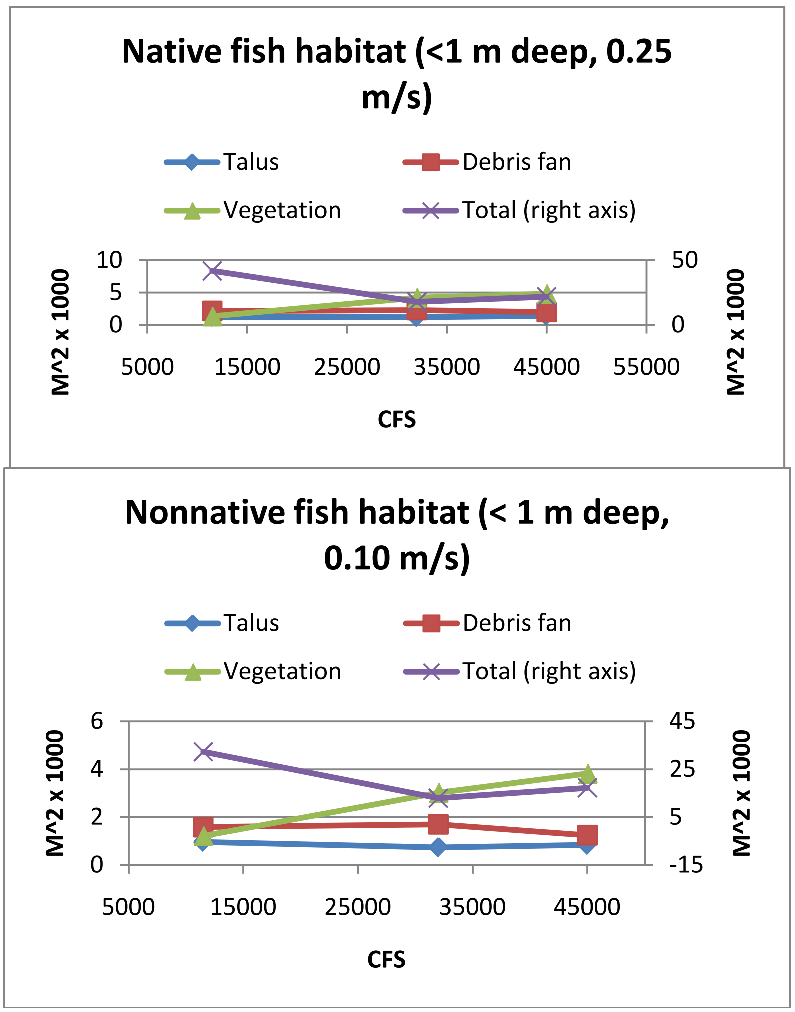



**Figure 11. Total suitable habitat (purple line, right axis) and breakdown by shoreline types (left axis) used by native fish (top; approximated by humpback chub parameters) and non-native fish (bottom). Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transect. Habitat conditions during regular MLFF (no action) for November and April are approximated by flows of 8,000-15,000 cfs.**

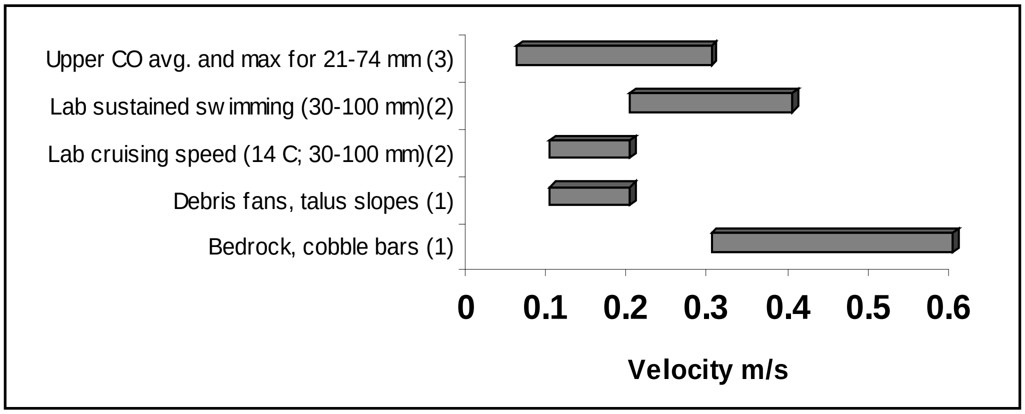



**Figure 12. Velocity preference criteria for humpback chub in the Colorado River, Grand Canyon. Sources include: (1) Converse et al. 1998; (2) Bulkley and Pimentel 1983; and (3) Valdez et al. 1990.**

### 3.2.14 Fish under Proposed Action

Impacts from the proposed action on resources considered in this EA are summarized in table 19 and 20. The assessment includes the impacts of a single HFE, two consecutive HFEs initiated in spring versus fall and more than two consecutive HFEs.

### 3.2.15 Humpback Chub Under Proposed Action

**Timing of HFEs**

HFEs in spring or fall are expected to cause short-term reductions in nearshore habitat of young fish and short-term reductions in foodbase in nearshore and backwater habitats. These effects are not expected to persist or have population-level effects for single HFEs. HFEs could displace young humpback chub from nearshore nursery habitat, especially in fall when the young-of-year are smaller and more susceptible to increased velocity and cold temperatures. HFEs in the fall also may affect young humpback chub due to monsoon storm driven floods in the LCR that flush these fish into the mainstem prior to the HFE. Depending on the size of LCR floods, which have been recorded up to 120,000 cfs, downstream displacement may occur with or without HFEs. Less displacement of young may occur in spring because most newly-hatched fish will still be in the LCR and young in the mainstem will be about 1 year of age and less susceptible to displacement. Kennedy and Ralston (2011) note, however, that spring HFEs likely will be of colder water and may therefore negatively impact swimming performance more than would fall HFEs. HFEs are not expected to affect adult habitat use, feeding, or movement to and from spawning sites in the LCR.

An indirect effect of HFEs could be an increased rainbow trout population in the Lees Ferry reach and subsequent movement of trout to nursery habitats near the LCR where they would prey upon and compete with the humpback chub (Yard et al. 2011). Spring HFEs in 1996 and 2008 increased survival and growth of young trout in the Lees Ferry reach, whereas the trout population appears to have declined following the fall 2004 HFE (Korman et al. 2011). Abundance of age-0 rainbow trout in July 2008 was more than 4X greater than expected based on the number of viable eggs that produced the fish and rainbow trout numbers near the Little Colorado River confluence were 800 percent larger in 2009 than in 2007 (Kennedy and Ralston 2011). The impact of a fall HFE on the trout population is uncertain due to a lack of data on trout response to the one fall HFE conducted in November 2004 and to confounding environmental factors that might also have influenced trout numbers. However, both brown and rainbow trout migrate to spawn in Bright Angel Creek in the fall (Sponholtz and VanHaverbeke 2007), thus trout spawning in tributaries could be affected by a November HFE.

**Magnitude of HFEs**
HFEs of 41,000 cfs to 45,000 cfs are expected to affect humpback chub equally with respect to habitat, foodbase, and displacement of young. HFEs of 31,500 cfs are expected to have less effect, whereas the effect of HFEs between 31,500 cfs and 41,000 cfs are uncertain because they have not been conducted. For the purpose of this analysis we presume that the low and high levels bracket the effects of the intermediate HFE in magnitude and duration.

**Duration of HFEs**
HFEs of greater duration are likely to have a greater effect on displacement of HBC than shorter duration HFEs. Native fish characteristically respond to high flows by moving into nearshore habitats inundated at higher stages, Whether they remain in those habitats will be influenced by a variety of factors including food supply, cover and susceptibility to predators. The longer the duration of the HFE the more these challenges are likely to affect the fish.

**Frequency of HFEs**
Single HFEs and two consecutive HFEs are expected to each have short-term effects on habitat, foodbase, and displacement, but no long-term population effects. The effects of more than two consecutive HFEs are uncertain, but periodic HFEs are expected to rebuild and maintain nearshore habitats and could stimulate foodbase production. Frequent consecutive HFEs could negatively affect the foodbase by reducing numbers of flood-susceptible invertebrates and retarding recovery of the foodbase. The effect of more than two HFEs will need to be investigated and monitored as identified in the HFE science plan.

**Downstream Displacement**
Humpback chub have high site fidelity (remain in a localized area) so displacement out of preferred can be significant. Adult humpback chub are highly adapted to extreme changes in flow regime and are expected to be affected very little by high flows (Hoffnagle et al. 1999; Valdez and Hoffnagle 1999), although high flows may occur at a time of the year different than the pre-dam hydrograph. Little is known about the extent to which humpback chub rely on changes in flow as a reproductive cue. Valdez and Ryel (1995) held that neither water quantity or quality serve as cues for gonadal development or staging behavior in humpback chub; rather they hypothesized that climatic factors, such as photoperiod, were important. Humpback chub typically begin to spawn on the receding hydrograph as water temperatures start to rise (Tyus and Karp 1989; Kaeding and Zimmerman 1983; Valdez and Ryel 1995; Kaeding et al. 1990), but the LCR population also spawns in years with little appreciable runoff.

High releases from Glen Canyon Dam have the potential to displace young humpback chub from nearshore nursery habitats. The area of greatest potential effect is an approximately 8.4-mile reach of the Colorado River (RM 57 to 65.4) that spans the confluence of the LCR at RM 61.3 (about 76 miles downstream of Glen Canyon Dam). This area is the principal nursery for young humpback chub that originate from spawning primarily in the LCR, but may also come from a small amount of mainstem spawning as far upstream as warm springs near RM 30 (Valdez and Masslich 1999; Ackerman 2007; Andersen et al. 2010).

Young humpback chub located in the LCR primarily originate from spawning that takes place from March to May. Larvae and post-larvae drift into the mainstem during early summer (Robinson et al. 1998), and older young-of-year chub disperse into the mainstem during late summer monsoonal rainstorm floods that may occur as early as mid-July (fish length: 30 mm TL), to mid-August (52 mm TL). By September the majority have actively or passively dispersed from the LCR. There are years, however, in which these monsoonal floods are much reduced and the dispersal of HBC is more limited.

By late October, these fish are about 6 months of age and range in size from about 52 mm to 74 mm TL (Valdez and Ryel 1995). Depending on habitat use and growth rate assumptions, humpback chub should be from 5 to 20 mm larger in March and April than in November at 8 to12 °C (Lupher and Clarkson 1994; Valdez and Ryel 1995; Petersen and Paukert 2005). In addition to these young-of-year (age 0), humpback chub of ages 1–3 are also found along nearshore habitats, but in greatly diminished numbers. Nearshore and offshore catches in the mainstem (Valdez and Ryel 1995) and in the LCR (Gorman and Stone 1999) show that these fish move to offshore habitats starting at age 1 and complete the transition by age 3,the approximate time of maturity for the species. Thus, the size range of humpback chub in nearshore nursery habitats is about 30to 180 mm TL, and includes fish of age 0 (young-of-year) to age 3 (Valdez and Ryel 1995). Valdez and Ryel also hypothesized, based on aging of juveniles from scales, that humpback chub smaller than 52 mm TL did not survive thermal shock in the cold mainstem following escapement from the warm LCR.

The principal nursery area is below the confluence of the LCR in the mainstem. Young humpback chub use the well-defined nearshore habitats characterized by low water velocity and complex lateral and overhead cover, primarily rock talus and vegetated shorelines (Converse et al. 1998), as well as backwaters (AGFD 1996). Because of the cold mainstem temperatures in this nursery reach (8.5–11 °C; Valdez and Ryel 1995) from dam releases upstream, swimming ability of these young fish is likely impeded, such that they may be displaced downstream by high water velocity, or their ability to escape predators is limited, or both. Bulkley et al. (1982) reported that swimming ability of juvenile humpback chub (73–134 mm TL) in a laboratory swimming tunnel was positively and significantly related to temperature. Humpback chub forced to swim at a velocity of 0.51 m/sec (1.67 ft/sec) fatigued after an average of 85 minutes at 20 °C, but fatigued after only 2 minutes at 14 °C, a reduction of 98 percent in time to fatigue. Time to fatigue is presumably further reduced below 14 °C, especially for the smallest individuals. These laboratory results have raised concern over the possible displacement of young humpback chub from nursery areas by high-flow events such as HFEs, especially near the LCR confluence, and has been identified as a potential adverse effect on the species since the 1995 Opinion.

Studies of drifting young within and from five Upper Colorado River Basin population centers of humpback chub support the hypothesis that there is little larval drift or long-distance displacement of any size or age (Valdez and Clemmer 1982; Valdez and Williams 1993; USFWS 2002a). Extensive larval drift-netting in many reaches of the Upper Basin (e.g., Muth et al.

2000) has yielded large numbers of drifting larval Colorado pikeminnow, razorback sucker, flannelmouth sucker, bluehead sucker, and speckled dace, but larval humpback chub are rarely caught. Furthermore, observations of recently-hatched humpback chub in a hatchery reveal a greater association by their larvae for cover, compared to other species more prone to drift, including Colorado pikeminnow and razorback sucker (Hamman 1982; Roger Hamman, Dexter National Fish Hatchery, personal communication). Furthermore, studies in and around populations in Black Rocks and Westwater Canyon (Valdez et al. 1982), as well as Cataract Canyon (Valdez and Williams 1993) revealed few juvenile humpback chub outside of these population centers, indicating little movement or displacement from these centers despite high seasonal flows (e.g., spring flows often exceed 30,000 cfs in Westwater Canyon and 50,000 cfs in Cataract Canyon).

**Effects of 1996, 2004, and 2008 HFEs on Displacement**

The need for studies to determine how high flows can impact young humpback chub in nearshore nursery habitats has been identified since the 1995 Opinion. The studies on habitat-specific catches rates and movement of humpback chub for the 1996 HFE and the limited sampling done for the 2004 HFE comprise the only empirical information on the subject. These studies do not provide conclusive evidence of displacement of young humpback chub by high flows, but suggest seasonal differences with greater potential for displacement in November than in March-April. Nevertheless, whether high flows transport young humpback chub from nursery habitats remains unanswered, and should be investigated with future HFEs. The ongoing Nearshore Ecology Study has not been conducted during an HFE and results are not available at this time, but this study could provide a valuable baseline of information for evaluating displacement with ensuring HFEs.

In the 1995 Opinion, the USFWS anticipated that incidental take would occur when some young humpback chub would be transported downstream from the mainstem reach near the LCR into unfavorable habitats due to habitat maintenance or habitat building flows. The USFWS acknowledged that this incidental take would be difficult to detect and identified the need for studies to determine how this take might occur and the impact on the year classes of humpback chub. Hoffnagle et al. (1999) sampled shorelines from RM 68 to RM 65.5 with electrofishing and minnow traps, and backwaters with seines before, during, and after the 7-day late-March, early-April 1995 HFE of 45,000 cfs. They reported shifts in habitat use by juvenile humpback chub (born in March–May of 1994) with changes in flow stage, but no significant decreases in catch rates and no discernible effect to the population. Valdez and Hoffnagle (1999) also reported shifts in use of offshore habitats by radiotagged adult humpback chub, but no downstream displacement of any of the 10 fish monitored, or differences in offshore catch rates of adults with trammel nets.

For the 3-day November 2004 HFE of 41,000 cfs, sampling was conducted with hoop nets in approximately 1-km sections in each of three locations (LCR inflow reach near RM 63, near Tanner Rapid near RM 68, and Unkar Rapid near RM 73) three days before and after the HFE. Catch rates of juvenile humpback chub declined by about 66 percent at the upper two sites following the November HFE, suggesting downstream displacement of fish by the high flow (GCMRC unpublished data). Length frequencies of fish in post-flood samples were shifted to fish roughly 10–20 mm larger than pre-flood fish, indicating a reduction of smaller fish during the flood.

It is unclear if the decline in juveniles was caused by local shifts in habitat use (as was seen with the 1996 HFE) that was not detectable with the limited extent of sampling—or if the displacement was real and reveals a different effect between spring and fall HFEs on juvenile humpback chub. Juvenile humpback chub in the mainstem were about 1 year of age (74–96 mm TL, Valdez and Ryel 1995) during the late-March, early-April 1995 HFE and may have been less susceptible to displacement than the younger fish (probably 6–8 months of age and 52–74 mm TL; Valdez and Ryel 1995) found in the mainstem during the November 2004 HFE. The results of the 2004 HFE may have been further confounded by an LCR flood that dramatically increased turbidity during the post-HFE sampling and could have reduced catch rates; Stone (2010) reported reduced hoop net catch efficiency with increased turbidity.

**Displacement Estimated with the Use of Models**
Lacking definitive evidence that supports or refutes long-distance displacement of humpback chub by high flows, models of nearshore depth and velocity are used to approximate possible displacement. It is hypothesized that humpback chub would be negatively impacted in their young-of-year or juvenile stages through physical displacement due to entrainment by high flows (31,500–45,000 cfs), primarily during the months of October and November. Under the proposed action, fall HFEs could occur with a slighter greater frequency than spring HFEs (58 percent vs. 42 percent of the time), and many of these HFEs would consist of flows approaching 45,000 for at least one and as many as 96 hours.

Effects of high flows were evaluated by comparing retention rates (i.e., the opposite of displacement, or percentage of fish able to maintain their position in a given reach) expected during a high-flow test to those predicted for the median monthly flow in March under MLFF. Retention rates over a range of flows was modeled using a particle tracking algorithm in conjunction with velocity predictions from a 2-D hydrodynamic model developed by Korman et al. (2004a). This model was developed using mainstem channel bathymetry from seven transects located between the LCR confluence (RM 61.5) and Lava Chuar Rapid (RM 65.5). The model contains four assumptions of fish swimming behavior: (1) passive, no swimming behavior; (2) rheotactic, in which particles (or "fish") swim toward lower velocity currents at 0.1 to 0.2 m/s; (3) geotactic, in which particles swim toward the closest bank at 0.2 m/s; and (4) upstream, in which the particle attempts to move upstream at 0.2 m/s. Passively drifting fish were the most susceptible to displacement but also the least sensitive to the effects of variable discharge magnitude. We assumed that passively drifting fish can be used to represent larval fish or the poor swimming ability of young-of-year humpback chub at low temperatures; this analysis applies mainly to the young-of-year however, since very few or no larval fish are expected to be present during March - April or October November.

Temperature of the Colorado River in the LCR inflow reach during the proposed time period for high-flow tests (October-November and March-April) is expected to range from about 10 °C to 15 °C (AGFD 1996). At these levels, subadults and young-of-year may fatigue rapidly and may be unable to withstand swift currents, forage efficiently, or escape predators. For these reasons, and also to identify the most conservative estimate of fish displacement, we focused primarily on results for passive behavior in this analysis.

Using the entrainment model of Korman et al. (2004a), we expect that 21–23 percent of age-0 fish will be able to maintain their position within a given river reach during high-flow tests of approximately 31,500 and 45,000 cfs, respectively. The retention rate at mean monthly flows for October, November, March, and April under MLFF (ca. modeled values of 8,000–15,000 cfs), by contrast, is predicted to be about 31 percent. Therefore we would expect retention to decrease by 10 percentage points during the proposed action. Assumptions of active swimming can be used to simulate displacement rates of more mature fish, as may be present during the proposed HFE windows. Based on that analysis, we expect total habitat availability (i.e., preferred depth and velocity over all substrate types) to decline by about 57 percent as flows increase from 12,000 cfs (an approximation of MLFF flows under no action) to about 31,500 cfs, and by 48 percent as flows increase to 45,000 cfs. These declines 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. Thus, if fish could exploit these unchanged or improved habitats as refuge from high flows, displacement could be minimized (see also Converse et al. 1998).

Survival of young humpback chub that are displaced from the LCR is unknown but displacement likely occurs often during the period of summer monsoonal floods. Based on the known response to native fish to floods and the time of year in which HFEs can occur, we anticipate most young native fish will experience only local displacement from HFEs (see Ward et al. 2003). Displacement may result in mortality or they may persist in main channel reaches below RM 65 (lowermost boundary of the simulation in Korman et al. (2004a). Fate of these fish in downstream reaches is unknown, as neither the exact river reaches they are likely to arrive at nor habitat conditions therein are known. Numbers of fish displaced by high flows are expected to vary markedly by the distribution of fish among discrete shoreline types, as certain shoreline types afford more refuge from high-flow velocities than others (i.e., talus slopes as compared to sandbars, etc.).

Downstream displacement could provide positive effects for humpback chub if they are carried to downstream aggregations, survive, and increase the size of these groups. The largest of these aggregations occurs at about RM 122 to RM 130 (60–68 miles downstream of LCR), which is the first time a transported fish would encounter shoreline complexity comparable to that of the LCR reach (Valdez and Ryel 1995). Chances of survival would increase with size of fish transported because of their swimming strength and their ability to survive longer without feeding (Harvey 1987). Modifications to the nearshore ecology study are planned to better estimate numbers of young humpback chub in the system. This work may help better determine the effects of HFEs on the displacement of young humpback chub.

**Displacement of Other Species**

It is also likely that repeated HFEs will disadvantage small-bodied warmwater non-native fish (fathead minnow, red shiner, plains killifish, small common carp, etc.) through physical downstream displacement by high flows. Displacement could be less pronounced for humpback chub than for warmwater non-native fish due to their preferences for lower water velocities and due to behavioral differences (Ward et al. 2003). Whereas the average preferred velocity for juvenile humpback chub is about 0.25 m/s (Korman et al. 2004a; Converse et al 1998; Bulkley et al. 1982; Valdez et al. 1990), non-native fish preferences average about 0.10 m/s, perhaps making them more susceptible to displacement by high flows. 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. Trammell et al. (2002) also documented displacement and slow re-colonization rates of fathead minnow as a result of the powerplant flows conducted during September 2000. Repeated HFEs could thus repeatedly disadvantage non-native fish to higher degrees than humpback chub, a species which evolved in a high-frequency disturbance regime.

**Predation and Competition**

The proposed action is expected to increase the rainbow trout population and thus, predation by trout on humpback chub, particularly if HFEs are implemented during March-April. The effect of an October-November HFE on the trout population is uncertain and cannot be determined from the fall 2004 HFE because of the confounding effects of dam operations, non-native fish control activities, and warm releases from a low reservoir (Korman et al. 2011; Makinster et al. 2010b). Single HFEs could contribute to greater rainbow trout abundance, and repeated HFEs could compound this problem by expanding the trout population long-term. Mean piscivory rates by salmonids on other fish calculated by Yard et al. (2011) range from 0.4 to 3.3 prey/rainbow trout/year, and 4.8 to 70 prey/brown trout/year. Of prey fish consumed, Yard et al. (2011) estimated that 27.3 percent were humpback chub. These rates don't suffice to estimate the population effect on HBC as that effect is dependent on the number of small HBC that would be affected by predation. That number can vary dramatically from year to year dependent on reproductive success and the number and extent of monsoonal floods in the LCR.

Estimated rainbow trout remaining in the LCR inflow reach after a 3-year mechanical removal effort in March 2009 was 427 to 1,427 fish (Makinster et al. 2010b). No brown trout were collected, but sampling intensity may not have been sufficient to detect them at low abundances. In some years, impacts to humpback chub due to predation by rainbow trout could be substantial. Additionally, based on high degrees of dietary overlap, rainbow trout are known to compete directly with humpback chub for food resources in the action area (Valdez and Ryel 1995; Valdez and Hoffnagle 1999). Thus, the degree of predation and competition experienced by humpback chub is directly related to rainbow and brown trout abundance.

Multiple lines of evidence indicate that the March 2008 HFE resulted in a large increase in early survival rates of age-0 rainbow trout because of an improvement in habitat conditions and possibly increased food availability (Korman et al. 2011). 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 (February 21–March 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. (2011) speculate that the 60-hour 2008 HFE increased interstitial spaces in the gravel bed and food availability or quality, leading to higher early survival of recently emerged trout and better growth of these fish through summer and fall. Finally, Korman et al. (2011) presented evidence that enhancement of rainbow trout year class strength due to spring HFEs could be sustained from one year to the next, as suggested by higher than predicted survival of age-1 rainbow trout in 2009 (which had hatched in spring of 2008).

Results from the 1996 HFE were not studied in as much detail as those from 2008, but available information shows that catch rates of age 1 rainbow trout declined immediately following the 1996 high-flow test (McKinney et al. 1999). This information, combined with increased catches of young rainbow trout about 80 miles downstream (Hoffnagle et al. 1999) suggest some downstream displacement, but overall McKinney et al. (1999) observed no lasting impacts to either trout abundance or condition. Numbers of age-1 rainbow trout increased during 1997, suggesting that enhanced survival of age-0 trout may have occurred after the 1996 HFE as well (McKinney et al. 2001). However, this increase was not nearly as dramatic as that observed in 2008, and no information exists linking the 1997 increase to the 1996 HFE.

There is a risk of increased predation 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 may be lower. 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. However, if spring HFE's take place in April, approximately one month or more after the peak spawning period, a larger fraction of that year's eggs would have been fertilized prior to the HFE. Korman et al. (2011) speculated that if the bulk of fertilization were to take place prior to an HFE, the resulting fry would not benefit from cleaner gravel and enhanced food availability as was observed in 2008 and their survival would be lower. Most of these fish would still be in the gravel when the HFE occurs in April and would be vulnerable to scour or burial, or would be vulnerable to displacement and mortality because of increased water velocity (Heggenes et al. 1990; Einum and Nislow 2005). Previous spring HFEs have occurred in March to early April thus a late April HFE is the next logical experiment in addressing the trout response.

The November 2004 HFE resulted in lower apparent survival of rainbow trout compared to that observed during more typical MLLF operations observed in 2008 (Korman et al. 2011), however the cause of this effect is not clear. Electrofishing catch rates for all sizes of trout before and after the November 2004 HFE were not significantly different, however, indicating that mortality and downstream displacement did not affect the population (Makinster et al. 2007). Since fall HFEs could occur slightly more often than spring HFEs, it is possible that negative effects to trout accrued during this period may counterbalance enhanced survival rates resulting from spring flows. However, if the effect of enhanced spring survival is cumulative among years as postulated by Korman et al. (2011) and the mechanism of decline due to fall HFEs is in fact downstream dispersal, negative consequences for humpback chub are expected to result from repeated HFEs of any magnitude or duration.

Inferences on the effect of HFEs on early survival and growth rates of trout 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 peak duration more than twice the 2008 HFE (7 days vs. 60 hours), but the rainbow trout monitoring methods used during the 2008 study had not yet been applied to the Lees Ferry reach. Korman et al. (2011) recommend that studies of survival rates of gravel-stage and older age-0 rainbow trout be repeated if future HFEs is conducted to determine if the trout responses are similar to those observed during the 2008 HFE.

A second uncertainty of effects of enhanced rainbow trout survival is that 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). Korman et al. (2011) reported that rainbow trout fry abundance in 2009 was twice what was expected given egg deposition estimates, suggesting positive effects on rainbow trout survival from the 2008 HFE persisted at least one year following the experiment. Thus, if the rate of trout migration downstream increases with upstream abundance, repeated HFEs could increase the risk of rainbow trout predation on or competition with humpback chub. This assumes that no negative impacts to the foodbase offsets age-0 rainbow trout survival.

Preliminary results from energetic-based models (EcoPath, EcoSim) show that the rainbow trout population in the Lees Ferry reach is likely to respond positively (i.e., increased survival of young) to either spring or fall HFEs with a subsequent increase in numbers. This increase in trout population size could result in downstream movement of young trout (Korman et al. 2011) that could occupy the nursery habitat of humpback chub near the LCR and compete with and prey on the young chubs. The net effects of the HFE Protocol from predation are uncertain because of uncertainties in the frequency of HFEs and the actual response by the trout population. Reclamation is proposing to implement non-native control during 2011–2015 through an EA being developed concurrent to the HFE EA (see Section 1.3). Non-native fish control would be implemented through further consultation with USFWS and in cooperation with GCMRC, NPS, GCDAMP tribes and other GCDAMP members. The net effect of non-native control actions implemented in these future years potentially could benefit the biological environment constituent element of critical habitat to a greater degree than the original proposed action depending on the efficacy of those actions in conserving humpback chub.

**Impact to Humpback Chub Population**

Effects on individuals don't necessarily transfer to population effects therefore it's important to look at trout effect at the population level. Mark-recapture methods have been used since the late 1980s to assess trend in adult abundance and recruitment of the LCR aggregation of humpback chub, the primary aggregation constituting the Grand Canyon population and the only population in the lower Colorado River Basin. These estimates indicate that the adult population declined through the 1980s and early 1990s but has been increasing for the past decade (Coggins et al. 2006; Coggins 2008; Coggins and Walters 2009). Coggins (2008a) summarized information on abundance and analyzed monitoring data collected since the late 1980s and found that the adult population had declined from about 8,900- 9,800 in 1989 to a low of about 4,500-5,700 in 2001.

The most recent estimate of humpback chub abundance (Coggins and Walters 2009) shows that it is unlikely that there are currently less than 6,000 adults or more than 10,000 adults, and that the current adult (age 4 years or more) population is approximately 7,650 fish. This is an increase from the 2006 estimate of 5,300-6,700 (Coggins 2008). These estimates indicate that there has been increased recruitment into the population from some year classes starting in the mid- to late-1990s. Increased humpback chub recruitment has previously been attributed in part to the results of non-native fish mechanical removal, increases in temperature due to lower reservoir elevations and inflow events, the 2000 low steady summer flow experiment, and/or other experimental flows. However, the most recent population modeling indicates the increase was due to increased recruitment as early as 1996 but no later than 1999 (Coggins 2007), which coincides with a period of increasing rainbow trout abundance (McKinney et al.1999, 2001; Makinster et al. 2010a). The increase in recruitment began at least four and as many as nine years prior to implementation of non-native fish control, incidence of warmer water temperatures, the 2000 low steady summer flow experiment, and the 2004 high-flow test. It is also unclear as to whether this increase is attributable to conditions in the mainstem or in the LCR. Population dynamics of non-native fish, humpback chub, hydrology, and other environmental variables in the LCR may have influenced the observed recruitment trends.

Although some negative impacts of the proposed action are expected from potential displacement of young-of-year or juvenile humpback chub, these effects are not expected to register at the population level. Results of before and after investigations of humpback chub associated with HFEs conducted to date suggest that such flows have negligible effects at the population level. This assumption is based largely on the positive population size trajectory documented during 2001–2009, during which two HFEs in excess of 41,500 cfs were conducted. Catch-per-unit effort (CPUE) of humpback chub did not differ in 1996 pre- versus post-flood periods. Valdez and Hoffnagle (1999) concluded there were no significant adverse effects on movement, habitat use, or diet of humpback chub. Catch rates of humpback chub declined immediately following the 2004 HFE (GCMRC, unpublished), but several studies (Coggins 2007; Coggins and Walters 2009; Lauretta and Serrato (2006) and SWCA (2008) showed that numbers of humpback chub have been stable or increasing since 2004, suggesting negligible effects of fall or spring HFEs on these fish at the population level.

Under the proposed action, effects of repeated HFEs over a 10-year period will manifest differentially on humpback chub depending on their frequency, which is driven by year-to-year variation in water and sediment availability. Based on results from prior experiments, HFEs conducted during 1996, 2004 and 2008 were fundamentally independent events with 8 years, 7 months, and 3 years, 4 months between events. Effects to biological resources of one HFE were likely dissipated by the time of the next event, and there is little information by which to determine the effect of more frequent HFEs. However, the more lasting effects of independent events (1996, 2004 and 2008) likely foretell some of the possible consequences of frequent, sequential high-flow releases.

Although there is little or no evidence that isolated HFEs impart significant impacts to humpback chub at the population level through displacement of age-0 or juvenile fish, effects of repeated HFEs are unknown but would stem from the cumulative effect of displacing multiple cohorts of age-0 or juvenile fish. Although humpback chub and other native fish evolved under highly variable environmental conditions, including high spring flows well beyond the magnitude of the proposed action, nothing is known of the response of these fish to frequent flow disturbances in the context of post-dam environmental conditions such as lower temperatures, daily flow fluctuations, clear water, and presence of non-native fish. For example, impairment of swimming ability due to sub-optimal water temperatures could make humpback chub more susceptible to displacement than under natural conditions, and coldwater predators such as trout could further reduce their survival through predation.

Reclamations conclusion on the proposed action for HBC is summarized in tables 18 and 19, found at the end of Section 3.4.

### 3.2.16 Razorback Sucker Under Proposed Action

A reproducing and self-sustaining population of razorback sucker exists in Overton Arm of Lake Mead, and adults have been found as recently as June 2010 in the Colorado River inflow, about 9 miles downstream of the lower end of this proposed action area near Pearce Ferry (Albrecht et al. 2010). Totals of 11, 22, and 7 recently-hatched larval razorback suckers were found in 2000, 2001, and 2010, respectively. The larvae found in 2000-2001 were distributed primarily between Grand Wash Bay and Iceberg Canyon, although one was located as far upstream as the bay at Pearce Ferry (Albrecht et al. 2008). Spawning is believed to have occurred in April 2010 on rock and gravel points between North Bay and Devil's Cove, which is in the lake interface about 10 miles downstream of Pearce Ferry. A total of seven recently-hatched larvae were found in the area on April 13-14, 2010, at a water temperature of 14–16ºC.

Although razorback sucker have not been reported between Glen Canyon Dam and Pearce Ferry since 1990 (Valdez 1996), it is possible that individuals from the Lake Mead population use lower Grand Canyon transiently or a few currently reside in the reach. Recent fish sampling in lower Grand Canyon has not reported razorback sucker in the action area (Makinster et al. 2010b), but this sampling may not be sufficient to detect small numbers of individuals Evidence for the presence of razorback comes from work in the Colorado River inflow area where both and adult and larval razorback sucker have recently been collected (pers. comm. M. McKinstry).

**Timing of HFEs**

A spring HFE has the potential to increase water flow and stage in the Lake Mead inflow area used by razorback sucker; an HFE of 45,000 for 96 hours could increase the level of Lake Mead by 1–2 feet. Adults and juveniles are expected to adjust with changing water level, but high flows could displace recently-hatched larvae (such as found in mid-April 2010) from nursery habitats. Larvae displaced from food-rich nursery habitats can starve in 2–3 days (Papoulias and Minckley 1990) or get eaten by predators (USFWS 2002b). Alternatively, a spring HFE could benefit larvae by transporting them into newly-inundated high-water habitats where food production would be stimulated. An HFE is likely to carry a large amount of sediment that can bury spawning bars with eggs and newly-hatched larvae. The only known spawning habitat for razorback sucker is about 11 miles downstream of the action area near Devil's Cove, as described above, where a spring HFE has the potential to deposit sand and sediment on spawning areas. However a spring HFE also increases lake levels potentially inundating vegetation and creating turbidity that provide cover for larvae and adults. A fall HFE is not expected to impact the razorback sucker.

**Magnitude of HFEs**

The magnitude of a dam release for an HFE could range from 31,500 cfs to 45,000 cfs. Depending on the flow stages of seven major tributaries through Marble and Grand canyons, the total amount of water reaching the Lake Mead inflow could be considerably greater than the initial dam release. The higher magnitude flows are likely to have a greater impact on the razorback sucker in the inflow area by displacing larvae, modifying habitat, enhancing the foodbase, or depositing sediment on spawning sites; however, these tributary inflows would occur under both the no action and proposed action alternatives.

**Duration of HFEs**

The duration of an HFE could range from 1 to 96 hours, but the wave of high flow will be extended and ameliorated by the time it reaches the Lake Mead inflow. The duration of an HFE is not expected to have as great an impact as timing, magnitude, or frequency because impacts to the fish are expected to occur with arrival of the high flow.

**Frequency of HFEs**

Direct short-term impacts of the proposed action are expected to the razorback sucker from modifications in habitat, changes in foodbase, possible burial of spawning bars, and potential displacement of young. These impacts are expected to be temporary for single HFEs and for two consecutive HFEs, where the habitat and the foodbase are expected to be restored shortly after each HFE. However, the impact of more than two consecutive HFEs is uncertain. For single or two HFEs, habitat would change with increases in water velocity and river stage, but the impact to adults is expected to be minimal. The large amount of material scoured and dislodged by an HFE could deliver a large amount of diverse food items for razorback suckers in the Lake Mead inflow, which are omnivorous and can feed on detritus and insects.

### 3.2.17 Impacts to Razorback Sucker Population

The largest magnitude and duration of HFE (45,000 cfs for 96 hours) will deliver about 400,000 acre-feet into Lake Mead and increase the elevation of the reservoir by 1 to 2 feet. The extent of impact to the razorback sucker depends on how far upstream they occur from the lower boundary of the action as the effect is expected to diminish downstream from the inflow area. The relationship of reservoir elevation to spawning locations is not currently known. However a spring HFE will rapidly increase lake levels potentially inundating vegetation and creating turbidity that provide cover for larvae and adults. Spawning has occurred in the inflow region of Lake Mead but it is unclear whether these fish are actually spawning in the free-flowing reaches of the Colorado River or in Lake Mead itself. Larvae resulting from this spawning activity may be displaced by the HFEs in Lake Mead. HFEs could enhance survival of larvae and post-larvae by increasing their food supply through inundation of nursery areas and stimulation of primary production. Increased turbidity at the river/lake interface will provide additional cover and improve survival of young however, fine sediments contributing to increased turbidity in spring could also settle out on spawning bars and suffocate eggs or embryos. All ages of razorback suckers will benefit from the influx of large amounts of organic matter that will bolster the food supply. With regards to increased risk of predation due to enhanced rainbow trout survival, there are very few rainbow trout in the lower reaches of the Colorado River in Grand Canyon so it is unlikely that razorback sucker will overlap with rainbow trout

Reclamation concludes that the proposed action would have direct short-term impacts to the razorback sucker from modifications in habitat, changes in foodbase, possible burial of spawning bars, and potential displacement of young. However these negative impacts may be offset by increases in lake levels potentially inundating vegetation and creating turbidity that provide cover for larvae and adults.

No incremental or cumulative impacts are expected to affect the razorback sucker from either a single or two consecutive HFEs. The cumulative impacts of more than two consecutive HFEs are uncertain, but are not expected to have a long-term impact on the population of the razorback sucker in lower Grand Canyon and the Lake Mead inflow.

### 3.2.18 Non-listed Native Fishes Under the Proposed Action

Impacts of a March-April HFE on non-listed native fish are not expected to be similar to effects on HBC based on results from the 1996 and 2008 HFEs which included predation caused by elevated numbers of rainbow trout as a result of spring HFEs (Korman et al. 2011,Yard et al. 2011). Population level effects on flannelmouth and bluehead sucker were not documented from data collected 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. Abundance of flannelmouth and bluehead sucker and speckled dace in backwaters increased during the months following the spring, 2008 HFE (Grams et al. 2010) although these could be considered normal seasonal occurrences.

Sampling was not conducted downstream from the Lees Ferry reach immediately before or after the fall 2004 HFE, effects on non-listed native fish cannot be evaluated directly. However, several studies (Lauretta and Serrato 2006; SWCA 2008; Makinster et al. 2010b) 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.

Based on the above observations from previous HFEs Reclamation concludes that HFEs would have similar impacts on non-listed native species as those seen for humpback chub.

### 3.2.18 Trout Under Proposed Action

#### Rainbow trout

The effects of an March-April HFE on juvenile and adult rainbow trout can be evaluated indirectly. Survival of fry and later age-0 fish would likely be enhanced, there is insufficient evidence to conclude that the effect would be as pronounced as it was in 2008 (Korman et al. 2011). Multiple lines of evidence indicate that the March 2008 HFE resulted in a large increase in early survival rates of age-0 fish (compensatory response) because of an improvement in habitat conditions (Korman et al. 2011). 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. (2011) speculate that the 60-hour 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. The trout population is strongly influenced by dam releases, and understanding the effect of HFEs on reproductive success, early life stage survival, and downstream movement is important for maintaining a quality recreational fishery in balance with its foodbase and with downstream native fish populations.

Although evidence exists for downstream displacement of juvenile rainbow trout from the Lees Ferry fishery due to the1996 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. 2010a, 2010b). Displacement or dispersal may vary considerably as a density-dependent phenomenon. Valdez and Ryel (1995) reported that of 151,000 marked rainbow trout released in the Lees Ferry reach in 1992 and 1993, only three were later captured downstream of Lees Ferry. They concluded that at that time the most likely source of rainbow trout in downstream reaches was the cold-water, spring-fed tributaries in Grand Canyon. One of those tributaries, Nankoweap Creek, has subsequently been altered by a flood debris flow and no longer has surface water connection with the mainstem; thus fish can not move between the tributary and mainstem.

Current thinking is that the most likely source of most rainbow trout that occur in the reach of the Colorado River where HBC populations are greatest, the confluence with the LCR, is the Lees Ferry reach (Coggins et al.2011). Downstream dispersal rates of rainbow trout from the Lees Ferry reach have not been quantified, however Coggins et al. (2011) estimated immigration rates into the reach of the Colorado river where mechanical removal was occurring. Coggins et al. (2011) hypothesized that the rate of downstream immigration is density dependant and varies with trout densities in upstream reaches.

Change in rainbow trout condition was not detected 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 condition (Makinster et al. 2010a). This is likely a result of increased metabolism and/or subsequent scour of the aquatic foodbase during the experiment. Concerns about a potential loss of the 2008 cohort due to food limitations were alleviated since trout condition returned to levels observed in previous years during summer and fall sampling. Aquatic foodbase analysis pre- and post-HFE suggested New Zealand mudsnails were negatively impacted by the experiment, which in conjunction with increased production and drift of chironomids and black flies, led to increased food availability, and improved food quality especially for young fish, following the experiment (Rosi-Marshall et al. 2010). Inferences on the effect of Glen Canyon Dam HFEs during late winter to early spring on early survival and growth rates are limited by the fact that only one treatment has been conducted and studied. The 1996 HFE consisted of 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. (2011) recommended that the study of survival rates of gravel-stage and older age-0 rainbow trout should be repeated if future HFEs were conducted to determine if the trout responses would be similar to those observed during the 2008 HFE.

We do not expect a single 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 (2011) 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 was not significantly different, indicating that mortality and downstream displacement did not affect the population (Makinster et al. 2007, 2010a). Trout condition declined slightly from 2004 to 2005, but the effect was size-specific and condition rebounded sharply by 2006. Sampling was not conducted downstream from Lees Ferry immediately before and after the 2004 so downstream dispersal of trout as an effect of high flows could not be evaluated directly.

Reclamations concludes that spring and fall HFEs are likely to have different effects on rainbow trout, although responses to the latter admittedly have been little studied in the Colorado River below Grand Canyon Dam. Rainbow trout reproductive success and growth likely will be improved by spring HFEs and some of the additional trout may disperse downstream where they will contribute to predation on the endangered humpback chub and other native fish. Effects of two successive HFEs likely also will differ, depending on the order of the HFEs. A spring HFE followed by a fall HFE likely will produce more trout, but have more extended negative effects on the aquatic foodbase than a fall HFE followed by a spring HFE. Neither of these combinations have yet been tested, so there is uncertainty in these projections. As the number of successive HFEs increases, this uncertainty rises markedly.

**Brown Trout**

Brown trout are primarily distributed in a small group of tributaries downstream of the LCR and in the mainstem in that same reach. They are fall spawners as opposed to rainbow trout that primarily spawn in the spring. They are present in lower numbers than rainbow trout, but because they are highly piscivorous they can have a far greater impact to native fish. There are no management objectives for brown trout under the GCDAMP as there are for rainbow trout in the Lees Ferry reach.

Brown trout are likely less affected by HFEs than are rainbow trout. There major reproductive effort occurs in Bright Angel and a small number of other spring-fed tributaries in Grand Canyon. Continued Reclamation and National Park Service conservation measure efforts to control brown trout in Bright Angel Creek should reduce predation on the endangered fish. Introduction of humpback chub into that tributary also has the potential to increase reproduction and recruitment of the chub.

### 3.2.19 Other Non-native Fishes Under Proposed Action

Effects of an April HFE are likely 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. 2011).

We expect impacts from single HFEs to be short term for other native fish, perhaps more so than humpback chub, due to their preferences for lower water velocities (Table 13). During flood, these rivers typically have very fast mainstem velocity yet also have areas where velocity is zero or is negative (upstream). The average speed of the 1996 flood of 45,000 cfs for the entire river length was 1.8 m/s, varying from; 1.5 to 2.1 m/s in different subreaches that were tens of kilometers in length. However, velocities varied greatly over shorter distances; in zones of flow separation and reattachment that determine the upstream and downstream ends of eddies current velocity was zero. Velocity elsewhere in eddies varied greatly, and was typically highest in the upstream return current (Schmidt et al. 2001) 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), non-native 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 temporarily 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. Native fish (flannelmouth and bluehead sucker, speckled dace) relative abundance also declined, but remained significantly higher than previous years. This suggested a disproportionate effect of powerplant (ca. 31,500 cfs) flows on small-bodied non-native fish. Trammell et al. (2002) did not report adverse effects of the powerplant flows on humpback chub, and Speas et al. (2002) documented no effects of the powerplant flow on age-1 non-native rainbow trout.

We do not expect non-native fish to be adversely impacted by a November HFE. Sampling was not conducted downstream from the Lees Ferry reach immediately before and after the 2004 HFE so effects on non-listed native fish can only be evaluated indirectly. However, several studies (Lauretta and Serrato 2006; SWCA 2008; Makinster et al. 2010b) 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 long-term impacts to these fish.

### 3.2.20 Fish Habitat Under Proposed Action

HFEs help to form more deeper and larger backwaters (Schmidt et al. 1999) Other than creation of backwater habitats, we do not expect other major fish habitat types (talus, debris fans, and vegetated shorelines) to be as affected by HFEs conducted during either release 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 a high flow.

**Table 13. Preferred water velocities (m/s) for non-native 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 | 0.10 | 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 | 0.10 | 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 | |

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 11, top). These decreases are due mainly to reductions in available habitat in cobble, bedrock and sandbar habitats. However, available habitat for 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 non-native fish if we assume depth preferences of less than one 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 11, bottom).

### 3.2.21 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 et al. 1987; Stevens et al. 1997a). 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).

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*), and 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. 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) also 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 augmented by a similar number of other birds, including loons, cormorants, grebes, herons, rails, and sandpipers, use the river corridor. There is a nearly continuous turnover in species throughout the winter months. 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 (USFWS 2007b). It currently maintains federal protection from the Bald and Golden Eagle Protection Act. 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 had increased dramatically by 1985 (Brown 1992; Brown and Stevens 1991, 1992; Brown et al. 1989). Territorial behavior, but no breeding activity, has been observed. This wintering population was monitored through the 1980s and 1990s in Marble Canyon and the upper half of Grand 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. 1995a). 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, there would be no expected change to current condition for bald eagle.

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; Stevens et al. 2009), many of which feed on invertebrate species (especially Diptera) that emerge out of the Colorado River and the adjacent riparian zone (Stevens et al. 1997b). In winter, a common prey item is waterfowl. Under no action, there would be no change to current condition for peregrine falcons.

**Southwestern Willow Flycatcher**

The southwestern willow flycatcher was designated by the USFWS as endangered in 1995. Critical habitat for the southwestern willow flycatcher was redesignated in October of 2005 and no longer includes habitat within the action area (USFWS 2005). The southwestern willow flycatcher 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 primarily occurs in non-native 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 (Tibbitts and Johnson 1999). Proximity to water is necessary and correlated with food supplies.

In recent years, southwestern willow flycatcher 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 small stretch of Marble Canyon and the lower Canyon near the inflow to Lake Mead (Sogge et al. 1995b; Tibbitts and Johnson 1999; Unitt 1987).

Population numbers have fluctuated between five breeding pairs and three territorial, but non-breeding, pairs in 1995 to one single breeding pair or none 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 southwestern willow flycatcher in 2010, six individual birds were detected in the river corridor between Lees Ferry and Pearce Ferry (Palarino et al. 2010). Breeding pairs were not detected. 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. Under no action, southwest willow flycatchers are not expected to exhibit any changes from current conditions.

**California Condor**

The California condor is listed as an endangered species and is found in the action area. On October 29, 1996, six California condors were released at Vermillion Cliffs in northern Arizona. Since then, there have been additional releases and the experimental population in spring 2002 was 32 birds (California Condor Reintroduction Program 2002). California condors are carrion-eaters. They are opportunistic scavengers, preferring carcasses of large mammals (Koford 1953) but will feed on rodents and, more rarely, fish. Depending upon weather conditions and the hunger of the bird, a California condor may spend most of its time perched at a roost. Roosting provides opportunity for preening, other maintenance activities, rest, and possibly facilitates certain social functions (USFWS 1996).

California condors often use traditional roosting sites near important foraging grounds. Cliffs and tall conifers, including dead snags, are generally used as roost sites in nesting areas. Although most roost sites are near nesting or foraging areas, scattered roost sites are located throughout the range. The beaches of the Colorado River through the Grand Canyon are frequently used by the Arizona/Utah experimental population of California condors (Sohie Osborn, Peregrine Fund, personal communication). Activities include drinking, bathing, preening, playing, and possibly feeding on the occasional fish carcass. Condor monitors noted an increase in interaction between rafters and condors in 2002 as rafting parties sought out unused beaches for lunch stops, exploration, and close observance of condors. There have also been several instances of the immature condors approaching campsites, possible keying into ravens that are experienced camp raiders. Under no action, California condor is not expected to exhibit any changes from current conditions.

### 3.2.22 Birds under Proposed Action

Many birds using the Colorado River below Glen Canyon Dam depend on the aquatic food chain associated with the green alga (*Cladophora glomerata*) and its diatom epiphytes or on insects that emerge in the riparian zone. No long-term adverse impacts to *Cladophora* and associated organisms or riparian zone insects are expected to result from the proposed HFE Protocol for a single HFE because none were observed during the 1996 experiment (Blinn et al. 1999; McKinney et al. 1999; Shannon et al. 2001). 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. Repeated HFEs may cause more protracted impacts, particularly if they occur at a frequency that truncates the recovery process following the HFE.

The length of the recovery period will vary and is expected to be longer following October-November HFEs than March-April HFEs. See aquatic food base section for more detail.

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. 1995a). 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. 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.

Peregrine falcons also are not expected to be negatively affected by single HFEs. Some disruption of energy flow in peregrine food chains may occur during and soon after these releases, but it is expected to be temporary and not affect reproduction or survival to any measurable extent. Multiple HFEs could extend the length of this affect, but resource assessments conducted prior to the high dam releases should serve to alert managers to the potential for unacceptable impacts.

The three prior large HFEs (1996, 2004, and 2008) occurred outside of the nesting time of southwestern willow flycatchers and did not impact the species. Breeding pairs have not been present in recent years and nesting usually occurs in May–June, so the HFEs did not interfere with nesting or feeding by adults near nest sites. The two windows for HFEs under the proposed action also avoid the nesting period. Reclamation's conclusion is that the proposed action is not likely to adversely affect the southwest willow flycatcher.

**California Condor**

There would likely be no adverse impact to California condors from the various HFEs described in the proposed action. Condors do not routinely forage along the river corridor nor do they appear to rely on any particular vegetation component associated with beach use. Nesting occurs far above the river corridor. California condors do use the Colorado River and beaches for bathing, drinking, resting, and feeding on available carrion. HFEs are designed to increase and/or restore beaches of the Colorado River through Grand Canyon. These flows may be beneficial to the California condor by temporarily increasing the amount of beach habitat available to the birds.

### 3.2.23 Mammals under No Action

Within GCNP 34 species of mammals have been recorded (Carothers and Aitchison 1976; Frey 2003; Kearsley et al. 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 of their existence has occurred since the 1970s (Kearsley et al. 2006). River otters are classified as extirpated and muskrats are considered extremely rare, but are found occasionally in the LCR (Stone 2010).

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 canyon habitats, 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.

Reclamation anticipates no change in existing conditions for mammals living in and along the Colorado River in Grand Canyon from the no action alternative.

### 3.2.24 Mammals under Proposed Action

Beaver are widespread throughout the Grand Canyon and appear to have increased in post dam conditions due to increased available riparian habitat (Turner and Karpiscak 1980). Mortensen et al. (2010) reported that observations of beaver or their sign occurred at 444 of 2,274 (19.4%) of their plots. Bank dwelling beaver foraging on willow in GCNP has led to a concern that beaver may facilitate an invasion of nonnative tamarisk and a decline in native willows (Johnson 1991).

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. Within a week of being born, the kits learn to swim and by three months of age they are weaned. Because the proposed action includes a relatively high flow that beaver do not experience on a regular basis, the high flow may temporarily disperse some sub-adult and adult beaver. Kits born prior to the high-flow-test and located below the flood stage could be harmed if they are unable to leave the lodge. High flows during March or April could affect some young beaver. High flows in October or November would likely have little long-term effect 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.

## 3.3 Cultural Resources

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.

### 3.3.1 Cultural Resources under No Action

Section 106 of the National Historic Preservation Act of 1966 requires federal agencies to take into account the effects of their undertakings on those historic properties listed on or eligible for inclusion in the National Register of Historic Places. For this undertaking, the area of potential effects (APE) within which historic properties and other cultural resources might be affected 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 45,000 cfs stage hydrologic models generated using LIDAR contour data, orthophoto data, and interpolation methods. While there are inaccuracies in how this area and the cultural resources within it have been mapped, the area measures about 10 square miles (2,500 hectares).

The APE includes two historic districts, one a National Register listed district at Lees Ferry in GCNRA; the other an historic district in GCNP that has been determined eligible to the Register through consensus. Appendix G is the consultation letter with the Arizona State Historic Preservation Officer. Identical letters were sent to other consulting parties.

Cultural resources also include Indian sacred sites as defined by Executive Order 13007. Under Executive Order 13007, an Indian sacred site is defined as a specific, discrete, narrowly delineated location on Federal land that is identified by an appropriately authoritative representative of an Indian religion as sacred by virtue of its established religious significance to, or ceremonial use by, an Indian religion. At least five federally-recognized Indian tribes consider the Colorado River through Grand Canyon a sacred site and they also have identified multiple individual locations as sacred sites.

### 3.3.2 Cultural Resources under Proposed Action

**Historic Properties**

Reclamation has not yet completed its Section 106 compliance. Pursuant to 36 CFR 800.4-5, one HFE would not be expected to result in loss of integrity for any of the sites or contributing elements to the historic districts and would result in a finding of "no historic properties affected" per 36 CFR 800.4(d)(1). However, with the probability of multiple HFEs occurring sequentially over the next 10 years, historic properties may be affected and the effect would be adverse per 36 CFR 800.5(2)(iv).

The rationale for this finding of adverse effect stems primarily from the level of uncertainty associated with the experimental nature of the undertaking over a ten year period. The uses of certain properties by the tribes could be altered due to inundation in the area of direct effect and there is some unknown potential for changes in the patterns of visitation and use in the area of indirect effect. For the contributing elements to the historic district that are eligible under criterion d, the potential frequency of inundation over the next 10 years and the altered visitation patterns could result in loss of integrity and information value. The repeated inundation of the contributing elements to the districts could result in a loss of site structure as artifacts or features are entrained in currents. Furthermore, one of the purposes of the proposed action is to determine how sediment might be moved downstream by high flows. An alteration in the deposition or removal of sediment from sites or contributing elements would constitute changes in the character of the eligible properties or possible changes in essential physical features that contribute to the property's significance.

**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 result in restrictions on tribal access to their sacred site or sites during the events. Following the requirements of EO 13007, Reclamation, working with the NPS and tribes, must find ways to continue to accommodate tribal access to and ceremonial use of their sacred sites and to develop notification procedures for the tribes with respect to HFEs.

While Reclamation has yet to complete consultation with all the Indian tribes that might consider the canyons and river sacred, at least one Indian tribe has indicated the change in river surface elevation could restrict access for Indian religious practitioners and for individual members of one or more Indian tribes. In the absence of notification procedures and final consultations with tribes regarding access, the effect of Indian sacred sites would be considered adverse.

## 3.4 Socio-economic 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. No effects were identified for population growth and housing, public health, traffic and transportation, and they are not further considered in this assessment.

### 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 is one component of a larger hydropower system, and it is included 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 13). 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 4,521 gigawatt hours (GWhs:1 GWh = 1 million kilowatt hours) from the Glen Canyon Dam powerplant. Generation from the Glen Canyon Dam powerplant and the other SLCA/IP electrical generators provides part of the electrical needs of an estimated 5 million customers in the seven Western states. They provide about 3 percent of the summer capacity in this seven-state region (Harpman 1999).

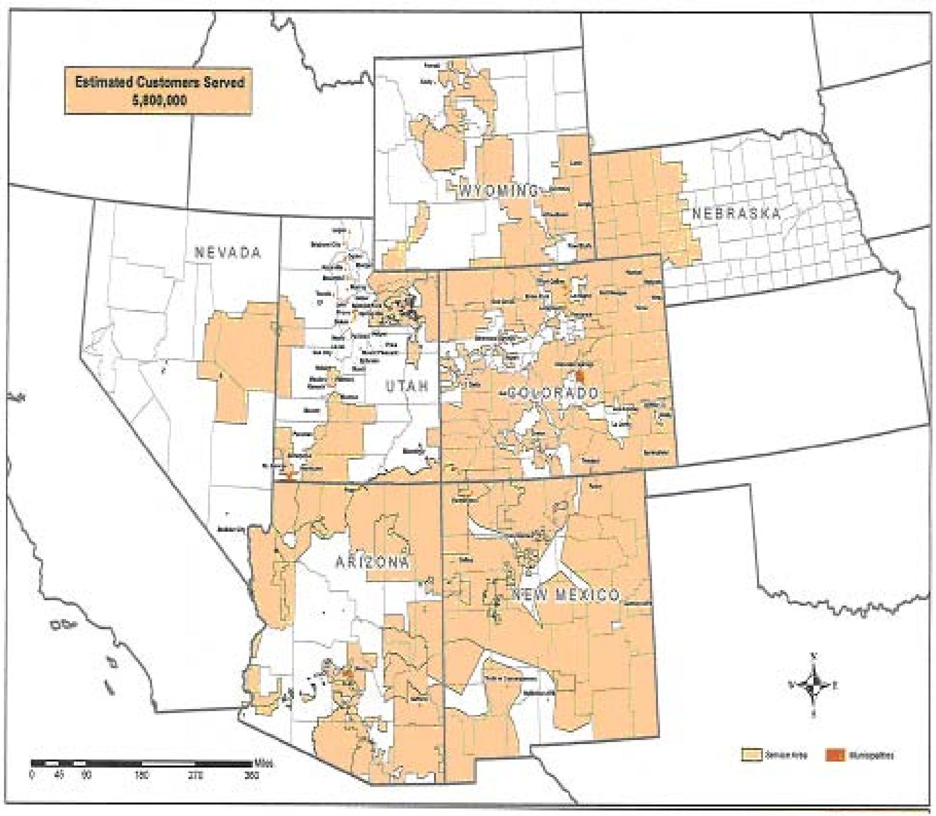



**Figure 13. Colorado River Storage Project management center service territory. Map courtesy of Western Area Power Administration.**

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.

Demand for electricity varies on a monthly, weekly, daily, and hourly basis, with the highest demand for electricity in the summer and winter when heating and cooling needs, respectively, are greatest. Demand for electricity is less in the spring and fall (Harpman 1999). During the day the demand for electricity is greater than at night-time hours. The daylight hours when demand is highest are called "on peak"hours. The on peak period is from 7:00 a.m. to 11:00 p.m., Monday through Saturday, although demand rises and falls during the on peak hours as well. Other hours are referred to as “off peak.”Normally Glen Canyon Dam operates in a way that conforms to changes in electrical demand: 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 technical, contractual, and environmental limitations, the availability of water, and limits 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 powerplant releases can change from one level to another is called a "ramp rate," measured 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 by Reclamation in the 2007 shortage guidelines EIS (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. Western has marketed the SLCA/IP electrical power as a “firm” electrical product: an amount of capacity and energy to be delivered in the amounts specified in the contract. This means that, during time of low electrical generation from the SLCA/IP (such as during a drought), Western must purchase supplemental electricity from electrical utilities and other suppliers to meet its contractual obligations. Western’s CRSP-MC includes $4 million per year in purchases in its current SLCA/IP long-term, firm rate (after 2013).

Under normal operations, Glen Canyon provides 40 MW of regulation and up to 98 MW of reserves to support electrical system reliability. These “ancillary services” are important in maintaining the reliability of the electrical and transmission grid. The 40 MW of regulation at Glen Canyon is implemented as instantaneous release adjustments to maintain stable conditions within the electrical generation and transmission system and results in momentary release fluctuations within a range that is about 1,100 cfs above or below the scheduled release rate. These momentary fluctuations for regulation are very short and typically balance out over the hour. Reserve generation is also maintained at Glen Canyon. When an unanticipated electrical outage event occurs within the electrical transmission system, this reserve generation at Glen Canyon can be called upon up to a limit of 98 megawatts (approximately 2,600 cfs of release) for a duration of up to 2 hours. Under normal circumstances, calls for reserve generation occur fairly infrequently and are for much less than the limit of 98 megawatts.

To utilize the full capacity of the powerplant during a high flow experiment, the 40 MW of regulation and up to 98 MW of reserves must be relocated from Glen Canyon to other facilities. Generally, it is easier to relocate reserves to other facilities, and more difficult to relocate regulation services. If an alternate location for regulation or reserves cannot be found during a high flow experiment, the full capacity of the powerplant would not be available. For example, if the 40 MW of regulation at Glen Canyon cannot be moved to an alternate location and needs to remain at Glen Canyon during a high flow, the release from the power plant would be 1,100 cfs below the capacity of the powerplant, so the that regulation service could be maintained.

### 3.4.2 Hydropower under the Proposed Action

Effects to hydropower would occur each time an HFE is conducted. This analysis identifies the electrical generation required to mitigate the power effects from an HFE, and estimates the associated costs (for methods see Appendix F).

HFEs at GCD affect power generation in six major ways:

1. Shifting water releases from one or more months in which peak electrical demands occur (summer and winter) to one or more months in other seasons (spring and fall). Shifting water releases to accommodate HFE schedules effectively reduces the amount of peak season generating capability at Glen Canyon Dam. Loss of peak season generating capability is the single largest economic consequence resulting from HFE releases.

2. Shifting electrical generation from more valuable hours of the day to less valuable hours (on-peak to off-peak or daytime to nighttime) – and from more valuable days of the week to less valuable days (weekdays to weekends).

3. Releasing water that bypasses the powerplant. When the amount of water released from the dam exceeds the capacity of the powerplant, the outlet works or bypass tubes are used to release the additional water. The powerplant is bypassed and water is "spilled" and does not produce electricity. The electrical power that replaces the power that could have been generated by the bypassed water is usually purchased from coal or natural gas-fired power plants at a higher price, and causes additional carbon-dioxide emissions.

4. Lowering the elevation of Lake Powell, thereby reducing the electrical generation efficiency - also known as reducing the powerplant head. The higher the head, the more kilowatt hours of electricity are produced from each acre foot of water that goes through the generators, and the more kilowatts of capacity are produced.

5. Reducing or eliminating the ability of the powerplant to match the continual fluctuations in customer electrical demand for the duration of the HFE.

6. Increasing water consumption at thermal power plants that meet electric customer needs,, when, as the result of an HFE, water either bypasses the Glen Canyon powerplant, or Glen Canyon generation is shifted from summer season months to non-summer season

months. The economic impacts associated with increased power plant water consumption were not accounted for in this analysis.

Electricity is unique among energy sources in that it must be produced at the same instant that it is needed by customers. Since electricity cannot easily or inexpensively be stored like other energy sources such as oil or natural gas, *when* electricity is generated has a large effect on how valuable it is to customers, and the price utilities are willing to pay for it. Electricity generated in the middle of the night, or on a Sunday, or in the month of October or April is worth less because people use less electricity at those times. Conversely, electricity generated at noon on a weekday, and in a month such as July or August is worth a lot more because people and businesses are using a lot of electricity during those times.

Electrical capacity is defined as the maximum amount of generation that is available from a power plant at any given period of time. Electrical capacity is important because it is necessary for the power system to have sufficient capacity to meet the peak demand, or the result will be problems such as blackouts and brownouts. The changes in operations at GCD from HFEs not only reduce energy production but may also reduce the electrical capacity produced by the plant. In addition to the cost of purchasing electrical energy, there may also be a cost for electrical capacity. Capacity costs are more related to the cost of constructing a power plant, while energy costs are more related to the cost of operating and maintaining the power plant. Electrical capacity is often specified and priced as a separate product from electrical energy in bulk power purchase and sale transactions.

Under some conditions, an electrical generator must be constructed or brought into service to replace lost GCD generation as a result of an HFE or series of HFEs. For example:

- The HFE Protocol is proposed as a 10-year action. HFEs would be scheduled for October/November and/or March/April. This means water may be added to these months from other months in the year. If implementing the protocol results in a reduction by Western of a capacity commitment to GCD electrical contractors, those contractors will need to add capacity resources as a result.

- Western purchases energy from electrical energy exchanges to meet its hourly contractual commitments. When capacity is in short supply in the region in which Western purchases power, or when transmission constraints require additional purchases, the price Western pays for electrical energy include a capacity premium.

- Western's power customers may be uncertain as to the stability and availability of the GCD resource under their long-term purchase contracts. Since the planning horizon for the construction of new electrical generators is long (10 – 20 years), utilities that have contracts for Federal power from the Colorado River Storage Project (CRSP) dams may "overbuild" when they undertake new generating capacity construction due to the uncertainty of the GCD resource.

This analysis did not attempt to measure whether new capacity would need to be constructed to replace capacity lost as a result of the HFE Protocol. Instead, the difference in available capacity between the No Action and the Proposed Action case for the peak month for each of the hydrologic and sediment cases has been calculated. Having identified those capacity losses, a capacity cost has been applied based on the annualized construction costs of an electrical generator that would be a likely replacement for GCD power.

**Results**

Tables 14 through 16 below provide the results of the GTMax modeling of the nine historic 10-year hydrologic traces used to model sand budgets for the HFE Protocol (see Appendix E)3. These are expressed in terms of differences from the no action trace in millions of 2010 dollars. The impacts described in Table 3 are a function of the change in timing of electrical generation at GCD as well as the vector of prices used. The magnitude of the impact therefore is a function of the prices used. In recent years, electrical energy prices have been higher. The use of market prices observed in recent years would result in higher dollar impacts.

The smallest cumulative impact to hydropower in the 10-year traces occurs in a wet hydrological condition with a low amount of tributary sand input. The largest impacts occur in a dry hydrological condition with moderate sand and a wet hydrological condition with moderate sand (Table 14).

**Likelihood of Events**

The nine conditions described in Table 3 are not equally likely to occur. The hydrological conditions were chosen to represent a wide range. The dry hydrological case is the 10th percentile and thus conditions wetter than this occur 90 percent of the time. Similarly, the wet hydrological case is the 90th percentile. Conditions wetter than this occur only 10% of the time. The median hydrological case is a condition in which during 50% of the time hydrological conditions are wetter and during 50% of the time they are drier. Therefore, the median hydrological conditions are much more like to occur than the dry or wet conditions. A similar probability description applies to the sand conditions. The low, moderate and high sand conditions were chosen to describe the same range as the hydrological conditions. A moderate amount of sand input is therefore much more likely to occur than a low or high sand condition.

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3 For the March 2008 HFE, the projected total cost of the high flow test for water year 2008 was estimated at $4.1 million, or a 9.4 percent increase in the purchase power requirement for 2008 For the analyses included in this document, the impact of an HFE or HFEs is considerably lower. This is because the proposed action includes HFEs of different magnitudes and durations. The #13 HFE, for example, is merely an hour in duration and its peak release is at powerplant capacity. In addition, prices used for this analysis are significantly lower than what has prevailed in recent history.

**Table 14. 10- year GCD Electrical Energy Cost for the Proposed Action Alternative.**

| Hydrologic Condition | Sand Condition | Total Cumulative Impact Difference from No Action (2010 $M) |
|---|---|---|
| Dry | Low | $17.1 |
| Dry | Moderate | $18.5 |
| Dry | High | $17.6 |
| Median | Low | $11.7 |
| Median | Moderate | $16.7 |
| Median | High | $10.8 |
| Wet | Low | $ 8.1 |
| Wet | Moderate | $18.6 |
| Wet | High | $16.1 |

Table 15 shows the results of the GTMax modeling of capacity loss from HFEs. The middle column shows the capacity loss in megawatts for each trace as compared to the no action case. This is the difference between the summer season peak month maximum available capacity in the no-action case and the summer season peak month maximum available capacity in each of the nine proposed action cases. The cost of this lost capacity is shown as a total over the 10-year period of the modeled scenario and is displayed in the last column.

**Table 15. GCD Electrical Capacity Cost for the Proposed Action Alternatives.**

| Hydrologic Condition | Sand Condition | Capacity (MW) Difference from No Action | Difference from No Action – Total over the 10-year study period (2010 $M) |
|---|---|---|---|
| Dry | Low | 76 | $ 80.6 |
| Dry | Moderate | 31 | $ 32.9 |
| Dry | High | 12 | $ 12.9 |
| Median | Low | 0 | $ 0 |
| Median | Moderate | 14 | $ 15.4 |
| Median | High | 0 | $ 0 |
| Wet | Low | 0 | $ 0 |
| Wet | Moderate | 97 | $103.6 |
| Wet | High | 78 | $ 83.1 |

There are some cases in which there are no capacity impacts. If one or two HFEs occur in a given year, no water is redistributed out of the peak power months of July and August and if there is no loss in Lake Powell elevation, then there is no change in capacity available from Glen Canyon Dam. For the three cases in Table 15 that indicate no loss in available capacity, water released for HFEs did not affect water available in July and August. The largest impact to capacity occurs in the dry hydrology/low sand input trace and the wet hydrology/high sand input trace. Earlier results identified that the greatest number of HFEs (14) occurred in the dry hydrology/low sand trace, while the wet hydrology/ moderate sand input and wet hydrology/high sand input had higher numbers of large magnitude and duration HFEs.

Table 16 shows the total cost of electrical generation losses, combining the energy and capacity losses from the two preceding tables. These figures represent a possible impact of the proposed action under a circumstance in which capacity is lost. Impacts in Table 16 fall roughly in line with the number of HFEs and the loss in capacity. Thus, wet hydrology/high sand input and wet hydrology/moderate sand input, the sets with larger impacts, also are the sets in which the highest number of large magnitude and duration HFEs occur. They are followed by the dry hydrology/low sand input trace, which has the highest total number of HFEs.

**Table 16. GCD Total Cost of the Proposed Action Alternatives.**

| Hydrologic Condition | Sand Condition | Difference from No Action (2010 $ M over the 10-year period) |
|---|---|---|
| Dry | Low | $ 97.7 |
| Dry | Moderate | $ 51.3 |
| Dry | High | $ 30.5 |
| Median | Low | $ 11.7 |
| Median | Moderate | $ 32.1 |
| Median | High | $ 10.8 |
| Wet | Low | $ 8.1 |
| Wet | Moderate | $122.2 |
| Wet | High | $ 99.2 |

**Annual Impacts and the Variability of Annual Impacts**

As noted previously, the 10-year action period will not consist of a single scenarios developed for the proposed action, but rather each year will bring a different combination of hydrological and sand conditions. Thus, it is instructive to look at the variation in annual impacts. For each of the proposed action cases, there is a significant amount of variability. Figure 14 displays a box plot that illustrates the variability of HFE impacts by hydrological condition from differences in the cost of electric energy between an HFE scenario and the no action scenario. The top and bottom edges of the box are located at the upper and lower quartiles of impacts. The lines (or whiskers) for each box extend to the maximum and minimum impacts. The median value is the solid black line within the box.

There is a significant amount of variability with the implementation of HFEs from one year to the next. The interquartile range is the range illustrated by the box (the middle 50% of cases).While the median and interquartile range of impacts for each hydrological condition is similar, the range of impacts for the dry condition is significantly larger than for the other two. Occasionally the implementation of the proposed action produces a benefit rather than a cost (whiskers extend to the negative [benefit] side of the graph). This is because, about one year in ten for each of the three hydrological conditions, implementation of HFEs results in redistribution of water from a month in which electrical energy is less valuable to an HFE month to a month in which electrical energy is more valuable..

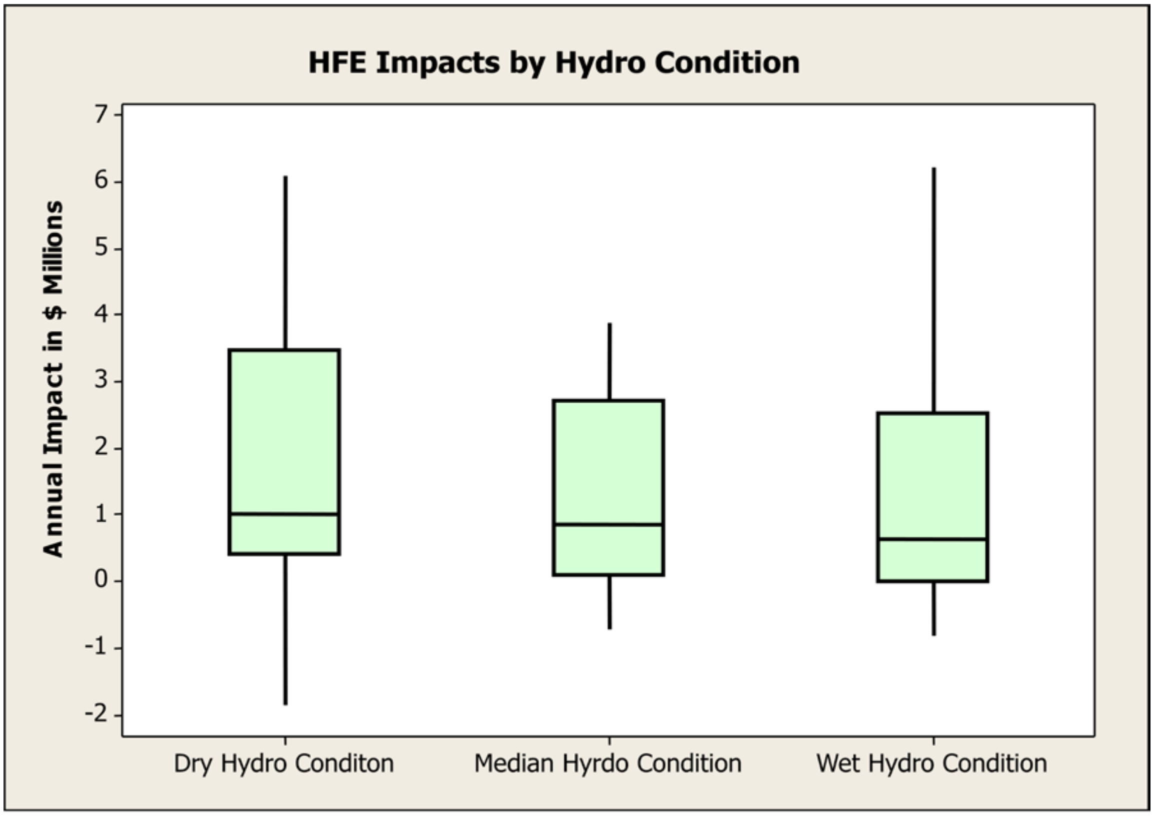



**Figure 14. Annual impacts in millions of dollars of HFEs during three different hydrological conditions.**

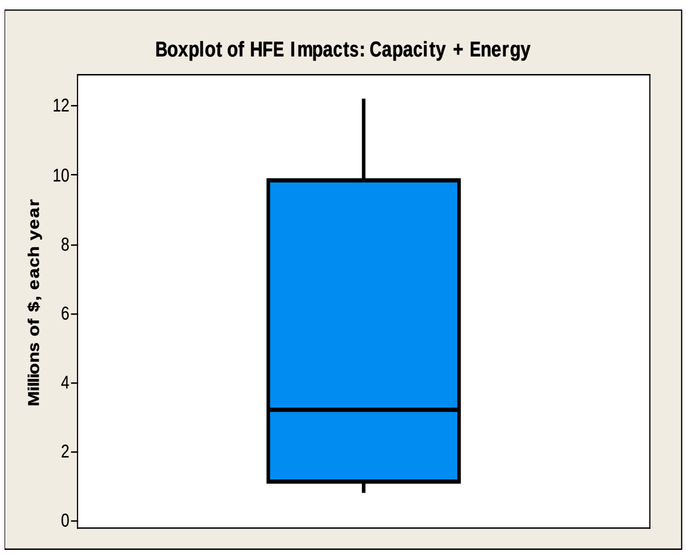



**Figure 15. An illustration of the variability of impacts of the proposed action on both energy <u>and</u> capacity.The blue box illustrates the interquartile range, the whiskers illustrate the range of impacts, from minimum to maximum.**

In Figure 15, impacts to capacity are added to impacts to energy. When capacity impacts are added, the range of impacts no longer includes benefits.

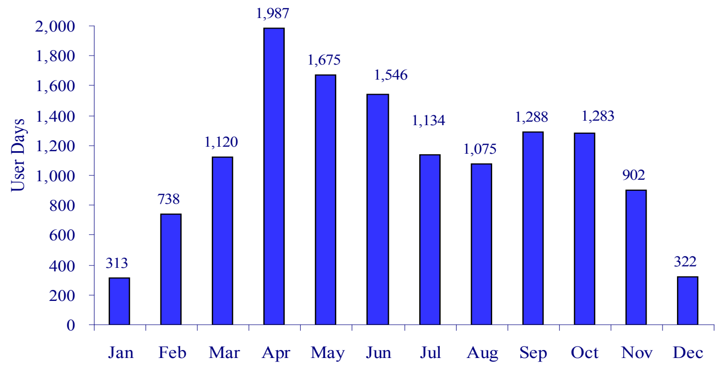
**Uncertainties**
Despite the sophistication of the water and power models used for the hydropower analysis in this Environmental Assessment, it does use a number of simplifying assumptions. This analysis should not be assumed sufficient for a more robust or complex assessment, as was developed for the 1995 GCD EIS.

### 3.4.3 Recreation under No Action

Recreational resources of concern include both 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 (Lichtkoppler 2011).

**Fishing in the Lees Ferry Reach under No Action**
The Colorado River from the dam to Lees Ferry is an important 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 or from shore.

The month with the highest number of user days for 2006 and 2009 was April (Figure 16). Angler use remains high from March through October, and months of lower use are December through February. 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).



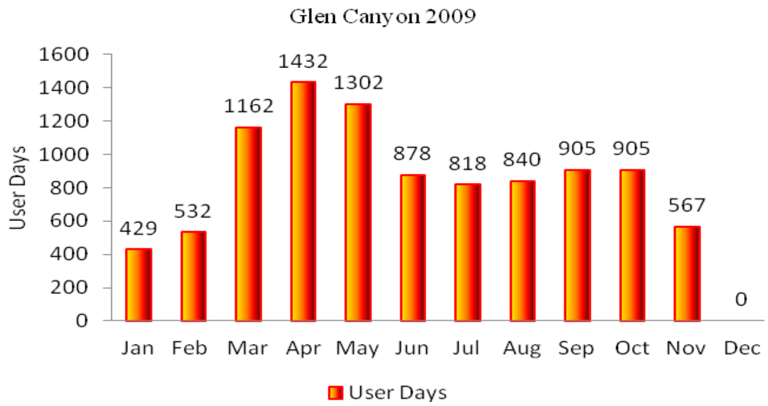




**Figure 16. Fishing user days by month in the Lees Ferry reach for 2006 (top) and 2009 (bottom).**

### Boating in the Lees Ferry Reach under No Action

There is a commercial recreational river rafting concession that operates in the 16 miles of the GCNRA below Glen Canyon Dam. Use occurs in most months, but the majority of trips are concentrated in the summer (Table 17). During previous 40,000-45,000 cfs HFEs, these trips were suspended over the period of the high release. Because no HFEs would occur without additional compliance, these suspensions would not be expected to occur in the future under no action.

**Table 17. Commercial river rafting user days for the 16-mile reach of the Colorado River below Glen Canyon Dam.**

| Month | 2009 | 2010 |
|---|---|---|
| January | 0 | 6 |
| February | 159 | 8 |
| March | 2,223 | 2,131 |
| April | 5,256 | 4,599 |
| May | 6,346 | 6,629 |
| June | 9,332 | 9,905 |
| July | 9,256 | 9,887 |
| August | 7,866 | 7,367 |
| September | 5,415 | 6,287 |
| October | 3,823 | 3,824 |
| November | 735 | 687 |
| December | 0 | 0 |
| Total | 50,411 | 53,340 |

**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; 2006a) with a lottery system.

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 2006) governs use in both the upper reach and the lower reach. Annual use in the Lees Ferry reach was projected to be 115,500 commercial user-days (one person on the river for one day) and approximately 113,500 noncommercial (private) user-days (National Park Service 2006). Higher use months for commercial operations extend from May through September, but there is relatively consistent use through the year for noncommercial boating (Figure 17).

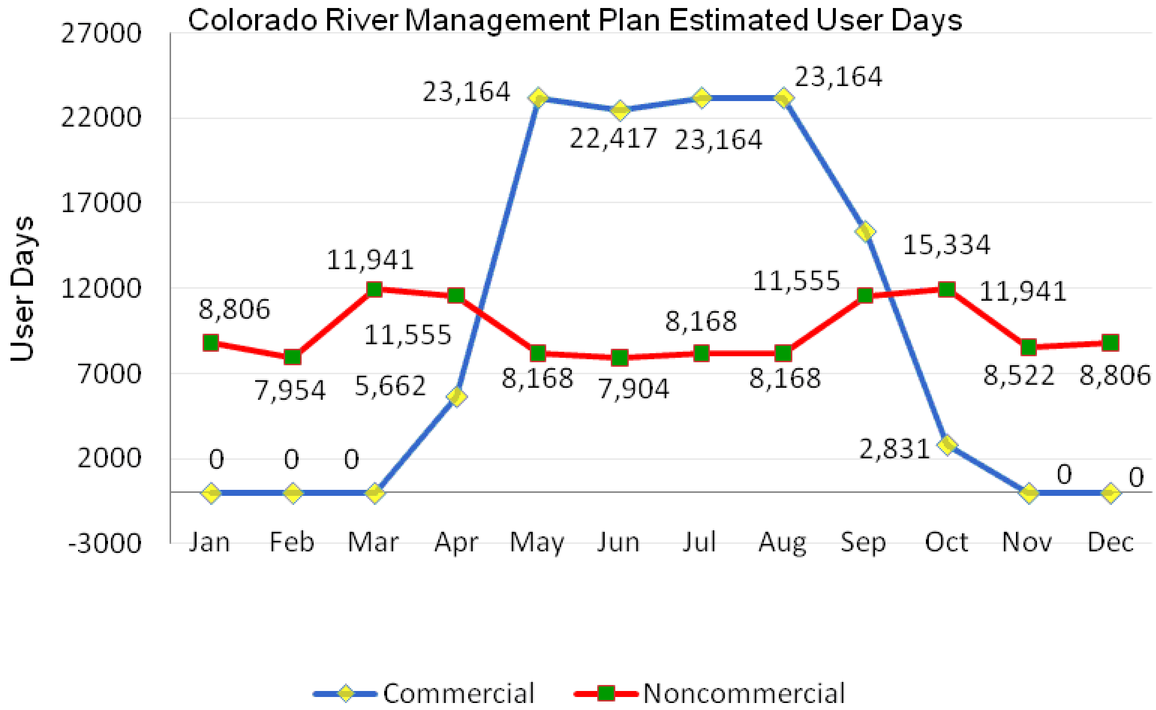



**Figure 17. Whitewater boating in the Grand Canyon, annual use by month (Grand Canyon National Park 2006).**

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 from Diamond Creek. Diamond Creek is at about mile 226, or about 242 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 31$^{st}$. Commercial day and overnight trips run by Hualapai River Runners (HRR) begin at Diamond Creek and end at Quartermaster or at Lake Mead (Pearce Ferry). 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 and 2006). Figure 18 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.

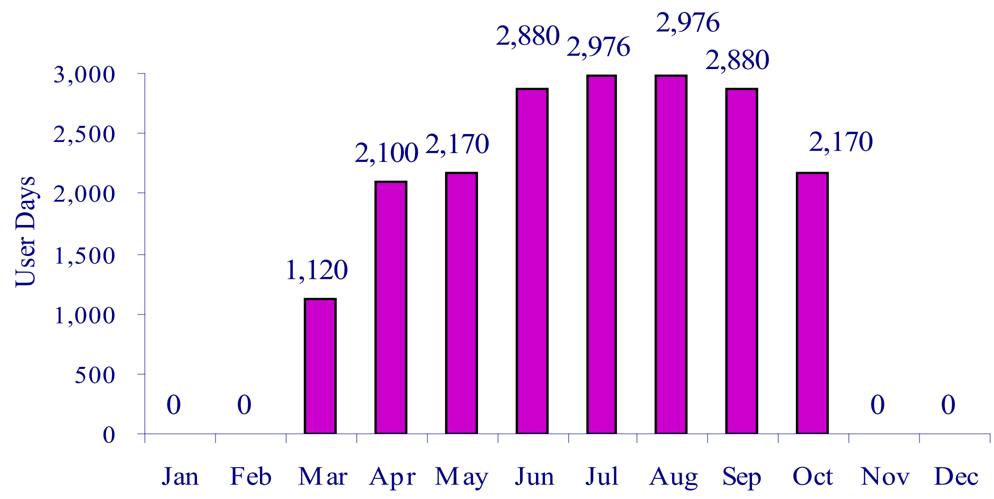



**Figure 18. Recreation use below Diamond Creek (HRR maximum possible).**

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 19). A comparable number of user days were recorded for trips launching before Diamond Creek and continuing past Diamond Creek.

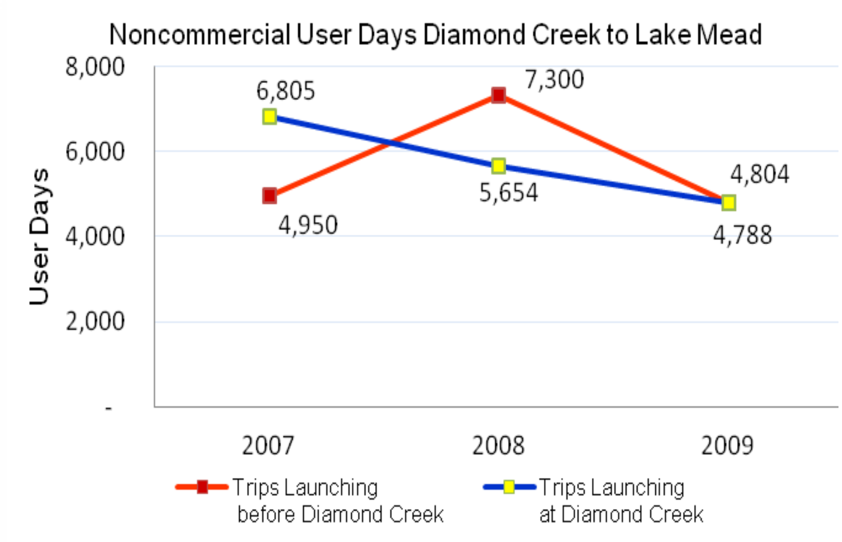



**Figure 19. Noncommercial user days – Diamond Creek to Lake Mead (National Park Service 2009).**

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. A maximum of approximately 175,200 passengers is expected annually, with a monthly range of 13,440 to 14,880.

Under the no action alternative there would be no effect on the number of visitors participating in whitewater rafting. No control actions would be implemented.

**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 (Reclamation 1995) 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 "non-use" or "passive use" value (King and Mazzotta 2000). 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 1996 Record of Decision for Glen Canyon Dam operations (Interior 1996).

### 3.4.4 Recreation under Proposed Action

**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. 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 et al. (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 HFE would experience rapid increases in river stage that would place them at risk if they were 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.

**Boating in the Lees Ferry Reach 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 were not 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 were not restricted from Lees Ferry access and boats could move upstream under NPS Whitewater Boating Safety Rules. These same restrictions and allowances are anticipated under the proposed action. Because of the higher use in March and April in comparison with October and November (Table 17), a somewhat higher impact would likely occur from spring as opposed to fall HFEs.

**Whitewater Boating under Proposed Action**

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 (Brown and Hahn 1988; Jalbert 1996) 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. Webb et al. (1999) showed that HFEs 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. The results of these studies are somewhat difficult to evaluate because they were relatively short term, the sampling strategy was not random, and the studies did not take into account non-flow factors such as boater experience.

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 HFE, 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.).

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 and potentially forcing users into old high water zone areas The greater the magnitude of the HFE the larger the decrease in campable area is expected. 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.

**Net Economic Use Value of Recreation under Proposed Action**
The net effect of the proposed HFEs on regional economic activity under the proposed action was estimated for recreational fishing and day-use boating for the highest and lowest magnitude and duration HFEs using the IMPLAN model (Lichtkoppler 2011). Negative impacts on fishing guides, anglers, and river runners were determined to be short-term due to the short duration of HFEs. Estimated expenditure impacts for recreational fishing ranged from approximately $22,000 for a November HFE to $58,000 for an April HFE. Day use boating regional impacts were estimated to range from a low of approximately $27,500 in November to a high of $815,000 for April. November estimates involved only Lees Ferry boating, whereas April included the Hualapai concessionaire downstream at Quartermaster Canyon.

**Table 18. Summary of impacts to 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. Impact is minor, moderate or high, depending on extent or severity; short-term for impact that is temporary, short-lived and does not affect future condition of resource; long-term for impact that is long-lasting or permanent.**

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Water Resources | No impact to annual delivery or monthly volumes or daily fluctuations. | No impact to annual delivery. Monthly volumes and daily fluctuations would change only as necessary for HFE reallocation and remain within MLFF limits. | | No impact to annual delivery or monthly volumes. | No impact to annual delivery. Monthly volumes and daily fluctuations would change only as necessary for HFE reallocation and remain within MLFF limits. | |
| Water Quality | Minor short -term impacts (days) to reservoir and river: slight reduction in downstream temperature and slight increase in salinity. | Minor short-term impacts (days) to reservoir and river: slight reduction in downstream temperature and slight increase in salinity. Temporary turbidity increase from scouring; temporary elevation in dissolved oxygen/carbon dioxide due to plant recovery following release. | | Minor short-term impacts (days) to reservoir and river: slight reduction in downstream temperature and slight increase in salinity. | Minor short-term impacts (days) to reservoir and river: slight reduction in downstream temperature and slight increase in salinity. Temporary turbidity increase from scouring; temporary elevation in dissolved oxygen/carbon dioxide due to plant recovery following release. | |
| Air Quality | No measureable impact. | Minor short-term impact (days): Addition of up to 32,000 metric tons of $CO_2$ or 0.02 percent of regional $CO_2$ emissions. | Minor short-term impact (days) : Addition of 39,000 to 63,000 metric tons of $CO_2$ or 0.05 percent of regional $CO_2$ emissions. | No measureable impact. | Minor short-term impact (days) : Addition of up to 32,000 metric tons of $CO_2$ or 0.02 percent of regional $CO_2$ emissions. | Minor short-term impact (days) : Addition of 39,000 to 63,000 metric tons of $CO_2$ or 0.05 percent of regional $CO_2$ emissions. |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Sediment | Short-term beneficial impac (month), duration will be influencedby ensuing flow volume and fluctuation: Additional sediment stored in sandbars, beaches, and eddies up to 33,200 cfs stage. Potential for management of fine sediment distribution to enhance positive effects of larger HFEs. Persistence of stored sediment dependent on subsequent flow regime. | Short-term beneficial impact (month), duration will be influenced by ensuing flow volume and fluctuation: Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage. Temporary increase in number and area of backwaters expected. | Short-term beneficial impact (month), duration will be influenced by ensuing flow volume and fluctuation: 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. Temporary increase in number and area of backwaters expected. | Short-term beneficial impact (month), duration will be influenced by ensuing flow volume and fluctuation: Additional sediment stored in sandbars, beaches, and eddies up to 33,200 cfs stage. Potential for management of fine sediment distribution to enhance positive effects of larger HFEs. Persistence of stored sediment dependent on subsequent flow regime. | Short-term beneficial impact (month), duration will be influenced by ensuing flow volume and fluctuation: Additional sediment stored in sandbars, beaches, and eddies up to 45,000 cfs stage. Temporary increase in number and area of backwaters expected. | Short-term beneficial impact (month), duration will be influenced by ensuing flow volume and fluctuation: 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. Temporary increase in number and area of backwaters expected. |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Riparian Vegetation | Minor short-term impact (months): some inundation of low elevation plants; minor scouring and/or burial of wetland vegetation in backwaters and beaches. Likely reestablishment of vegetation in successional process. Some dispersal of tamarisk seeds; little germination expected. | Moderate short-term impact (months to years): inundation and burial of plants in flood zone; scouring and/or burial of wetland vegetation in backwaters and beaches. Likely reestablishment of vegetation in successional process. Some dispersal of tamarisk seeds; little germination expected. | | Minor short-term impact (months): some inundation of low elevation plants; minor scouring and/or burial of wetland vegetation in backwaters. Likely reestablishment of vegetation in successional process. Minimal dispersal of tamarisk seeds; very little germination expected. | Moderate short-term impact (months to years): inundation and burial of plants in flood zone; scouring and/or burial of wetland vegetation in backwaters and beaches. Inundation of flowering plants could reduce reproduction. Likely reestablishment of vegetation in successional process. Minimal dispersal of tamarisk seeds; very little germination expected. | |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Terrestrial Invertebrates and Herptofauna | Minor short-term impact (days to months): lowest elevation animals and habitat would be inundated and some exported. Insects and small invertebrates washed into river produce major temporary increase in fish food. | Moderate short-term impact (days to months): some animals and habitat inundated and exported up to 45,000 cfs stage. Insects and small invertebrates washed into river produce major temporary increase in fish food. | | Minor short-term impact (days to months): lowest elevation animals and habitat would be inundated and some exported. Insects and small invertebrates washed into river produce major temporary increase in fish food. | Moderate short-term impact (days to months): some animals and habitat inundated and exported up to 45,000 cfs stage. Insects and small invertebrates washed into river produce major temporary increase in fish food. | |
| Kanab ambersnail | Minor short-term impact (days to months): lowest elevation animals and habitat would be inundated and some exported. | Moderate short-term impact (days to months) up to 17 percent of habitat inundated and some animals exported up to 45,000 cfs stage. Habitat and animals in inundation zone will be temporarily relocated as part of conservation measure. | | Minor short-term impact (days to months): lowest elevation animals and habitat would be inundated and some exported. | Moderate short-term impact (days to months): up to 17 percent of habitat inundated and some animals exported up to 45,000 cfs stage. Habitat and animals in inundation zone will be temporarily relocated as part of conservation measure. | |
| Aquatic Foodbase | Minor reduction (days to months) in select taxa in specific reaches. No lasting impacts expected. | Potential lasting impact (months): scouring of most algae, invertebrates (greater for mudsnails and *Gammarus*), plants; recovery may be delayed until following spring because of reduced photosynthesis during winter. | | Minor reduction (days to months) in select taxa in specific reaches. No lasting impacts expected. | Moderate short-term impact (months): scouring of most algae, invertebrates (greater for mudsnails and *Gammarus*), plants; improved production and drift of chironomids and black flies; recovery expected in 1-4 months. | |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Humpback Chub | Minor short-term impact (days) from reduction in habitat during HFE; some displacement of young. | Moderate short-term impact (days to months) from reduction in foodbase and habitat; moderate displacement of young; no long-term population effect. Increase in backwater habitat. | | Minor short-term impact from reduction in habitat (days); possible increased predation of young due to increased escapement of trout from Lees Ferry. | Moderate short-term impact (days to months)from reduction in foodbase and habitat; minor displacement of young; March-April y-o-y not yet present in mainstem habitats; Oct-Nov most y-o-y large enough to be little affected by HFEs; increased predation of young likely when HFEs result in increased production and escapement of trout from Lees Ferry. Increase in backwater habitat. | |
| Razorback sucker | Minor short-term impact (days) from reduction in foodbase and habitat; small number of adults present in Lake Mead inflow where effect of HFE will depend on lake level. | Minor short-term impact (days) from reduction in foodbase and habitat; small number of adults present in Lake Mead inflow where effect of HFE will depend on lake level. | | Minor short-term impact (days) from reduction in foodbase and habitat; small number of adults may be spawning in Lake Mead inflow where effect of HFE will depend on lake level. | Moderate short-term impact (days to months) from reduction in foodbase and habitat; small number of adults may be spawning in Lake Mead inflow where effect of HFE will depend on lake level. | |
| Non-Listed Native Fish | Minor short-term impact (days)from reduction in foodbase and habitat. | Minor short-term impact (days) from reduction in foodbase and habitat; minor displacement or habitat relocation of young; no long-term population effect. | | Minor short-term impact (days) from reduction in foodbase and habitat. | Minor short-term impact (days to months) from reduction in foodbase and habitat; moderate displacement or habitat relocation of young; no long-term population effect. | |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Trout | Minor short-term impact (days): cropping of foodbase and scouring of sediment in Lees Ferry may improve condition of fish. | Possible moderate short-term impact: decline in survival and condition from reduced foodbase and increased recovery period; downstream dispersal or displacement of young probable at high fish density. | | Moderate beneficial impact: scour of sediment will increase survival of young; downstream dispersal or displacement of young possible at high fish density. | Long-term beneficial impact to population; increased YOY survival from compensatory response; temporary decline (ca. 3-4 mo.) in condition; probable downstream displacement of young under high fish densities. | |
| Other Non-native Fish | Minor short-term impact (days): little displacement of small-bodied fish from backwaters. | Minor short-term impact from reduction in foodbase and habitat (days to months): displacement of small-bodied fish from backwaters and shorelines. | | Minor short-term impact (days): displacement of newly-hatched young and small-bodied fish from backwaters and shorelines. | Minor short-term impact (days) from reduction in foodbase and habitat: displacement of newly-hatched young and small-bodied fish from backwaters and shorelines. | |
| Birds | Minor short-term impact to waterfowl related to food availability (days); no impact to SWFL since birds not present during HFE. | | | Minor short-term impact (days) to waterfowl related to food availability; no impact to SWFL since birds not present during HFE. | | |
| Mammals | Minor short-term impact (days) to riparian and aquatic mammals which would temporarily move. | | | Minor short-term impact (days): small numbers of young beaver could drown in dens; adult mammals would be temporarily displaced. | Moderate short-term impact (days to months): more young beaver could drown in dens; adult mammals would be temporarily displaced. | |

| Timing | 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 | 1–8 hrs | 1–48 hrs | 60–96 hrs | 1–8 hrs | 1–48 hrs | 60–96 hrs |
| Historic Properties | Minor short-term adverse impact: access to properties temporarily restricted. | Minor short-term adverse impact: access to properties temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. | | Minor short-term adverse impact: access to properties temporarily restricted. | Minor short-term adverse impact: access to properties temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. | |
| Sacred Sites | Minor short-term adverse impact: access to sites temporarily restricted. | Minor short-term adverse impact: access to sites temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. | | Minor short-term adverse impact: access to sites temporarily restricted. | Minor short-term adverse impact: access to sites temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. | |
| Hydropower | Minor short-term impact: cost of replacement power $20,000-$30,000. | Moderate short-term impact: cost of replacement power $0.02-$1.67 million. | Moderate short-term impact: cost of replacement power $2.09-$3.34 million. | Minor short-term impact: cost of replacement power $20,000 | Moderate short-term impact: cost of replacement power $0.02-$1.43 million. | Moderate short-term impact: cost of replacement power $1.78-$2.85 million. |
| Recreation | Minor short-term impact to boating, rafting, angling. | Minor short-term impact: more anglers in Lees Ferry reach in Oct than Nov; some risk to rafters; less impact with shorter duration. | Moderate short-term impact: more anglers in Lees Ferry reach in Oct than Nov; risk to rafters; greater impact with longer duration. | Minor short-term impact to boating, rafting, angling. | Moderate short-term impact: high angler use in Lees Ferry reach in Mar and Apr; some risk to rafters; less impact with shorter duration. | Moderate short-term impact: higher angler use in Lees Ferry reach in Mar and Apr; risk to rafters; greater impact with longer duration. |

**Table 19. Summary of impacts to resources from two or more, consecutive high-flow experiments (HFEs) with a magnitude of 41,000-45,000 cfs. The "spring" period by March-April and the "fall" period are represented by October-November. Larger magnitude and longer duration HFEs are assessed with the assumption that they have greater impacts than lower magnitude and shorter duration HFEs, and we presume that the impacts of lesser HFEs are adequately considered in this analysis.**

| Resource | Spring HFE Followed by Fall HFE | Fall HFE Followed by Spring HFE | More Than Two Consecutive HFEs |
|---|---|---|---|
| Water Resources | Impact same as single HFEs. | | |
| Water Quality | Impact same as single HFEs. | | |
| Air Quality | Doubles impact of single HFE: Addition of 64,000 to 126,000 metric tons of $CO_2$ in a year or 0.10 percent of regional $CO_2$ emissions. | | Annual impact is described in previous two columns; long-term impact depends on number of consecutive HFEs and total number over 10-year period; cumulative impact could result in greater $CO_2$ emissions. |
| Sediment | Beneficial impact: Additional sediment stored in sandbars, beaches, and eddies that may better balance sediment budget; ongoing sediment transport and erosion is expected to continue between and after HFEs. | | Potential for long-term beneficial impact: Additional sediment could be stored in sandbars, beaches, and eddies up to 45,000 cfs stage. Potential for better balancing sediment delivery between upstream and downstream reaches and long-term conservation to offset ongoing sediment transport and erosion. |
| Riparian Vegetation | Impact same as single HFEs; may increase organics in sandbars and beaches, or coarsen sand depending on antecedent organic load in sediment; may favor native clonal species and suppress certain flowering plants. | | Moderate to high impact, depending on number of consecutive HFEs; vegetation below median flow stage would be eliminated; frequent HFEs with low organic load could coarsen sand which favors native clonal species. |
| Terrestrial Invertebrates and Herptofauna | Impact same as single HFEs. | | Moderate to high impact, depending on number of consecutive HFEs; habitat below median flow stage would be used transiently and population expected to relocate to higher elevation. |
| Kanab ambersnail | Impact same as single HFEs. | | Moderate to high impact, depending on number of consecutive HFEs; habitat below median flow stage would be used transiently and |

| Resource | Spring HFE Followed by Fall HFE | Fall HFE Followed by Spring HFE | More Than Two Consecutive HFEs |
|---|---|---|---|
| | | | population expected to relocate to higher elevation. |
| Aquatic Foodbase | Impact same as single HFEs. | Impact greater than single HFEs: recovery from fall HFE may not be complete before additional scouring from spring HFE; full recovery from both HFEs may not occur until summer after second HFE leading to reduced or altered foodbase. | Moderate to high impact, depending on number of consecutive HFEs; foodbase may not fully recover between HFEs; foodbase expected to transition to flood-adapted species with multiple consecutive HFEs (number of HFEs needed for this effect unknown). |
| Humpback Chub | Minor short-term impact from changes in foodbase and habitat from both HFEs; little displacement of young expected in spring, some displacement in fall; moderate impact from increased dispersal of trout from Lees Ferry leading to increased predation and competition. | | Moderate short-term impact from changes in foodbase and habitat; moderate displacement of young; uncertain long-term population effect. |
| Razorback sucker | Minor short-term impact from changes in foodbase and habitat; may affect reproduction in spring; moderate displacement of young; no long-term population effect expected. | | Minor short-term impact from changes in foodbase and habitat; small number of adults present in Lake Mead inflow where effect of HFE will depend on lake level. |
| Non-Listed Native Fish | Impact same as single HFEs. | | Minor short-term impact from changes in foodbase and habitat; most spawning in tributaries is unaffected; unknown impact to little mainstem spawning; little displacement of young expected because of habitat relocation. |
| Trout | Moderate impact: scouring of sediment in Lees Ferry likely to increase egg/alevin survival in spring and recruitment of young; may expand population size; fall HFE could reduce foodbase leading to reduced condition and survival of fish and could increase downstream dispersal. | Lesser impact than spring/fall: scouring of foodbase in fall may reduce survival, condition of fish, and reproductive potential in spring; scouring of foodbase in spring expected, but improvement of reproductive habitat and rapid recovery of foodbase in summer could offset impact. | Major impact expected: periodic scouring of sediment could improve survival of eggs/alevins; scouring of foodbase could reduce long-term food supply; increase in Lees Ferry trout population expected. |
| Other Non- | Moderate short-term impact from changes in foodbase and displacement of | | Major long-term impact expected from changes |

| Resource | Spring HFE Followed by Fall HFE | Fall HFE Followed by Spring HFE | More Than Two Consecutive HFEs |
|---|---|---|---|
| native Fish | small-bodied fish; short-term reduction in populations of fathead minnow, red shiner, plains killifish, other small-bodied fish expected. | | in foodbase and displacement of small-bodied fish; long-term reduction in populations of fathead minnow, red shiner, plains killifish, other small-bodied fish expected. |
| Birds | Impact same as single HFEs. | | Minor impact from possible reduction in low elevation riparian vegetation; not expected to impact nesting or feeding. |
| Mammals | Impact same as single HFEs. | | Minor impact: animals likely to adjust to higher elevation habitat. |
| Historic Properties | Impact same as single HFEs. | | Minor short-term adverse impact: access to properties temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. |
| Sacred Sites | Impact same as single HFEs. | | Minor short-term adverse impact: access to sites temporarily restricted. Long-term beneficial effect from sandbar and beach building that would help protect properties from erosion. |
| Hydropower | Doubles impact of single HFEs: cost of replacement power $0.02-$1.67 million. | | Moderate to high impact, depending on replacement costs for number, magnitude, duration of HFEs. |
| Recreation | Impact same as single HFEs. | | Moderate to high impact: frequent HFEs of high magnitude and low shoulder flows could increase difficulty and risk for angler access and rafting through rapids; could affect long-term recreational use in Grand Canyon. |

### 3.4.5 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.

### 3.4.6 Environmental Justice

Environmental justice refers to those issues resulting from a proposed action that disproportionately affect minority or low-income populations. To comply with 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 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.

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. 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.

### 3.4.7 Wild and Scenic Rivers and Wilderness

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.

# 4 Consultation and Coordination

## 4.1 Tribal Consultation

Consultation with American Indian Tribes on a government-to-government basis will be conducted and results incorporated into the final document. The following tribes are being consulted.

Hopi Tribe of Arizona
Hualapai Indian Tribe of the Hualapai Indian Reservation, Arizona
Kaibab Band of Paiute Indians of the Kaibab Indian Reservation, Arizona
Navajo Nation, Arizona, New Mexico and Utah
Paiute Indian Tribe of Utah
Yavapai-Apache Nation of the Camp Verde Reservation, Arizona
Zuni Tribe of the Zuni Reservation, New Mexico

## 4.2 Public Scoping and Review Activities

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).

The HFE 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 (GCDAMP) 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 socio-economic 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 (Reclamation 2010b). 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 socio-economics 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).

Aquatic and riparian communities and ecosystem (includes wildlife and invasive plants).

Cultural resources including American Indian Tribes traditional cultural properties.

Hydropower.

Listed species including the endangered humpback chub and Kanab ambersnail.

Recreation including boating and fishing.

Safety of wading anglers and boaters.

Sediment including camping beaches and habitat for aquatic species.

Socio-economics, including costs of the experiment including lost incomes, effects on local families and businesses, and costs of replacement power for hydropower losses.

Water resources or water supply and dam operations.

A draft of the EA was released for public review on January 14, 2011 and the public comment period closed on March 18, 2011. This revised draft, which includes consideration of comments received on the initial draft, is being published for additional public review in July 2011.

## 4.3 Cooperating Agencies

Multiple federal and state agencies and American Indian tribes were invited to become cooperating agencies in the preparation of this EA. Communication and consultation with Cooperating Agencies occurred throughout the process of preparing this EA. A review of a draft EA by cooperating agencies occurred from November 21 to December 6, 2010.

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

American Indian Tribes:
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.*

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# Appendix B: Science Plan

science for a changing world

# General Monitoring and Research Plan for High-Flow Experimental Protocol

Prepared by the Southwest Biological Science Center
Grand Canyon Monitoring and Research Center
January 7, 2011

**U.S. Department of the Interior**
**U.S. Geological Survey**

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Cover: Glen Canyon Dam jet tubes release experimental high flows of Colorado River water on the morning of March 5, 2008. (Anne Phillips, U.S. Geological Survey photo.)

# General Monitoring and Research Plan for High Flow Experimental Protocol

# PLAN 12.P6.11-12

## Start Date

2011

## End Date

2020 (as defined in the HFE Protocol Environmental Assessment)

## Principal Investigator(s)

Helen Fairley, Paul Grams, 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 ecosystem from the forebay of Glen Canyon Dam to the westernmost boundary of Grand Canyon National Park (river miles -15 to 277)

## 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). The details of high flow triggering criteria are in the {date} Environmental Assessment for the Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020 (hereafter referred to as the HFE EA).

The second goal will be to evaluate the effects of implementation of the High Flow Experiment Protocol on a variety of other priority AMP resources including aquatic food base, native fish, Lees Ferry trout and angler satisfaction, riparian vegetation, campsites, and archaeological sites. Special focus will be on assessing the effects of the seasonal timing of high flows on Lees Ferry rainbow trout early life-stage survival, recruitment, downstream migration and HFE impacts on native fishes especially the endangered humpback chub (*Gila cypha).*

## Need for Project

Previous high flow experiments (HFE) from Glen Canyon Dam were conducted in 1996, 1997 2000, 2004, and 2008. These experiments generally concluded that the only tool 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. The HFE EA is intended to build on the knowledge gained in the previous experiments and implement HFEs on a more regular basis. A brief summary of some elements of the protocol as described in the November 19, 2010 draft EA follows:

> "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.
>
> 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."

The purpose of this general science plan is to outline how ongoing monitoring and research projects (USGS, 2011) will address the evaluation of the effectiveness of the HFEs. Changes to this science plan may be needed based on availability of funds and as HFEs are implemented and adjusted in an adaptive management framework (Williams and other, 2008). Additional revisions may also be required to address additional experimental activities that may be identified in the Long Term Experimental and Management Plan EIS, which will be initiated by the Department of the Interior in 2011.

The proposed approach will rely on existing quality of water, sediment, aquatic biology and other resource monitoring projects to assess the effects of HFEs. No new studies would be added, however, some existing monitoring and research efforts would be expanded or adjusted to provide information that is directly relevant to the evaluation of the HFEs.

This science plan is focused on assessing the effects of the "store and release approach" described in the HFE EA. A separate science plan could be developed to assess the effects of the "rapid response approach" described in the HFE EA, once the details of that approach are more fully described. It is expected that many of the studies described below will inform both HFE approaches, but more specific short term investigations may be needed to evaluate the efficacy of the rapid response approach.

## Strategic Science Questions

A major task of GCMRC in 2010 was the synthesis of the results of the 1996, 2004 and 2008 high flow experiments (Melis and others, in press). The concluding chapter of the synthesis by

Wright and Kennedy (in press) provides direction that is relevant to the primary focus of HFE science activities:

> "HFEs are an important tool for rebuilding sandbars. The three previous HFEs have demonstrated the effectiveness of individual HFEs for rebuilding sandbars, particularly when they occur after sand has been stored on the channel bed downstream from the dam. A logical next step in the adaptive-management process of the GCDAMP is to evaluate the cumulative effects of multiple HFEs over longer periods of time. This would be helpful because it is still uncertain whether sandbar building during HFEs can offset or exceed the sandbar erosion that occurs during periods of typical dam operations between HFEs. Thus, it is important to consider the frequency of HFEs and the erosion of sandbars between HFEs for future HFE planning. The fundamental sandbar-related science question therefore is:
>
> - Can sandbar building during HFEs exceed sandbar erosion during periods between HFEs, such that sandbar size can be increased and maintained over several years?
>
> Based on studies that have been conducted to date, HFEs do not appear to be a tool that can be used to benefit humpback chub. Rainbow trout pose a threat to juvenile humpback chub rearing in the mainstem near the confluence with the Little Colorado River due to increased competition and predation. Beneficial effects of the March 2008 HFE on rainbow trout populations appear to be largely responsible for the 38-fold increase in rainbow trout observed near the confluence between 2006 and 2009. A large increase in rainbow trout near the confluence with the Little Colorado River also occurred in the year following the 1996 HFE. The November 2004 HFE did not benefit rainbow trout populations, but a preexisting downward trend in rainbow trout populations and the absence of data make this finding highly uncertain. Thus, natural-resource managers might consider proceeding with caution when implementing any HFE strategies, particularly those involving frequent spring-time events, because currently (2010) the biological response to HFEs appears to be inconsistent with management goals for humpback chub. A logical next step in the HFE process is evaluating whether the seasonal timing of HFEs affects the rainbow trout recruitment response. If fall-timed HFEs do not lead to increases in rainbow trout populations near the confluence with the Little Colorado River (or it is later demonstrated that rainbow trout do not exert strong influence on humpback chub rearing), then managers might be able to balance goals for sandbars and native fish without the need for substantial rainbow trout mitigation or removal. The fundamental fish-related science question therefore is:
>
> - Does the seasonal timing of HFEs influence the rainbow trout response?
>
> An adaptive-management process for HFE decision-making would be flexible and incorporate relevant scientific information, such as near real-time information about sediment conditions downstream from the dam and information on adult population trends for rainbow trout and humpback chub, as well as other resources. Indeed, as more HFEs are conducted, strong links connecting other resources to dam operations may be identified and incorporated into subsequent HFE strategies. An integrated science-based strategy would allow for effective management of the available post-dam sand supply while considering the impacts of the strategy on other resources within an adaptive-management framework."

In addition to these fundamental strategic science questions, the HFE science plan will focus on assessing the effects of HFEs on other priority AMP resources, including the aquatic food base, native fish (especially humpback chub), Lees Ferry trout and angler satisfaction, riparian vegetation, recreational campsites, and archaeological sites.

Table 1 identifies the specific HFE science questions associated with these resources that would be addressed with available funding included in the approved Glen Canyon Dam Adaptive Management Program Biennial Budget and Work Plan—Fiscal Years 2011-12 (USGS, 2011) (hereafter referred to as the FY 2011-12 BWP). These HFE science questions were developed by GCMRC based on the high flow synthesis report (Melis and others, in press), other relevant literature, and input provided by the HFE EA cooperating agencies.

Wright and Kennedy (in press) emphasize that there is substantial uncertainty about the outcome that may result from implementation of the HFE protocol. For example, the biological responses to fall HFEs are difficult to predict. Thus, modification of the HFE protocol may be required based on knowledge gained from biological responses to future HFEs. Modification of the protocol in response to sandbar-monitoring results may also be required, and a different HFE strategy may be justified during wet and dry climatic periods. Because of these uncertainties, the annual "status check" outlined in the EA will be a critical component of an adaptive HFE strategy. This status check would involve reviewing recent monitoring data for sand budgets, sandbar size, native and nonnative fish population trends and other resource responses. Based on the findings of these reviews, the HFE protocol may need to be adapted to address undesirable resource responses. Likewise the HFE science plan may need to be adapted based on new knowledge and learning and to address new science questions.

Science questions and related projects that had to be deferred due to funding constraints are provided in Appendix A.

## Methods and Tasks

Tasks related to high flow monitoring and research are summarized below. Refer to the individual project descriptions in the FY 2011-12 BWP for more detailed descriptions. Implementation of these projects assumes that (a) the respective annual work plan projects are funded at the level indicated in the approved BWP and (b) additional funding is not available to provide expanded research and monitoring of the effects of the HFE protocol. Additional funding or reprogramming of existing the FY 2011-12 BWP would be required to expand the scope of the work. While the tasks are listed separately below, in reality many of the studies are linked. Studies will be coordinated and integrated as needed to provide a comprehensive assessment of the effect of the HFE on priority AMP resources. The priority focus will be to address and answer, to the extent possible, the HFE science questions identified in Table 1.

## Task 1. Monitoring In-Channel Sediment Storage—SedTrend

Information Needs

**HFE protocol science question:** 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:** 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.M2.11-12). 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. Thus, in some years that have high flows, channel mapping may be postponed or deferred. In the event channel mapping is deferred, about $110,000 in logistical and other expenses would be available for other uses. Personnel are retained to continue with data processing and reporting. Please refer to project PHY 8.M2.11-12 in the FY 11-12 BWP for more details on this project.

## Task 2. Monitor High-Elevation Sandbar Study Sites

Information Needs

**HFE protocol science question:** Will multiple high flows conducted over a period of 10 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. While the focus of task 1 is monitoring total changes in sand storage, including sandbars, at infrequent measurement intervals, this task will monitor a subset of sandbars at more frequent intervals. 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. To enable comparison with historical conditions, it is essential that this task monitor the same set of study sites (up to about 50 sites) that have been the basis of past sandbar monitoring. The data collected in task 1, above, and task 4, below, will be used to address the issues relating to the use of this small set of monitoring sites relative to the large number of sandbars that are in Grand Canyon. Only be collecting and analyzing the more spatially robust data outlined in tasks 1 and 4 will it be possible to improve the understanding of the behavior of these study sites relative to system wide behavior. 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. (This trip would also collect campsite data, as described under Task 3). 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. Please refer to project PHY 8.M2.11-12 in the FY 11-12 BWP for more details on this project.

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

Information Needs

**HFE protocol science question:** 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 1996 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 campsites on the higher elevation open sand areas that form the major component of campable area in the CRE also decrease, although much of the change appears due to vegetation encroachment and aeolian reworking of open sand areas. 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. 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. Please refer to project REC 9.R1.11–12 in the FY 11-12 BWP for more details on this project.

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

Information Needs

**HFE protocol science question:** 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 system-wide 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 evaluate the degree to which the more precise measurements made of sandbar volume in task 2 are representative of sandbar trends throughout the CRE. 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. Remote sensing data collection is scheduled to occur every 4 years.

## Task 5. Monitor Archaeological Site Condition and Stability in Response to Repeated HFEs

Information Needs

**HFE protocol science question:** 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 be used to evaluate system-wide changes at archaeological sites due to dam operations, including changes resulting from any high flows conducted as part of the HFE 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 HFE protocol at archaeological sites, although timing of the monitoring trips may be adjusted to maximize the potential of the monitoring data to track HFE effects.

## Task 6. Monitoring Sediment Flux

Information Needs

**HFE protocol science question:** 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.

## Task 7. Monitoring the Aquatic Food Base

Information Needs

**HFE protocol science question:** What is the effect of a fall HFE on the food base at Lees Ferry?

*This task is also central to answering questions related to the following HFE science questions (see Tasks 8, 10 and 11 below):*

- *How does HFE timing and frequency affect Lees Ferry rainbow trout population dynamics and outmigration?*
- *Is it possible to manage the Lees Ferry trout population with a spring HFE held at slightly different times?*

- *What are the direct (for example, displacement) and indirect (for example, increases in rainbow trout) effects of HFEs on humpback chub?*

*This question is related to* ***Strategic Science Question 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 (AFB) project has been working since 2006 to establish a monitoring protocol that accurately captures key metrics relevant to other resources in the Colorado River, including 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 at Lees Ferry and at Diamond Creek, and monthly monitoring of drifting organisms is important information that supports assessment of all Glen Canyon Dam release regimes, whether modified low fluctuating flows, an experimental high flow, or other flows. Quarterly AFB sampling in Lee Ferry and Diamond Creek is included in the final FY 11 BWP (BIO 1.1M.11); while monthly sampling was funded for FY 12. GCMRC recommends additional funding to implement monthly sampling of AFB in FY 11 and beyond to support the evaluation of the future HFEs. The monthly sampling protocol was effective at detecting significant changes in AFB at Lees Ferry in response to the March 2008 HFE. These data helped explain the strong positive rainbow trout response in Lees Ferry. Monthly AFB sampling is recommended to provide the statistical power needed to detect potential changes in the AFB due to future HFEs. Collecting these data in years without a high flow provides important baseline information, including assessment of seasonal variability. Collecting these data in years when an HFE occurs allows assessment of the amount of change, if any, which occurs as a result of the high flow. See project BIO 1.1M.11-12 for a more detailed description of this project.

## Task 8. Lees Ferry Fish Monitoring and the Paria River to Badger Rapids Study

Information Needs

**HFE protocol science questions:** How does HFE timing and frequency affect Lees Ferry rainbow trout population dynamics and outmigration? Is it possible to manage the Lees Ferry trout population with a spring HFE held at slightly different times?

*The answer to these questions relates to 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, 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. In addition, a sampling trip to specifically look for nonnative fishes is now conducted. The monitoring of rainbow trout redds (egg nests composed of gravel) 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 method in assessing impacts of dam operations on young life stages of rainbow trout. A new research project included in the final FY 11-12 BWP adds additional fish monitoring below Lees Ferry. This additional work is intended to evaluate the age structure of rainbow trout and timing of their movement immediately downstream from Lees Ferry. The new work below Lees Ferry, conducted from the mouth of the Paria River to Badger Rapids, 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 River and Badger Rapids is intended to be a precursor to and inform potential trout removal efforts in this reach. See projects a BIO 4.1M.11-12 and BIO 2.E18.11-12 for more details.

## Task 9. Evaluate Lees Ferry Recreation Experience Quality

Information Needs

**HFE protocol science question:** How will multiple high flows conducted over the next 10 years affect recreational experience quality in the Colorado River corridor in Glen Canyon?

*This question 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

The FY2011-2012 BWP includes a recreation experience valuation study for the Glen Canyon reach of the Colorado River. 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 and Little Colorado River Fish Monitoring and Near Shore Ecology Study

Information Needs

**HFE protocol science question:**

1. What are the direct effects of a fall HFE on displacement of humpback chub?
2. What are the indirect effects of increases in rainbow trout associated with HFEs on humpback chub?

*This task is also related to* ***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

The direct and indirect effects of HFE on humpback chub will be assessed based primarily on the three projects in the FY11-12 BWP: (1) The Mainstem Fish Monitoring Project, (2) Little Colorado River Fish Monitoring Project, and (3) the Near Shore Ecology (NSE) Study. These studies will also utilize information from the aquatic food base project (Task 7, above) to help assess the relative effects of factors that may be contributing to changes in humpback chub populations.

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 Glen 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 four years in the decade of the 2000s this regular pair of trips was accompanied by intensive data collection associated with 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 native and nonnative small-bodied fishes (juveniles and adults) in backwaters. 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 as well as fish life stages difficult, if not impossible, to sample. 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. See BIO 2.4M.11-12 for more details.

Data collected as part of the mainstem monitoring along with the systematic and intensive sampling of humpback chub in the Little Colorado River (see BIO 2.M1.11-2) have previously been and will continue to be used with the ASMR model to provide estimates of adult humpback chub population size and survival and inferential assessments of juvenile humpback chub population responses to HFEs.

GCMRC and cooperators, primarily the University of Florida, have established an intensive habitat-specific research program, the NSE project, to help define small-bodied fish distributions (including juvenile humpback chub) and responses to flow changes in the mainstem just below the mouth of the Little Colorado River. The NSE Study is providing the first direct estimates of juvenile humpback chub abundance and survival in the mainstem just below the Little Colorado River. Combined with mainstem and LCR fish monitoring, these sampling efforts and resulting population estimates can be used to assess positive or negative short-term (<1-year) responses of fish populations to HFEs from events such as downstream displacement. In addition, these projects can be used to help assess long-term responses in humpback chub (and other fish species) populations due to increases in rainbow trout populations or changes in aquatic food base that may be associated with repeated HFEs.

In 2011, the NSE project will be conducting field studies below the confluence of the Little Colorado River. Using juvenile fish previously tagged during summer and fall 2010 and sampling efforts for these fish planned for 2011 (July, August, September, and October trips), this intensive effort will be able to detect large, localized (within sampling reach) changes in small bodied fish. Any detected change could be due to downstream displacement of tagged fish from an HFE, predation by rainbow trout, or other unknown factors. A key expected outcome is that the NSE project will be able to provide a direct assessment of small-bodied and juvenile fish population responses following a spring 2011 HFE whereas previous assessments primarily assessed juvenile population responses indirectly by assessing adult populations in subsequent years. GCMRC is considering possible modifications to the NSE Study to allow for more definitive assessment of the direct and indirect effects of a HFE on humpback chub.

NSE field work is scheduled to end in the fall of 2011 and reports will be finalized and published in 2012. It may be necessary to continue some components of the NSE study to address the key science questions related to the effects of repeated HFEs on humpback chub. However, funding to support continuation of the NSE project has not been identified. See BWP project BIO 2.R15.10–11 for more details on the NSE project.

## Task 11. Riparian Vegetation Monitoring

Information Needs

**HFE protocol science question :** How does HFE timing and frequency affect woody riparian and marsh vegetation composition? How does riparian vegetation influence sandbar building, campable area, and wind-blown transport of sand?

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

Addressing the questions and information will require integration with Task 2-5.

Project Description

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 and subsequent even number years (2014, 2016, etc). Monitoring vegetation in years with a high flow release allows for assessment of high flow short and long term impacts to riparian vegetation. The approved budget covers the cost of field transect monitoring in 2011. See BIO 6.1M.11-12 and DASA 12.D9.11-12 for details.

## Task 12. Kanab Ambersnail Monitoring

Information Needs

**HFE protocol science question:** How do KAS populations and habitat vary over a 10 year period of repeated high flows?

***This task is also related to CMIN 5.1.1.*** *Determine and track the abundance and distribution of Kanab ambersnail at Vaseys Paradise in the lower zone (below 100,000 cfs) and the upper zone (above 100,000 cfs);* ***RIN 5.1.9.*** *How can incidental take for Kanab ambersnail at Vaseys Paradise be minimized?; and* ***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 1996 Record of Decision, unanticipated event, or other management action?*

Project Description

Knowing the extent of habitat is needed in the event of a high flow experiment to develop a biological opinion and to determine snail densities. Changes in snail numbers can be associated with changes in vegetation. Vegetation monitoring at Vaseys Paradise indirectly monitors the snails by assuming that if the preferred habitat is present, snails are present. Total habitat can be measured using remote methods, but the composition of the habitat may still require on-the-ground sampling.

Annual monitoring will focus on determining the percent cover, diversity, and distribution of vegetation that constitutes KAS habitat. This project will:

- Monitor relocated vegetation associated with high-flow experimental conservation measures
- Sample vegetation plots at Vaseys Paradise to determine patch composition and areal extent (fall of each year) and sample for the presence of KAS in plots
- Compare previous vegetation composition to previous vegetation/habitat surveys to assess habitat
- Provide abundance estimates of snails

In prior experimental high flows the low-elevation habitat for Kanab ambersnail has been temporarily removed during the experiment, then replaced so as to maintain this habitat. The cost of implementing this management action is approximately $16,400 in addition to annual monitoring costs. Refer to BIO 5.R1.11 for more details.

## Task 13. Lake Powell and Lees Ferry Water Quality Monitoring

Information Needs

**HFE protocol science question:** How do high flow releases affect water quality (especially DO and temperature) in the fore bay of Lake Powell and in the Colorado River between the Dam and Lees Ferry?

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.

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.

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. The primary focus will be 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. See BIO 7.1M.11-12 for details

## Task 14. Evaluate Effects to Hydropower from Repeated HFEs

Information Needs

**HFE protocol science question** What are the effects of repeated HFEs on hydropower production and marketable capacity at Glen Canyon Dam?

*This task is also relevant to **CMIN 10.1.** Determine and track the marketable capacity and energy produced through dam operations in relation to various release scenarios; and **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.R1.11-12 for specifics about the proposed study.

## Products/Reports

Primary reporting of results of the above tasks 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 in the FY 2011-12 BWP). In addition, a summary of relevant results and 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

GCMRC anticipates that the tasks described above will be funded as part of ongoing monitoring and research projects included in the approved GCDAMP BWP, including the use of experimental funds as summarized in Table 2. Changes to the work plans included in the FY 11-12 BWP or in the allocation of experimental funds (Table 2) could adversely impact implementation of the tasks described above and the ability to address the science questions listed in Table 1. Several funding shortfalls are identified in Table 2, including:

1. No funding is currently available to collect and analyze monthly aquatic food base samples (as opposed to quarterly sampling which is now funded) ($100K in FY 11).
2. The NSE study is suited to assessing the direct and indirect effects of repeated HFEs on humpback chub. Only one field season remains in this project (FY11) and adjustments or amendments to the NSE study will be needed to specifically address issues related to the impacts of rainbow and brown trout on humpback chub or assess possible displacement of young humpback chub by a fall HFE (amount to be determined)
3. No funding is currently available for annual riparian vegetation monitoring ($50K every other year beginning in FY 12)
4. No funding is currently available for to monitor water quality in the forebay of Lake Powell and the tailwater of GCD shortly before and after an HFE ($9.3K)

Finally, additional funding would be needed to address the HFE science questions/projects outlined in Appendix B and to implement a yet to be developed science plan for the "rapid response HFE" described in the HFE EA.

## Science Support for a Potential Spring 2011 HFE

A scaled-down version of this plan would be implemented in response to a potential March-April 2011 HFE owing to the short lead time available to plan and execute a full scale science plan. The primary focus of that plan would be to assess the rainbow trout response to a spring HFE, preferably, at a time later than either the 1996 or the 2008 HFE.

**Table 1**. HFE science questions that will be the focus the HFE EA Science Plan

**Sandbars, Camping Beach, and Archaeological Sites**

1. Will multiple high flows conducted over a period of 10 years result in net increases in sandbar area and volume?
2. With the available sand supply (i.e. tributary inputs) is the approach of using repeated floods to build sandbars sustainable?
3. Will multiple high flows conducted over a period of 10 years result in net increases in campable area within the Colorado River ecosystem?
4. Will multiple high flows conducted over a period of 10 years improve archaeological site condition as reflected in increased sand deposition, increased site stability, and reduction in rates of erosion?

**Aquatic Food Base and Fish**

5. What is the effect of a fall HFE on the food base at Lees Ferry?
6. How does HFE timing and frequency affect Lees Ferry rainbow trout population dynamics and out-migration?
7. Is it possible to manage the Lees Ferry trout population with a spring HFE held at slightly different times?
8. What are the direct effects of a fall HFE on displacement of humpback chub?
9. What are the indirect effects of increases in rainbow trout associated with HFEs on humpback chub?

**Recreation**

10. How will multiple high flows conducted over a period of 10 years affect recreational experience quality in the Colorado River corridor in Glen Canyon?

**Riparian Vegetation and Springs**

11. How does HFE timing and frequency affect woody riparian and marsh vegetation composition?
12. How does riparian vegetation influence sandbar building, campable area, and wind-blown transport of sand?
13. How do Kanab ambersnail populations and habitat vary over a 10 year period of repeated high flows?

**Water Quality**

14. How do high flow experiments affect water quality (especially DO and temperature) in the forebay of Lake Powell and in the Colorado River between the Dam and Lee's Ferry?

**Hydropower**

15. What are the effects of repeated HFEs on hydropower production and marketable capacity at Glen Canyon Dam?

**Table 2A.** FY 2011 budget for research and monitoring projects related to the proposed high flow experimental protocol as included in the approved FY 2011-12 BWP. The amount of Experimental Funds that will be used in year with and without an HFE is also shown.

| Task | Project Number | FY 11 Budget* | Exp Funds No HFE | Exp funds With HFE |
|---|---|---|---|---|
| Task 1 – SedTrend | PHY 8.M2.11-12 | $464,476 | $250,000 | $140,000 |
| Task 2 – Sandbar monitoring | PHY 8.M2.11-12 | See task 1 | 50,000 | 50,000 |
| Task 3 – Campable area monitoring | REC 9 R1.11-12 | 74,319 | | |
| Task 4 – Remote sensing of sandbars | DAS 12.D9.11-12 | 243,873 | | |
| Task 5 – Archeological site monitoring | CUL 11.R1.11-12 | 352,279 | | |
| Task 6 – Sediment flux monitoring | PHY 7.M1-11-12 | 984,888 | | 110,000 |
| Task 7 – Aquatic food base monitoring | BIO 1.M1.11-12 | 236.568 | **a** | **a** |
| Task 8 – Lees Ferry trout | | | | |
| • Adult and YOY trout monitoring | BIO 4.M2.11-12 | 215,710 | 22,709 | 22,709 |
| • Paria to Badger Rapid Study | BIO 2.E18.11-12 | 432,518 | 195,918 | 195,918 |
| Task 9 – Lees Ferry recreation experience | REC 9.R4.11 | 25,000 | 25,000 | 25,000 |
| Task 10 – Native Fish | | | | |
| • Mainstem fish monitoring | BIO 2.M4.11 | 283,090 | | |
| • LCR fish monitoring | BIO 2.M1.11 | 572,942 | | |
| • Nearshore Ecology Study | BIO 2.R15.11 | 697,039 | | **b** |
| Task 11 – Riparian vegetation | | | | |
| • Veg transect ((biannual) | BIO 6.M2.11 | 149,883 | | |
| • Veg Mapping | BIO 6.M1.11 | 84,883 | | |
| Task 12 – Kanab Ambersnail Monitoring w/o mitigation | BIO 5.M1.11 | 20,506 | | |
| Task 13 – Lake Powell and Lee Ferry Water Quality | BIO 7.R1.11 | 182,002 | | **c** |
| Task 14 – Hydropower | HYD 11.WAPA | 106,950 | | **d** |
| Total | | $5,126,926 | $543,627 | $543,627 |

* FY 11 budget is based on the assumption that **no** HFE will be conducted. Budget amounts will be adjusted up or down depending on whether an HFE is conducted.

**a.** $100K needed in FY 11 to restore monthly food base sampling

**b.** Additional funding would be needed to amend/extend the NSE project to address effects of HFEs on juvenile HBC (displacement and rainbow trout effects)

**c.** $9,300 required to monitor water quality in the forebay of Lake Powell and the tailwater of GCD shortly before and after a HFE

**d.** Scope of the economic analysis will depend on ultimate scope of Goal 10 (Hydropower) activities supported in the BWP

**Table 2B.** FY 2012 budget for research and monitoring projects related to the proposed high flow experimental protocol as included in the approved FY 2011-12 BWP. The amount of Experimental Funds that will be used in year with and without an HFE is also shown.

| Task | Project Number | FY 12 Budget | Exp Funds- No HFE | Exp funds With HFE |
|---|---|---|---|---|
| Task 1 – SedTrend | PHY 8.M2.11-12 | $429,183 | $250,000 | $140,000 |
| Task 2 – Sandbar monitoring | PHY 8.M2.11-12 | See task 1 | | 50,000 |
| Task 3 – Campable area monitoring | REC 9 R1.11-12 | 40,298 | | |
| Task 4 – Remote sensing of sandbars | DAS 12.D9.11-12 | 254,975 | | |
| Task 5 – Archeological site monitoring | CUL 11.R1.11-12 | 359,362 | | |
| Task 6 – Sediment flux monitoring | PHY 7.M1-11-12 | 1,002,389 | | 110,000 |
| Task 7 – Aquatic food base monitoring | BIO 1.M1.11-12 | 329,349 | 100,000 | 100,000 |
| Task 8 – Lees Ferry trout | | | | |
| • Adult and YOY trout monitoring | BIO 4.M2.11-12 | 223,710 | 22,709 | 22,709 |
| • Paria to Badger Rapid Study | BIO 2.E18.11-12 | 453,029 | 195,918 | 195,918 |
| Task 9 – Lees Ferry recreation experience | REC 9.R4.11 | 25,000 | 25,000 | 25,000 |
| Task 10 – Native Fish | | | | |
| • Mainstem fish monitoring | BIO 2.M4.11 | 539,107 | | |
| • LCR fish monitoring | BIO 2.M1.11 | 595,001 | | |
| • Nearshore Ecology Study | BIO 2.R15.11 | Reporting only | | **a** |
| Task 11 – Riparian vegetation | | | | |
| • Veg transect ((biannual) | BIO 6.M2.11 | 0 | **b** | **b** |
| • Veg Mapping | BIO 6.M1.11 | 61,063 | | |
| Task 12 – Kanab Ambersnail Monitoring w/o mitigation | BIO 5.M1.11 | 20,684 | | |
| Task 13 – Lake Powell and Lee Ferry Water Quality | BIO 7.R1.11 | 188,063 | | **c** |
| Task 14 – Hydropower | HYD 11.WAPA | ?? | | **d** |
| Total | | $4,521,213 | $568,627 | $643,627 |

* FY 12 budget is based on the assumption that **no** HFE will be conducted. Budget amounts will be adjusted up or down depending on whether an HFE is conducted.

**a.** Additional funding would be needed to amend/extend the NSE project to address effects of HFEs on juvenile HBC (displacement and rainbow trout effects)
**b.** $50K additional required for annual vegetation monitoring
**c.** $9,300 required to monitor water quality in the forebay of Lake Powell and the tailwater of GCD shortly before and after a HFE
**d.** Scope of the economic analysis will depend on ultimate scope of Goal 10 (Hydropower) activities supported in the BWP

**Appendix A.** List of deferred science questions and related projects to address those questions

To be complete later

# Appendix C: Biological Assessment

RECLAMATION

*Managing Water in the West*

# Biological Assessment: 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**

**January 21, 2011**

## Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

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.

# Table of Contents

# 1 Introduction and Background

This document serves as the biological assessment (BA) for the Bureau of Reclamation's (Reclamation) proposed action to develop and implement a protocol for high-flow experimental releases (HFEs) from Glen Canyon Dam during the years 2011–2020. Four species identified as endangered are addressed in this BA: humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), Kanab ambersnail (*Oxyloma haydeni kanabensis*), and southwestern willow flycatcher (*Empidonax traillii extimus*). Reclamation has also previously consulted on the bald eagle (*Haliaeetus leucocephalus*), American peregrine falcon (*Falco peregrinus anatum*), and California condor (*Gymnogyps californianus*). The California condor is an endangered species that would not be affected by this action. The peregrine falcon and bald eagle have been removed from the list of threatened and endangered species and were not addressed in this BA.

This BA was prepared by Reclamation as part of its compliance with the Endangered Species Act of 1973, as amended (ESA; 87 Stat. 884; 16 U.S.C. §1531 *et seq.*). A biological assessment evaluates the potential effects of the action on listed and proposed species and designated and proposed critical habitat and determines whether any such species or habitat are likely to be adversely affected by the action (50 CFR 402.12). This BA is provided to the U.S. Fish and Wildlife Service (USFWS) to be used in developing its biological opinion (Opinion) which determines if the proposed action is likely to jeopardize the continued existence of a species or result in the destruction or adverse modification of critical habitat.

Reclamation is the agency within the U.S. Department of the Interior (Interior) that operates Glen Canyon Dam of the Colorado River Storage Project as a multipurpose storage facility in northern Arizona. Construction of the dam was authorized by the 1956 Colorado River Storage Project Act. Operation of the dam is governed by a complex set of compacts, federal statutes and regulations, court decrees, and an international treaty collectively and commonly referred to as the Law of the River and as further described below in Section 1.3.

## 1.1 Overview of Proposed Federal Action

The proposed action was announced in a Federal Register Notice on December 31, 2009 (74 FR 69361) and is described in detail in Reclamation's Environmental Assessment (EA) on the *Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020* (Reclamation 2011a). The protocol is designed to determine whether and how sand conservation can best be achieved in the Colorado River corridor through Grand Canyon National Park (GCNP), Arizona (Figure 1). This proposed protocol is part of the ongoing implementation of the Glen Canyon Dam Adaptive Management Program (GCDAMP), and is a component of Interior's compliance with the Grand Canyon Protection Act of 1992 (Public Law 102-575, GCPA).

The proposed action is tiered from two final environmental impact statements (FEIS)—Reclamation's 1995 *FEIS on the Operation of Glen Canyon Dam* (Reclamation 1995a) and the associated 1996 Record of Decision (ROD; U.S. Department of the Interior 1996); and Reclamation's 2007 *FEIS on Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lakes Powell and Mead* (Reclamation 2007a) and the associated

2007 ROD (U.S. Department of the Interior 2007). The 1996 ROD implemented the Modified Low Fluctuating Flows (MLFF) to govern releases from Glen Canyon Dam at short time increments, down to monthly, daily, and hourly releases. The 2007 ROD governs annual releases from Lake Powell in coordination with water volumes in Lake Mead. There is also an ongoing program of experimental releases (low steady flows from September 1 through October 31) from Glen Canyon Dam in effect from 2008 through 2012, under an EA and Finding of No Significant Impact (FONSI; Reclamation 2008).

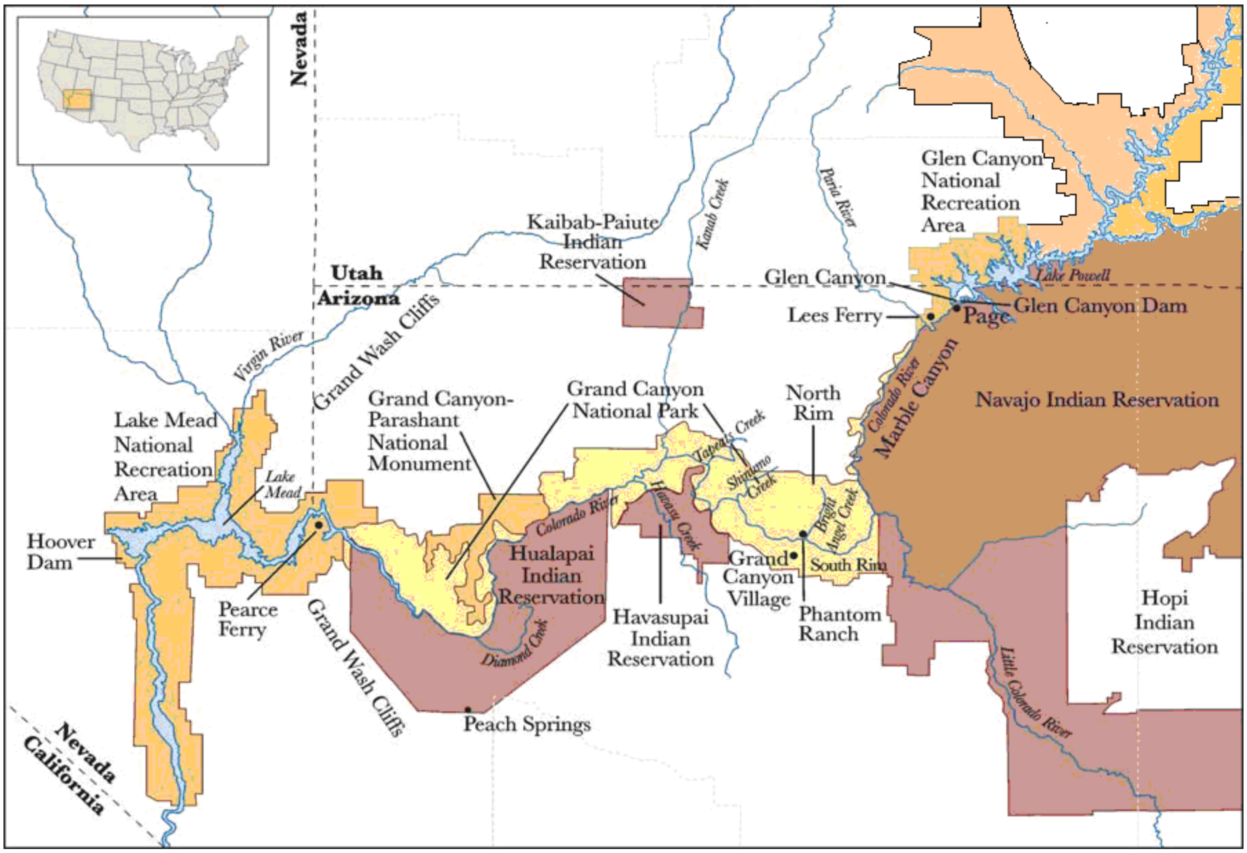


**Figure 1. Action area from Glen Canyon Dam to Pearce Ferry, Arizona.**

## 1.2 Concurrent Environmental Assessment

Reclamation is concurrently developing an environmental assessment for *Non-native Fish Control Downstream from Glen Canyon Dam, 2011–2020* (Forthcoming, Reclamation 2011b). The action analyzed in the non-native fish EA: (1) addresses requirements of prior ESA compliance and (2) would also serve to control trout population increases resulting from implementation of the HFE protocol. These EAs are interrelated or interdependent because they are being conducted concurrently in the same geographic area, during overlapping time frames, and because elements of the proposed actions affect each other. The HFE EA proposes a program of high-flow releases that are likely to increase the numbers of rainbow trout (*Oncorhynchus mykiss*) in the Lees Ferry reach, as an unintended consequence of the action. An increased in the trout population could result in greater downstream dispersal of trout into reaches of the Colorado River that are occupied by the humpback chub, where they prey upon and compete with this endangered species. Predation and competition by rainbow trout and brown trout (*Salmo trutta*) have been identified as sources of mortality for juvenile humpback chub (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2008). This added mortality reduces recruitment and possibly the overall size of the population of humpback chub (Coggins 2008a). One purpose of the non-native fish control EA will be to assess and mitigate the effects of the increased predation and competition by reducing the numbers of trout in areas from which the trout may disperse and in reaches that they occupy together with humpback chub. In this regard, the NPS, as part of a Reclamation conservation measure, is engaged in removal of non-native fish (principally rainbow trout and brown trout) from Bright Angel Creek. Bright Angel Creek is a known source of brown trout to the LCR reach.

## 1.3 Progress on Conservation Measures and Other Proposed Offsetting or Mitigating Actions

Section 7(a)(1) of the ESA directs Federal agencies to utilize their authorities to further the purposes of the law by carrying out conservation programs for the benefit of endangered and threatened species. Conservation measures are discretionary agency activities that minimize or avoid adverse effects of a proposed action on listed species or critical habitat, help implement recovery plans or develop additional information. Conservation measures were developed and presented in the 2007 and 2008 biological opinions and the 2009 Supplemental Opinion. These conservation measures have been incorporated into the GCDAMP and have resulted in significant benefits to listed species in the area affected by Glen Canyon Dam operations.

Many of these conservation measures have already been initiated and are ongoing or work on them has been completed. Reclamation remains committed to working with the USFWS and GCDAMP on all the conservation measures in order to offset and mitigate the effects of this proposed action. These conservation measures are described in detail in the 2010 BA (Reclamation 2010), and summarized as follows, as they relate to the proposed action.

***Fish Research and Monitoring***

Reclamation has been a primary contributor to the development of the GCDAMP's Comprehensive Plan for the Management and Conservation of Humpback Chub in Grand Canyon. Reclamation plans to utilize this plan in cooperation with the USFWS and other GCDAMP members to determine what actions remain to be accomplished, and find additional funding sources that will be provided by other willing partners to help achieve recovery of the humpback chub.

Reclamation continues to support fish research and monitoring efforts in Grand Canyon in 2011 that will help to better determine effects of the proposed action on the endangered species. These efforts include continued population estimates of humpback chub in the LCR and ongoing monitoring of native fish in the mainstem Colorado River, an ongoing nearshore ecology study, non-native fish control, humpback chub translocation and refuge establishment, research on effects of parasites, razorback sucker habitat potential in lower Grand Canyon, sediment research, LCR watershed planning, a monthly flow transition study, continued monitoring of the southwestern willow flycatcher and the Kanab ambersnail. Some of these efforts are contained within conservation measures further described in this section.

### *Non-native Fish Control*

In the past decade, Reclamation has provided financial and/or technical support to control non-native fish species in the Colorado River and its tributaries as a way to minimize effects of predation and competition on native fish species. These activities include ongoing non-native control planning, non-native control methods pilot testing, removal of rainbow trout from the LCR reach of the Colorado River, increased fluctuating flows during the months of January through March to increase mortality of young rainbow trout, and mechanical removal of brown trout through weir operations at Bright Angel Creek.

Reclamation has also funded and helped to conduct a non-native fish workshop and meetings with American Indian Tribe representatives to address concerns about mechanical removal of nonnative fish in the LCR inflow reach. Reclamation recently conducted a structured decision-making workshop to help identify science-based alternatives for non-native fish control downstream of Glen Canyon Dam, and Reclamation's Lower Colorado Regional Office (LCRO) has budgeted $20,000 to support an international symposium on the use and development of genetic biocontrol of non-native invasive aquatic species.

Reclamation will conduct further analysis on the effects from non-native fish removal and analysis of incidental take through its concurrent EA and proposed action on non-native fish control downstream of Glen Canyon Dam (see Section 1.2). The analysis will be directed at further refinement of targets for non-native fish control to determine a level of effort that would effectively reduce non-native numbers to benefit humpback chub, and better understand the link between nonnative control and status and trend of humpback chub. The action on non-native fish control would help to mitigate the unintended consequences of an increased rainbow trout population that is likely to result from the HFE protocol.

As an additional mitigating measure, Reclamation will continue to work with the NPS to implement removal of non-native rainbow trout in Shinumo Creek as part of the humpback chub translocation project and will help support such control measures in Havasu and Bright Angel creeks in advance of future humpback chub translocations in those systems.

### *Humpback Chub Translocation and Refuge*

Reclamation has supported translocation of humpback chub to the LCR above Chute Falls since 2003 and has been involved with the NPS translocation plan and logistics coordination for Shinumo Creek since late summer 2007. During July 2008 and 2009, humpback chub were translocated to areas above Chute Falls, and additional fish were collected for the purposes of establishing a hatchery refuge population and translocation to Shinumo Creek during both years. Reclamation assisted the USFWS with development and funding of a broodstock management plan and creation and maintenance of the refuge population at the Dexter National Fish Hatchery and Technology Center, New Mexico. These translocations and the refuge population help to offset losses of young humpback chub to predation and displacement of young by HFEs.

### *Parasite Monitoring*

A considerable amount of research has been done on parasites of the humpback chub in Grand Canyon (e.g., Clarkson et al. 1997; Choudhoury et al. 2001; Cole et al. 2002; Hoffnagle et al.

2006). In coordination with the GCDAMP participants and through the GCDAMP, Reclamation will continue to support research on the effects of parasites, such as the Asian tapeworm (*Bothriocephalus acheilognathi*) on humpback chub and potential methods of controlling these parasites.

### *Razorback Sucker Habitat Assessment and Potential Augmentation*

As part of the USFWS concurrence with the determinations made for Reclamation's adoption and implementation of the interim guidelines, the 2007 Opinion (USFWS 2007) states that "Reclamation will, as a conservation measure, undertake an effort to examine the potential of habitat in the lower Grand Canyon for the species (razorback sucker), and institute an augmentation program in collaboration with FWS, if appropriate." Reclamation has initiated a contract for this study with a comprehensive evaluation of razorback sucker habitat and convened a Science Panel in fall of 2010 to evaluate the suitability of habitat in lower Grand Canyon and Lake Mead inflow. Reclamation is undertaking this effort in collaboration with the USFWS, GCDAMP, Lower Colorado River Multi-Species Conservation Program (MSCP), NPS, GCMRC, Nevada Department of Wildlife (NDOW), and the Hualapai Tribe. This measure will help to better understand the status of the razorback sucker in the lower end of the HFE protocol action area and could lead to a better understanding of how to offset effects of the proposed action.

### *Sediment Research*

Reclamation has modified releases from Glen Canyon Dam and supported studies on the effects of sediment transport on humpback chub habitats. Substantial progress has been made toward these efforts. High Flow Experiments (HFE) conducted in 1996, 2004, and 2008 have enhanced our knowledge of sediment transport and its effects on humpback chub habitat. Extensive data collection and documentation has resulted from these tests (Hazel et al. 1999; Schmidt 1999; Topping et al. 2000a, 2000b, 2006; Rubin et al. 2002; Schmidt et al. 2004; Wright et al. 2005; Melis et al. 2010; Melis in press). In coordination with other DOI GCDAMP participants and through the GCDAMP, Reclamation will continue to support monitoring of the effect of sediment transport on humpback chub habitat and will work with the GCMRC to develop and implement a scientific monitoring plan acceptable to the USFWS. This sediment research will also help to quantify the amount of sediment available for an HFE, and could help to determine the proportion of the inorganic sand component and the finer organic component that is important to the aquatic ecosystem in Grand Canyon.

### *Little Colorado River Watershed Planning*

Reclamation will continue its efforts to help other stakeholders in the LCR watershed development planning efforts, with consideration for watershed level effects to the humpback chub in Grand Canyon. Under contract with Reclamation, SWCA, Inc. has developed a draft LCR Management Plan that has, to date, identified some of the primary water development risks to sustainable humpback chub critical habitat, steps toward effective risk management, and key players in the implementation of the management plan (Valdez and Thomas 2009).

***Monthly Flow Transition Study***

Transitions between monthly flow volumes from August, a large flow volume month, to September, a low flow volume month, can potentially have negative effects on nearshore habitats and endangered fish. Such transitions can result in a river stage level that is below the varial zone of the previous month's flow, and may be detrimental to fishes and food base for fish. In 2009, Reclamation adjusted daily flows between months in an attempt to attenuate these transitions such that they are more gradual. Reclamation has also committed to study the biological effects of these transitions through the Nearshore Ecology Study. Reclamation has also worked to adjust September and October monthly flow volumes to achieve improved conditions for young-of-year, juvenile, and adult humpback chub. This transition study will help inform the HFE protocol by identifying potential effects of flow transitions on fish and their habitats and food base.

## 1.4 Relevant Statutory Authority

Reclamation is responsible for defining the extent of its discretionary authority with respect to this action in compliance with Section 7(a)(2) of the ESA and its implementing regulations. Reclamation's authority for operation of Glen Canyon Dam stems from a body of documents commonly referred to as the Law of the River, as described below. While there is no universally accepted definition of this term, the Law of the River comprises numerous operating criteria, regulations, and administrative decisions included in federal and state statutes, interstate compacts, court decisions and decrees, an international treaty, and contracts with the Secretary of the Interior (Secretary).

Notable among these documents are:

1. The Colorado River Compact of 1922 (Compact);

2. The 1944 Treaty (and subsequent minutes of the International Boundary and Water Commission);

3. The Upper Colorado River Basin Compact of 1948;

4. The Colorado River Storage Project Act of 1956 (CRSPA);

5. The 1963 U.S. Supreme Court Decision in Arizona v. California;

6. The 1964 U.S. Supreme Court Decree in Arizona v. California (the Decree was supplemented over time after its adoption and the Supreme Court entered a Consolidated Decree in 2006);

7. The Colorado River Basin Project Act of 1968 (CRBPA);

8. The Colorado River Basin Salinity Control Act of 1974; and

9. The Grand Canyon Protection Act of 1992.

## 1.5 Detailed Description of Proposed Federal Action

### 1.5.1 Operation of Glen Canyon Dam

Implementation of the HFE protocol will be done in concert with coordinated river operations as described above in Section 1.4. Reclamation prepares an Annual Operating Plan each year that describes the past year's annual releases and projects the current year's releases. 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 Operations of Colorado River Reservoirs (LROC) that includes a minimum objective release of 8.23 million acre-feet (maf). The interim guidelines for lower basin shortages and the coordinated reservoir operations 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 (e.g., during low reservoir conditions). A more thorough description of Reclamation's process for determining and implementing annual release volumes is available in the 2007 FEIS (Reclamation 2007a), the 2007 ROD (U.S. Department of the Interior 2007), and the 2007 Opinion (USFWS 2007).

The proposed action provides for continued operation of Glen Canyon Dam under MLFF and all applicable prior decisions, with the inclusion of a protocol for high-flow experimental releases from Glen Canyon Dam for the 10-year period, 2011 through 2020. The proposed action is intended to meet the need for high-flow experimental releases during limited periods of the year when large amounts of sand from tributary inputs are likely to have accumulated in the channel of the Colorado River. Annual releases would follow prior decisions, including the MLFF, interim guidelines for lower basin shortages and coordinated reservoir operations, and the steady flows as identified in the 2008 Opinion and the 2009 Supplemental Opinion. The timing of HFE releases from Glen Canyon Dam would be March-April (spring) and October-November (fall); the magnitude would be from 31,500 cfs to 45,000 cfs; and the duration would be from less than one hour to 96 hours. The number and sequence of HFEs over the 10-year experimental period cannot be predicted because of the uncertainty of water availability and sediment input, but one or two HFEs in a given year are possible, as are more than two consecutive HFEs (see Section 1.4.2 below).

The timing, magnitude, duration, and frequency of HFEs are not expected to impact water delivery because Reclamation plans to reallocate water within or among months to achieve the necessary yearly volumes, while complying with the MLFF. The HFE protocol may call for high flow events during a fall and spring HFE implementation periods. High flow events under the HFE protocol could potentially require more water than what is scheduled for monthly release through the coordinated operating process. In order to conduct these high flow events as prescribed by the HFE protocol, reallocation of monthly releases from Glen Canyon Dam may be necessary. If Reclamation determines that it is not possible to achieve the high flow event within the monthly release volume projected for October-November or March-April, Reclamation will adjust the projected monthly release volumes as necessary for the following December through March period, or May through August period, respectively. A more complete description of dam operations is provided in the HFE EA.

### 1.5.2 Proposed HFE Protocol

The HFE protocol is a decision-making process that consists of three components: (1) planning and budgeting, (2) modeling, and (3) decision and implementation. A more complete description of the proposed HFE protocol is provided in the HFE EA. An important aspect of planning and budgeting is the preparation, development, and implementation of research and monitoring activities appropriate to monitor the effects of the HFEs. An annual Interior agency report would assimilate and synthesize the information on the effects of HFEs and the status and trends of key resources. This information would be provided to Interior to assist with the decision and implementation component of this protocol.

The second component of the protocol is modeling, which is based on an evaluation of the hydrology and the sand budget. The sand budget is the net amount of sand in metric tons that has accrued in the river channel during each of two accounting periods—fall and spring (Figure 2). The primary reach of the Colorado River that would be monitored for sand accrual for this protocol is Marble Canyon (Paria River to Little Colorado River [LCR]), which receives sand primarily from the Paria River. Average monthly sand load (i.e., the amount of sand being imported) is greatest for the Paria River during two periods—July through October and January through March. During these two periods, sand is being accumulated at a higher rate than in the remaining months, and the maximum accumulation of sand in the river channel usually occurs in November and April, respectively. It is important to note that sand in sandbars and beaches, as well in the river channel, is being continually eroded and transported downstream by water released from the dam; at a higher rate during high magnitude releases and fluctuating flows, and at a lower rate during low magnitude releases and more stable flows (Grams et al. 2010).

This progressive accumulation of sand is the fundamental basis of the store and release approach being evaluated with this protocol. The store and release approach relies on accumulation of sand during periods of above-average sediment input from tributaries to achieve sediment-enriched conditions called for in the development of the HFE protocol (74 FR 69361). An approach similar to store and release was used for the 2004 and 2008 HFEs and these were effective at redepositing sediment. Sand or sediment is accumulated over a period of several months and at which time a recommendation is made to release or not release a high flow from the dam. HFEs in November and April would likely be the most effective times for HFEs because of the greatest sand accumulation during these months. However, to accommodate the decision process that begins with hydrology and sediment modeling on October 1 and March 1, the HFE windows (times when an HFE could be conducted) are broadened to October-November and March-April. These 2-month windows also accommodate logistical preparation for monitoring, as well as an evaluation of the status of resources. As this decision process is refined and made more efficient with the experience of conducting HFEs, it is likely that the time necessary to make HFE decisions can be decreased, and it may be possible to conduct an HFE on a shorter notice.

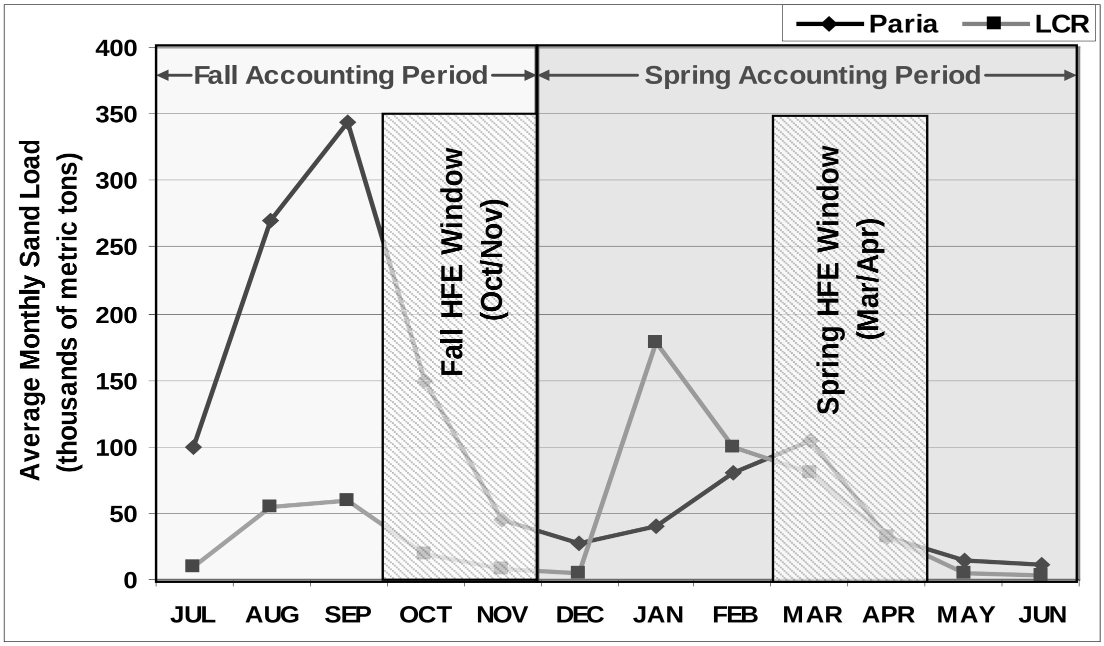


**Figure 2. The two sand accounting periods and the two high-release periods with average monthly sand loads for the Paria River and the Little Colorado River. Note that although average monthly sand load from the Paria River for the fall accounting period is August and September, greatest accumulation of sand occurs in October and November.**

Sand availability at the onset of each HFE window is determined by the amount of sand received from the Paria River during the accounting period less the amount transported downstream as estimated by the sand routing model (Wright et. al. 2010; see HFE EA for a description of this model). Sand in Grand Canyon received from the LCR is viewed as an added benefit to the amount received from the Paria River. The LCR input cycle largely follows the same accrual periods as the Paria River; however, only sand inputs from the Paria River would be used in HFE modeling recommendations in this protocol.

The third component of the protocol is the decision and implementation process for conducting an HFE. The hydrology model and sediment model (Russell and Huang 2010), as identified above, help to define the magnitude and duration of an HFE that is possible given the conditions for hydrology and sediment during each of the accounting periods. The range of possible HFEs is 31,500 cfs to 45,000 cfs for durations of about 1 hour to 96 hours. It is projected that because of ongoing maintenance of the eight generating units at Glen Canyon Dam, a maximum release of only 42,000 cfs (i.e., 27,000 cfs from the power plant and 15,000 cfs from the bypass valves) may be possible for much of the 10-year period, rather than 45,000 cfs.

### 1.5.3 Modeled HFE Magnitude, Duration, and Frequency

Because the hydrology and sediment conditions are unpredictable, the magnitude, duration, and frequency of HFEs cannot be prescribed in advance. Although hydrological conditions can be forecast months in advance with the Colorado River Simulation System (CRSS; Reclamation 2007b), sediment condition depends on periodic and unpredictable tributary floods. For the purpose of this effects analysis, model runs were done for nine traces using dry, moderate, and wet hydrology settings for each of three 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. It is important to note that this modeling procedure was conducted to evaluate the possible HFEs during a 10-year period, and differs from the actual future determination of an HFE in that actual tributary sediment data and forecasted hydrology will be used as model inputs.

Each of the nine traces was evaluated against 13 described HFEs to determine their possible occurrence in spring and fall for a hypothetical 10-year period (Table 1). The type of HFE possible was determined by the volume of available sediment and water, as predicted through the modeling process. Based on these model simulations, an HFE could occur 56 percent of the time. Of these HFE's, 91 percent had a peak magnitude of 45,000 cfs. Typically, HFEs occur in groups (consecutive HFEs); 80 percent of the HFEs had an HFE in the neighboring accounting periods.

The numbers of HFEs for the nine traces of sediment and hydrology indicate that HFEs are most likely to occur during low sediment with dry hydrology conditions, followed by a tie among low sediment with moderate hydrology, high sediment with dry hydrology, and high sediment with moderate hydrology. These conditions of suitability reveal the influence of hydrology and the consequent magnitude of MLFF 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. Conversely, low year-round dam releases allow for a greater accumulation of sediment than high releases that have higher velocity and a greater scouring effect.

Summary statistics relevant to this BA are included in Table 2 (magnitude, duration) and Table 3 (frequency, timing). Summary statistics are based on modeling simulations for traces of sediment and hydrology based on Table 1, but because the likelihood that sediment and hydrology combinations will be the same from year to year is low, the model does not necessarily reflect what may happen during the 10-year HFE protocol period. Nevertheless, the numbers provide an insight into a possible range of HFE magnitude, duration, and frequency. Table 2 indicates that flows of 45,000 cfs for 96 h could be relatively frequent (occurring in about a third of all model runs), whereas lower frequency flows of this magnitude (1–24 hours) account for another third of all model runs. If one or more of the eight-powerplant units were not available, the HFE magnitude would be adjusted to the maximum release possible. In terms of frequency and timing, Table 3 indicates that 58 percent of HFEs could occur in fall months and 42 percent in spring. Overall, an average of 1.1 HFEs could be conducted per year over the 10-year period, and for a given trace of sediment and hydrology, 3 to 5 consecutive HFEs could occur, with no more than 2 HFEs in one year.

**Table 1. Type of HFE by month for each of the nine traces of sediment (Low, Moderate, and High) and hydrology (Dry, Moderate, Wet). Numbers in cells represent HFEs of different magnitudes and durations as shown in Table 2 (e.g., a type 5 HFE is 45,000 cfs for 36 hours).**

| Months - Year | Low, Dry | Low, Mod. | Low, Wet | Mod, Dry | Mod, Mod. | Mod, Wet | High, Dry | High, Mod. | High, Wet |
|---|---|---|---|---|---|---|---|---|---|
| Mar/Apr Yr 1 | 5 | 5 | | | | | 7 | 7 | |
| Oct/Nov Yr 1 | 2 | 2 | | 6 | 6 | | 6 | 6 | |
| Mar/Apr Yr 2 | | | | | | | | | |
| Oct/Nov Yr 2 | | 7 | | | | | | | |
| Mar/Apr Yr 3 | 6 | 12 | | 1 | 2 | 1 | 8 | | |
| Oct/Nov Yr 3 | 3 | 8 | 4 | 1 | 2 | 1 | 1 | 1 | 1 |
| Mar/Apr Yr 4 | 10 | | | 1 | 1 | 1 | 2 | 8 | 3 |
| Oct/Nov Yr 4 | 1 | 1 | 7 | 8 | 8 | | 6 | 8 | |
| Mar/Apr Yr 5 | | | | | | | 2 | 7 | 1 |
| Oct/Nov Yr 5 | 1 | | 4 | 8 | | | | | |
| Mar/Apr Yr 6 | 11 | 8 | 8 | 5 | 1 | 1 | | 12 | 9 |
| Oct/Nov Yr 6 | | | 8 | | | | 1 | 1 | 1 |
| Mar/Apr Yr 7 | 8 | 8 | | | 8 | | 9 | 10 | |
| Oct/Nov Yr 7 | 7 | 7 | | | | | 1 | 1 | 1 |
| Mar/Apr Yr 8 | | | 7 | 8 | | 4 | 4 | 9 | 1 |
| Oct/Nov Yr 8 | 4 | 3 | 3 | 1 | 1 | 1 | 6 | 7 | 8 |
| Mar/Apr Yr 9 | | | | | | | | | |
| Oct/Nov Yr 9 | 9 | 7 | | 1 | 1 | 1 | | | |
| Mar/Apr Yr 10 | 1 | 1 | 2 | | | | | | |
| Oct/Nov Yr 10 | 2 | 2 | 1 | 5 | 6 | 2 | 6 | 7 | 1 |
| No. of HFEs | 14 | 13 | 9 | 11 | 10 | 8 | 13 | 13 | 9 |

**Table 2. Total number and frequency of HFEs for all nine traces of sediment and hydrology, from a possible 100 occurrences (see Table 1).**

| HFE | Flow Magnitude (cfs) | Duration (hours) | Number and Percent Frequency |
|---|---|---|---|
| 1 | 45,000 | 96 | 33 |
| 2 | 45,000 | 72 | 10 |
| 3 | 45,000 | 60 | 4 |
| 4 | 45,000 | 48 | 5 |
| 5 | 45,000 | 36 | 4 |
| 6 | 45,000 | 24 | 9 |
| 7 | 45,000 | 12 | 11 |
| 8 | 45,000 | 1 | 15 |
| 9 | 41,500 | 1 | 4 |
| 10 | 39,000 | 1 | 2 |
| 11 | 36,500 | 1 | 1 |
| 12 | 34,000 | 1 | 2 |
| 13 | 31,500 | 1 | 0 |

**Table 3. Frequency and timing of HFEs possible under the proposed action. Number of HFE series to the number of instances where HFEs occur as two or more consecutive HFEs, and maximum consecutive HFEs refer to the number of HFEs possible in any given series (see Table 1).**

| Sediment/ Hydrology | No. HFEs | No. Fall HFEs | No. Spring HFEs | Average HFEs/yr | No. of HFE Series | Max.Consecutive HFEs |
|---|---|---|---|---|---|---|
| Low/Dry | 14 | 6 | 8 | 1.4 | 5 | 4 |
| Low/Mod. | 13 | 5 | 8 | 1.3 | 4 | 3 |
| Low/Wet | 9 | 3 | 6 | 0.9 | 3 | 3 |
| Mod./Dry | 11 | 4 | 7 | 1.1 | 3 | 4 |
| Mod./Mod. | 10 | 4 | 6 | 1.0 | 1 | 4 |
| Mod./Wet | 8 | 4 | 4 | 0.8 | 2 | 3 |
| High/Dry | 13 | 6 | 7 | 1.3 | 3 | 5 |
| High/Mod. | 13 | 6 | 7 | 1.3 | 3 | 6 |
| High/Wet | 9 | 4 | 5 | 0.9 | 3 | 3 |
| Total | 100 | 58 | 42 | Ave: 1.1/yr | | |

### 1.5.4 Basis and Approach to Proposed Action

The Colorado River downstream from Glen Canyon Dam is depleted of its natural sediment load due to the presence of the dam, and ongoing dam operations that 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 (Topping et al. 2010). Sandbars and beaches provide key wildlife habitat, protect archeological sites and vegetation structure, and provide camping opportunities in Grand Canyon; and backwaters can be important nursery habitat for young fishes and islands of productivity (Stevens 1996). One of the best tools available for rebuilding sandbars and beaches is to use dam operations to release short-duration high flows, preferably after sediment-laden tributary floods deposit new sand into the main channel.

This protocol is intended to be experimental in nature and is designed to provide a better understanding of how to incorporate high releases into future dam operations in a manner that effectively conserves sand in the long-term. The HFE protocol is designed to help determine the timing, magnitude, duration, and frequency of HFEs that may occur during ongoing hydrologic conditions and sand budgets. The HFEs conducted through this protocol would help to build on knowledge acquired from previous adaptive management experiments and would provide information that will lead to a better understanding of how to conserve sand in the Colorado River through Grand Canyon. Sand deposited as sandbars and beaches is a primary component of the historic Colorado River ecosystem, and determining how sand conservation can be achieved in areas within GCNP downstream of Glen Canyon Dam is a high priority of the GCDAMP and Interior.

This protocol is designed as a multi-year, multi-experimental approach, and constitutes the next logical step in adaptive management with respect to high-flow testing at Glen Canyon Dam. High flows mobilize sand stored in the main river channel and rebuild sandbars, beaches, and associated backwater habitats along shorelines. Sandbars are dynamic features, however, that are progressively degraded and reduced by the erosive forces of the same river that forms them during floods. Developing this protocol is important for implementing a strategy of high-flow releases over a period longer than one year or one event. In the past, Reclamation has conducted 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 during sediment-rich conditions and under consistent criteria can better conserve sediment resources while not negatively impacting other resources. Previous HFEs from Glen Canyon Dam above the powerplant capacity of 31,500 cfs were conducted in 1996, 2004, and 2008. Other high dam releases of near powerplant capacity were conducted, one in 1997 and two in 2000. All of these experiments provided valuable information and increased the understanding of responses by physical and biological resources to high-flow releases.

This protocol is intended to be experimental in nature, and is designed to learn how to incorporate high releases into future dam operations in a manner that effectively conserves sediment and sediment-dependent resources in the long-term. A number of hypotheses may be tested through this experimental protocol. These hypotheses could be directed at varying the timing, magnitude, duration, and frequency of HFEs to determine the effectiveness on sand conservation. Two approaches have been put forward with respect to timing of a high release in response to the delivery of sediment into the river channel. The "store and release" approach was developed by USGS and was first introduced as the basis for the HFE protocol in a June 2010 modeling workshop. The "rapid response" approach was provided later in September by Western Area Power Administration.

The store and release approach relies on accumulation of sand during periods of above-average sediment input from tributaries to achieve sediment-enriched conditions called for in the development of the HFE protocol (74 FR 69361). An approach similar to store and release was used for the 2004 and 2008 HFEs and these were effective at redepositing sediment. Sand or sediment is accumulated over a period of several months and at which time a recommendation is made to release or not release a high flow from the dam. In contrast, the rapid response approach relies on real-time measurements of flood events by stream gages in the tributary supplying the sediment (i.e., Paria River). This information must be transmitted to dam operators in sufficient time so they can release water from the dam to coincide with the flood input from the tributary. The success of the rapid response approach requires coupling of tributary floods and dam releases to transport sediment-enriched water downstream. The decision process for rapid response must occur within a matter of hours, with the assumption that a report of resource condition shows no potential adverse effect to other resources in the canyon. It is anticipated that the possible impacts of a rapid response HFE will need to be addressed in a supplemental environmental assessment after initiation of the HFE EA. Prior to the implementation of the rapid response approach, a science plan will also need to be developed.

### 1.5.5 Geographic Scope and Extent of Action Area

The area directly and indirectly affected by this proposed action is the Colorado River corridor from Glen Canyon Dam in Coconino County, Arizona downstream to the inflow of Lake Mead near Pearce Ferry, Mohave County, Arizona (Figure 1). This action area includes Glen Canyon National Recreation Area (GCRA) in a 20.3-mile reach from Glen Canyon Dam to Navajo Bridge; and Grand Canyon National Park (GCNP), a 274-mile reach from Navajo Bridge to a point about 1.7 miles upstream of Pearce Ferry. Three distinct canyons lie within the proposed action area and are referenced in this document: Glen Canyon encompasses the 16-mile reach from the dam to the Paria River; Marble Canyon is the 61-mile reach from the Paria River to the LCR; and Grand Canyon is the 217-mile reach from the LCR to near Pearce Ferry.

# 2 Environmental Baseline

The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early Section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process (50 CFR 402.02).

## 2.1 Regulatory Context

Several Federal and states agencies and tribes have authority over land and various resources within the action area. Past consultations have evaluated the impact of proposed actions on the threatened and endangered species that live in the Colorado River and its floodplain between Glen Canyon Dam and the inflow area of Lake Mead. This anticipated area of effect lies within Glen Canyon National Recreation Area and Grand Canyon National Park, and the Colorado River inflow of Lake Mead in the Lake Mead National Recreation Area, all of which are administered by the National Park Service. The action area is bordered by, or is in proximity to, tribal lands of the Navajo Nation, Hopi Tribe, Pueblo of Zuni, Paiute Tribe, Havasupai Tribe, and Hualapai Tribe. These lands are administered by the respective tribal governments, and the Bureau of Indian Affairs has fiduciary responsibility to assist these tribes. The Arizona Game and Fish Department (AGFD), through its Commission, manage the fish populations in the action area, including the sport fish, native fish, and non-native fish populations, in cooperation with the NPS. The Commission sets fishing regulations that are enforced by the AGFD.

## 2.2 Related Consultation History

Reclamation has consulted with the U.S. Fish and Wildlife Service under Section 7 of the ESA on the effects of various projects on federally listed species and designated critical habitat. Since 1995, Reclamation has consulted with the USFWS on a total of five important experimental actions, and has undertaken a sixth experimental action that did not require separate ESA consultation. This history is listed and described below. The USFWS issued a "jeopardy" determination in the 1995 Opinion, but non-jeopardy opinions on all other actions.

### 2.2.1 1996 Record of Decision on the Operation of Glen Canyon Dam

Reclamation received a final biological opinion from the USFWS on the preferred alternative for the *Final Environmental Impact Statement on the Operation of Glen Canyon Dam* in January 1995. The USFWS concluded that without the included reasonable and prudent alternative, implementation of the MLFF alternative was likely to jeopardize the continued existence of the humpback chub and razorback sucker and was likely to destroy or adversely modify their critical habitat, but was not likely to jeopardize the bald eagle, Kanab ambersnail, and peregrine falcon. The 1995 Opinion identified one reasonable and prudent alternative (RPA) containing four elements that were necessary to avoid jeopardizing the continued existence of the humpback chub and razorback sucker. Reclamation implemented these elements through the principles of adaptive management starting in 1996 within the GCDAMP, and the USFWS has agreed with

Reclamation that sufficient progress has been made on these elements. The 1995 Opinion was replaced by the 2008 Opinion and the 2009 Supplemental Opinion, as described below.

### 2.2.2 Spring 1996 High Flow Test from Glen Canyon Dam

Consultation was initiated in November of 1995 for a proposed high flow test from Glen Canyon Dam in the spring of 1996 in the Colorado River. Consultation with the USFWS was reinitiated on the preferred alternative from the 1995 FEIS because a new species was listed since the original consultation (southwestern willow flycatcher with proposed critical habitat), and new information[1] revealed that incidental take for the Kanab ambersnail determined in the 1995 Opinion would be exceeded. Reclamation concluded in its BA that the test would have no effect on the endangered peregrine falcon, threatened bald eagle, or the endangered razorback sucker. The USFWS concurred and concluded in its biological opinion that the proposed test was not likely to jeopardize the continued existence of the humpback chub, Kanab ambersnail, or southwestern willow flycatcher, and was not likely to destroy or adversely modify humpback chub critical habitat. The USFWS also provided a conference opinion that the test was not likely to destroy or adversely modify proposed critical habitat for the southwestern willow flycatcher.

### 2.2.3 November 1997 Fall Test Flow from Glen Canyon Dam

The 1997 action was proposed as a test of a near powerplant capacity release of 31,000 cfs for 48 hours. While powerplant capacity releases were described in the 1995 draft EIS as habitat maintenance flows, such a test in the fall was not addressed in the 1995 FEIS, which necessitated additional consultation. The USFWS in its biological opinion concluded that the test flow was not likely to jeopardize the continued existence of the humpback chub or Kanab ambersnail and was not likely to destroy or adversely modify designated critical habitat for the humpback chub. The USFWS concluded the action was not likely to jeopardize the bald eagle or the American peregrine falcon.

### 2.2.4 2000 Steady Flow Test from Glen Canyon Dam

During the period March 25 through September 30, 2000, Reclamation conducted a 6-month flow test that included steady flows of about 8,000 cfs from June 1 to September 4, and short-term (48 hours) high flow releases of near powerplant capacity (31,000 cfs) during early May and early September. The steady flows were intended to determine if stable flows would provide more reliable, warm habitat for young humpback chub. The high spring release was designed to

[1] In its December 21, 1994, Final Biological Opinion, the Service evaluated impacts to Kanab ambersnail from the operation of Glen Canyon Dam according to operating and other criteria of the preferred alternative contained in the FEIS. The Service determined implementation of the preferred alternative would not jeopardize the continued existence of the Vasey's Paradise Kanab ambersnail population. This opinion also supported the concept of a beach/habitat building flow of 40,000 to 45,000 cfs, which is part of the preferred alternative. At the time of the 1994 Biological Opinion, the Service thought that 10 percent of habitat would be lost in a 45,000 cfs flow and set this amount, as vegetation rather than number of snails, to be the expected incidental takes. Information obtained in ensuing investigations showed that the incidental take in a 45,000 cfs release could be as much as 17 percent of snail habitat (Service 1996), and, pursuant to that finding, the Service adjusted the incidental take to be 17 percent (Service 2000).

determine if ponding would occur at tributary mouths to provide a warm transition zone for young native fish escaping from the warm tributary into the cold mainstem. The fall release was designed to determine if high flows could be used to displace and reduce numbers of small-bodied non-native fish. This test was performed in accordance with an element of the reasonable and prudent alternative of the 1995 Opinion, so no additional consultation with USFWS was conducted.

### 2.2.5 2002–2004 Experimental Releases and Removal of Non-Native Fish

In 2002, Reclamation, the National Park Service, and the U.S. Geological Survey (USGS) consulted with the USFWS on: (1) experimental releases from Glen Canyon Dam, (2) mechanical removal of non-native fish from the Colorado River in an approximately 9-mile reach in the vicinity of the mouth of the LCR to potentially benefit native fish, and (3) release of non-native fish suppression flows having daily fluctuations of 5,000–20,000 cfs from Glen Canyon Dam during the period January 1–March 31. Implicit in the experimental flows and mechanical removal proposed action was the recognition that modification of dam operations alone likely would be insufficient to achieve objectives of the GCDAMP, which include removal of jeopardy for the humpback chub and razorback sucker.

In their biological opinion, the USFWS concluded that the proposed action was not likely to jeopardize the continued existence of the humpback chub, Kanab ambersnail, bald eagle, razorback sucker, California condor, or southwestern willow flycatcher. The December 2002 Opinion included incidental take of up to 20 humpback chub during the non-native fish removal efforts and the loss of up to 117 $m^2$ of Kanab ambersnail habitat.

Two conservation measures were included in the 2002 Opinion. The first measure included relocation of 300 humpback chub above Chute Falls in the LCR where predation was low to increase the likelihood of humpback chub surviving throughout the LCR during inclement environmental conditions. The second conservation measure consisted of temporary removal and safeguard of approximately 29–47 $m^2$ (25–40 percent) of Kanab ambersnail habitat that would be inundated by the experimental release. The relocated habitat and ambersnails would be replaced once the high flow was complete to facilitate re-establishment of vegetation.

The USFWS translocated young humpback chub above Chute Falls in the LCR (ca. 16 km from the confluence). Under contract with the GCMRC, USFWS translocated nearly 300 young humpback chub above a natural barrier in the LCR located 16 km above the confluence in August 2003. This translocation was followed by another 300 fish in July 2004 and by another 567 fish in July 2005 (Sponholtz et al. 2005; Stone 2006). Results indicate that this experiment has been a success: translocated fish survival and growth rates are high; limited reproduction and downstream movement below Chute Falls has been documented; and recent increases in the humpback chub population are likely partially attributable to this effort (Coggins and Walters 2009).

The sediment input triggered high experimental flow was analyzed for an indefinite period of time because of the uncertainty of knowing when the sediment trigger would be reached. The other two actions were analyzed for water years 2003 and 2004. Consultation was reinitiated in 2004 to make several changes to the timing and duration of the proposed experiments described in the 2002 consultation. The 2004 high flow experiment was intended to occur immediately following significant tributary sediment inputs, while the 2002 high flow experiment was proposed to occur in winter or spring. In the November 2004 Opinion, the USFWS concurred with Reclamation that the action was not likely to adversely affect razorback sucker or its critical habitat, California condor, or southwestern willow flycatcher. The USFWS concluded that the action was not likely to jeopardize the continued existence of the humpback chub, Kanab ambersnail, or bald eagle. The USFWS also concluded that the action was not likely to destroy or adversely modify designated critical habitat for humpback chub.

The 2004 Opinion included the 2002 conservation measures related to humpback chub including the continuation of translocating humpback chub in the LCR, and further study and monitoring of the results, as well as a study of effects on chub from various flow conditions. The Kanab ambersnail conservation measures included removal and safeguard of Kanab ambersnail habitat that would be inundated by the experimental release. Reclamation implemented conservation measures for Kanab ambersnail and humpback chub in conjunction with the proposed activities (Peterson 2002).

### 2.2.6 2007 Colorado River Interim Guidelines and Coordinated Operations

In October 2007, Reclamation issued a FEIS on *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (Reclamation 2007a). A Record of Decision (Shortage ROD) was issued on December 13, 2007, which adopted these interim guidelines and coordinated reservoir operations (U.S. Department of the Interior 2007). This Shortage ROD specified reduction of consumptive uses below Lake Powell during times of low reservoir conditions and modification of the annual release volumes from Lake Powell. The Shortage ROD established annual release volumes from Glen Canyon Dam, but did not, in any manner, alter the constraints imposed by the 1996 ROD or as adopted in the 1997 Glen Canyon Dam Operating Criteria (discussed in Section 1.3). Since many of the potential resource impacts identified in that FEIS were being investigated in the GCDAMP, the biological opinion made use of this institutional arrangement as a key mechanism for addressing impacts.

The USFWS issued a final biological opinion on this Federal action on December 12, 2007 (USFWS 2007). In that 2007 Opinion, the USFWS determined that implementation of the guidelines was not likely to jeopardize the continued existence of the humpback chub, the southwestern willow flycatcher, or the Kanab ambersnail, and was not likely to destroy or adversely modify designated critical habitat for the humpback chub or the southwestern willow flycatcher. The 2007 Opinion did not render a determination for the razorback sucker because of the perceived absence of the species from the action area. However, in its concurrence for adoption and implementation of these guidelines, USFWS determined that Reclamation would, as a conservation measure, undertake an effort to examine the potential of habitat in the lower Grand Canyon for the species, and institute an augmentation program in collaboration with USFWS, if appropriate. Reclamation has implemented a project to address this measure starting in 2010.

As part of the 2007 Opinion, Reclamation, through the GCDAMP, will continue to monitor Kanab ambersnail and its habitat in Grand Canyon and the effect of dam releases on the species.

Reclamation will also continue to assist USFWS in funding morphometric and genetic research to better determine the taxonomic status of the subspecies. Reclamation will also continue to monitor southwestern willow flycatcher and its habitat and the effect of dam releases on the species throughout Grand Canyon and report findings to USFWS, and will work with the NPS and other GCDAMP participants to identify actions to conserve the flycatcher. Five conservation measures were identified in the 2007 Opinion to help reduce the threat to the humpback chub. The status of these conservation measures is described in Section 1.3.

#### 2.2.7 2008 Biological Opinion

On February 27, 2008, the USFWS issued a biological opinion on the operation of Glen Canyon Dam for the period 2008–2012. That 2008 Opinion concluded that implementation of a March 2008 high flow test and a five-year implementation of MLFF with steady releases in September and October, as proposed, 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. The Incidental Take Statement in the 2008 Opinion states that incidental take would be exceeded if the proposed action resulted in detection of more than 20 humpback chub mortalities during the high-flow test of March 2008 that were attributable to the high flow. The 2008 Opinion identified eight conservation measures for the humpback chub that expanded on the measures identified in the 2007 Opinion, including a Humpback Chub Consultation Trigger, a Comprehensive Plan for the Management and Conservation of Humpback Chub in Grand Canyon, Humpback Chub Translocation, Non-native Fish Control, Humpback Chub Nearshore Ecology Study, Monthly Flow Transition Study, Humpback Chub Refuge, and LCR Watershed Planning. These are further described in the *Reissuance Of the 2009 Supplemental Biological Opinion on The Operation of Glen Canyon Dam 2008-2012* (USFWS 2010).

On May 26, 2009, the District Court of Arizona, in response to a lawsuit brought by the Grand Canyon Trust, ordered the USFWS to reevaluate the conclusion in the 2008 Opinion that the MLFF does not violate the ESA (Case number CV-07-8164-PHX-DGC). The Court ordered the USFWS to provide an analysis and a reasoned basis for its conclusions in the 2008 Opinion, and to include an analysis of how MLFF affects critical habitat and the functionality of critical habitat for recovery purposes by October 30, 2009.

#### 2.2.8 2009 Supplement to the 2008 Biological Opinion

On October 29, 2009, the USFWS issued a supplement to the 2008 Opinion for the operation of Glen Canyon Dam, as a result of the Court Order of May 26, 2009, and affirmed the 2008 Opinion that the action 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. The Incidental Take Statement in the 2009 Supplemental Opinion states that incidental take would be exceeded if the proposed action caused the conditions of the consultation trigger to be met. The consultation trigger was identified in the 2008 Opinion as a conservation measure, and states in the 2009 Supplemental Opinion that "Reclamation and USFWS agree to specifically define this reinitiation trigger relative to humpback chub, in part, as being exceeded if the population of adult humpback chub (≥200 mm [7.87 in] TL) in Grand Canyon declines significantly, or, if in any single year, based on the age-structured mark recapture model (ASMR; Coggins 2008a), the population drops below 3,500 adult fish within the 95 percent confidence interval." Based on the recommendation of the GCDAMP Protocol Evaluation Panel (PEP), the decision was made to employ the ASMR model once every three years. Hence, the ASMR would not be utilized annually, but only employed to test the humpback chub consultation trigger if other data, such as annual mark-recapture, closed population estimates of humpback chub abundance in the LCR, indicated that the population was declining to the abundance level defined in the trigger.

On June 29, 2010, the District Court of Arizona ruled that the 2009 Supplemental Opinion adequately explained the USFWS conclusion that the proposed action was not likely to neither jeopardize the humpback chub nor adversely modify its critical habitat. However, the incidental take portion of the 2009 Supplemental Opinion was remanded back to the USFWS, and addressed in separate documentation. On September 1, 2010, in response to the June 29 District Court of Arizona order, a revised incidental take statement and biological opinion were issued (Reissuance of the 2009 Supplemental Opinion, USFWS 2010).

### 2.2.9 Cancellation of Non-native Fish Removal in 2010

On March 5, 2010, Reclamation requested reinitiation of formal consultation (2009 Supplemental Opinion) to accommodate a modification of the 5-year experimental nonnative fish removal efforts planned for May and June 2010. Concerns were expressed by American Indian Tribes over the killing of fish as loss of life in sacred areas, and a draft biological opinion was submitted by USFWS to Reclamation on October 14, 2010, evaluating the cancellation of nonnative mechanical removal in 2010.

The focus of this consultation was the cancellation of two nonnative removal trips scheduled for May and June 2010. All other aspects of the proposed action remained the same as described in the 2009 Supplemental Opinion described above. Conservation measures such as parasite monitoring, potential razorback sucker augmentation, and the monthly flow transition study, as described in the 2008 and 2009 Opinions, would likely not occur during the 13-month period but were planned for the future. Other conservation measures, such as the Nearshore Ecology Study and the Fall Steady Flow Plan are proceeding. Because the high flow test conservation measure had already occurred in March of 2008, it was not addressed in this consultation. The flows for this consultation, which have been addressed in earlier biological opinions, were to occur as follows: flows in March–August 2010 will occur under the MLFF strategy, September-October 2010 will consist of steady flows, and November 2010 through April 30, 2011 will return to MLFF which is the preferred alternative as described in the 1996 ROD on Glen Canyon Dam Operations.

This reinitiated consultation resulted after meetings with American Indian Tribes and with the GCDAMP members. Due to cultural and religious concerns regarding the taking of life associated with mechanical removal of nonnative fishes as a conservation measure, it was decided that the two nonnative removal trips scheduled for May and June 2010 would be cancelled. This resulted in a modification of the action proposed as addressed in the 2008 and 2009 Opinions.

The USFWS determined that proposed action was not likely to jeopardize the continued existence of the humpback chub or destroy or adversely modify its critical habitat. The USFWS also concluded that the proposed action was not likely to destroy or adversely modify critical habitat for the razorback sucker. Although razorback sucker critical habitat was not addressed in the formal consultation portion of the 2008 Opinion, it was addressed in the 2010 Opinion, at Reclamation's request. All other effects determinations remained the same as for the 2008 and 2009 Opinions for the razorback sucker, Kanab ambersnail, and southwestern willow flycatcher.

For the 2010 Biological Opinion, the USFWS anticipated that between 1,000 and 24,000 y-o-y or juvenile humpback chub would be lost to predation by trout as a result of the modified proposed action during the 13-month period. The USFWS adopted the incidental take estimate provided in the April 2010 BA, of 10,817 young-of-year and juvenile humpback chub for the 13-month period. Even with the occurrence of other lethal and nonlethal stressors from suboptimal water temperatures and unstable shoreline habitat associated with fluctuating flows, except for September and October, USFWS did not anticipate that incidental take would exceed the 24,000 estimate. Reclamation has committed in the 2007 Opinion to the monitoring and control of non-native fish in coordination with other Interior agencies and working through the GCDAMP (USFWS 2007).

## 2.3 Description of Species Identified for Analysis

Four endangered species are identified within or near the area affected by the proposed action: the humpback chub, razorback sucker, Kanab ambersnail, and the southwestern willow flycatcher. Descriptions of these species and their legal status, life history, current range, and abundance are provided below. More detailed information on the four species analyzed in this BA can be found in Reclamation's 2007 BA (Reclamation 2007a).

### 2.3.1 Humpback Chub

The humpback chub was included in the List of Endangered Species on March 11, 1967 (32 FR 4001) and was listed as endangered with passage of the ESA in 1973. The humpback chub recovery plan was approved on September 19, 1990 (USFWS 1990) and Recovery Goals were developed in 2002 (USFWS 2002a). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994. Designated critical habitat occurs in two reaches within or near the action area: the lower 8 miles of the LCR 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). The LCR is a seasonally-warmed tributary with a spring-fed base flow of about 230 cfs and highly turbid floods of over 10,000 cfs; light gravel deposits are principal spawning sites for humpback chub, and young inhabit rocky shorelines while adults use deep pools. The mainstem habitat remains too cold most years (<15°C) for spawning by humpback chub, but young escape from the LCR and inhabit rocky nearshore areas while adults use large deep eddy complexes.

The humpback chub is a moderately large cyprinid fish endemic to the Colorado River system (Miller 1946). It is surmised from various reports and collections that the species occupies about 68 percent of its historic habitat of about 470 miles of river (USFWS 2002a). Range and population reductions are thought to have been caused primarily by streamflow regulation and habitat modification (including cold-water dam releases and habitat loss), competition with and predation by non-native fish species, parasitism, hybridization with other native *Gila*, and pesticides and pollutants. Six humpback chub populations are currently known—all from canyon-bound reaches. Five are in the upper Colorado River Basin and the sixth, known as the Grand Canyon population, is located in Marble and Grand Canyon's of the lower basin. Upper basin populations range in size from a few hundred individuals to about 5,000 adults.

The most recent estimate of the Grand Canyon population is between 6,000 and 10,000 adults (most likely estimate at 7,650 adults; Coggins and Walters 2009). The majority of individuals in this population are located in the LCR and in a 10-mile reach of the Colorado River above and below the confluence of the two rivers. There are eight other small aggregations of humpback chub in Grand Canyon: seven are located at distances up to 150 miles below the confluence and one is located 30 miles above the confluence (Valdez and Ryel 1995).

Young-of-year and juvenile humpback chub are found primarily in the LCR and the Colorado River near the LCR inflow, although many have been found upstream of the LCR (Figure 3), presumably from spawning at warm springs near RM 30 (river miles downstream from Lees Ferry) (Valdez and Masslich 1999). Reproduction by humpback chub occurs annually in spring in the LCR, and the young fish either remain in the LCR or disperse into the Colorado River. Dispersal of these young fish has been documented as nighttime larval drift during May through July (Childs et al. 1998; Robinson et al. 1998), as density dependent movement during strong year classes (Gorman 1994), but primarily as movement with summer floods caused by monsoonal rainstorms 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 an unknown number of fish survive and return to the LCR and contribute to recruitment. The cold mainstem temperatures appear to suppress growth of young humpback chub when compared to growth in the LCR, but growth of adults in the mainstem may be greater or comparable to that of adults in the LCR (Valdez and Ryel 1995; Coggins 2008b). These different growth rates may also be influenced by available food supplies in the two systems (Rosi-Marshall et al. 2010).

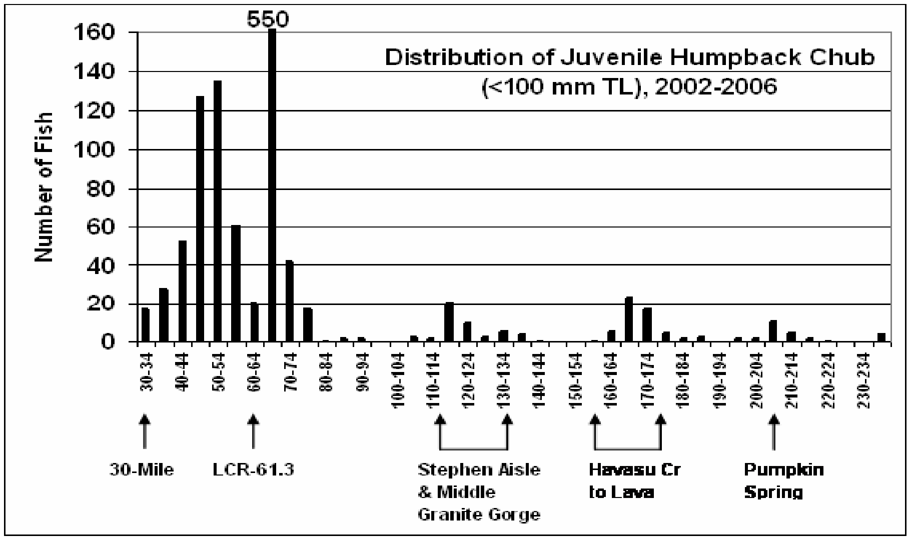


**Figure 3. Distribution of juvenile humpback chub < 100 mm TL during 2002-2006 by 5-miles increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from Ackerman and Valdez 2008)**

Survival of humpback chub is also affected by diseases and parasites (e.g., Asian tapeworm, *Bothriocephalus acheilognathi*, and parasitic copepod, *Lernaea cyprinacea*; Hoffnagle et al. 2000), available food supply, and downstream displacement of young (Valdez and Ryel 1995). The extent and disposition of downstream displacement is not known, but was not significant for the late-March, early-1996 HFE (Hoffnagle et al. 1999). Evidently, some fish that disperse downstream survive. Aggregations located downstream from the LCR include fish that were marked and released near the LCR, as well as fish that likely were produced locally. Predation by rainbow trout and brown trout in the LCR 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 2008a; Yard et al. 2008).

### 2.3.2 Razorback Sucker

The razorback sucker was listed as endangered under the ESA on October 23, 1991 (56 FR 54957). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994. 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 full pool elevation. A recovery plan was approved on December 23, 1998 (USFWS 1998a) and Recovery Goals were approved on August 1, 2002 (USFWS 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 non-native fish species; and pesticides and pollutants (Bestgen 1990; Minckley 1991; USFWS 2002b).

The razorback sucker is endemic to the Colorado River System. Historically, it occupied most of the middle and lower elevations of the mainstem Colorado River and many of its tributaries. Distribution and abundance of razorback sucker declined throughout the 20$^{th}$ century over all of its historic range, and the species now exists naturally only in a few small, discontiguous populations or as dispersed individuals. In the last 40–50 years, numbers of razorback suckers have declined sharply because of little natural reproduction and recruitment, and the few remaining wild populations are comprised primarily of old adults.

The razorback sucker has not been reported upstream of about Pearce Ferry 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 blind female razorback sucker at Upper Bass Camp (RM 107.5) in 1984, and Minckley (1991) reported five adults in the lower LCR from 1989–1990. A full complement of habitat types (large nursery floodplains, broad alluvial reaches for feeding and resting, and rocky canyons for spawning), as used by razorback suckers in the Upper Colorado River Basin (USFWS 2002b), does not appear to be available between Glen Canyon Dam and Pearce Ferry; however, alluvial gravel bars off tributary mouths and side canyons are available for spawning, a few backwaters are available for nursing by young, and alluvial reaches are present for resting and feeding. If razorback suckers use lower Grand Canyon, it most likely involves fish that spend at least part of their life cycle in the more complex habitat offered by the Lake Mead inflow downstream from Pearce Ferry.

The largest reservoir population, estimated at 75,000 in the 1980s, occurred in Lake Mohave, Arizona and Nevada, but it had declined to about 60,000 in 1989 (Marsh and Minckley 1989), to 25,000 in 1993 (Marsh 1993; Holden 1994), to about 9,000 in 2000 (Burke 1994), and to less than 3,000 by 2001 (Marsh et al. 2003). Mueller (2005, 2006) reported that the wild Lake Mohave razorback sucker population was approaching 500 individuals, while the most recent 2009 estimate is approximately 30 wild fish remaining (Pacey 2009). Today, the Lake Mohave population is largely supported by periodic stocking of captive-reared fish (Marsh et al. 2003, 2005). Adult razorback sucker are most evident in Lake Mohave from January through April when they congregate in shallow shoreline areas to spawn, and larvae can be numerous soon after hatching.

A second razorback sucker population of approximately 500 adults exists in Lake Mead. The Lake Mead population is the only known recruiting population of razorback sucker in the Lower Colorado River Basin (Holden et al. 2000; Abate et al. 2002; Albrecht and Holden 2005; Albrecht et al. 2008a, 2008b). From 1990 through 1996, 61 razorback sucker were collected, 34 from the Blackbird Point area of Las Vegas Bay and 27 from Echo Bay in the Overton Arm (Holden et al. 1997). Two razorback sucker larvae were collected by in 1995 near Blackbird Point, confirming suspected spawning in this area. In addition to the captures of these wild fish, Nevada Department of Wildlife also stocked subadult (sexually immature) razorback sucker into Lake Mead; a total of 26 were stocked into Las Vegas Bay in 1994 and 14 were stocked into Echo Bay in 1995.

From 1996 to 2008, netting efforts have yielded more than 750 total razorback suckers captured or stocked, represented by nearly 500 unique individuals (Kegerries et al. 2009). In 1997, four subadult razorback suckers were captured in Echo Bay, indicating that recent, natural reproduction and recruitment had occurred within the Lake Mead population. Seventeen additional wild subadults were captured in the Blackbird Point area of Las Vegas Bay through 2005. During 2005–2008, an additional 39 subadults were captured in Lake Mead, indicating continued, natural reproduction and recruitment. Of 186 razorback sucker aged from fin-ray cross sections, adults were 7–36 years old and subadults were 2–6 years of age.

Kegerries et al. (2009) hypothesized that lake-level fluctuation, which promotes growth and inundation of shoreline vegetation, is largely responsible for the recruitment observed in the Lake Mead razorback sucker population. The inundated vegetation likely serves as protective cover that, along with turbidity, allows young razorback sucker to avoid predation by nonnative fishes. Recent nonnative introductions, such as quagga mussels (*Dreissena rostriformis bugensis*) and gizzard shad (*Dorosoma cepedianum*), could also affect the razorback sucker population in Lake Mead, but the nature and severity of these new potential stressors remains unknown.

During the last several years, declining Lake Mead elevations have affected the use of several spawning sites by razorback sucker in Lake Mead (Figure 4). From 1997 to 2001, aggregations of sonic-tagged adults, nest locations, and larval concentrations indicate that spawning was occurring at the back of Echo Bay along the south shore. Specifically, it appeared that adults were spawning at the base of a 50-foot cliff, but by the end of the spawning season in May 2001, this site was dry. As lake levels declined during 2002–2009, this population continued to find new spawning sites in Echo Bay at lower elevations, as sites from previous years dried.
At Las Vegas Bay during 1996–2004, most razorback sucker larvae were captured along the western shore and tip of Blackbird Point, suggesting that the same portion of Blackbird Point was used for spawning every year. However, the depth in this area changed dramatically as lake levels dropped and possible siltation occurred from Las Vegas Wash. In the late 1990s, at a high lake elevation, the spawning site was thought to be at a depth of about 80 feet, but by 2003, the spawning depth was closer to 20 feet and by the end of 2004, the area was dry. Spawning was not observed at Blackbird Point during 2003–2004, and only four larval razorback suckers were captured during the entire season at Las Vegas Bay, a site that once harbored the largest razorback sucker population in Lake Mead. However, during the 2005 spawning period (January through April), Lake Mead elevations rose more than 20 feet, allowing access to the Blackbird Point spawning site. However, in 2006 and in 2007, lake elevation lowered and the spawning aggregate shifted locations from Blackbird Point to the southwestern shore of Las Vegas Bay.


**Figure 4. Lake Mead elevation from January 1935 to June 2009 with the number of razorback sucker that were born each year lake-wide, based on ages of fish captured during 2005-2008 (figure from Kegerries et al. 2009). Note that the historic decline in numbers of fish is not necessarily a measure of spawning success for given years, but reflects the numbers of fish surviving over time from those spawning periods.**

In 2000 and 2001 larval razorback sucker were captured in the Colorado River inflow region of Lake Mead (Kegerries et al. 2009). During the 2002 and 2003 spawning periods, no larval razorback suckers were captured in this area. This spawning site was either not used in 2002–2003, or spawning took place outside of the sampling area. Alteration of spawning sites resulting from lake elevation changes may be responsible for the apparent inconsistent use of spawning sites in the Colorado River inflow region, as in other sites on Lake Mead described above.

In spring of 2010, larval sampling in the Colorado River inflow area (presently in the Gregg Basin region of Lake Mead) resulted in the capture of seven larval razorback sucker, one larval flannelmouth sucker (*Catostomus latipinnis*), and four larval fish thought to be either flannelmouth sucker or hybrid flannelmouth x razorback sucker (Albrecht et al. 2010). Although catch per unit effort was low, the identification of larval razorback sucker in the Colorado River inflow helped confirm the presence of spawning adult razorback sucker and documented successful spawning in 2010. Spawning is believed to have occurred on rock and gravel points between North Bay and Devil's Cove, in the lake interface about 10 miles downstream from Pearce Ferry. Moreover, Albrecht et al. (2010) reported that trammel netting in the inflow area yielded three wild razorback suckers, four razorback x flannelmouth sucker hybrids, and 52 flannelmouth suckers. All three razorback sucker were males expressing milt, which helped confirm spawning activities. Two of these individuals were 6 years old and one was 11 years old. Sonic-tagged razorback sucker released near the Colorado River inflow in 2010 used the riverine habitat and inflow region as far upstream as the mouth of Devil's Cove, about 8 miles downstream from Pearce Ferry.

### 2.3.3 Kanab Ambersnail

The Kanab ambersnail was listed as endangered in 1992 (USFWS 1992) with a recovery plan completed in 1995 (USFWS 1995). No critical habitat is designated for this species. Fully mature snail shells are translucent amber with an elongated first whorl, and measure about 23 mm in shell size (Sorensen 2007). Two populations of Kanab ambersnail currently exist in Grand Canyon National Park: one at Vasey's Paradise, a spring and hanging garden at the right bank at RM 31.8, and a translocated population at Upper Elves Chasm, at the left bank at RM 116.6 (Gloss et al. 2005). The Elves Chasm population is located above an elevation that could be inundated by HFEs of up to 45,000 cfs. Intensive searches at more than 150 springs and seeps in tributaries to the Colorado River between 1991 through 2000 found no additional Kanab ambersnail (Sorensen and Kubly 1997, 1998; Meretsky and Wegner 1999; Meretsky 2000; Webb and Fridell 2000).

The Kanab ambersnail lives approximately 12–15 months and is hermaphroditic and capable of self-fertilization (Clarke 1991; Pilsbry 1948). Mature Kanab ambersnail mate and reproduce in May–August (Stevens et al. 1997a; Nelson and Sorensen 2001). Adult mortality increases in late summer and autumn leaving the overwintering population dominated by subadults. Young snails enter dormancy in October–November and typically become active again in March–April. Over-winter mortality of Kanab ambersnail can range between 25 and 80 percent (Interagency Kanab Ambersnail Monitoring Team [IKAMT] 1997; Stevens et al. 1997a). Populations fluctuate widely throughout the year due to variation in reproduction, survival, and recruitment (Stevens et al. 1997a).

The number of ambersnails at Vasey's Paradise has remained stable since 1998 (Ralston 2005), although flows greater than 45,026 cfs are thought to decrease the population by up to 17 percent in the short-term (Stevens et al. 1997a, 1998b). Microclimatic conditions such as higher humidity and lower air temperatures relative to the surrounding environments and high vegetative cover may be important habitat features related to Kanab ambersnail survival (Sorenson and Nelson 2002). Kanab ambersnail are pulmonate or air-breathing mollusks, but are able to survive underwater for up to 32 hours in cold, highly oxygenated water (Pilsbry 1948).

Stevens et al. (1997a) defined primary habitat at Vasey's Paradise as crimson monkey-flower (*Mimulus cardinalis*) and non-native watercress (*Nasturtium officinale*), and secondary, or marginal, habitat as patches of other species of riparian vegetation that are little or not used by Kanab ambersnail. Surveys in 1995 revealed rapid changes in vegetative cover over the growing season, with 5.9–9.3 percent of the primary habitat occurring below the 33,000 cfs stage, and 11.2–16.1 percent occurring below the 45,000 cfs stage. Area of primary habitat varied from 850–905 $m^2$ in March–September 1995. The same vegetation occupied from 7.0–12.5 percent of the area below 45,000 cfs from 1996–1999 following a 45,000 cfs beach/habitat building flow (BHBF) test (GCMRC 1999).

The total estimated population of Kanab ambersnail at Vasey's Paradise increased from approximately 18,500 snails in March 1995 to 104,000 snails in September 1995 as reproduction took place in mid-summer (Stevens et al. 1997a). The proportion of the total estimated population occurring below the 33,000 cfs stage rose from 1.0 percent in March to 7.3 percent in September, and that occurring below the 45,000 cfs stage was 3.3 percent in March, 11.4 percent in June, and 16.4 percent in September 1995. Subsequent surveys have reported population estimates of between approximately 5,000 and 52,000 individuals (Interagency Kanab Ambersnail Monitoring Team [IKAMT] 1998; GCMRC 1999; Meretsky and Wegner 1999). Nelson and Sorensen (2001) analyzed sampling and analytical techniques used for these estimates and concluded that overestimation of actual population size has occurred in monitoring reports, and pointed out that these errors make more difficult the assessment of risk to the population.

Current threats to Kanab ambersnail include loss and adverse modification of wetland habitats, which are scarce in this semi-arid region (USFWS 1995). Historically, the Grand Canyon often experienced annual floods of 90,000 cfs or greater and Kanab ambersnail were periodically swept downstream and drowned (Stevens et a. 1997a). Today, Glen Canyon Dam limits such floods, although numerous high flows (>45,000 cfs) have occurred in the last 30 years. For example, during the late-March, early-April 1996 HFE, up to 16 percent of Kanab ambersnail habitat at Vasey's Paradise was lost or degraded and hundreds of snails were lost. Recovery of this habitat to pre-flood conditions required over two years (IKAMT 1998; Stevens et al. 1997b).

### 2.3.4 Southwestern Willow Flycatcher

The southwestern willow flycatcher was designated as endangered on February 27, 1995 (USFWS 1995a). A final recovery plan was completed in August 2002 (USFWS 2002c). Critical habitat was initially designated in 1997 (62 FR 39129), but was rescinded by court order in 2001. Designation of critical habitat was finalized in October 2005, and includes portions of the lower Colorado River below Grand Canyon National Park (USFWS 2005b). The affected environment for this action does not include any critical habitat for this species.

The southwestern willow flycatcher is about 15 cm long, and weighs approximately 11 g. It has a grayish-green back and wings, whitish throat, light grey-olive breast, and pale yellow belly. Recognition of the different subspecies in the field is nearly impossible and is mainly based on differences in color and morphology using museum specimens (Unitt 1987; Paxton 2000). Southwestern willow flycatchers have been documented along the Colorado River between RM 47 and RM 54, at RM 71, and at RM 259 (Unitt 1987; Sogge et. al. 1995; Tibbets and Johnson 1999, 2000). Presence-absence surveys and life history studies of the species have been conducted along the Colorado River since 1996 (McKernan and Braden 1997, 1998, 1999, 2001, 2006a, 2006b; Koronkiewicz et al. 2004, 2006; McLeod 2005). These studies show that the bird has consistently nested along the river in Grand Canyon from Separation Canyon to the delta of Lake Mead, as new riparian habitat, primarily tamarisk, has developed in response to regulated river flows (Gloss et al. 2005). The expansion of riparian vegetation in Grand Canyon may have provided additional habitat for the southwestern willow flycatcher, but birds in the upper river corridor persist at a very low level at only one or two sites.

The southwestern willow flycatcher breeds across the Southwest from May through August. The birds typically arrive on breeding grounds between early May and early June. Along the lower Colorado River, main nest substrates include Goodding's willow (20–30 percent), coyote willow (5–15 percent), Fremont cottonwood (5 percent) and tamarisk (50–70 percent). Egg lying can start as early as late May, but is usually in early to mid-June (Sogge et al. 1997a, 1997b). The female usually incubates the eggs for approximately 12 days, and all eggs usually hatch within

24–48 hours of one another. Nestlings fledge usually within 12–15 days (Paxton and Owen 2002). Chicks are usually present from mid-June through early August.

At most sites along the Colorado River and tributaries, occupied habitats usually have high canopy closure with no distinct understory, overstory, or structural layers (Koronkiewicz et al. 2006). Nest sites are usually located within 200 m of open or standing water and usually contain soils that are higher in water content than non-use sites (McKernan and Braden 2001; Stoleson and Finch 2003; Paradzick 2005; Koronkiewicz et al. 2006). Water or moist soils help regulate temperature and relative humidity within the stand, produce the right conditions for insect development and survival, and are associated with creating a greater foliage density (USFWS 2002c; Paradzick 2005; Koronkiewicz et al. 2006).

Population numbers have fluctuated between five breeding pairs and three territorial, but non-breeding pairs in 1995, to a single breeding pair more recently. 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. Between 2005 and 2009, three individuals were detected between Lees Ferry and Phantom Ranch, all in 2009 (Northrip et al. 2008; Slayton et al. 2009). Nesting flycatchers have not been confirmed at Grand Canyon National Park since 2003; however, nest searching has not taken place since 2004. As there are several habitat patches between Lees Ferry and Pearce Ferry that meet the habitat criteria for breeding southwestern willow flycatchers, Grand Canyon National Park conducted surveys in 2010 from RM 0 to RM 275 (Palarino et al. 2010). In May 2010, the NPS surveys found one individual at RM 28.5 and one individual at RM 196. In June, they located two individuals at RM 217 and two individuals at RM 274.5. Breeding pairs were not detected (NPS 2010 draft report). Given these low numbers, the continued presence of the SWWF in Grand Canyon appears tenuous.

The southwestern willow flycatcher has been detected within lower Grand Canyon–upper Lake Mead since surveys began in 1997 with breeding flycatchers detected in 1999–2001, but not in 2002 or 2003. A single breeding pair was detected in 2004, an unpaired male occupied this same area in 2005, and two nests were detected during the 2006 breeding season (Koronkiewicz et al. 2006). Due to extreme drops in water levels 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 Effects Analysis

## 3.1 Attributes of HFEs Analyzed

Analysis of effects is based on 50 CFR 402.02, in which "[e]ffects of the action refers to the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline." The environmental baseline is described in Section 2 of this BA.

The proposed action is a decision strategy based primarily on water availability and sand storage (see Section 1.4). Because of the uncertainty of these two principle components in the decision-making process, it is not possible to prescribe in advance when an HFE will occur, or its magnitude or duration. Hence, it is difficult to predict effects on threatened and endangered species found in the action area. Furthermore, it is not possible to predict the frequency or sequence of HFEs within or among years over the 10-year period of this protocol. It is possible, however, to determine the most likely timing, magnitude, and duration of an HFE, based on model simulations using historical records for water availability and sand storage (see Section 1.4.3). Additionally, information on effects of previous experiments on natural resources helps to identify likely effects of the proposed action on listed species in the action area.

In order to better define the proposed action for this BA, four principal attributes of an HFE are considered during the course of this analysis—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 the interval of time between HFEs or how often HFEs are conducted. The first three attributes (timing, magnitude, and duration) are related to a single HFE, and the fourth (frequency) is related multiple HFEs.

Based on the previous descriptions of possible HFEs, the following assumptions are made for the purpose of effects analysis:

- The timing of HFEs would be either spring (March and April) or fall (October and November).
- The magnitude of HFEs would range from 31,500 cfs to 45,000 cfs.
- The duration of HFEs would range from an instantaneous release to 96 hours.
- The frequency of HFEs within a year and among years cannot be predicted, but one or two HFEs per year and more than two consecutive HFEs are possible.

Based on these assumptions, the effects analysis of this BA is based on three phases: (1) an evaluation of attributes for a single HFE, (2) an evaluation of likely effects of two consecutive HFEs, and (3) an evaluation of likely effects of more than two consecutive HFEs.

Thirteen types of possible HFEs were evaluated through modeling (see Table 2). These 13 types provide a range of magnitude and duration for HFEs that may occur in March-April and

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 impacts of these HFEs were evaluated and documented, and provide baseline information for the effects analysis of this BA. 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.

For the purposes of this BA, it is assumed that effects of timing, magnitude, and duration for a single HFE will be similar to effects observed during previous experiments. Effects of the proposed action on endangered species are expected to vary in intensity along a continuum from short duration powerplant releases (31,500 cfs for one hour) to longer duration flows (ca. 96 h) of 45,000 cfs. Together with results from the protocol simulations, results from investigations conducted during powerplant releases of 1997 and 2000 will be used to evaluate future HFEs consisting of 31,500 cfs. Results from HFEs conducted in 1996, 2004, and 2008 will be used to evaluate future HFE's consisting of 41,000 to 45,000 cfs. Effects to endangered species due to untested flows (between 31,500 and 41,000 cfs) are expected to fall between the extremes documented for previous experiments.

A number of uncertainties exist with respect to the effects of timing, magnitude, duration, and frequency of HFEs on various resources, including the endangered species. Some of these questions are listed as research questions in the EA and will be addressed in a Science Plan being developed by GCMRC.

## 3.2 Summary of Effects from Previous HFEs

Effects of previous high flow experiments on listed species are summarized in Table 4. The 1996 HFE had no discernible effects on humpback chub. Local shifts in habitat use were recorded with changing flows, but there was little evidence of downstream displacement (Valdez and Hoffnagle 1999). No population-level effects were detected. Sandbars were rebuilt and new backwater habitats were created, although many eroded quickly due to fluctuating flows (Andrews et al. 1999; Brouder et al. 1999). The value of backwater habitats to humpback chub and other native fishes is not clear, although these fish are commonly found in this habitat type. Effects of the powerplant capacity releases of 1997 and 2000 were either not studies, or no effects were detected. For the fall 2004 HFE, there was a possible short-term displacement of young humpback chub, but there was no evidence for lasting effects to the population. Similar findings were reported for the spring 2008 HFE, except there was no evidence of displacement of humpback chub.

For Kanab ambersnail, the 1996 HFE inundated and scoured about 17 percent of 851 $m^2$ of habitat at Vasey's Paradise, and recovery of this habitat delayed 2.5 years (KAIMT 1997). In contrast, for the 2004 HFE, all snails and 1-$m^2$ plots of habitat in the inundation zone at Vasey's Paradise were moved to higher elevation and returned after the HFE (Sorenson 2005). This immediate relocation of habitat and the cooler temperatures in fall enabled the habitat to recover in 6 months. For the spring 2008 HFE, all snails and all habitats in the inundation zone were moved and relocated, and the habitat recovered in about 6 months (Sorensen 2009).

For the southwestern willow flycatcher, no biologically significant impacts were detected with the 1996 HFE, and there were little long-term negative impact to nesting or foraging habitats (Palarino et al. 2010). Effects of the fall 1997 and spring and fall 2000 high releases were not studied for the listed species, but there were no discernible population-level effects on any of the four listed species.

**Table 4. Summary of existing information on all HFEs and powerplant releases from Glen Canyon Dam to conserve sediment resources and their effects on threatened and endangered species. Conclusion is based on a weight-of-evidence evaluation of likely impacts to aquatic resources. HFE = high flow experiment, HMF = habitat maintenance flow.**

| **Parameter** | **1996 HFE** | **1997 HMF** | **2000 HMF** | **2000 HMF** | **2004 HFE** | **2008 HFE** |
|---|---|---|---|---|---|---|
| **Timing** | **Mar-Apr** | **Nov** | **May** | **Sept** | **Nov** | **Mar** |
| **Magnitude** | **45,000 cfs** | **31,000 cfs** | **31,000 cfs** | **31,000 cfs** | **41,000 cfs** | **41,500 cfs** |
| **Duration** | **7 days** | **48 hours** | **48 hours** | **48 hours** | **60 hours** | **60 hours** |
| Humpback chub | Local shift in habitat use with changing flows, little evidence of downstream displacement, no population effects detected[1]; Creation of backwater habitat [2,3] | Not studied. | No pre/post sampling. | No effects detected[4]. | Possible short-term displacement[5]. No evidence for lasting impacts (population size stable or increasing since 2004[6,7,8]). | Creation of backwater habitat[9]; Population size increasing[10] |
| Razorback sucker | Not studied. | Not studied. | Not studied. | Not studied. | Not studied. | Not studied. |
| Kanab ambersnail | Snails in inundation zone at Vasey's Paradise were removed; 17 percent of 851 $m^2$ of habitat inundated and scoured[11]; habitat delayed 2.5 years to recover.[12] | Not studied | Not studied | Not studied | All snails and 1-$m^2$ plots of habitat in inundation zone at Vasey's Paradise were moved to higher elevation and returned after HFE; habitat recovered in 6 months.[13] | All habitat with snails in inundation zone at Vasey's Paradise were moved to higher elevation and returned after HFE; habitat recovered in 6 months.[14] |
| Southwestern willow flycatcher | No biologically significant impacts; little long-term negative impact to nesting or foraging habitats.[15] | Not studied. | Not studied. | Not studied. | Not studied. | Nesting flycatchers not confirmed since 2003; none seen between 2003 and 2008.[16] |

[1]Valdez and Hoffnagle 1999
[2]Andrews et al. 1999
[3]Brouder et al. 1999
[4]Trammell et al. 2002
[5]GCMRC, unpublished data (Power Point presentation)
[6] Lauretta and Serrato 2006
[7]Ackerman and Valdez 2008
[8] Makinster et al. 2010a
[9]Grams et al. 2010
[10] Coggins and Walters 2009
[11]1996 Biological Opinion (February 16, 1996)
[12]IKAMT 1998
[13]Sorenson 2005
[14]Sorenson 2009
[15]Stevens et al. 1996
[16] Palarino et al. 2010

## 3.3 Humpback Chub Effects Analysis

The proposed action is likely to adversely affect the humpback chub and is likely to adversely affect its designated critical habitat. These effects are not expected to be of sufficient magnitude to negatively impact the overall population of humpback chub. This conclusion was reached based on the following effects that are described in detail in the following sections:

- Take could occur from downstream displacement of young into unsuitable habitat, especially during fall HFEs. Effects of displacement, if it occurs, are largely unknown.

- Direct short-term reductions in near-shore habitat could occur in the vicinity of the LCR with changes in flow stage, but long-term benefit is expected from sand redeposition that rebuilds and maintains near-shore and backwater nursery habitats.

- Direct short-term reductions in food supply could occur with scouring and changes in flow stage, but long-term benefit is expected from stimulated food production.

- Increased predation from expanded population of rainbow trout is expected, especially with spring or multiple HFEs.

### 3.3.1 Downstream Displacement

Adult humpback chub are expected to be little affected by high flows (Hoffnagle et al. 1999; Valdez and Hoffnagle 1999), although high flows may occur at a time of the year different from the pre-dam hydrograph. Little is known about the extent to which humpback chub rely on changes in flow as a reproductive cue. Valdez and Ryel (1995) held that neither water quantity or quality serve as cues for gonadal development or staging behavior in humpback chub; rather they hypothesized that climatic factors, such as photoperiod, were important. Humpback chub typically begin to spawn on the receding hydrograph as water temperatures start to rise (Tyus and Karp 1989; Kaeding and Zimmerman 1983; Valdez and Ryel 1995; Kaeding et al. 1990), but the LCR population also spawns in years with little appreciable runoff.

#### *3.3.1.1 Potential for Downstream Displacement of Young*

High releases from Glen Canyon Dam have the potential to displace young humpback chub from nearshore nursery habitats. The area of greatest potential effect is an approximately 8.4-mile reach of the Colorado River (RM 57 to 65.4) that spans the confluence of the LCR at RM 61.3 (about 76 miles downstream of Glen Canyon Dam). This area is the principal nursery area for young humpback chub that originate from spawning primarily in the LCR, but may also come from a small amount of mainstem spawning as far upstream as warm springs near RM 30 (Valdez and Masslich 1999; Ackerman 2007); where there is evidence of overwinter survival of young humpback chub in some years (Andersen et al. 2010).

Most young humpback chub in this LCR reach originate from spawning that takes place in the LCR during March–May. A few drift into the mainstem as larvae and post-larvae (Robinson et al. 1998), but most escape into the mainstem with late summer monsoonal rainstorm floods as early as mid-July (fish length: 30 mm TL), usually in mid-August (52 mm TL), and most escape by September. By late October, these fish are about 6 months of age and range in size from about

52 mm to 74 mm TL (Valdez and Ryel 1995). Depending on habitat use and growth rate assumptions, humpback chub should be from 5 to 20 mm larger in March and April than in November at 8–12 °C (Lupher and Clarkson 1994; Valdez and Ryel 1995; Gorman and VanHoosen 2000; Petersen and Paukert 2005). In addition to these young-of-year (age 0), humpback chub of ages 1–3 are also found along nearshore habitats, but in greatly diminished numbers. Nearshore and offshore catches in the mainstem (Valdez and Ryel 1995) and in the LCR (Gorman and Stone 1995) show that these fish move to offshore habitats starting at age 1 and complete the transition by age 3—the approximate time of maturity for the species. Thus, the size range of humpback chub in nearshore nursery habitats is about 30–180 mm TL, and includes fish of age 0 (young-of-year) to age 3 (Valdez and Ryel 1995). Valdez and Ryel (1995) also hypothesized, based on aging of juveniles from scales, that humpback chub smaller than 52 mm TL did not survive thermal shock in the cold mainstem following escapement from the warmer LCR.

Young humpback chub in this principal nursery area use well-defined nearshore habitats characterized by low water velocity and complex lateral and overhead cover, primarily rock talus and vegetated shorelines (Converse et al. 1998), as well as backwaters (AGFD 1996a). Because of the cold mainstem temperatures in this nursery reach (8.5–11 °C; Valdez and Ryel 1995) from dam releases upstream, swimming ability of these young fish is likely impeded, such that they may be displaced downstream by high water velocity, or their ability to escape predators is limited, or both. Bulkley et al. (1982) reported that swimming ability of juvenile humpback chub (73–134 mm TL) in a laboratory swimming tunnel was positively and significantly related to temperature. Humpback chub forced to swim at a velocity of 0.51 m/sec (1.67 ft/sec) fatigued after an average of 85 minutes at 20 °C, but fatigued after only 2 minutes at 14 °C, a reduction of 98 percent in time to fatigue. Time to fatigue is presumably further reduced below 14 °C, especially for the smallest individuals. These laboratory results has raised concern over the possible displacement of young humpback chub from nursery areas by high-flow events such as HFEs, especially near the LCR confluence, and has been identified as a potential adverse effect on the species since the 1995 Opinion.

Studies of drifting young within and from five Upper Colorado River Basin population centers of humpback chub support the hypothesis that there is little larval drift or long-distance displacement of any size or age (Valdez and Clemmer 1982; Valdez and Williams 1993; USFWS 2002a). Extensive larval drift-netting in many reaches of the Upper Basin (e.g., Osmundson and Seal 2009; Muth et al. 2000) has yielded large numbers of drifting larval Colorado pikeminnow, razorback sucker, flannelmouth sucker, bluehead sucker, and speckled dace, but larval humpback chub are rarely caught. Furthermore, observations of recently hatched humpback chub in a hatchery reveal a greater association by their larvae for cover, compared to other species more prone to drift, including Colorado pikeminnow and razorback sucker (Hamman 1982; Personal communication, Roger Hamman, Dexter National Fish Hatchery). Furthermore, studies in and around populations in Black Rocks and Westwater Canyon (Valdez et al. 1982), as well as Cataract Canyon (Valdez and Williams 1993) revealed few juvenile humpback chub outside of these population centers, indicating little movement or displacement from these centers despite high seasonal flows (e.g., spring flows often exceed 30,000 cfs in Westwater Canyon and 50,000 cfs in Cataract Canyon).

#### *3.3.1.2 Effects of 1996, 2004, and 2008 HFEs on Displacement*

In the 1995 Opinion, the USFWS anticipated that incidental take would occur when some young humpback chub would be transported downstream from the reach of the mainstem below the LCR into unfavorable habitats due to habitat maintenance or habitat building flows. The USFWS acknowledged that this incidental take would be difficult to detect and identified the need for studies to determine how this take might occur and the impact on the year classes of humpback chub. Hoffnagle et al. (1999) sampled shorelines from RM 68 to RM 65.5 with electrofishing and minnow traps, and backwaters with seines before, during, and after the 7-day late-March, early-April 1995 HFE of 45,000 cfs. They reported shifts in habitat use by juvenile humpback chub (born in March–May of 1994) with changes in flow stage, but no significant decreases in catch rates and no discernible effect to the population. Valdez and Hoffnagle (1999) also reported shifts in use of offshore habitats by radiotagged adult humpback chub, but no downstream displacement of any of the 10 fish monitored, or differences in offshore catch rates of adults with trammel nets.

For the 3-day November 2004 HFE of 41,000 cfs, sampling was conducted with hoop nets in approximately 1-km sections in each of three locations (LCR inflow reach near RM 63, near Tanner Rapid near RM 68, and Unkar Rapid near RM 73) three days before and after the HFE. Catch rates of juvenile humpback chub declined by about 66 percent at the upper two sites following the November HFE, suggesting downstream displacement of fish by the high flow (GCMRC unpublished data).. Length frequencies of fish in post-flood samples were shifted to fish roughly 10–20 mm larger than pre-flood fish, indicating a reduction of smaller fish during the flood.

It is unclear if the decline in juveniles was caused by local shifts in habitat use (as was seen with the 1996 HFE) that was not detectable with the limited extent of sampling—or if the displacement was real and reveals a different effect between spring and fall HFEs on juvenile humpback chub. Juvenile humpback chub in the mainstem were about 1 year of age (74–96 mm TL, Valdez and Ryel 1995) during the late-March, early-April 1995 HFE and may have been less susceptible to displacement than the younger fish (probably 6–8 months of age and 52–74 mm TL; Valdez and Ryel 1995) found in the mainstem during the November 2004 HFE. The results of the 2004 HFE may have been further confounded by an LCR flood that dramatically increased turbidity during the post-HFE sampling and could have reduced catch rates; Stone (2010) reported reduced hoop net catch efficiency with increased turbidity.

The need for studies to determine how high flows can impact young humpback chub in nearshore nursery habitats has been identified since the 1995 Opinion. The studies on habitat-specific catches rates and movement of humpback chub for the 1996 HFE and the limited sampling done for the 2004 HFE comprise the only empirical information on the subject. These studies do not provide conclusive evidence of displacement of young humpback chub by high flows, but suggest seasonal differences with greater potential for displacement in November than in March-April. Nevertheless, whether high flows transport young humpback chub from nursery habitats remains unanswered, and should be investigated with future HFEs. The ongoing Nearshore Ecology Study has not been conducted during an HFE and results are not available at this time, but this study could provide a valuable baseline of information for evaluating displacement with ensuring HFEs.

#### *3.3.1.3 Displacement Estimated with the Use of Models*

Lacking definitive evidence that supports or refutes long-distance displacement of humpback chub by high flows, models of nearshore depth and velocity are used to approximate possible displacement. It is hypothesized that humpback chub would be negatively impacted in their young-of-year or juvenile stages through physical displacement due to entrainment by high flows (31,500–45,000 cfs), primarily during the months of October and November. Under the proposed action, fall HFEs could occur with a slighter greater frequency than spring HFEs (58 percent vs. 42 percent of the time), and many of these HFEs would consist of flows approaching 45,000 for at least one and as many as 96 hours.

Effects of high flows were evaluated by comparing retention rates (i.e., the opposite of displacement, or percentage of fish able to maintain their position in a given reach) expected during a high flow test to those predicted for the median monthly flow in March under MLFF. Retention rates over a range of flows was modeled using a particle tracking algorithm in conjunction with velocity predictions from a 2-D hydrodynamic model developed by Korman et al. (2004). This model was developed using mainstem channel bathymetry from seven transects located between the LCR confluence (RM 61.5) and Lava Chuar Rapid (RM 65.5). The model contains four assumptions of fish swimming behavior: 1) passive, no swimming behavior; 2) rheotactic, in which particles (or “fish”) swim toward lower velocity currents at 0.1 to 0.2 m/s; 3) geotactic, in which particles swim toward the closest bank at 0.2 m/s; and 4) upstream, in which the particle attempts to move upstream at 0.2 m/s. Passively drifting fish were the most susceptible to displacement but also the least sensitive to the effects of variable discharge magnitude. We assumed that passively drifting fish could be used to represent larval fish or the poor swimming ability of young-of-year humpback chub at low temperatures; this analysis applies mainly to the latter group, however, since very few or no larval fish are expected to be present during March-April or October-November (AGFD 1996a; Hoffnagle and Valdez 1999).

Temperature of the Colorado River in the LCR inflow reach during the proposed time period for high flow tests (October-November and March-April) is expected to range from about 10 °C to 15 °C (AGFD 1996b). At these levels, subadults and young-of-year may fatigue rapidly and may be unable to withstand swift currents, forage efficiently, or escape predators (see discussion of Bulkley et al. 1982). For these reasons, and to identify the “worst case scenario” of fish displacement, we focused primarily on results for passive behavior in this analysis.

Using the entrainment model of Korman et al. (2004), we expect that 21–23 percent of age-0 fish will be able to maintain their position within a given river reach during high flow tests of approximately 31,500 and 45,000 cfs, respectively (Korman et al. 2004; Figure 5). The retention rate at mean monthly flows for October, November, March, and April under MLFF (ca. modeled values of 8,000–15,000 cfs), by contrast, is predicted to be about 31 percent. Therefore, we would expect retention to decrease by 10 percentage points during the proposed action. Assumptions of active swimming can be used to simulate displacement rates of more mature fish, as may be present during the proposed HFE windows (Korman et al. 2004). Under these sets of assumptions, 57 percent of fish would be retained under the mean MLLF monthly flow and 39 percent retained at the level of HFE, a decline of 18 percentage points. Since Korman et al.’s (2004) study simulated high flows lasting 1.7 hours, we assumed that retention rates would decline further for HFEs lasting longer than this duration.

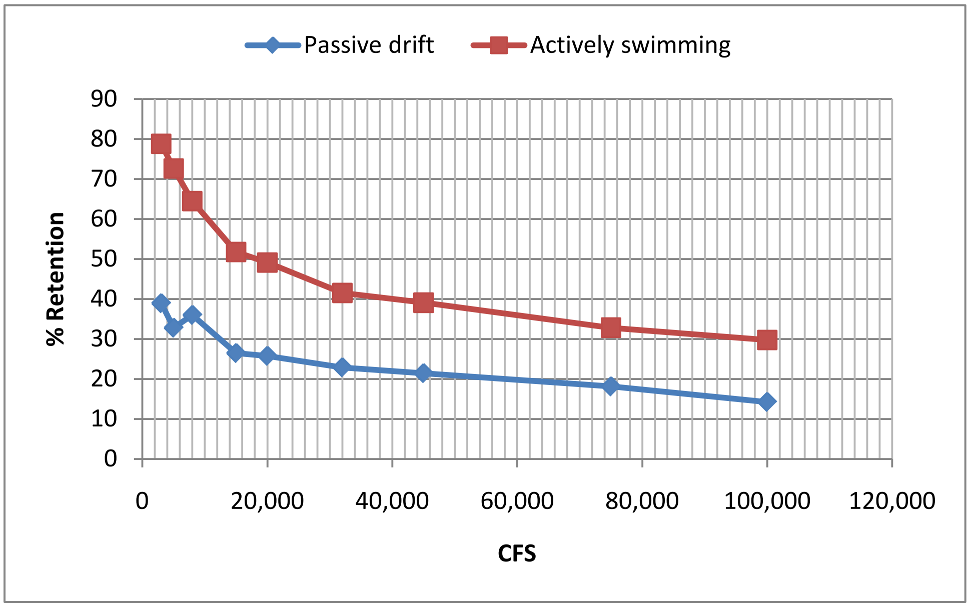


**Figure 5. Average percent of simulated young-of-year fish retained within a given river reach over a range of river flows and swimming behavior assumptions. Legend refers to swimming performance assumptions (see text). Data are from Korman et al. 2004.**

Effects on survival of these fish are unknown, although it is expected that these fish would be displaced to main-channel reaches below RM 65 (lowermost boundary of the simulation in Korman et al. 2004). Fate of these fish in downstream reaches is unknown, as neither the exact river reaches they are likely to arrive at nor habitat conditions therein are known. Numbers of fish displaced by high flows are expected to vary markedly by the distribution of fish among discrete shoreline types, as certain shoreline types afford more refuge from high flow velocities than others (i.e., talus slopes as compared to sandbars, etc.). Downstream displacement could possibly provide positive effects for humpback chub if they are carried to downstream aggregations, survive, and increase the size of these groups. The largest of these aggregations occurs at about RM 122 to RM 130 (60–68 miles downstream of LCR), which is the first time a transported fish would encounter shoreline complexity comparable to that of the LCR reach (Valdez and Ryel 1995). Chances of survival would increase with size of fish transported because of their greater swimming strength and ability to escape predators, as well as their ability to survive longer without feeding.

Korman et al. (2004) also used a 2-D hydrodynamic model to predict humpback chub preferred depth and velocity to the range of substrata, flows, and monthly volumes in the same study area described above. Based on that analysis, we expect total habitat availability (i.e., preferred depth and velocity over all substrate types) to decline by about 57 percent as flows increase from 12,000 cfs (an approximation of MLFF flows under No Action) to about 31,500 cfs and by 48 percent as flows increase to 45,000 cfs (Figure 6). These declines 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. Thus, if fish could exploit these unchanged or improved habitats as refuge from high flows, displacement could be minimized (see also Converse et al. 1998).

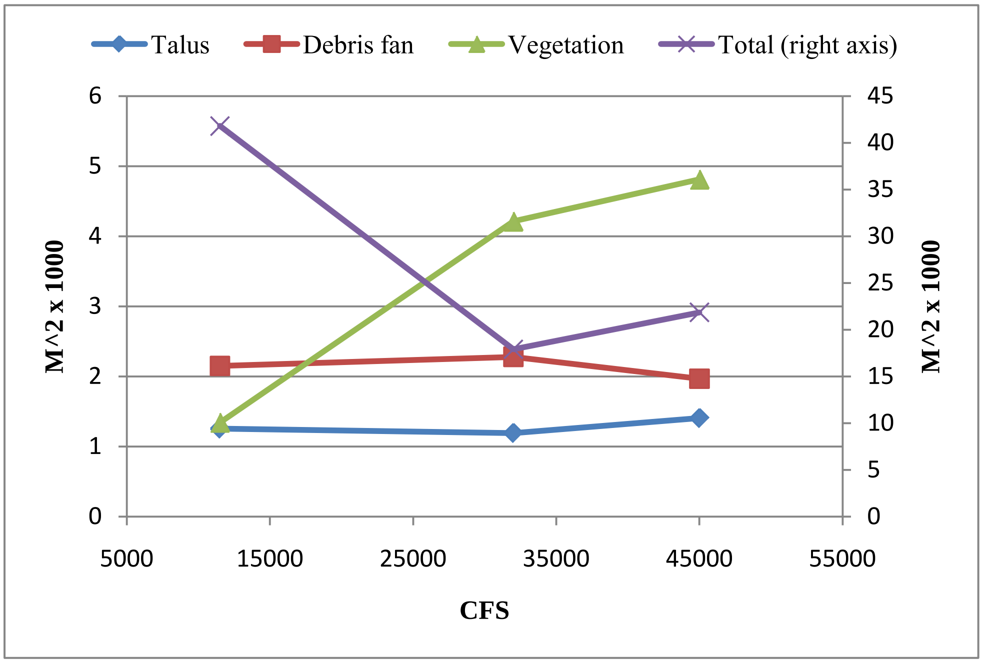


**Figure 6. Total suitable shoreline habitats of humpback chub by river flow. Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transect.**

### *3.3.1.4 Displacement of Other Species*

It is also likely that repeated HFEs will disadvantage small-bodied warmwater non-native fish (fathead minnow, red shiner, plains killifish, small common carp, etc.) through physical downstream displacement by high flows. Displacement could be less pronounced for humpback chub than for warmwater non-native fish due to their preferences for lower water velocities (Table 5). Whereas average preferred velocity for juvenile humpback chub is about 0.25 m/s (Korman et al. 2004; Converse et al 1998; Bulkley et al. 1982; Valdez et al. 1990), non-native fish preferences average about 0.10 m/s, perhaps making them more susceptible to displacement by high flows. 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. Trammell et al. (2002) also documented displacement and slow re-colonization rates of fathead minnow as a result of the powerplant flows conducted during September 2000. Repeated HFEs could thus repeatedly disadvantage non-native fish to higher degrees than humpback chub, a species that evolved in a high-frequency disturbance regime.

**Table 5. Preferred water velocities (m/s) for non-native fish found in the vicinity of the Little Colorado River.**

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

### 3.3.2 Effects on Critical Habitat

#### *3.3.2.1 Background*

Direct short-term reductions in habitat and food supply, as well as increases in rainbow trout abundance, have the potential to indirectly affect the humpback chub, as well as directly affect elements of critical habitat. For the purpose of this effects analysis, these environmental components are considered as part of critical habitat for the species, and Reclamation has determined that the proposed action may adversely affect designated critical habitat of the humpback chub. Critical habitat designation for the humpback chub is described in Section 2.4.1 of this document.

Effects on critical habitat in this BA relied on 50 CFR 402.02, in which "[d]estruction or adverse modification means a direct or indirect alteration that appreciably diminishes the value of critical habitat for both the survival and recovery of a listed species. Such alterations include, but are not limited to, alterations adversely modifying any of those physical or biological features that were the basis for determining the habitat to be critical." In its analysis of critical habitat, Reclamation has also relied on the 9th Circuit Court ruling of August 6, 2004 (Gifford Pinchot Task Force v. USFWS, 378 F.3d 1059) to consider whether the action appreciably diminishes the value of critical habitat for either the survival or recovery of a listed species (see p. 4-34, U.S. Fish and Wildlife Service and National Marine Fisheries Service 1998). We analyzed whether the proposed modification would adversely modify any of those physical or biological features that were the basis for determining the habitat to be critical. The physical or biological features that determine critical habitat are known as the primary constituent elements (PCEs). To determine if an action results in an adverse modification of critical habitat, we must also evaluate the current condition of all designated critical habitat units, as well as the PCEs of those units, to determine the overall ability of all designated critical habitat to support recovery. A more detailed description of critical habitat and its PCEs is provided in the original rule designating critical habitat (59 FR 13374) and in the 2009 Supplemental Opinion (USFWS 2009a).

The proposed action is likely to affect the following primary constituent elements: water (water quality W1), physical habitat including nursery (P2) and feeding habitat (P3), and the biological environment including food supply (B1), predation from non-native fish species (B2), and competition from non-native fish species (B3). Water quality (W1), specifically temperature, is a function of the amount of nearshore habitat in which water velocity is absent or near zero, such as backwaters. Owing to slightly warmer temperatures and greater organic matter standing stocks (Behn et al. 2010); backwaters also provide humpback chub with both nursery (P1) and feeding habitat (P2). Elements W1, P1 and P2 are directly linked through formation and maintenance of backwaters and other low-velocity nearshore habitats, which are highly sediment dependent. Food supply (B1) is a function of nutrient supply, productivity, and availability of food to each life stage of the species. Predation and competition (B2 and B3) are normal components of the ecosystem, but are out of balance in these units because of introduced fish species. Despite the possible short-term adverse effects to critical habitat of humpback chub, periodic HFEs are expected to rejuvenate the habitat and benefit the species.

#### *3.3.2.2 Creation of Backwater Rearing Habitats (W1, P2, P3)*

Since the 1995 FEIS, backwaters in Grand Canyon have been promoted as a habitat that is essential to young life stages of the humpback chub (e.g., AGFD 1996a; Hoffnagle 1996; Brouder et al. 1999; Stevens and Hoffnagle 1999; Gloss and Coggins 2005). One of the principal objectives for high-flow releases from Glen Canyon Dam has been to rebuild sandbars in eddy-return channels that help to form and maintain backwaters (e.g., Reclamation 1995a, 1995b; U.S. Department of the Interior 1996; Schmidt et al. 1999; Goeking et al. 2003). Backwaters have also been recognized as important foundations for marsh-like habitats (Stevens and Hoffnagle 1999) and as important sources for nutrients (Parnell et al. 1997; Parnell and Bennet 1999).

Impacts of high flow tests on near-shore and backwater habitats manifest both at short-term (i.e., weeks to months following high flow tests) and long-term time scales. While a good deal of information exists on short-term impacts to backwaters (Brouder et al. 1999; Parnell et al. 1997; Wiele et al. 1999), long-term impacts are more difficult to predict because of varied sediment availability prior to the test and uncertainties of post-test flow regimes. Effects of high flow tests will be evaluated qualitatively and will weigh short-term impacts to backwater habitats against potential long-term outcomes, as well as impacts to the non-native fish community and other aspects of the proposed action.

In this biological assessment, the assumption is that number of backwaters is correlated with those of reattachment sandbars in eddy complexes. That is, since backwaters in Grand Canyon are mostly inundated, but non-flowing, eddy return current channels, sandbars are a requisite condition for their occurrence. Another assumption is that elevation of sandbars and depth of recirculation channels are significant correlates reflecting the availability of backwaters over range of flows (Brouder et al. 1999; Grams et al. 2010). First, the higher the sandbar elevation, the more likely the separation of the backwater from main-channel currents would occur over a range of flows. The depth of the recirculation channel serves the same function as height of the sandbar, with the greatest depths creating availability that is more frequent over the greatest range of flows. Finally, high flow tests tend to increase the elevation of the sandbar and deepen the return current channel (Andrews et al. 1999; Goeking et al. 2003), although there are exceptions to this general pattern (Parnell et al. 1997).

Weight-of-evidence approach using unpublished information and limited findings conclude that backwaters are not exceptionally high-quality rearing habitat for juvenile humpback chub relative to other potential rearing habitats (Kennedy and Ralston in press). This determination is based on an unreported nearshore ecology study in Grand Canyon that compares shoreline habitats with backwaters, and on two recent studies (Behn et al. 2010; Rosi-Marshall et al. 2010) which indicate that high turnover rate limits the productivity of backwaters. Data and information from prior studies (e.g., AGFD 1996a; Johnstone and Lauretta 2007) were not incorporated into the determination. We assume for the purpose of this BA that backwaters in Grand Canyon continue to be valuable habitats for young humpback chub, as well as other native fishes, since the ecological value of backwaters in Grand Canyon has not been scientifically reconciled.

One of the desired outcomes of HFE protocol implementation is frequent rebuilding of sandbars and beaches through resuspension and deposition of channel sediment deposits at higher elevations. Sandbars are formed in eddies, which are commonly associated with tributary debris fans (Schmidt and Graf 1990; Schmidt and Rubin 1995). Nearly all sandbars in Grand Canyon are associated with recirculation zones that consist of one or more eddies. Sandbars are highly valued for their role as camping beaches and their occurrence is frequently accompanied by backwaters in the eddy return channel. 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 nearshore habitats from the cold, high velocity main-channel environment.

Due to their low water velocity, warm water, high levels of benthic organic matter and high levels of biological productivity, backwaters provide potential ideal rearing habitats for humpback chub and other native fish. During summer months, backwaters offer low velocity, relatively warm, protected, food-rich environments when compared to nearby mainstream habitats (Maddux et al. 1987; Grabowski and Hiebert 1989; AGFD 1996a; Hoffnagle 1996). Humpback chub and other native fish consistently use backwaters with the same or greater frequency than main-channel habitats. During 1990–1995, 2,619 age-0 and 1,521 juvenile humpback chub were caught along shorelines between the LCR and Bright Angel Creek for a total of 4,140 fish (Valdez and Ryel 1995). This compares to a total of 3,734 humpback chub caught in backwaters in the same reach during 1991–1994 (AGFD 1996a). Although these numbers are not directly comparable because of different gear types and sampling effort, the fish were taken in nearly the same time period and for the same amount of time (6 years).

Within individual sampling trips, AGFD (1996a) consistently documented greater abundance of native fish and humpback chub in backwaters compared to similar samples from main-channel habitats, and similar trends were observed in zooplankton and benthic invertebrate standing stocks. In more recent years, numbers of humpback chub captured from backwaters were similar to those captured from main-channel habitats during 2003, 2004 and 2006 (Johnstone and Lauretta 2007); when standardized by total numbers of samples collected, humpback chub were always more abundant in backwater samples than those from main-channel habitats during 2000 through 2006 (SWCA 2002, 2003, 2004a, 2004b, 2006, 2007; Table 6).

**Table 6. Numbers of humpback chub collected from main-channel habitats and backwaters by SWCA, Inc., during 2000-2006. Numbers in parentheses are average number of fish caught per sample.**

| Year | Main-channel habitats | Backwaters |
|---|---|---|
| 2000 | 241 (0.15) | 76 (0.20) |
| 2001 | n/a | n/a |
| 2002 | 38 (0.02) | 13 (0.09) |
| 2003 | 142 (0.06) | 125 (0.39) |
| 2004 | 161 (0.07) | 163 (0.55) |
| 2005 | 847 (1.53) | 231 (3.6) |
| 2006 | 160 (0.11) | 169 (0.68) |

Immediate physical impacts of high flow tests (1996, 2004, and 2008) on backwater habitats were positive and included increased relief of bed topography, increased elevation of reattachment bars and deepened return current channels (Andrews et al. 1999; Topping et al. 2006; Grams et al. 2010; Hazel et al. 2010). While dam releases following historic high flow tests have had a significant effect on newly created sandbar deposits (and hence backwaters), high flows which followed the 1996, 2004, and 2008 HFEs have been implicated in the rapid erosion of these sandbars (Schmidt et al. 2004; Topping et al. 2010). Whereas the 1996 high flow test 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; Schmidt et al. 2004). 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 March 2008 HFE caused widespread sand deposition at elevations above the 8,000 cfs stage and resulted in greater area and volume of associated backwaters than before the HFE (Grams et al. 2010; Hazel et al. 2010). Total sand volume in all sediment-flux monitoring reaches was greater following the 2008 HFE than following the two previous HFEs (Hazel et al. 2010). Analysis of backwater habitat area and volume for 116 locations at 86 sites, comparing one month before and one month after the HFE, shows that total habitat area increased by 30 percent to as much as a factor of 3 and that volume increased by 80 percent to as much as a factor of 15 (Grams et al. 2010). These changes resulted from an increase in the area and elevation of sandbars, which isolate backwaters from the main channel, and the scour of eddy return-current channels along the bank where the habitat occurs. In the months following the 2008 HFE, erosion of sandbars and deposition in eddy return-current channels caused reductions of backwater area and volume. However, sandbar relief was still 5 to 14 percent greater in October 2008 than in February 2008, prior to the HFE. Sandbar relief was also sufficient to afford backwater persistence across a broader range of discharges than in February 2008. Native fish (including humpback chub) use of these backwaters increased during the first 6 months after creation of these backwaters (Grams et al. 2010), although this might be a seasonal effect.

Biologically, the 1996 high flow caused an immediate reduction in benthic invertebrate numbers and fine particulate organic matter (FPOM) through scouring of backwaters (Brouder et al. 1999;

Parnell and Bennet 1999). Invertebrates rebounded to pre-test levels by September 1996 and 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). Also during the 1996 high flow test, Parnell and Bennet (1999) 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 proposed action is thus expected to have the same effects on backwaters: an immediate reduction in benthic invertebrate numbers and fine particulate organic matter, but over time, a potential beneficial change in backwaters.

#### *3.3.2.3 Food Supply (PCE B1)*

Short-term adverse modification of the aquatic foodbase is expected for single HFEs followed by a period of stimulated production. The food supply of humpback chub is not expected to be adversely modified by the proposed action if HFEs are implemented frequently (i.e., twice a year or more than two consecutive HFEs), based on findings from other rivers with artificial floods (Uehlinger et al. 2003; Robinson and Uehlinger 2008). Implementation of the proposed action to minimize foodbase impacts will require long term monitoring to detect impacts such that this information can be considered in decision-making processes on HFE frequency. Effects of fall HFEs on the aquatic foodbase are also an uncertainty that will likely require monitoring before and after such events, as well as among years. HFEs in fall would occur at a time of year when few historic high-flow events occurred. These HFEs are anticipated to temporarily reduce food supplies, especially in backwaters, but the foodbase is expected to recover within 2-4 months.

Based on available information, we do not expect powerplant capacity flows of 31,500 cfs to negatively impact the benthic community of the Colorado River ecosystem, either immediately downstream from the dam or further downstream in critical habitat of humpback chub. Shannon et al. (1998) reported no discernable impact on the benthic community in the Lees Ferry reach; similarly, Rogers et al. (2003) reported no short-term reduction in densities of aquatic macrophytes, periphyton, chlorophyll-*a* or macroinvertebrates 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, but these effects were not realized across all reaches and taxa.

We expect a large portion of the aquatic foodbase in the Lees Ferry reach to be scoured by a spring HFE of 41,000 to 45,000 cfs. The foodbase is expected to recovery 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). *Gammarus lacustris*, a common food item of fish, will be slower to recover because of their greater susceptibility to export than other invertebrate species. Also, the New Zealand mudsnail (*Potamopyrgus antipodarum*) is expected to be exported in large numbers, which will be a benefit to the foodbase by making more digestible items available to the 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).

Although effects of repeated HFEs on the foodbase have not been investigated, the more lasting effects of independent events (1996, 2004, and 2008) likely foretell some of the possible consequences of frequent, sequential high-flow releases. Although more information is needed on the effect of a fall HFE on the foodbase, it is likely that a fall HFE followed by a spring HFE could cause long-term damage to the foodbase. 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 chironomids may recover within 3 months; Brouder et al. 1999). This effect could be exacerbated if recovery from the fall HFE is delayed until the following spring by reduced photosynthetic activity during winter months. 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 effect because presumably recovery of the foodbase (for most taxa) from the first HFE would have occurred by fall.

A common theme of artificial floods in rivers is the scouring effect of high velocities on riverbed sediments and on the community of primary producers, as well as stored organic detritus. For 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. In the River Spöl of the Swiss Alps, a series of 9 floods over 3 years (averaging 3 events/year) each reduced periphyton biomass by about 90 percent, but because of these multiple floods, disturbance impact and recovery patterns were not uniform (Uehlinger et al. 2003). In the years following this sequence of floods, moreover, taxa of primary producers shifted toward communities more resistant to flooding. The flood sequence also reduced particulate organic carbon, phosphorus, and P/R ratios periodically increased with each flood (Robinson and Uehlinger 2008).

In a another study of multiple flooding on the River Spöl, Robinson and Uehlinger (2008) found that the first few of 15 floods over 8 years (2000–2007; about 2/year) reduced macroinvertebrate abundance by about 50 percent (including dominant forms such as *Gammarus* sp. and chironomids, which are also key fish food items in the action area). 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. Taxa richness declined and stabilized at a lower level during the first three years of the study, during which flood frequency was at its highest, which is consistent with other studies (Robinson and Minshall 1986).

Findings from the River Spöl and other studies suggest that more frequent floods in Grand Canyon could cause significant shifts in the primary producer community and shifts to more resistant macroinvertebrate taxa or to new taxa that would colonize the river. Analysis of the proposed action suggests that as many as 1.3 to 1.4 HFEs may be conducted per year; at least 3 consecutive HFEs could occur under any combined hydrologic and sediment scenario, and as many as 5 or 6 consecutive HFEs could conceivably occur (average of 1.1 per year), although the likelihood of this is low. Nevertheless, these frequencies are comparable to the artificial flood regime of the River Spöl, and so risks encountered in that example should be considered in implementation of the proposed action in Grand Canyon. Additionally, many of these flows could approach levels known to scour benthic communities and their substrates (ca. 45,000 cfs) and occur during months when recolonization potential is low (i.e., in the fall).

Similar to the River Spöl example, shifts induced by frequent, large (ca. 45,000 cfs) floods in the action area could involve declines of large-bodied taxa such as *Gammarus lacustris* which are more adapted to low frequency disturbances (and an important fish food organism) and replaced by more resistant taxa. However, if these resistant taxa are not present, if a source of new taxa is not available, or source taxa are not adapted to other aspects of the Colorado River ecosystem (such as low water temperatures), then the result of frequent floods may be a reduction in macroinvertebrate diversity and abundance. 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.

Whereas the preceding assessment of impacts to the benthic community applies mainly to those communities colonizing substrates in the free-flowing component of the river ecosystems, these findings are probably not transferable to communities found in areas of little or no water velocity associated with eddy complexes and backwaters. Biologically, the 1996 high flow caused an immediate reduction in benthic invertebrate numbers and fine particulate organic matter (FPOM) through scouring (Brouder et al. 1999; Parnell and Bennet 1999), but invertebrates rebounded to pre-test levels by September 1996 and 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). Also during the 1996 high flow test, Parnell and Bennet (1999) 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.

Spring HFEs are expected to result in an immediate reduction in benthic invertebrate numbers and fine particulate organic matter, but could also benefit a potential beneficial change in backwaters due to replenishment of nutrients and particulate organic matter. Effects of more frequent disturbances (such as fall followed by spring HFEs) are largely unknown but presumably would be similar to those observed in flowing-water habitats and also depend on ability of HFEs to export organic matter and nutrients relative to the rate at which it enters the system.

We expect that the food supply of humpback chub to be adversely modified by the proposed action if HFEs are implemented too frequently (i.e., twice a year or more than two consecutive HFEs). Frequencies of HFEs under the proposed action are not possible to predict, but our analysis of protocol implementation over a range of sediment availability and hydrology modeling indicates that HFE frequency would be an overall average of 1/year. This is less than the frequency observed in the River Spöl example, which included 15 high flows over 8 years with at least one flow every year (Robinson and Uehlinger 2008), and many of these flows would be of low intensity and duration (i.e., 31,500 cfs for one hour). However, our simulation of protocol implementation shows that multiple instances of HFEs occurring within 4–5 months of each other are possible within the 10-year timeframe of the proposed action. It is also possible for as many as two HFEs to occur within one year, which is similar to the frequency observed during the early years of the River Spöl study when taxa richness and abundance declined rapidly. Therefore, extreme shifts in community composition or lasting reductions in abundance could occur under the proposed action if such disturbance frequency thresholds are neglected in the decision making process.

#### *3.3.2.4 Predation and Competition (PCE B2, B3)*

The proposed action is expected to increase predation by rainbow trout on humpback chub, particularly if HFEs are implemented during March-April. The effect of an October-November HFE on the trout population is uncertain and cannot be determined from the fall 2004 HFE because of the confounding effects of dam operations, non-native fish control activities, and warm releases from a low reservoir (Korman et al. 2010; Makinster et al. 2010b). Single HFEs could contribute to greater rainbow trout abundance, and repeated HFEs could compound this problem by expanding the trout population long-term. Piscivory rates by salmonids on other fish calculated by Yard et al. (2008) range from 1.7 to 7.1 prey/rainbow trout/year, and 18.2 to 106 prey/brown trout/year. Of prey fish consumed, Yard et al. (2008) estimated that 27.3 percent were humpback chub.

Estimated rainbow trout remaining in the LCR inflow reach after a 3-year mechanical removal effort in March 2009 was 427 to 1,427 fish (Makinster et al. 2010b), although no brown trout were collected. In some years, impacts to humpback chub due to predation by rainbow trout could be substantial. Additionally, based on high degrees of dietary overlap, rainbow trout are known to compete directly with humpback chub for food resources in the action area (Valdez and Ryel 1995; Valdez and Hoffnagle 1999). Thus, the degree of predation and competition experienced by humpback chub is directly related to rainbow and brown trout abundance. Past and ongoing investigations show that most brown trout in Grand Canyon, and in the LCR reach, originate from the Bright Angel Creek area (Valdez and Ryel 1995; Makinster et al. 2010a).

Multiple lines of evidence indicate that the March 2008 HFE resulted in a large increase in early survival rates of age-0 rainbow trout because of an improvement in habitat conditions and possibly increased food availability (Korman et al. 2010). 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 (February 21–March 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 based on otolith microstructure, support this hypothesis. Korman et al. (2010) speculate that the 60-hour 2008 HFE increased interstitial spaces in the gravel bed and food availability or quality, leading to higher early survival of recently emerged trout and better growth of these fish through summer and fall. Finally, Korman et al. (2010) presented evidence that enhancement of rainbow trout year class strength due to spring HFEs could be sustained from one year to the next, as suggested by higher than predicted survival of age-1 rainbow trout in 2009 (which had hatched in spring of 2008).

Results from the 1996 HFE were not studied in as much detail as those from 2008, but available information shows that catch rates of age 1 rainbow trout declined immediately following the 1996 high flow test (McKinney et al. 1999). This information, combined with increased catches of young rainbow trout about 80 miles downstream (Hoffnagle et al. 1999) suggest some downstream displacement, but overall McKinney et al. (1999) observed no lasting impacts to either trout abundance or condition. Numbers of age-1 rainbow trout increased during 1997, suggesting that enhanced survival of age-0 trout may have occurred after the 1996 HFE as well

(McKinney et al. 2001). However, this increase was not nearly as dramatic as that observed in 2008, and no information exists linking the 1997 increase to the 1996 HFE.

There is a risk of increased predation 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 may be lower. 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. However, if spring HFE's take place in April, approximately one month or more after the peak spawning period, a larger fraction of that year's eggs would have been fertilized prior to the HFE. Korman et al. (2010) speculated that if the bulk of fertilization were to take place prior to an HFE, the resulting fry would not benefit from cleaner gravel and enhanced food availability as was observed in 2008 and their survival would be lower. Most of these fish would still be in the gravel when the HFE occurs in April and would be vulnerable to scour or burial, or would be vulnerable to displacement and mortality because of increased water velocity (Einum and Nislow 2005).

The November 2004 HFE resulted in lower apparent survival of age-0 rainbow trout compared to that observed during more typical MLLF operations observed in 2008 (i.e., decline in abundance between November and December in 2004 was 1.7-fold greater than in 2008; Korman et al. 2010), however the cause of this effect is not clear. Electrofishing catch rates for all sizes of trout before and after the November 2004 HFE were not significantly different, however, indicating that mortality and downstream displacement did not affect the population (Makinster et al. 2007). Since fall HFEs could occur slightly more often than spring HFEs, it is possible that negative effects to trout accrued during this period may counterbalance enhanced survival rates resulting from spring flows. However, if the effect of enhanced spring survival is cumulative among years as postulated by Korman et al. (2010) and the mechanism of decline due to fall HFEs is in fact downstream dispersal, negative consequences for humpback chub are expected to result from repeated HFEs of any magnitude or duration.

Inferences on the effect of HFEs on early survival and growth rates of trout 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 peak duration more than twice the 2008 HFE (7 days vs. 60 hours), 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 the monitoring effort employed in their study (i.e., estimate survival rates of gravel-stage and older age-0 rainbow trout) be repeated if future spring HFEs are conducted to determine the effect of timing on survival.

A second uncertainty of effects of enhanced rainbow trout survival is that 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). Korman et al. (2010) reported that rainbow trout fry abundance in 2009 was twice what was expected given egg deposition estimates, suggesting positive effects on rainbow trout survival from the 2008 HFE persisted at least one year following the experiment. Although Hilwig and Makinster (2010) documented no downstream movement of acoustic-tagged trout during the 2008 HFE, Korman et al. (2010) suggests that a large fraction of the 2008 rainbow trout cohort (smaller fish than tracked by Hilwig and Makinster) may have migrated downstream into reaches occupied by humpback chub. Thus, if the rate of trout migration downstream increases with upstream abundance, repeated HFEs could increase the risk of rainbow trout predation on or competition with humpback chub. This assumes that no negative impacts to the foodbase offset age-0 rainbow trout survival.

Preliminary results from energetic-based models (EcoPath, EcoSim) show that the rainbow trout population in the Lees Ferry reach is likely to respond positively (i.e., increased survival of young) to either spring or fall HFEs with a subsequent increase in numbers. This increase in trout population size could result in downstream movement of young trout (Korman et al. 2010) that could occupy the nursery habitat of humpback chub near the LCR, compete with, and prey on the young chubs. The net effects of the HFE protocol from predation are uncertain because of uncertainties in the frequency of HFEs and the actual response by the trout population. Reclamation is developing an environmental assessment for non-native fish control downstream of Glen Canyon Dam concurrent with this EA (see Section 1.2). One of the purposes of the non-native fish control EA will be to assess the effect of and mitigate for increased predation and competition by rainbow trout and brown trout on humpback chub.

The proposed action is expected to increase predation and competition on humpback chub through from increased survival of rainbow trout, particularly if HFEs are implemented during the months of March or April. Reclamation intends to implement non-native control during 2011–2020 through an EA being developed concurrent to the HFE EA (see Section 1.2). Non-native fish control would be implemented through further consultation with USFWS and in cooperation with GCMRC, NPS, and GCDAMP members. The net effect of non-native control actions implemented in these future years potentially could benefit the biological environment constituent element of critical habitat to a greater degree than the original proposed action depending on the efficacy of those actions in conserving humpback chub.

### 3.3.3 Effects to Humpback Chub Population

Mark-recapture methods have been used since the late 1980s to assess trend in adult abundance and recruitment of the LCR aggregation of humpback chub, the primary aggregation constituting the Grand Canyon population and the only population in the lower Colorado River Basin. These estimates indicate that the adult population declined through the 1980s and early 1990s but has been increasing for the past decade (Coggins et al. 2006a, Coggins 2008a, Coggins, and Walters 2009) (Figure 7). Coggins (2008) summarized information on abundance and analyzed monitoring data collected since the late 1980s and found that the adult population had declined from about 8,900- 9,800 in 1989 to a low of about 4,500-5,700 in 2001.

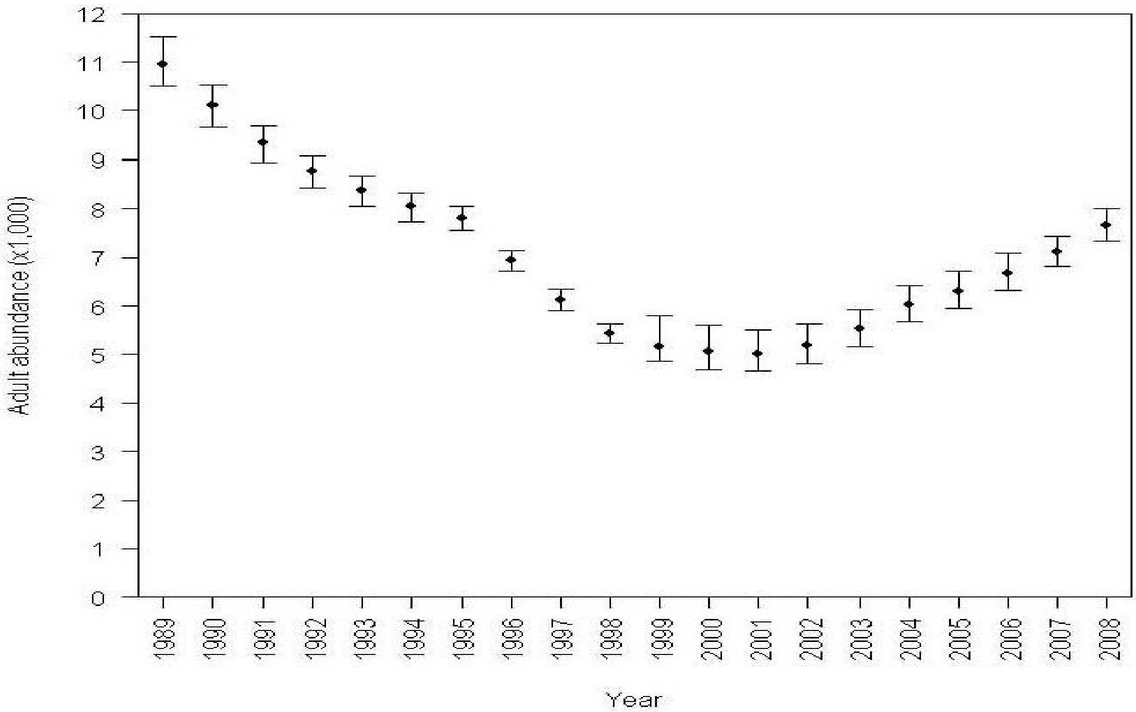


**Figure 7. Estimated adult humpback chub abundance (age 4+). Point estimates are average values and error bars represent maximum and minimum 95 percent confidence intervals. From Coggins and Walters (2009).**

The most recent estimate of humpback chub abundance (Coggins and Walters 2009) shows that it is unlikely that there are currently less than 6,000 adults or more than 10,000 adults, and that the current adult (age 4 years or more) population is approximately 7,650 fish. This is an increase from the 2006 estimate of 5,300-6,700 (Coggins 2008a). These estimates indicate that there has been increased recruitment into the population from some year classes starting in the mid- to late-1990s. Increased humpback chub recruitment has previously been attributed in part to the results of non-native fish mechanical removal, increases in temperature due to lower reservoir elevations and inflow events, the 2000 low steady summer flow experiment, and/or other experimental flows (USGS 2006a). However, the most recent population modeling indicates the increase was due to increased recruitment as early as 1996 but no later than 1999 (Coggins 2008a), which coincides with a period of increasing rainbow trout abundance (Figure 8; McKinney et al.1999, 2001; Makinster et al. 2010b). The increase in recruitment began at least four and as many as nine years prior to implementation of non-native fish control, incidence of warmer water temperatures, the 2000 low steady summer flow experiment, and the 2004 high flow test (Speas 2004). It is also unclear as to whether this increase is attributable to conditions in the mainstem or in the LCR. Population dynamics of non-native fish, humpback chub, hydrology, and other environmental variables in the LCR may have influenced the observed recruitment trends.

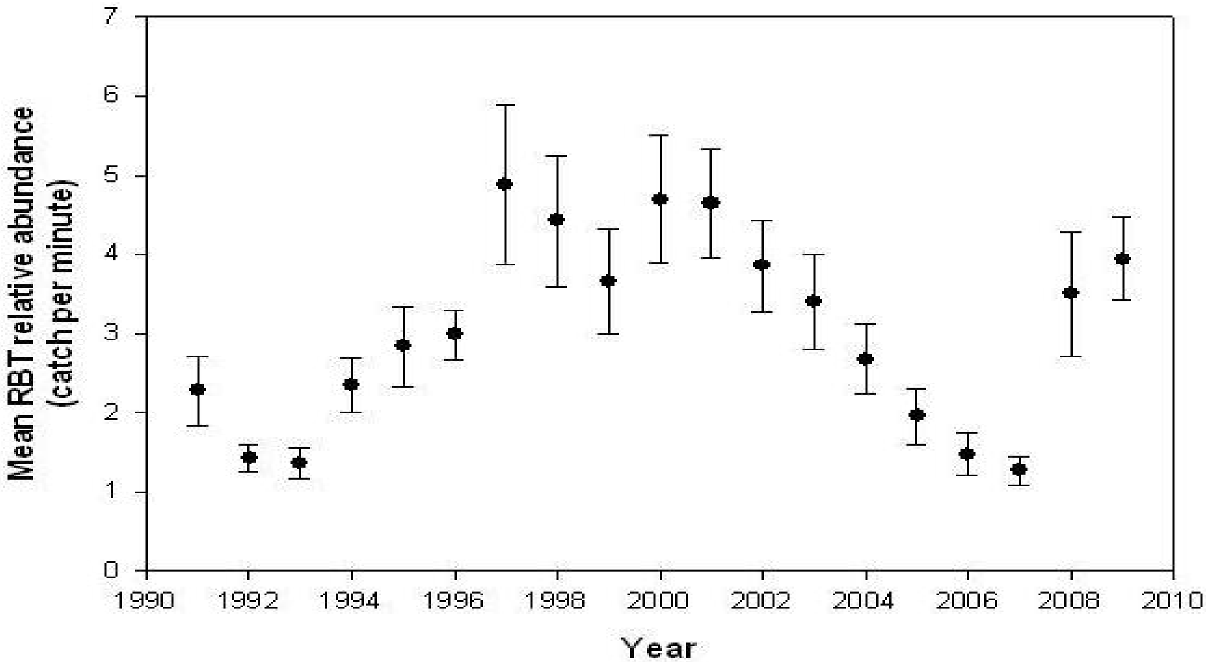


**Figure 8. Rainbow trout mean relative abundance (catch per minute) in the Lees Ferry tailwater fishery, 1991-2009. Figure represents data from all size classes in both fixed and random transects. Points represent the average among sites and seasons while bars represent ± 2 standard errors of the average, an approximation for a 95 percent confidence interval. See Makinster et al. (2010b) for details.**

Although some negative impacts of the proposed action are expected from potential displacement of young-of-year or juvenile humpback chub, these effects are not expected to register at the population level. Results of before and after investigations of humpback chub associated with HFEs conducted to date suggest that such flows have negligible effects at the population level. This assumption is based largely on the positive population size trajectory documented during 2001–2009, during which two HFEs in excess of 41,500 cfs were conducted (Figure 8). Catch-per-unit effort (CPUE) of humpback chub did not differ in 1996 pre- versus post-flood periods. Valdez and Hoffnagle (1999) concluded there were no significant adverse effects on movement, habitat use, or diet of humpback chub. Catch rates of humpback chub declined immediately following the 2004 HFE (GCMRC, unpublished), but several studies (Coggins 2008a; Coggins and Walters 2009; Lauretta and Serrato (2006) and Ackerman and Valdez (2008) showed that numbers of humpback chub have been stable or increasing since 2004, suggesting negligible effects of fall or spring HFE on these fish at the population level.

Under the proposed action, effects of repeated HFEs over a 10-year period will manifest differentially on humpback chub depending on their frequency, which is driven by year-to-year variation in water and sediment availability. Based on results from prior experiments, HFEs conducted during 1996, 2004 and 2008 were fundamentally independent events with 8 years, 7 months, and 3 years, 4 months between events. Effects to biological resources of one HFE were likely dissipated by the time of the next event, and there is little information by which to determine the effect of more frequent HFEs. However, the more lasting effects of independent events (1996, 2004 and 2008) likely foretell some of the possible consequences of frequent, sequential high-flow releases.

Although there is little or no evidence that isolated HFEs impart significant impacts to humpback chub at the population level through displacement of age-0 or juvenile fish, effects of repeated HFEs are unknown but would stem from the cumulative effect of displacing multiple cohorts of age-0 or juvenile fish. Although humpback chub and other native fish evolved under highly variable environmental conditions, including high spring flows well beyond the magnitude of the proposed action, nothing is known of the response of these fish to frequent flow disturbances in the context of post-dam environmental conditions such as lower temperatures, daily flow fluctuations, clear water, and presence of non-native fish. For example, impairment of swimming ability due to sub-optimal water temperatures could make humpback chub more susceptible to displacement than under natural conditions, and coldwater predators such as trout could further reduce their survival through predation.

## 3.4 Razorback Sucker Effects Analysis

The proposed action is likely to adversely affect the razorback sucker, although the action may also be beneficial to some aspect of the life history of the species. A reproducing and self-sustaining population of razorback sucker exists in Overton Arm of Lake Mead, and adults have been found as recently as June 2010 in the Colorado River inflow, about 9 miles downstream from the lower end of this proposed action area near Pearce Ferry (Albrecht et al. 2010). Spawning is believed to have occurred in April 2010 on rock and gravel points between North Bay and Devil's Cove, which is in the lake interface about 10 miles downstream from Pearce Ferry. A total of seven recently hatched larvae were found in the area on April 13-14, 2010, at a water temperature of 14–16ºC. Although razorback sucker have not been reported between Glen Canyon Dam and Pearce Ferry since 1990 (Valdez 1996), it is possible that individuals from the Lake Mead population use lower Grand Canyon transiently or a few currently reside in the reach. Recent fish sampling in lower Grand Canyon has not reported razorback sucker in the area (Makinster et al. 2010a), but this sampling may not be sufficient to detect small numbers of individuals.

Direct short-term effects of the proposed action are expected to the razorback sucker from modifications in habitat, changes in foodbase, possible burial of spawning bars, and potential displacement of young. The numbers of larvae in the Lake Mead inflow are likely to be small, based on numbers captured in recent years in 10-mile reach below Pearce Ferry (RM 282); i.e., 11 in 2000, 22 in 2001, and 7 in 2010 from ongoing annual sampling (Kegerries et al. 2009; Albrecht et al. 2010). These effects are expected to be temporary for single HFEs and for two consecutive HFEs, where the habitat and the foodbase are expected to be restored shortly after each HFE. However, the effects of more than two consecutive HFEs are not known. For single or two HFEs, habitat would change with increases in water velocity and river stage, but the effect to adults is expected to be minimal. The large amount of material scoured and dislodged by an HFE could deliver a large amount of diverse food items for razorback suckers in the Lake Mead inflow, which are omnivorous and can feed on detritus and insects. An HFE is likely to carry a large amount of sediment that can bury spawning bars with eggs and newly hatched larvae. The only known spawning habitat for razorback sucker is about 11 miles downstream of the action area near Devil's Cove, as described above, where a spring HFE has the potential to deposit sand and sediment on spawning areas.

A spring HFE also has the potential to increase water flow and stage in the inflow area used by razorback sucker; an HFE of 45,000 for 96 hours could increase the level of Lake Mead by 1–2 feet. Adults and juveniles are expected to adjust with changing water level, but high flows could displace recently hatched larvae (such as found in mid-April 2010) from nursery habitats. Larvae displaced from food-rich nursery habitats can starve in 2–3 days (Papoulias and Minckley 1990) or are eaten by predators (USFWS 2002). Alternatively, high flows could benefit larvae by transporting them into newly inundated high-water habitats where food production would be stimulated. The fate of newly hatched razorback sucker during an HFE should be investigated.

### 3.4.1 Effects to Critical Habitat

The proposed action may adversely affect designated critical habitat of the razorback sucker. Designated critical habitat extends through most of the action area, from the Paria River downstream to Hoover Dam. Razorback sucker have not been reported between Glen Canyon Dam and Pearce Ferry since 1995, and prior to that time, only 10 confirmed fish had been reported from Grand Canyon (Valdez 1996). However, razorback sucker have recently been documented near the lowermost (downstream) boundary of the action area (Albrecht et al. 2010), so adverse modifications to razorback sucker critical habitat is considered in this BA. The effects of Federal actions on the razorback sucker and its critical habitat in Grand Canyon had not been evaluated prior to the 2010 Opinion because of the presumed absence of the species from the area and the unknown habitat requirements for the area.

The primary constituent elements (PCE) addressed in this analysis include: water quality (W1), physical habitat including nursery (P2) and feeding habitat (P3), the biological environment including food supply (B1), predation from non-native fish species (B2), and competition from non-native fish species (B3). Depending on the magnitude of an HFE, a high release is not likely to alter water quality in a manner that detrimentally affects the razorback sucker. The only possible effect is to water quality during spawning and nursing of young in the inflow area of Lake Mead; razorback sucker larvae were found about 10 miles downstream from Pearce Ferry in April 2010 in a water temperature of 14–16ºC. A spring HFE is likely to cool river and inflow temperatures, which may delay spawning or temporarily slow feeding or growth of the larvae. Larval razorback sucker require quiet food-rich areas for nursery habitat. These may become inundated by high flows—or productivity of newly inundated areas may provide a food-rich environment. Predation from non-native fish is always a potential in a lake environment such as Lake Mead. At least bass (*Micropterus* spp.), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), and sunfish (*Lepomis* spp.) have been documented as consuming larval razorback sucker in Lake Mead (Holden et al. 1997). Displacement of razorback sucker larvae could expose them to predation by these species.

### 3.4.2 Effects to Razorback Sucker Population

The razorback sucker population in closest proximity to the action area is found in Echo Bay, Las Vegas Wash, and the Virgin/Muddy confluence of Overton Arm in north-central Lake Mead. These areas are located about 100 miles down-reservoir from Pearce Ferry, the approximate southern boundary of the action area. In 2000 and 2001 larval razorback sucker were captured in the Colorado River inflow region of Lake Mead (about 11 miles from Pearce Ferry). During the

2002 and 2003 spawning periods, no larval razorback sucker was captured in this area, but in 2010, seven larvae and three adults were captured in the same area. Based on observations of other spawning areas, adults evidently shift locations to spawn depending on lake elevation. Alteration of spawning sites resulting from lake elevation changes may be responsible for the apparent incremental spawning in the Colorado River inflow region. Nevertheless, the spawning location and larval captures in the inflow region are within the area of influence of an HFE released from Glen Canyon Dam about 305 miles upstream.

The largest magnitude and duration of HFE (45,000 cfs for 96 hours) will deliver about 400,000 acre-feet into Lake Mead and likely increase the elevation of the reservoir by 1–2 feet. This increase in lake level in spring could either encourage or discourage spawning by razorback suckers in former spawning sites; the relationship of reservoir elevation to spawning locations is not currently known. Because one or more HFEs could be adverse or beneficial to the razorback sucker in Lake Mead, the effect to the population cannot be determined. It is likely however, that an HFE will enhance survival of larvae and post-larvae by increasing their food supply through inundation of areas and stimulated primary production. Increased turbidity at the river/lake interface will provide cover and is also likely to increase survival of young. The influx of large amounts of organic matter is also likely to bolster the food supply for all ages of razorback suckers.

The extent of impact to the razorback sucker depends on how far upstream they occur from the lower boundary of the action. While spawning of razorback sucker has been determined in the inflow region of Lake Mead, it is unclear whether these fish are actually spawning in the free-flowing reaches of the Colorado River or in Lake Mead itself. Thus, it is uncertain whether larvae resulting from this spawning activity will be displaced by HFEs. With regards to increased risk of predation due to enhanced rainbow trout survival, it is unlikely that razorback sucker overlap with the present distribution of rainbow trout, as no razorback sucker have been documented in areas occupied by trout for at least two decades.

## 3.5 Kanab Ambersnail Effects Analysis

The proposed action is likely to adversely affect the Kanab ambersnail because of the potential for high flows to inundate and scour habitat and snails at Vasey's Paradise. There is no designated critical habitat for the Kanab ambersnail, and an effects analysis of critical habitat was not done for this species. The majority of habitat occupied by the snails occurs above the elevation inundated by the maximum allowable MLFF flow of 25,000 cfs (Sorensen 2009). Based on the following analysis, there is potential for take of individual Kanab ambersnails and Reclamation has concluded that the proposed action may affect and is likely to adversely affect the species. During the 1996 high flow test (45,000 cfs) in the Grand Canyon, up to 119.4 $m^2$ (17 percent) of potential Kanab ambersnail habitat at Vasey's Paradise was inundated and scoured, hundreds of snails were lost, and it took 2.5 years for the habitat to recover to pre-flood conditions (Stevens et al. 1997b; IKAMT 1998). When habitat and snails were temporarily removed and relocated for the 2004 and 2008 HFEs, recovered of habitat and snail densities to pre-flood conditions occurred in approximately six months (Sorensen, 2009). Flows of 31,500 to 33,000 cfs are expected to scour and cover with sediment between 10 and 17 percent of the Kanab ambersnail primary habitat at Vasey's Paradise (Reclamation 2002; USFWS 2000).

During the normal course of events in any given year, Kanab ambersnail primary habitat is expected to increase somewhat as new plant growth begins, probably by mid-February. The most proximate estimate for snail habitat below the 45,000 cfs stage for this evaluation is the April 2002 estimate, which was 117 $m^2$ (Reclamation 2002), slightly less than the 120 $m^2$ present in March 1996 prior to the HFE. Irrespective of which month HFEs occur, high flows are expected to remove or damage most of the primary habitat and cause mortality of most Kanab ambersnails up to the stage of the flow. The actual numbers of Kanab ambersnail lost due to high flows will depend greatly on the amount of ensuing winter mortality, which can vary dramatically among years depending on the severity of winter temperatures (Stevens et al. 1997a; IKAMT 1998). Based on best available data, the area of primary habitat will not exceed the amount that was present in prior to the 1996 HFE of 45,000 cfs, and thus the amount of incidental take (17 percent) identified by the USFWS (2000) should not be exceeded. The proposed action will have no effect on the water flow from the side canyon spring that maintains wetland and aquatic habitat at Vasey's Paradise. Also, an HFE will not affect the population of Kanab ambersnail at Elves Chasm because the habitat for that population is located above the elevation that could be reached by a 45,000 cfs flow.

## 3.6 Southwestern Willow Flycatcher Effects Analysis

The proposed action may affect, but is not likely to adversely affect the southwestern willow flycatcher. The northern boundary of designated critical habitat for the species forms the southern boundary of the action area. Downstream flows as a result of the proposed action are not expected to have adverse effects below Separation Canyon. Breeding pairs are not likely to be present during HFE periods in March-April or October-November. Individuals have been observed in May, June, and July, outside of proposed HFE release windows. Nesting flycatchers have not been confirmed in Grand Canyon since 2003.

Southwestern willow flycatchers are known to nest in tamarisk along the Colorado River in the Grand Canyon. The southwestern willow flycatcher can be affected by high flows through scouring and destruction of willow-tamarisk shrub nesting habitat or wetland foraging habitat. The southwestern willow flycatcher nests primarily in tamarisk shrub in the lower Grand Canyon, which is quite common along the river corridor. An important element of flycatcher nesting habitat is the presence of moist surface soil conditions. Moist surface soil conditions are maintained by overbank flow or high groundwater elevations supported by high river stage. Willow flycatcher nests in the Grand Canyon are typically above the 45,000 cfs stage (Gloss et al. 2005), which will not be exceeded by the high-flow experimental releases.

## 3.7 Effects of Climate Change

The Fourth Assessment Report (Summary for Policymakers) of the Intergovernmental Panel on Climate Change (IPCC 2007), presented a selection of key findings regarding projected changes in precipitation and other climate variables as a result of a range of unmitigated climate changes projected over the next century. Although annual average river runoff and water availability are projected to decrease by 10–30 percent over some dry regions at mid-latitudes, information with regard to potential impacts on specific river basins is not included. Recently published projections of potential reductions in natural flow on the Colorado River Basin by the mid 21st century range from approximately 45 percent by Hoerling and Eischeid (2006), to approximately 6 percent by Christensen and Lettenmaier (2006). As documented in the Shortage EIS (Reclamation 2007a), however, these projections are not at the spatial scale needed for CRSS, the model used by Reclamation to project future flows for the Colorado River.

The hydrologic model, CRSS, used as the primary basis of the effects analysis does not project future flows or take into consideration projections such as those cited above, but rather relies on the historic record of the Colorado River Basin to analyze a range of possible future flows. Using CRSS, projections of future Lake Powell reservoir elevations are probabilistic, based on the 100- year historic record. This record includes periods of drought and periods with above average flow. However, studies of proxy records, in particular analyses of tree-rings throughout the upper Colorado River Basin indicate that droughts lasting 15–20 years were not uncommon in the late Holocene. Such findings, when coupled with today's understanding of decadal cycles brought on by El Niño Southern Oscillation and Pacific Decadal Oscillation (and upstream consumptive use), suggest that the current drought could continue for several more years, or the current dry conditions could shift to wetter conditions at any time (Webb et al. 2005). Thus, the action period may include wetter or drier conditions than today. An analysis of hydrologic variability and potential alternative climate scenarios is more thoroughly discussed in the Shortage EIS (Reclamation 2007a) and is incorporated by reference here.

Although precise estimates of the future impacts of climate change throughout the Colorado River Basin at appropriate spatial scales are not currently available, these impacts may include decreased mean annual inflow to Lake Powell, including more frequent and more severe droughts. Such droughts may decrease the average storage level of Lake Powell, which could correspondingly increase the temperature of dam releases. Maximum temperature of water released from Glen Canyon Dam during recent low reservoir elevation (3603 asl) was 15°C in November of 2005. Depending on time of year, a temperature of 15°C at the dam could translate to about 18°C at the LCR because of downstream warming. Increased release temperatures have been cited as one potential factor in the recent increase of juvenile humpback chub (USGS Fact Sheet 2007) but concerns also exist that warmer aquatic environment would also increase the risk of warm water non-native fish predation. Reclamation has committed in the 2007 Opinion to the monitoring and control of non-native fish in coordination with other Interior agencies and working through the GCDAMP (USFWS 2007).

## 3.8 Effects Determination

A summary of effects determinations for the four listed species is presented in Table 7. Analysis of effects determination are based 50 CFR 402.02, in which "[e]ffects of the action refers to the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process."

Based on the evaluation contained in this BA, Reclamation has determined that the proposed action may affect and is likely to adversely affect the humpback chub, and may adversely affect its designated critical habitat. This determination is based on short-term adverse effects on habitat and foodbase from high flows and on the potential downstream displacement of young-of-year and juveniles. These combined effects could result in lower survival of young fish and less recruitment to the adult population. The unintended consequence of an increased rainbow trout population that could result from especially spring HFEs would likely increase downstream dispersal of trout into the vicinity of the LCR where they could prey on and compete with young humpback chub. This effect would also reduce recruitment of humpback chub and possibly the overall population size. A concurrent EA on control of non-native fish downstream of Glen Canyon Dam would reduce numbers of rainbow trout and brown trout in the vicinity of the LCR and is expected to reduce this predation and competition effect on humpback chub.

The HFEs are also expected to have long-term beneficial effects to the humpback chub population. Although periodic high flows would likely temporarily affect habitat and reduce the foodbase, multiple HFEs would be expected to rebuild and maintain backwater habitats, so long as sufficient fine sediment was available, and stimulate productivity in backwaters and nearshore habitats. A large number of consecutive HFEs could reduce populations of flood-sensitive invertebrate species and reduce overall densities of organisms that comprise the foodbase. This could have a detrimental effect on humpback chub condition, increase competition among fish species, and reduce reproductive capability. The number of consecutive HFEs that would benefit the ecosystem (e.g., rebuilding and maintenance of habitat, stimulate foodbase productivity)—or adversely modify or alter the ecosystem from periodic scouring is unknown and needs to be investigated as part of this HFE protocol.

Reclamation has also determined that the proposed action may affect and is likely to adversely affect the razorback sucker, and may adversely affect its designated critical habitat. This determination is based on potential short-term effects of high flow on habitat of areas in the Lake Mead inflow that were confirmed spawning sites in 2001, 2002, and 2010 (ripe fish and larvae were found; Albrecht et al. 2010). A high inflow could inundate spawning and nursery areas, transport larvae (recently hatched fish) from safe habitats, and make them more susceptible to starvation or predation. A large HFE of 45,000 cfs for 96 hours could raise the level of Lake Mead by over 1 foot and cover spawning and nursery areas with sediment that could suffocate the embryos. The HFEs could also have beneficial effects on the razorback sucker. Increase sediment load will increase turbidity that larvae use as cover from predators (Kegerries et al. 2009). Increased levels of Lake Mead could inundate vegetated areas and stimulate productivity that larvae could use as sheltered food sources. The large volume of water will also carry a large volume of organic matter that can supplement food for all ages of razorback suckers.

Reclamation has also determined that the proposed action may affect and is likely to adversely affect the Kanab ambersnail. There is no designated habitat for this species, and this analysis did not evaluate primary constituent elements. This determination is based on short-term adverse effects on habitat and snails located in the inundation zone at Vasey's Paradise. Habitat and snails below the high water line are expected to be scoured and transported downstream with little or no survival of snails. The proportion of habitat and the number of snails affected would vary with the magnitude of the high release. For the past HFEs, Reclamation has removed habitat and snails from the projected inundation zone. When the habitat was relocated, the vegetation recovered within about 6 months, but when the habitat was not relocated, recovery was delayed about 2.5 years.

Reclamation has determined that the proposed action may affect and is not likely to adversely affect the southwestern willow flycatcher. This determination is based on the fact that the birds are not expected to be in the action area during the spring HFE release window—March-April—and high flows of 45,000 cfs or less are not likely to adversely affect their nesting and feeding sites. Nesting activity, nests, or young would not be expected to be present during an HFE and no indirect effects are expected since nests of southwestern willow flycatchers have not been found below an elevation equivalent to the 45,000 cfs stage. Designated critical habitat for the southwestern willow flycatcher does not occur in the area of the proposed action.

**Table 7. Summary of effects determinations for the four listed species.**

| Species | Determination | Basis for Determination |
|---|---|---|
| Humpback chub | May affect, likely to adversely affect species and critical habitat | • Take could occur from downstream displacement of young into unsuitable habitat, especially during fall HFEs. Effects of displacement, if it occurs, are largely unknown.<br>• Direct short-term reductions in near-shore habitat could occur in the vicinity of the LCR with changes in flow stage, but long-term benefit is expected from sand redeposition that rebuilds and maintains near-shore and backwater nursery habitats.<br>• Direct short-term reductions in food supply could occur with scouring and changes in flow stage, but long-term benefit is expected from stimulated food production.<br>• Increased predation from expanded population of rainbow trout is expected, especially with spring or multiple HFEs. |
| Razorback sucker | May affect, likely to adversely affect species and critical habitat | • Short-term beneficial impacts to food supply from large influx of organic material during HFEs.<br>• Short-term beneficial effect from inundated vegetation and increased turbidity as protective cover from predators.<br>• Potential displacement of young in Lake Mead inflow by spring HFEs, but possible creation of productive nursery habitats from increased reservoir level and reshaping of near-shore deposits.<br>• Potential short-term burial of spawning bars and other habitats by fine sediment during HFEs. |
| Kanab ambersnail | May affect, likely to adversely affect; no critical habitat designated | • Up to 119.4 $m^2$ (17 percent in 1996) of potential habitat may be inundated by 45,000 cfs.<br>• Proportionally less habitat area scoured and fewer numbers of snails would be displaced by lower magnitude HFEs.<br>• Sequential HFEs could reinundate and scour primary habitat prior to full recovery from previous HFE. |
| Southwestern willow flycatcher | May affect, not likely to adversely affect; critical habitat not in area of proposed action | • Birds will not be present during spring HFEs, and nesting and feeding sites are not expected to be adversely affected.<br>• Birds will be off nests by Sept-Oct, but birds will be foraging and there could be some indirect effect to their food supply. |

# 4 Incidental Take

The USFWS has issued seven biological opinions related to the operation of Glen Canyon Dam between 1978 and 2010. The most recent is the 2008 Opinion for the Operation of Glen Canyon Dam (February 27, 2008; USFWS 2008), supplemented on October 29, 2009 as a result of the Court Order of May 26, 2009, with a revised Incidental Take Statement on November 9, 2010. A summary of these opinions is provided below.

In this biological assessment, Reclamation has evaluated the effects of the proposed action on each of the four listed species. We have identified the potential effects of the different attributes of HFEs, including effects to the species and their respective critical habitats. Reclamation has not attempted to estimate incidental take, as this is the responsibility of the USFWS under Section 9 of ESA. However, Reclamation is interested in providing information that helps to gauge the amount of incidental take and continues to strive to reduce this take where possible and through conservation measures.

As acknowledged by the USFWS in prior opinions, measuring take as a consequence of dam operations, or similar experimental actions, is difficult to detect because of the inaccessibility of the vast mainstem river and because the effect is expected primarily on small fish that are difficult to mark and track. Hence, Reclamation would like to continue to work with the USFWS in designing and implementing studies that will help to better discern take as a consequence of these proposed actions.

Reclamation and the USFWS have defined the humpback chub consultation trigger for reinitiation contained in the conservation measure as being exceeded if the population of adult humpback (≥200mm [7.87 in] TL) in Grand Canyon declines significantly, or if in any single year, based on the age-structured mark recapture model (ASMR; Coggins 2008a), the population drops below 6,000 adult fish within the 95 percent confidence interval. The abundance of adult humpback chub increased approximately 50 percent between 2001 and 2008. The most likely estimate of the population in 2008 was 7,650 adults with a likely range of 6,000 to 10,000 adults (Coggins and Walters 2009), which exceeds the consultation trigger. The level of 6,000 adults was used because that was the number of adult humpback chub estimated in the action area when the USFWS received the biological assessment for the project (April 30, 2010). Conversely, if the population of humpback chub expands significantly, USFWS and Reclamation will consider the potential for reinitiation of consultation to determine if steady flows continue to be necessary, in accordance with standard reinitiation triggers as found in 50 CFR 402.14.

The following summarize the effects determinations and incidental take statements contained in each opinion for the four species addressed in this BA:

1. ***1978 Biological Opinion of the Effects of Glen Canyon Dam on the Colorado River as it Affects Endangered Species (May 25, 1978; USFWS 1995)***

    a. Humpback chub

        i. Jeopardizing continued existence by limiting distribution and population size.

2. ***1995 Biological Opinion on Operation of Glen Canyon Dam (January 7, 1995; USFWS 1995)***

    a. Humpback chub and razorback sucker

        i. Likely to jeopardize continued existence and likely to destroy or adversely modify designated critical habitat.

        ii. Incidental take: some young humpback chub could be transported downstream, but difficult to detect due to inaccessibility.

    b. Kanab ambersnail

        i. Likely to jeopardize continued existence.

        ii. Incidental take: 10 percent of habitat with snails expected to be scoured.

3. ***1996 Biological Opinion for Proposed High Flow Test (January 7, 1996; USFWS 1996)***

    a. Humpback chub (razorback sucker not addressed)

        i. Not likely to jeopardize continued existence and not likely to destroy or adversely modify designated critical habitat.

        ii. Incidental take: some young humpback chub could be transported downstream, but difficult to detect due to inaccessibility.

    b. Kanab ambersnail and southwestern willow flycatcher

        i. Not likely to jeopardize continued existence.

        ii. Incidental take: 10 percent of habitat with snails expected to be scoured.

4. ***1997 Biological Opinion for a Fall Test Flow (January 7, 1996; USFWS 1996)***

    a. Humpback chub (razorback sucker not addressed)

        i. Not likely to jeopardize continued existence and not likely to destroy or adversely modify designated critical habitat.

        ii. Incidental take: some young humpback chub could be transported downstream, but difficult to detect due to inaccessibility.

    b. Kanab ambersnail and southwestern willow flycatcher

        i. Not likely to jeopardize continued existence.

5. ***2002 Biological Opinion for Proposed Experimental Releases from Glen Canyon Dam and Removal of Non-native Fish (December 6, 2002; USFWS 2002a; revised August 12, 2003; USFWS 2003)***

   a. Humpback chub (razorback sucker not addressed)

      i. Not likely to jeopardize continued existence and not likely to destroy or adversely modify designated critical habitat.

      ii. Incidental take: 400 humpback chub expected to be captured; 20 expected to be killed.

   b. Kanab ambersnail and southwestern willow flycatcher

      i. Not likely to jeopardize continued existence.

      ii. Incidental takes of Kanab ambersnail: 117 $m^2$ of habitat with snails lost over the course of the two years.

6. ***2007 Final Biological Opinion for the Proposed Adoption of the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (December 12, 2007; USFWS 2007)***

   a. Humpback chub (razorback sucker not addressed)

      i. Not likely to jeopardize continued existence and not likely to destroy or adversely modify designated critical habitat.

      ii. Incidental take: as surrogate measure , take exceeded if 50 percent increase in non-native fish species abundance in LCR reach from 2007 levels, if increase persists for five consecutive years, and significant decline in humpback chub recruitment or survivorship is solely attributable to proposed action.

   b. Kanab ambersnail and southwestern willow flycatcher

      i. Not likely to jeopardize continued existence.

      ii. Incidental take of Kanab ambersnail: as surrogate measure, take exceeded if reduction of more than 20 percent of habitat at Vasey's Paradise from 2007, and reduction continues over a 5-year period.

7. ***2008 Biological Opinion for the Operation of Glen Canyon Dam (February 27, 2008; USFWS 2008; Supplemented October 29, 2009; USFWS 2009;revised November 9, 2010; USFWS 2010 )***

a. Humpback chub (razorback sucker addressed in the 2009 Supplemental Opinion at the request of Reclamation)

    i. Not likely to jeopardize continued existence and not likely to destroy or adversely modify designated critical habitat.

    ii. Incidental takes for 2008 Opinion: based on Humpback Chub Consultation Trigger, take exceeded if population drops below 3,500 adult fish within the 95 percent confidence interval.

    iii. Incidental take statement reissued September 1, 2010: take exceeded if population drops below 6,000 adult fish within the 95 percent confidence interval.

    iv. Incidental take for cancelling non-native fish removal for 13 months: 1,000 and 24,000 y-o-y or juvenile humpback chub will be lost to predation by trout.

b. Kanab ambersnail and southwestern willow flycatcher

    i. Not likely to jeopardize continued existence.

    ii. Incidental takes of Kanab ambersnail: as surrogate measure, take exceeded if the proposed action results in more than 117 $m^2$ (1259 $ft^2$) of Kanab ambersnail habitat, being removed at Vasey's Paradise and this loss is attributable to the high flow test.

# 5 Conservation Measures

Reclamation recognizes that conservation measures contained in the 2007 Opinion (Section 2.2.6) will materially contribute to the conservation and protection of listed species in the action area. Progress on these measures and other offsetting or mitigating actions are described in Section 1.3.

***Humpback chub***

There are currently eight conservation measures designed to reduce adverse effect to the humpback chub, including fish research and monitoring, non-native fish control, humpback chub translocation and refuge, parasite monitoring, sediment research, LCR watershed planning, and the monthly flow transition study. In addition to the anticipated positive benefits to humpback chub expected from the conservation measures and some aspects of the proposed action, during the ten-year experimental period, Reclamation will also use its available discretion in determining monthly release volumes so that releases during the proposed HFEs are transitioned. Our ability to achieve this transition depends not only on the state of the reservoir and on any need for equalization releases, but also the official inflow forecast received from the Colorado River Forecast Center throughout the water year and consultation within the Colorado River Management Work Group. A more gradual transition in the dam release volumes of those months should minimize sudden changes in humpback chub habitat type and any bioenergetic costs associated with their adaptation to the change. Notwithstanding the potential for modest variation in the monthly volumes during HFEs, Reclamation will implement the high releases as set forth in the proposed action.

***Kanab ambersnail***

In 1996, a controlled 45,000 cfs experimental flood from Glen Canyon Dam lasted for 7 days. Approximately 16 percent of the total habitat of Kanab ambersnail was lost as a result of this flood. A flow of 45,000 cfs resulted in the inundation, scouring, and destruction of occupied habitat and ambersnails. Despite predications that the habitat would recovery within one year of this high release, field studies indicated that less than half of the habitat lost (49 percent) had recovered in one year and appears to take over three years to fully recover.

In October of 1997, a fall test flow of 31,000 cfs for scoured an additional small area (approximately 29.8 $m^2$ or 3.5 percent) of the existing primary habitat. Individual snails that are not salvaged from the inundated habitat are expected to be displaced and lost by high velocity flows or floating debris. It is not known how long the snails survive inundation. Although it is possible that the Kanab ambersnail could be transported safely downstream to a new location, there is no evidence that any individuals have been survived this downstream transport and subsequently found suitable habitat to result in a new population. Consequently, snails transported downstream are considered unsalvageable.

Experience gained during the 1996 high flow test (45,000 cfs) revealed that nearly all vegetation and snails below the level of inundation were scoured and carried downstream. This experience also indicated that, without supplementation, it took nearly three years for the vegetation to reach its former area and volume. To alleviate this take of habitat and snails, a conservation measure was identified by Reclamation and the NPS in the 2002 BA and by the USFWS in the 2002 Opinion. This conservation measure was designed to decrease the incidental take from mortality during experimental flows.

A second potential agency action for Kanab ambersnail, which was identified in the September 2002 environmental assessment/biological assessment, was to augment the Elves Chasm population that was established by translocation of individuals from Vasey's Paradise in 1998. Periodic augmentation of translocated populations by Kanab ambersnails from Vasey's Paradise was identified in the biological opinion on the 1998 translocation as an action that the NPS may undertake. The primary purpose of augmentation would be to help ensure that the genetic identity of the translocated population does not deviate from the source population at Vasey's Paradise.

The Elves Chasm translocation was one of three undertaken by the NPS, AGFD, and cooperators in an attempt to achieve a goal of redundant populations in the recovery plan and to address a reasonable and prudent measure in the February 1996 biological opinion on the 1996 high flow test. Reclamation has supported monitoring of both Vasey's Paradise and Elves Chasm populations of Kanab ambersnail through the GCDAMP. This reasonable and prudent measure was removed by the USFWS on July 12, 2000, pursuant to their discovery that the level of incidental take for the beach habitat building flow had been underestimated.

For the November 2004 HFE, the action agencies proposed to temporarily remove and safeguard 25–40 percent (29–47 $m^2$) of the Kanab ambersnail habitat that would be flooded by a high experimental flow (41,000 cfs), if the sediment trigger occurred during the autumn months or anytime before December 31. The habitat and snails were held locally above the level of inundation until the high flow ended, approximately 60 hours. Habitat and snails were replaced in a manner that would facilitate regrowth of vegetation.

For the March 2008 HFE, Reclamation, through the AMP, temporarily removed and safe-guarded all Kanab ambersnails found in the zone that would be inundated during the high flow test, as well as approximately 15 percent (17 $m^2$ [180 $ft^2$]) of the Kanab ambersnail habitat that would be flooded by the experimental high flow test. The ambersnails were released above the inundation zone, and habitat was held locally above the level of inundation until the high flow test ended (approximately 60 hours). Habitat was replaced in a manner that would facilitate regrowth of vegetation. Subsequent monitoring of this conservation measure for the 2004 and 2008 HFEs has been coordinated with GCMRC.

The USFWS is in the process of evaluating the genetic status of the Vasey's Paradise population of Kanab ambersnail. Reclamation recommends that at the conclusion of this work that Reclamation and the USFWS discuss what measures, if any, should be taken with respect to the Elves Chasm population of Kanab ambersnail.

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# Appendix D: Hydrology Input to Sediment Model

RECLAMATION

*Managing Water in the West*

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

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

January 14, 2011

## Hydrologic Trace Selection

Bureau of Reclamation's long-term planning model Colorado River Simulation System (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 hydrologies. Wet traces were those closest to the $90^{th}$ percentile (9.6% exceedance to 10.4% exceedance probability), moderate traces the $50^{th}$ percentile and dry traces, the $10^{th}$ 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 timeseries 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).

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.

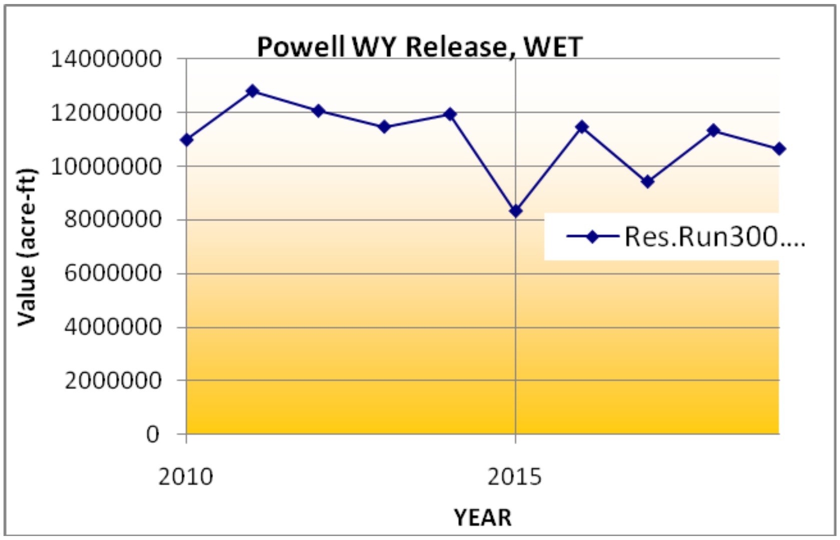


**Figure 1. Lake Powell water year releases, wet trace.**

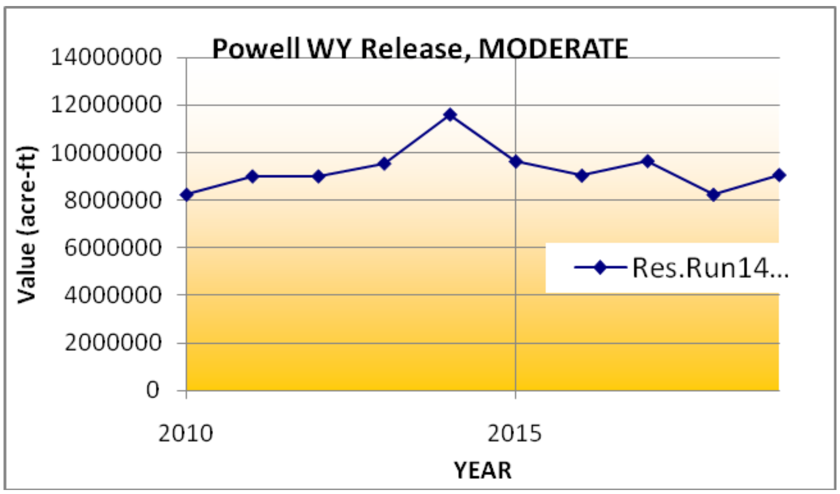


**Figure 2. Lake Powell water year releases, moderate trace.**

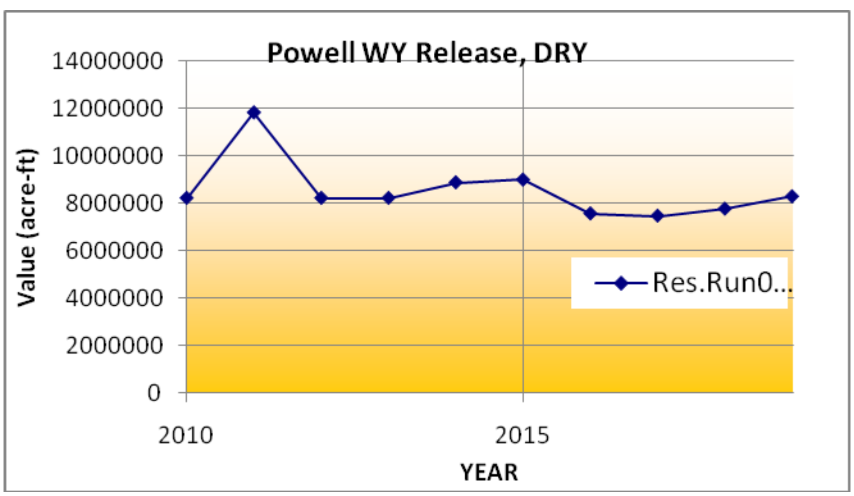


**Figure 3. Lake Powell water year releases, dry trace.**

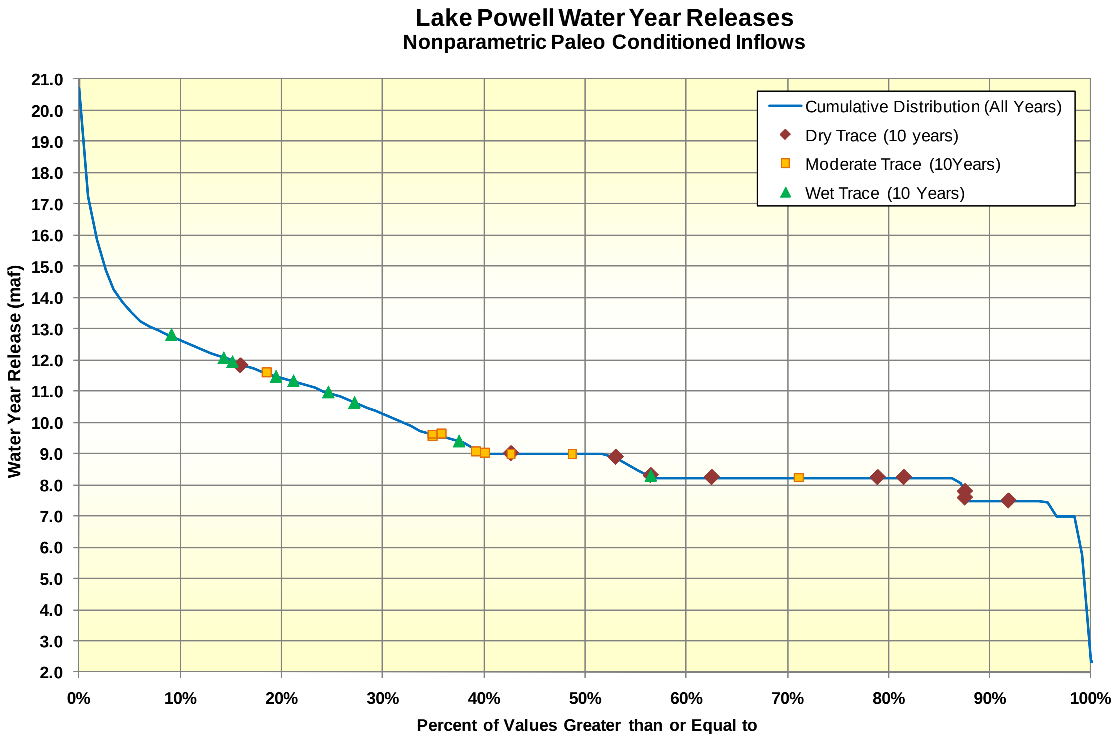


**Figure 4. Lake Powell water year releases, all CRSS runs with values from selected dry, moderate, and wet traces highlighted.**

# 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)

**Table 1. Monthly release volumes and associated maximum daily change.**

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

- 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

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 2. GTMax Matrix Output**

| Output Folder | Run | Reservoir Elevation (ft) | Monthly Release (TAF) 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 Sediment Budget Modeling Methods Using CRSS Hydrology Output

RECLAMATION

*Managing Water in the West*

# Sediment Analysis for Glen Canyon Dam High Flow Experiment Protocol Environmental Assessment

**Upper Colorado Region, AZ**

U.S. Department of the Interior
Bureau of Reclamation

December 2010

## Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to 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.

Cover Photo: Colorado River upstream of Lees Ferry taken in June, 2010.

# Sediment Analysis for Glen Canyon Dam High Flow Experiment Protocol Environmental Assessment

## Upper Colorado Region, AZ

Peer Review Certification: This document has been peer reviewed per guidelines established by the Technical Service Center and is believed to be in accordance with the service agreement and standards of the profession.

*Prepared by*


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**U.S. Department of the Interior**
**Bureau of Reclamation**

**December 2010**

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# Executive Summary

An environmental assessment (EA) is being produced by the Bureau of Reclamation's Upper Colorado (UC) Regional Office to determine the impact of high flow experiments (HFE) from Glen Canyon Dam on natural resources downstream. In order to determine impacts to sandbars and other resources downstream of Glen Canyon Dam, the approximated frequency, magnitude and duration of high flows is required. A sand budget model developed by U.S. Geological Survey (USGS) was modified to determine how many HFEs could occur based on estimated future dam releases, sediment input from the Paria River, and downstream sediment mass balance.

Based on previous scientific findings, the key criteria that determined the model decision making include maximizing flow magnitude to generate the largest possible sand concentrations and area of inundation, increasing the duration to keep sand concentrations elevated as long as there is available sand, and selecting the maximum HFE in an implementation month while maintaining a positive sand balance for the accounting period.

The modified model has multiple limitations including that sandbar building is not assessed in the model. The model only considers sand mass balance; it does not differentiate between sediment in the channel and sediment in the sandbars. Key input parameters to the modified sand budget model consist of release hydrographs and tributary inputs. Three 10-year release hydrographs were utilized based on simulations run by the Colorado River Simulation System (CRSS) model. Three tributary inputs were selected by analyzing the Paria River sand-load record. Thirteen options for HFEs were tested in the modified sand budget model ranging from a peak discharge of 45,000 $ft^3$/sec with peak duration of 96 hours to a peak discharge of 31,500 $ft^3$/sec with peak duration of 1 hour.

The modified sand budget model was used to simulate nine combinations of hydrology and tributary sediment traces. An HFE was selected by the model in 56% of the potential implementation windows for the nine traces simulated. Of these HFE's, 92% had a peak magnitude of 45,000 $ft^3$/sec whereas eight of the thirteen possible HFEs had a peak magnitude of 45,000 $ft^3$/sec. Typically HFEs occur in groups; 80% of the predicted HFEs had an HFE in the neighboring accounting periods. In the model, the occurrence of an HFE can be triggered by a certain level of sediment regardless of the hydrology because water is not considered limiting and can be reallocated within the month. For the nine traces, the average monthly Paria sand load that always resulted in an HFE was 500,000 metric tons per month.

Using previous literature, the HFEs recommended by the modified sand budget model will likely cause an increase in the sand volume above the 8,000 $ft^3$/sec water surface elevation. Some sediment will be eroded from the lower eddies, but this amount will be minimized based on previous tributary inputs ensuring the system is not depleted within the accounting period. The redistributed sand will erode in the months following the HFE and the rate will be dependent on dam releases and any new tributary inputs.

# 1 Introduction

An environmental assessment (EA) is being produced by Bureau of Reclamation's Upper Colorado (UC) Regional Office to determine the impact of high flow experiments (HFE) from Glen Canyon Dam on natural, cultural and socioeconomic resources downstream. The EA will consider impacts over a ten (10) year period, 2011-2020. Sediment and sandbars along the Colorado River are important downstream resources in Grand Canyon National Park and have linkages to recreation, aquatic and terrestrial habitat, and cultural resources.

In order to determine impacts to sandbars downstream of Glen Canyon Dam, the approximated frequency, magnitude and duration of high flows is required. A sand budget model developed by U.S. Geological Survey (USGS) was modified to determine how many HFEs could occur based on estimated future dam releases. In addition, the impacts to sediment and sandbars are assessed for a variety of HFEs over a 10-year period. This analysis includes approximately 77 river miles from Glen Canyon Dam to the Little Colorado River.

## 1.1 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. The value of sand in the ecosystem for purposes other than sandbar building was not considered. Once the high flows have been estimated, a qualitative assessment of sandbar response is provided. Specific questions are:

1. How many HFEs might occur in the next 10 years (represented as 2010 through 2019)?
2. What is the expected magnitude and duration of high flows?
3. What are the limitations and assumptions of the HFE analysis?
4. Using the predicted HFEs, what is the qualitative assessment of sandbar effects over the next 10 years based on currently published literature?

# 2 Methods

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 USGS (Wright et. al. 2010). The model uses empirically based rating curves for specific particle sizes. It computes the sand budget in three reaches:

1) upper Marble Canyon from Lees Ferry and Paria River confluence (River Mile (RM) 0) to RM 30,
2) lower Marble Canyon from RM 30 to Little Colorado River (RM61), and
3) eastern Grand Canyon from Little Colorado River to Phantom Ranch (RM 87) as shown in Figure 1.

The model was calibrated and validated on historical sediment and discharge information from September 2002 to March 2009 that included the 2004 and 2008 high flow experiments. 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.

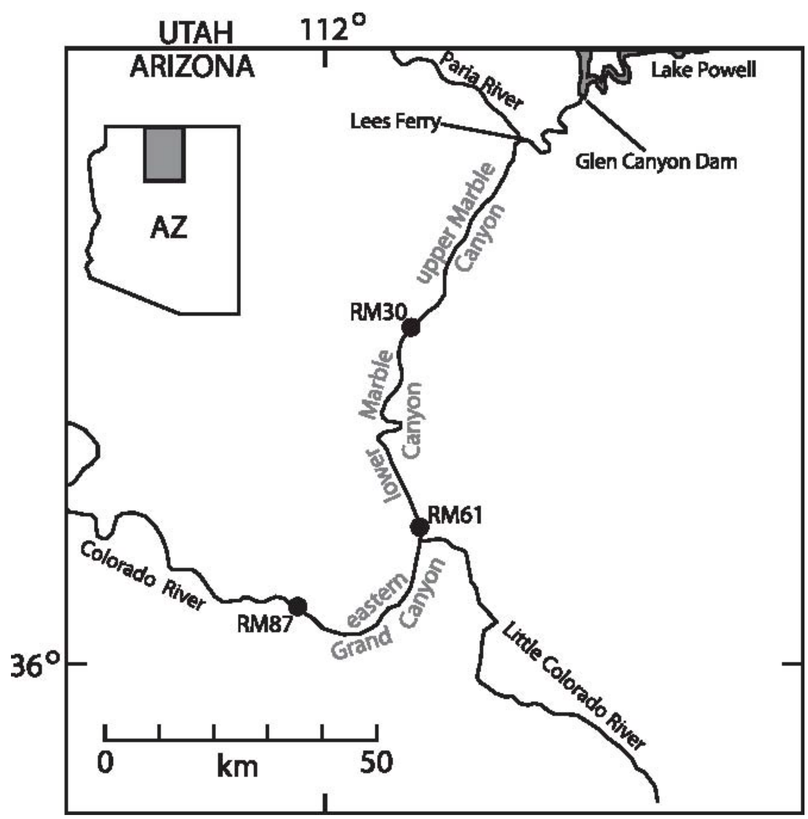



Figure 1. Sand budget model reaches (from Wright et al. 2010)

For the Environmental Assessment (EA), the sand budget model was combined with decision criteria on whether or not to conduct HFEs and then applied to help determine how many HFEs could hypothetically occur in the next 10 years given the decision criteria.

## 2.1 Model Decision Criteria

The decision to develop the model framework is predicated on the finding that conducting an HFE under sand enriched conditions has the potential to build sandbars repeatedly. "*Three definitive conclusions that have important implications for designing future sediment-management strategies can be drawn from these studies:*

1) *HFEs are effective at building sandbars by transferring sand from the channel bed to sandbars along the channel margins*
2) *HFEs conducted soon after tributary-derived sand has accumulated on the channel bed are more effective at building sandbars, and less likely to result in erosion of sand stored on the channel bed and in sandbars prior to the tributary inputs, compared to HFEs conducted when sand in the mainstem is depleted*
3) *Sandbars tend to erode quickly in the weeks and months following HFEs, depending on flow releases from the dam as well as ongoing tributary sand supply"* (Wright and Kennedy, in press).

Based on these findings, the 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 and there is still space available to deposit sand; thus high flows should be of as long a duration as can be maintained with available sand.
- For each October-November and March-April HFE implementation months, 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.

From the findings and subsequent model decision making criteria, the model framework was created to ensure that an HFE would only be conducted under sand enriched conditions in an accounting period. Therefore, the sand balance in any one accounting period must be positive for an HFE to occur. In addition, multiple HFEs (maximum of two) can be conducted in a year if conditions warrant. This potentially compensates for the erosion that will inevitably occur between sandbar building/flood events.

The framework of the model is outlined below:

1. The sand balance at the beginning of the sediment year, July 1st is the starting point for the fall accounting period (July 1st to November 30th).
2. As sand is supplied from the Paria River or ungaged tributaries and exported downstream, the model keeps track of the cumulative sand balance in the accounting period for the sum of upper and lower Marble Canyon (reaches 1 and 2).
3. On November 1st the model determines whether an HFE can be implemented. The decision is based solely on the cumulative sand balance at the end of the accounting period.
    a. The model runs through the list of possible HFEs in the order provided.
    b. For each HFE, it inserts the HFE hydrograph on the 1st of the month, calculates steady flow for the remainder of the month so the amount of additional water required for the HFE is provided from the HFE month, and determines if the cumulative sand balance is positive on November 30th.
        i. If the cumulative sand balance is positive, the HFE is selected, and the model moves to the next accounting period.
        ii. If the cumulative sand balance is negative, the next HFE in the list is tested.
        iii. If the last HFE in the list produces a negative cumulative sand balance, the model will not conduct an HFE and moves to the next accounting period.
4. The sand balance on December 1st is the starting point for the spring accounting period (December 1st to June 30th).
5. The model repeats steps 2 and 3 for the next accounting period using April 1st instead of November 1st.
6. The model repeats steps 1 through 5 for the next nine years of interest.

A more detailed flow chart of the modeling process is shown in Figure 2. This framework is for the modeling protocol only. In practice the implementation protocol will be different and will potentially include decision points on October 1st and March 1st in addition to November 1st and April 1st so that there is sufficient time for the decision process.

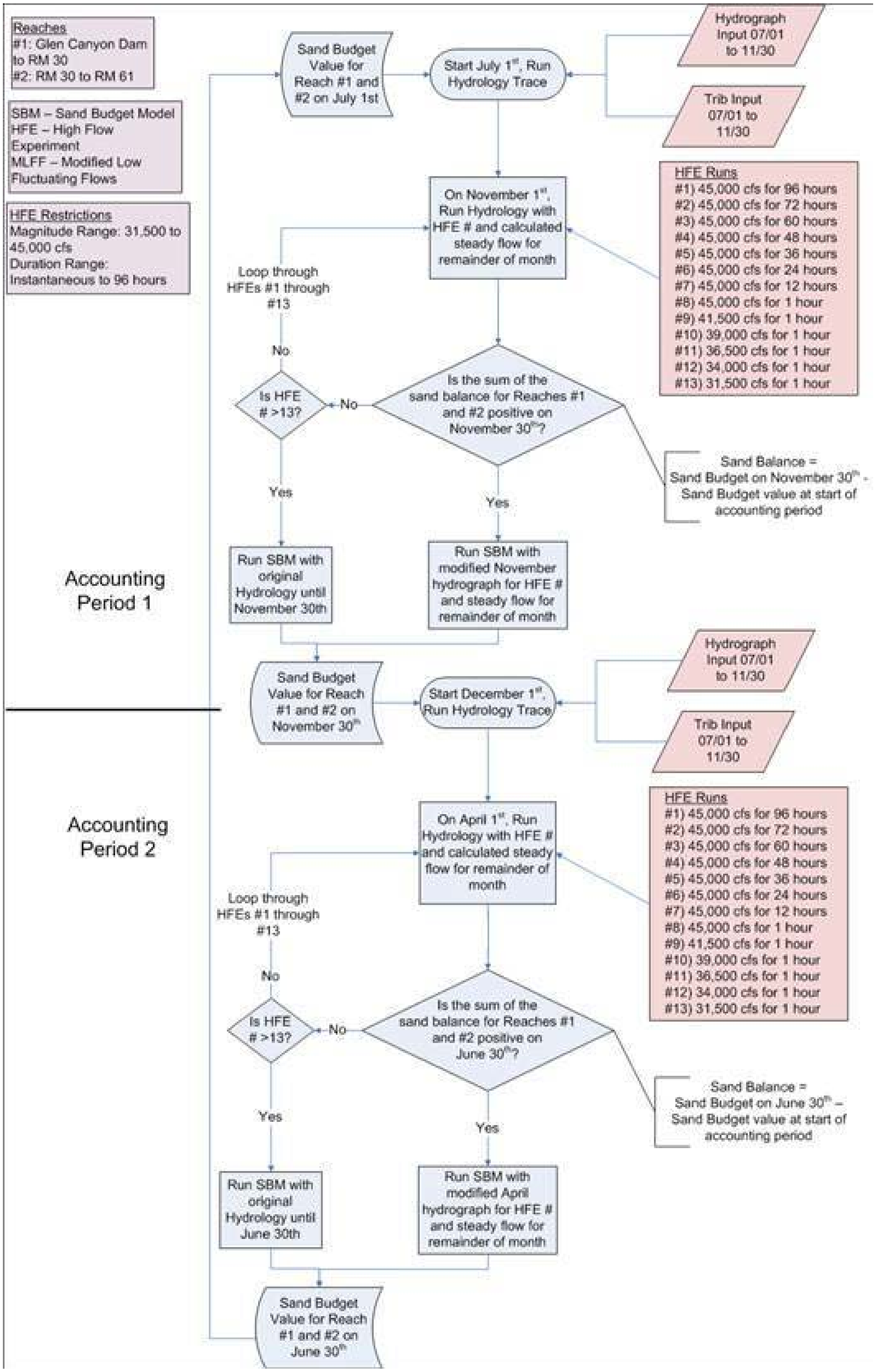



Figure 2. Detailed flow chart of modified sand budget model framework.

## 2.2 Model Assumptions and Limitations

The original sand budget numerical model (Wright et al. 2010) can be implemented for a variety of uses; however there are limitations due to the empiricism and simplifications made in the model. In summary, the model limitations are:

- The model parameters' coefficients are specific to the study reach (Colorado River below Glen Canyon Dam).
- The model does not capture effects of the pool-rapid-eddy morphology on sediment transport.
    - The model does not distinguish between sand on the main channel bed, eddies, and within the sandbars.
- The model doesn't account for changes in the area of sand covering the bed at a given time.
- The model cannot capture rapid changes in bed particle size and suspended-sand concentration.
    - The model cannot accurately capture changes due to tributary flooding.
- The model cannot capture particle size changes in relation to elevation. It is assumed that the sand is completely mixed.
    - The model does not include bed armoring effects.

In addition to the limitations of the sand budget model, there are also boundaries to the applicability and uses of the modified sand budget model. These limitations are described in the following sections.

### 2.2.1 General Limitations

- The model does not include any stakeholder/cooperating agency input which might modify or cancel a scheduled HFE. In addition the model does not incorporate any factors other than sand balance such as past HFE response, present sandbar volume, habitat conditions, cultural resources, etc.
- All 10-year simulations are assumed to be "perfect knowledge" of the future. Therefore, the model uses information in future months to make decisions in the current month.

### 2.2.2 Sediment Limitations

- Sandbar building is not assessed in the model. The model only considers sand mass balance; it does not differentiate between sediment in the channel and sediment in the sandbars. Based on monitoring, floods have been shown to transfer sand from the channel to the bars.
- The sand transport at the upstream boundary (Glen Canyon Dam) is zero.
- Flow from the Paria River is ignored; only the sediment inputs are used.
- Sand from the Paria River is input as average monthly loads and does not include any affects related to the magnitude and intensity of tributary flooding.

- To account for ungaged tributaries in upper Marble Canyon, the Paria River sediment inputs are increased by 10%.
- The model does not include any input from the Little Colorado River because they occur at the downstream end of Marble Canyon. Therefore only results from reaches 1 and 2 are considered in the HFE decision.
- The modified sand budget model provides the predicted sand balance. In practice, comparisions of the observed and predicted sand balances should be monitored.

### 2.2.3 Discharge Limitations

- The model only attempts a discrete number of HFE options. In reality, a wide range of HFE flow magnitudes and durations could be implemented.
- The model only allows an HFE to be implemented starting on April 1st and/or November 1st of a given water year. In practice, HFEs could occur on any day in the months of October-November or March-April as specified in the Environmental Assessment.
- The model is not able to simulate Modified Low Fluctuating Flows (MLFF) powerplant releases during the remainder of the month that an HFE is conducted. If an HFE is conducted, the flow in the remainder of the implementation month is assumed to be steady flow. In practice the remainder of the implementation month may have fluctuating flow.
- 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 flow release volume also could be accommodated by adjustment to the monthly release volumes for the remainder of the water year.

## 2.3 Model Input

Key input parameters to the modified sand budget model consist of release hydrographs and tributary inputs.

### 2.3.1 Release Hydrographs

The Glen Canyon Dam release hydrographs were based on simulations run in Colorado River Simulation System (CRSS) model by Grantz and Patno, 2010. The operation of Lake Powell and Lake Mead in the CRSS modeling is pursuant to the December 2007 Record of Decision on Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and Lake Mead (Interim Guidelines), which includes the equalization operational tier. Upper Basin depletions come from the new (2007) Upper Colorado River Commission (UCRC) depletion schedule. The new Intentionally Created Storage (ICS) assumptions used in the bi-national modeling effort and in the official January 2010 CRSS run were also used.

To produce the traces, 500 simulations were run with the nonparametric paleo-conditioned (NPC) inflow hydrology. Based on a statistical analysis of the ranked average annual inflow volumes from 2010-2019, five dry, five moderate, and five wet traces were selected. The dry traces were closest to the 10% non-exceedance, moderate traces closest to 50% non-exceeedance, and wet traces closest to 90% non-exceedance. The Glen Canyon Dam annual releases corresponding to the 15 NPC inflow hydrologies were evaluated by visual inspection to select the traces with the greatest variability, the least amount of trend and eliminate those with step-functions. A wet, moderate and dry trace that maintained the consecutive ten-year duration was selected (Grantz and Patno, 2010).

CRSS distributes the Glen Canyon Dam annual release volumes on a monthly basis pursuant to rules consistent in the detailed criteria and operating plans contained in the 1996 Glen Canyon Dam Record of Decision (1996 ROD). This operation criteria is referred to in the 1996 ROD as MLFF. MLFF operating criteria exist for both daily and hourly operations at Glen Canyon Dam. The traces were disaggregated into hourly releases while maintaining the operational requirements of the MLFF operating criteria. Figure 3 shows the yearly volumes for each trace.

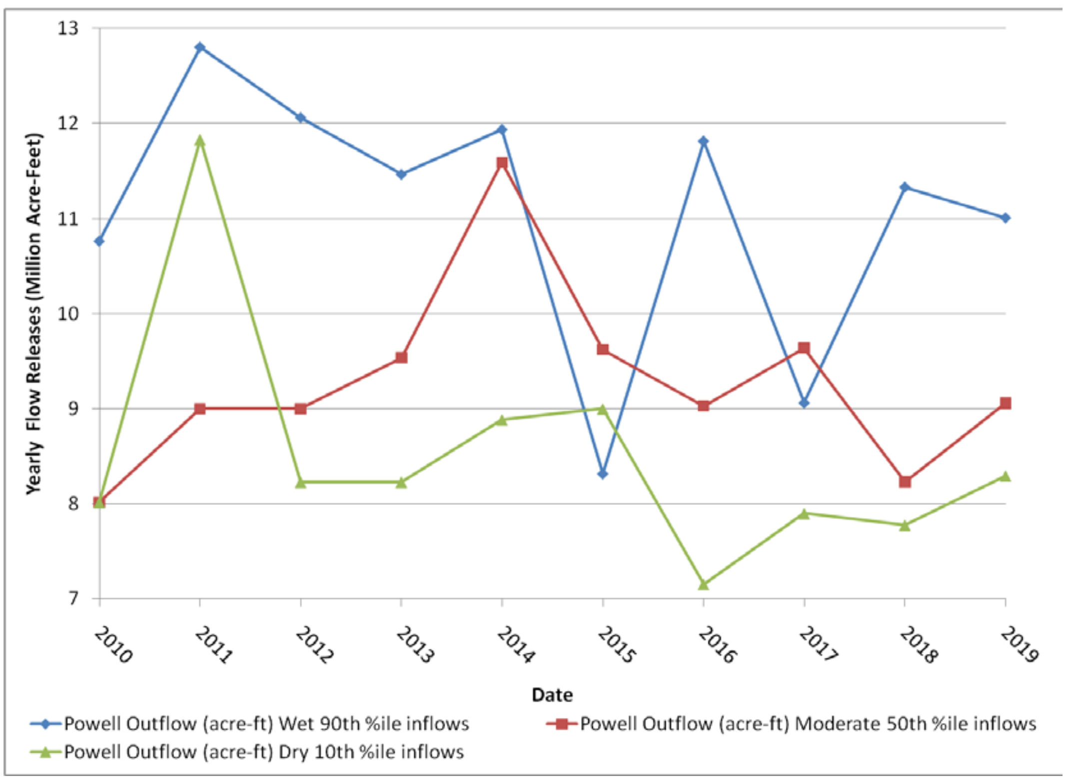


Figure 3. Yearly volumes for three Glen Canyon Dam release traces.

The Colorado River Flow, Stage, and Sediment (CRFSS) model has a reach-averaged one-dimensional, unsteady-flow model component. This component was used to route the three hydrology traces to calculate the hydrographs at RM 31, RM 60, and RM 87.3 to generate input for the modified sand budget model. The CRFSS model uses average channel geometry based on previously measured cross sections in Marble and Grand Canyons (Wiele and Griffin 1996, Wiele and Smith 1997).

In addition to routing the hydrology traces, the CRFSS model was also used to route the HFE hydrographs. Thirteen options for HFEs were tested in the modified sand budget model ranging from a peak discharge of 45,000 $ft^3$/sec with peak duration of 96 hours to a peak discharge of 31,500 $ft^3$/sec with a peak duration of 1 hour.

Table 1 shows the list of HFE options. The options were chosen to 1) maximize the peak discharge, 2) decrease the peak duration and 3) then decrease the peak discharge.

Table 1. List of possible HFEs tested by the modified sand budget model in order of preference.

| HFE No. | Peak Magnitude ($ft^3$/sec) | Peak Duration (hrs) |
|---|---|---|
| 1 | 45,000 | 96 |
| 2 | 45,000 | 72 |
| 3 | 45,000 | 60 |
| 4 | 45,000 | 48 |
| 5 | 45,000 | 36 |
| 6 | 45,000 | 24 |
| 7 | 45,000 | 12 |
| 8 | 45,000 | 1 |
| 9 | 41,500 | 1 |
| 10 | 39,000 | 1 |
| 11 | 36,500 | 1 |
| 12 | 34,000 | 1 |
| 13 | 31,500 | 1 |

Each HFE has an upramp rate of 4,000 $ft^3$/sec/hour and a downramp rate of 1,500 $ft^3$/sec/hour to follow MLFF criteria. Figure 4 shows an example of the dam release hydrograph (blue color) with the CRFSS generated hydrographs at RM 31 and RM 60. There is a lag time in the peak duration; however there is no attenuation of the peak magnitude.

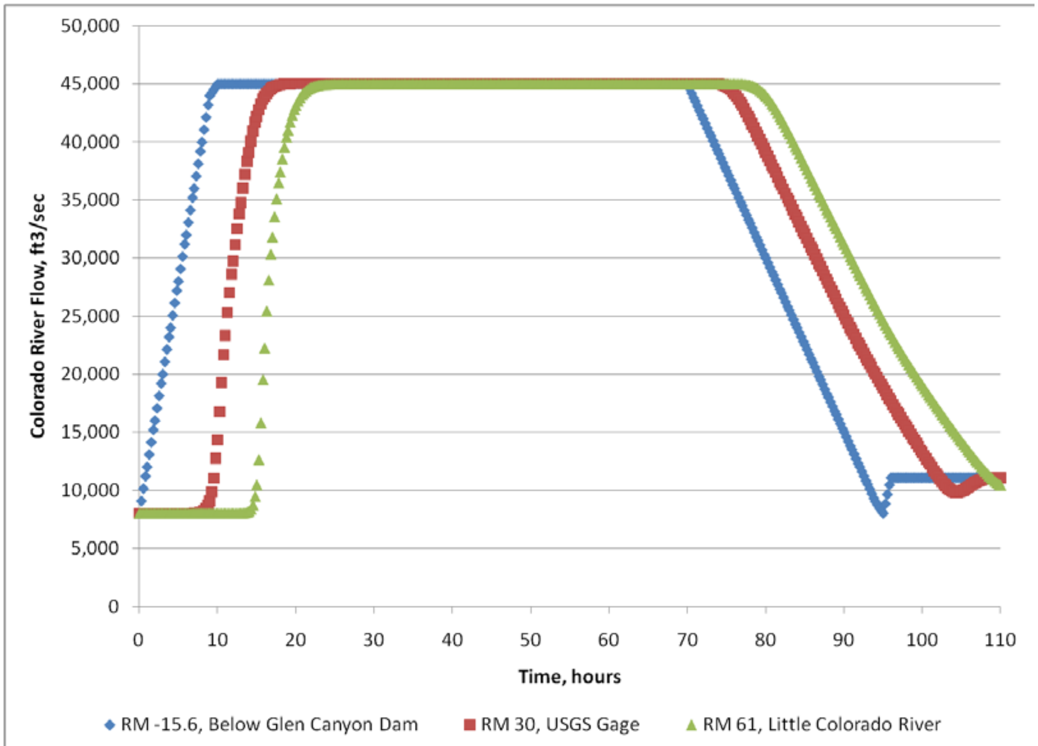


Figure 4. Flow hydrographs for HFE 3 (45,000 $ft^3$/sec for 60 hours) at RM -15.6, RM 30, and RM 61.

### 2.3.2 Tributary Inputs

The tributary inputs were developed by analyzing the Paria River sand-load record provided by USGS Grand Canyon Monitoring and Research Center (David Topping, U.S. Geological Survey, unpub. data) using a stochastic method. A forward looking ten-year (calendar year) moving average was calculated and then ranked. Figure 5 shows the results of the ten-year moving average.

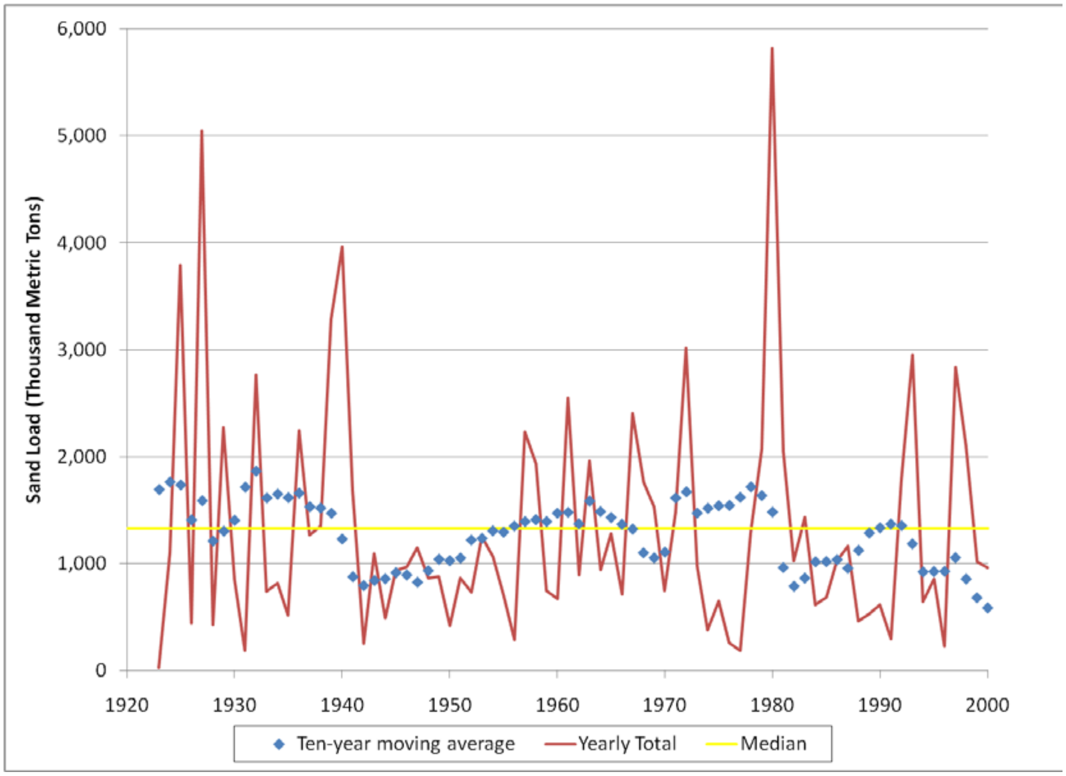
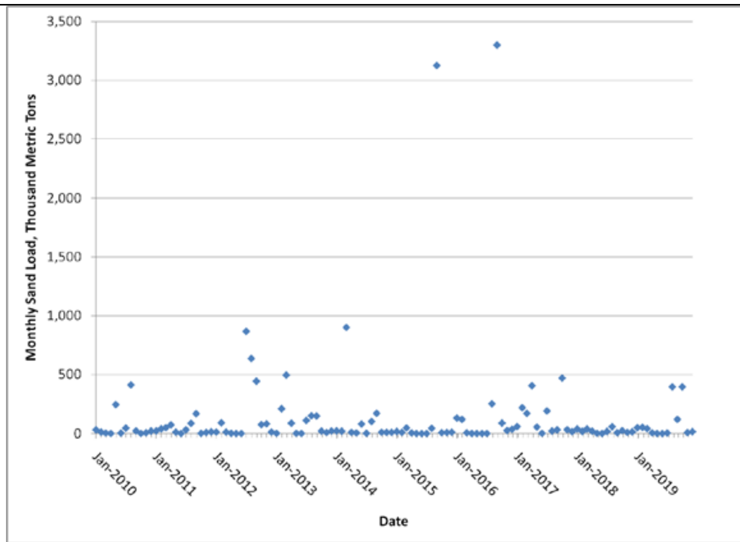



Figure 5. Yearly Paria River sand loads with calculated ten-year moving average.

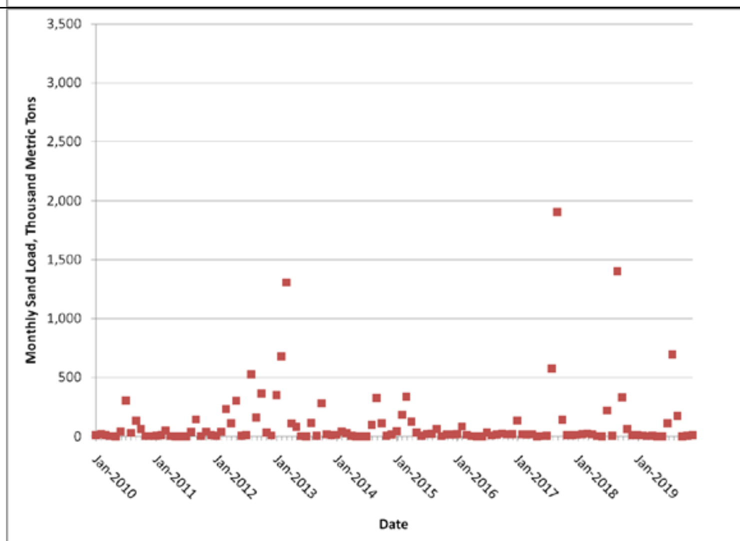
Three ten-year historical traces were selected from the ranked ten-year moving averages. 1983-1992 was selected as the 10% non-exceedance or low sediment trace. The 50% non-exceedance or moderate sediment trace selected was the sediment data from 1990-1999. The 90% non-exceedance or high sediment trace selected was from 1934-1943. The monthly sand loads for each trace are shown in Figure 6.

For each trace the monthly load was divided into 15 minute time step values to meet the sand budget model input requirements. Using an average monthly load rather than instantaneous sediment data does not take into account the effects of short duration tributary flooding. The total monthly load of sediment is valid and the simplification is assumed to not impact the results since the accumulation periods are over multiple months.

a) High Sediment Monthly Load Trace




b) Moderate Sediment Monthly Load Trace




c) Low Sediment Monthly Load Trace

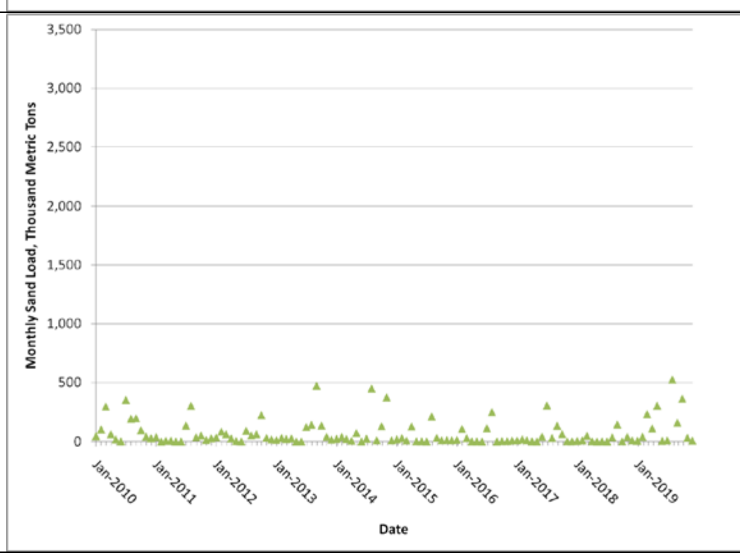



Figure 6. Total monthly sediment loads for the low, moderate, and high Paria River sediment traces.

### 2.3.3 Antecedent Conditions

The transport relation parameters' values, developed by Wright et. al. 2010, were unchanged for the modified sand budget model. The sand thickness, bed material gradation, and particles size distribution used are shown in Table 2. These values represent the March 2009 conditions (end of the validation simulation for the sand budget model) and were previously developed for simulations completed by Wright and Grams (2010).

Table 2. Initial bed and sediment conditions for the sand budget model reaches.

| | **Upper Marble Canyon** | **Lower Marble Canyon** | **Eastern Grand Canyon** |
|---|---|---|---|
| Bed thickness (m) | 0.45 | 0.48 | 0.56 |
| Bed $D_{50}$ (mm) | 0.35 | 0.32 | 0.30 |
| Particle size distribution standard deviation | 2.0 | 2.0 | 2.0 |

### 2.3.4 Simulations

The modified sand budget model was used to simulate nine combinations of hydrology and tributary sediment traces shown in Table 3.

Table 3. Modified sand budget model simulations completed.

| **Hydrology input** | **Tributary input** |
|---|---|
| 10% hydrology trace | 10% tributary sand supply<br>50% tributary sand supply<br>90% tributary sand supply |
| 50% hydrology trace | 10% tributary sand supply<br>50% tributary sand supply<br>90% tributary sand supply |
| 90% hydrology trace | 10% tributary sand supply<br>50% tributary sand supply<br>90% tributary sand supply |

# 3 Results and Discussion

## 3.1 Modified Sand Budget Modeling

The model outputs include the number of HFEs that would occur during each ten-year simulation 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. Although nine simulations were completed, this section focuses on the moderate hydrology coupled with the moderate sediment simulation. Appendix A has the results of all nine simulations. It should be noted that the hydrology and sediment traces are all predictions of what may happen. It is unlikely that the actual hydrology and sediment conditions will exactly match any of the scenarios tested, but the range of simulations should cover the range of likely results.

The different traces do not have an equal probability of occurring; however there are some general trends that can be seen in looking at the entire set. For the nine traces, there were 180 opportunities for an HFE to occur. 100 of 180 HFEs were selected in the modeling or 56% of the time an HFE was selected. Of these HFE's, 92% had a peak magnitude of 45,000 $ft^3$/sec. The HFE that was selected most frequently had a peak magnitude of 45,000 $ft^3$/sec for 96 hours. Typically HFEs occur in groups; 80% of the HFEs had at least one other HFE in a neighboring accounting period.

The nine traces produce more variability than the moderate hydrology, moderate sediment trace. Table 4 displays the HFEs selected by the model to be conducted with the moderate hydrology, moderate sediment trace. For this trace, there were no HFEs selected with a peak magnitude less than 45,000 $ft^3$/sec. However, the peak discharge durations varied from 1 hour to 96 hours. HFEs occur in both April and November. Some years have two HFEs, while some years do not have any HFEs. The maximum length without an HFE is 18 months. There is one period where there are four consecutive HFEs. The amount of water required to be reallocated in this trace varied from 45,000 to 326,000 acre-feet.

Table 4. HFEs to be conducted for the moderate hydrology, moderate sediment trace.

| Month of Potential HFE | HFE No. | Peak Magnitude ($ft^3$/sec) | Peak Duration (hrs) |
|---|---|---|---|
| 4/1/2010 | | | |
| 11/1/2010 | 6 | 45,000 | 24 |
| 4/1/2011 | | | |
| 11/1/2011 | | | |
| 4/1/2012 | 2 | 45,000 | 72 |
| 11/1/2012 | 2 | 45,000 | 72 |
| 4/1/2013 | 1 | 45,000 | 96 |
| 11/1/2013 | 8 | 45,000 | 1 |
| 4/1/2014 | | | |
| 11/1/2014 | | | |
| 4/1/2015 | 1 | 45,000 | 96 |
| 11/1/2015 | | | |
| 4/1/2016 | 8 | 45,000 | 1 |
| 11/1/2016 | | | |
| 4/1/2017 | | | |
| 11/1/2017 | 1 | 45,000 | 96 |
| 4/1/2018 | | | |
| 11/1/2018 | 1 | 45,000 | 96 |
| 4/21/2019 | | | |
| 11/1/2019 | 6 | 45,000 | 24 |

Based on the model results, the occurrence of an HFE can be triggered by a certain level of sediment regardless of the hydrology. The average monthly Paria sand load that always results in an HFE was 500,000 metric tons. This may not be a correct value under all circumstances, but was valid for the nine traces simulated in the model. Figure 7 shows the average daily dam releases and the sand load with the HFE months marked for the moderate hydrology, moderate sediment trace. When the sand supply rate is below 500,000 metric tons per month, an HFE may or may not occur depending on the overall sand balance and the hydrology. For example, the September, 2011 monthly load is 143,000 metric tons per month and an HFE is not selected to occur in November, 2011. However in February, 2016 the monthly load is 82,000 metric tons per month and an HFE is selected to occur in April, 2016. The upstream sediment supply rate can override the hydrology and antecedent conditions in the modeling traces if it was larger than 500,000 metric tons, otherwise the other variables play a more significant role.

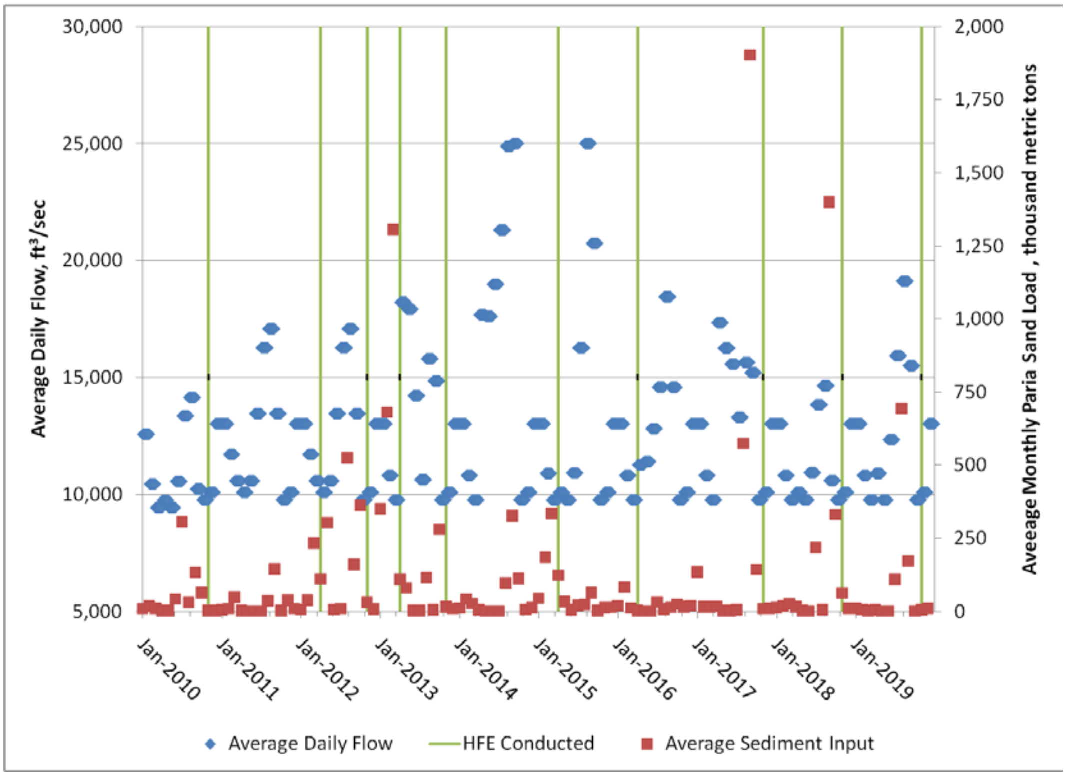



Figure 7. Average daily flow and average monthly sand loads for the moderate hydrology, moderate sediment trace with the HFEs resulting from the modified sand budget model.

Figure 8 tracks the cumulative sand balance throughout the modeling timeframe. The starting point, or zero, is the amount of sediment in the system on January 1, 2010. This is an arbitrary starting condition and is not meant to represent an optimal, average or target amount of sand in the system. Rather, it is a point of reference for the modeling. Since the modeling only considers the sand balance within each individual accounting period and resets at the beginning of each accounting period, this starting condition does not influence whether an HFE is conducted or not for any period, other than from January, 2010 through June, 2010. An HFE will be scheduled as long as there is a positive sand balance within the accounting period even if the cumulative sand balance, as displayed in Figure 8, is negative.

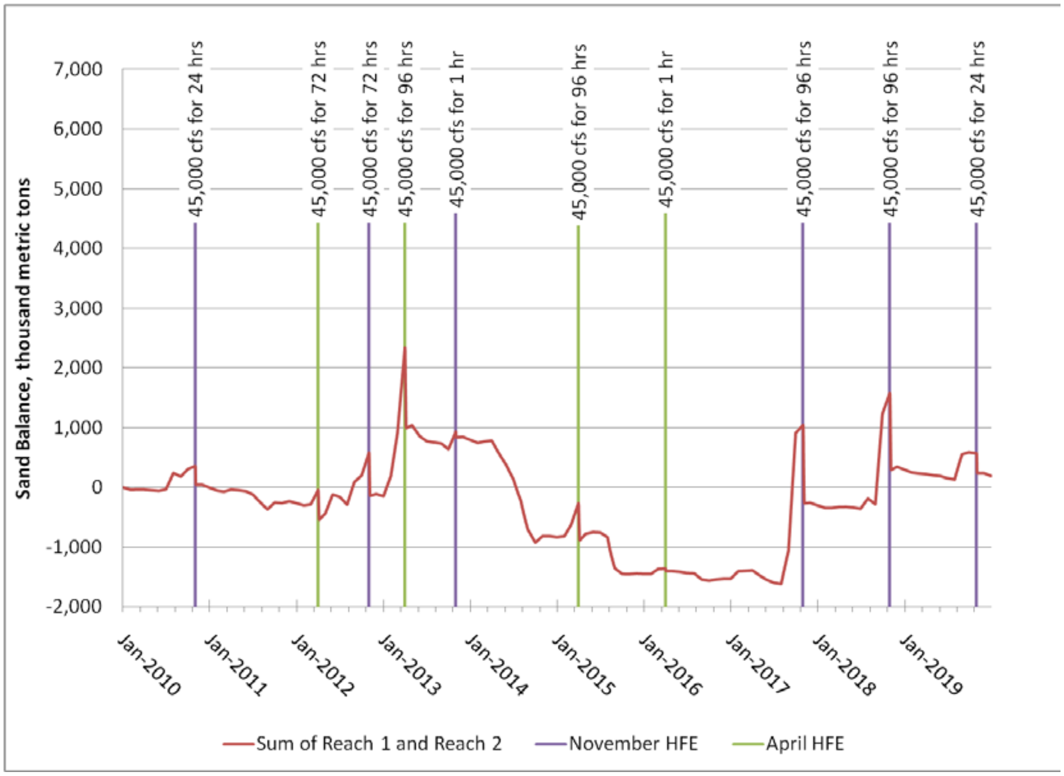


Figure 8. The cumulative sand balance (sum of Reach 1 and Reach 2) for the moderate hydrology, moderate sediment trace with the HFEs resulting from the modified sand budget model.

One of the concerns with conducting multiple HFEs, is the overall mass sand budget. For the moderate hydrology, moderate sediment trace, the ten-year overall sand budget increases by 99,000 metric tons. Of the nine traces simulated, five are negative and four are positive. The goal is to utilize the sediment when it enters the system to build sandbars, but not to drive the entire system into a large sediment deficit through the use of HFEs. It was possible to accomplish this goal in all the simulated traces.

It is important to realize that sand is being transported downstream and exported out of each of the reaches whether an HFE is conducted or not. Topping et al. (2000) discussed that in the pre-dam era, sediment was being conveyed or eroded when flows were over 8,800 $ft^3$/sec. The majority of times during MLFF, dam releases are over 8,800 $ft^3$/sec. The effects of regular dam releases without an HFE can be seen in Figure 8 between January, 2014 and January, 2015. No HFE was selected to occur in this year, but the sand balance decreased 1,630,700 metric tons. In addition, there were not many tributary inputs during this time (Figure 7).

Since sand is being exported whether or not an HFE occurs, it is still important to utilize “new” tributary sand when possible even if the overall sand balance is negative. This ensures that sand is moved to higher elevations before downstream transport. The April 2015 HFE is a good example of when this occurs. In March, 2015 the average monthly sand input is 335,000 metric tons. Although the overall sand balance is negative, an HFE is scheduled to utilize the recent input sand and relocate the sand to higher elevations.

## 3.2 Qualitative Sandbar Assessment

The model only considers sand mass balance; it does not differentiate between sediment in the channel and sediment in the sandbars. However, anticipated sandbar response to an HFE can be concluded from the literature available on previous high flows. To date, there have been three high-flow experiments as well as three habitat-maintenance flows, which can be considered smaller discharge high-flow experiments. A quick summary of the high-flow experiments is displayed in Table 5 and described below.

Table 5. Previously conducted high flow experiment parameters.

| Date | Peak Magnitude ($ft^3/sec$) | Peak Duration (hr) |
|---|---|---|
| March-April, 1996 | 45,000 | 168 |
| November, 1997 | 30,700 | 48 |
| May, 2000 | 30,700 | 72 |
| September, 2000 | 30,700 | 96 |
| November, 2004 | 42,000 | 60 |
| March, 2008 | 42,500 | 60 |

The 1996 HFE was conducted without a recent tributary input. The HFE resulted in increases to sand volume at elevations around the 25,000 $ft^3/sec$ water surface elevation and scour to lower elevation eddies. "*Results from the 1996 controlled flood experiment indicate that, during sediment-depleted conditions, sand deposited at higher elevation in downstream eddy sandbars is derived from the lower-elevation parts of upstream sandbars. Thus, controlled floods conducted under these conditions result in decreases in total eddy-sandbar area and volume (especially in Marble Canyon)*" (Topping et. al. 2006). It is not recommended to run future HFEs when these is no recent tributary sediment input and the channel sediment is depleted since it will erode sediment from long-term eddy storage (Hazel et. al. 2006a).

The 1997 high flow of 30,700 $ft^3/s$ was conducted in November after Paria River flooding in August and September (Hazel et. al. 2000). The flow did not completely inundate the sand bars and the net bar thickness above 25,000 $ft^3/sec$ did not increase. This was due to erosion of the existing high-elevation deposits offsetting any new deposition.

In 2000, another set of powerplant capacity flows (30,700 $ft^3/s$) were released during the low summer steady flows (LSSF) experiment. Unfortunately, there were little tributary sand inputs during 2000. Still the May and September 2000

HFEs did significantly increase volume and area of fine sediment in the eddy sandbars between the 8,000 $ft^3$/sec elevation and the 25,000 $ft^3$/sec elevation (Schmidt et. al. 2007). Changes above 25,000 $ft^3$/sec elevation were insignificant because these elevations were not deeply inundated. The volume below the 8,000 $ft^3$/sec water surface elevation decreased. Comparing the September 2000 HFE with the 1996 HFE shows that "*6 times less sediment was deposited as high-elevation eddy bars and channel-margin deposits, during the lower-discharge September 2000 Powerplant Capacity Flow, and a greater percentage of sediment was exported from Marble Canyon*." (Hazel et. al. 2006).

For the 2004 HFE, it was estimated that about 0.63 million metric tons of sand was supplied from the Paria River in the previous year (Topping et. al. 2010). The 2008 HFE had 1.12 million metric tons of sand. In 2004, the sandbars in Upper Marble Canyon were larger in total volume and area than after the 1996 flood. However, in Lower Marble Canyon, only 18% of the sandbars were larger in total volume and area above the 8,000 ft3/sec elevation than following the 1996 flood (Topping 2006). This was due to the fact that most of the new tributary sand in the system was located in Upper Marble Canyon when the HFE was conducted.

Based on monitoring surveys, the 2008 HFE deposited sand above the elevation reached by 25,000 $ft^3$/sec at nearly every study sight (Hazel et. al. 2010). Sandbars did not have a consistent response to the HFE, the total eddy thickness change are from -1.88 m to 1.13 m. Often, deposition above the 8,000 $ft^3$/sec elevation was offset by erosion below this elevation. The results showed that the total-site sand volume was greater for the 2008 HFE than for the 1996 and 2004 HFEs (Hazel et. al. 2010). In addition, there was less erosion at low elevations and in the main channel than from the 1996 and 2004 HFEs.

There was not a consistent response from every sandbar in Marble Canyon. The increases that are presented for total sand volume do not represent the site specific changes. There were four styles of sandbar change documented in the 2008 HFE response (Hazel et. al. 2010). The most common response was Style 1 (45%), which is characterized by a net increase in sand volume above and below the 8,000 $ft^3$/sec elevation. Style 2 (37%) is characterized by an increase in volume above the 8,000 $ft^3$/sec elevation, and degradation below this stage. Style 3 (16%) is characterized as net erosion at all stages and Style 4, which occurred at 1 site, is erosion above the 8,000 $ft^3$/sec stage and deposition below (Hazel et. al. 2010).

Using the comparison of the HFEs several lessons were discovered to be implemented of future HFEs. These are:

- A higher magnitude of flow will produce a larger sandbar response. Using a stage-discharge relationship developed for multiple locations within Marble Canyon (Hazel et. al. 2006b), the predicted stage increase is 3.5 feet between 31,500 $ft^3$/sec and 45,000 $ft^3$/sec. Therefore the sand can be deposited in higher available space for larger magnitude HFEs.

- The antecedent conditions are an important factor in the sandbar response. The three flows above 42,000 $ft^3$/sec resulted in increases in sandbar volume above the 8,000 $ft^3$/sec water surface elevation. Even though levels of sand enrichment were different for the three flows, the sandbar volume above 8,000 $ft^3$/sec was similar in Marble Canyon (Grams et. al. 2010). However, the 1996 flood *"resulted in a large net decrease in the total sand volume contained at the study site in Marble Canyon, while the 2004 and 2008 controlled floods resulted in smaller decreases in total sand volume"* (Grams et. al. 2010). Therefore, lesser enrichment results in greater erosion from the lower elevation portions of the eddies and degradation of the overall sand balance. This may not be a concern when HFEs are occurring many years apart and there is time to increase the sand balance with tributary inputs. However, if HFEs are happening once or twice per year, the overall sand balance and sand in the lower portions of the eddies becomes more of a concern.

These lessons were applied to the protocol that was set up for the EA. Based on the sandbar responses from previous HFEs, sand will be transported from lower eddy elevations to the higher elevations. The sandbars will begin to erode following an HFE. After the 2008 flood the median sandbar volume had returned to pre-HFE values in Marble Canyon 6 months after the HFE. The rate of erosion after each HFE differed and was "*positively correlated with the magnitude of average dam releases and inversely related to the magnitude of Paria River sand inputs for Marble Canyon*" (Grams et. al. 2010). The 2004 HFE has the lowest erosion rates while the 1996 HFE had the highest. These results provide motivation to conduct HFEs often to reverse the erosion that will inevitably occur. No experiments have been conducted where HFEs could potentially occur as often as every six months, monitoring and tracking the results and effects from repeated HFEs will be necessary.

Based on the literature summarized above, the HFEs recommended to occur by the modified sand budget model will cause an increase in the sand volume above the 8,000 $ft^3$/sec water surface elevation. Some sediment will be eroded from the lower eddies, but this amount will be minimized based on previous tributary sand inputs ensuring the system is not depleted. The redistributed sand will erode in the months following the HFE and the rate will be dependent on dam releases and any new tributary sand inputs.

A concept discussed in the existing literature is accommodation space, which is defined as the amount of space any one sandbar has to store sand. The success of frequent HFEs will depend on how much accommodation space is emptied from the previous HFE and available for sand storage in the next HFE. Depending on the rate of erosion there may be a diminishing rate of return on conducting multiple and consecutive HFEs. However, if the erosion rate is rapid, there may always be enough accommodation space in the sandbars to make an HFE efficient and successful at redistributing the sand to higher elevations. It is unknown how the system will react to frequent HFEs or multiple consecutive HFEs.

# 4 Conclusions

For the EA being produced by Bureau of Reclamation, the number of future HFEs (estimated frequency, magnitude, and duration) that could potentially occur was needed. A protocol was developed to determine when the conditions were feasible for an HFE to occur based upon past scientific monitoring and analysis. The protocol states that an HFE should be conducted when the increased flows will not cause a negative sand budget for the current accounting period. In addition, the HFE should be maximized for magnitude and duration to redistribute as much available sand as possible. A sand budget model developed by USGS (Wright 2010) was modified based on the protocol.

Future hydrology and sediment input traces were generated and used to run nine simulations in the modified sand budget model. Based on these, a HFE is performed in 56% of the potential implementation windows. Of these HFE’s, 92% had a peak magnitude of 45,000 $ft^3$/sec. Typically HFEs occur in groups; 80% of the predicted HFEs had an HFE in the neighboring accounting periods. In the model, the occurrence of an HFE can be triggered by a certain level of sediment regardless of the hydrology. For the nine traces, the average monthly Paria sand load that always resulted in an HFE was 500,000 metric tons.

Based on the literature, the HFEs recommended by the modified sand budget model will cause an increase in the sand volume above the 8,000 $ft^3$/sec water surface elevation. Some sediment will be eroded from the lower eddies, but this amount will be minimized based on previous tributary sand inputs ensuring the system is not depleted. The redistributed sand will erode in the months following the HFE and the rate will be dependent on dam releases and any new tributary sand inputs.

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# Appendix F: Methods for Estimating the Impacts of HFEs on Hydropower at Glen Canyon Dam

Assumptions and Methodologies:

The implementation of an HFE requires that water released through Glen Canyon Dam (GCD) be redistributed from when it would have been released in the no action case to another month, day or hour to produce the desired HFE. While most of the water that is redistributed to implement an HFE is released through the powerplant, some of the redistributed water bypasses the powerplant. The primary economic impact of an HFE comes from this redistribution of water.

The amount of water redistributed to implement an HFE varies significantly from one HFE to another. Table 1 below provides a summary of the water used in each of the 13 HFEs.

Table 1
Water Volume Required for Each of 13 HFEs

| | HFE Total (af) | Bypass (af) |
|---|---|---|
| HFE#1 | 344,628 | 100,413 |
| HFE#2 | 271,240 | 76,612 |
| HFE#3 | 234,545 | 64,711 |
| HFE#4 | 197,851 | 52,810 |
| HFE#5 | 161,157 | 40,909 |
| HFE#6 | 124,463 | 29,008 |
| HFE#7 | 87,769 | 17,107 |
| HFE#8 | 54,132 | 6,198 |
| HFE#9 | 44,215 | 3,182 |
| HFE#10 | 37,025 | 1,488 |
| HFE#11 | 32,810 | 744 |
| HFE#12 | 26,653 | 83 |
| HFE#13 | 21,157 | 0 |

Description of Analysis Method[4]: Computing Energy and Capacity Prices
ENERGY: Electricity is unique among energy sources in that it must be produced at the same instant that it is needed by customers. Storing electricity on a utility scale is costly and

4 The analysis for this EA was completed by Western Area Power Administration, CRSP Management Center in Salt Lake City.

so it is not done except in a few special circumstances. Since electricity cannot be stored like other energy sources such as oil or natural gas, *when* electricity is generated has a large effect on how valuable it is to customers, and the price utilities are willing to pay for it. Electricity generated in the middle of the night, or on a Sunday, or in the month of October or April is worth less because people use less electricity at those times. Conversely, electricity generated at noon on a weekday, and in a month such as July or August is worth a lot more because people and businesses are using a lot of electricity during those times.
When Western analyzes what a particular change in the operations of a hydroelectric powerplant such as GCD costs, the overriding factor in determining the value is changes to, or restrictions to, *when* the power is generated.

An important step in calculating the cost of HFEs is deciding what price of electrical power (capacity and energy) should used in the analysis by determining how much the electricity that is being produced will cost the customers. For this analysis, electricity futures prices were used for pricing electrical energy. Futures prices are commercially available projections of the price electric energy will sell for during a particular period of time in the future, delivered at a particular location on the electrical grid.

Energy futures prices are widely used in the electrical utility industry for buying and selling energy to be delivered at a future date. Futures prices are quoted as a standard product for either on-peak periods (Monday through Saturday, 16 daytime hours) or off-peak periods (8 nighttime hours, plus all day Sunday). Bulk purchases and sales of electrical energy are commonly made in quantities of megawatt hours (one megawatt hour is equal to 1,000 kilowatt hours), and are priced in dollars per megawatt hour, abbreviated $/MWh. The price is quoted at a particular location on the electrical transmission system ("trading hub"), usually a location where many buyers and sellers of electricity have access.

One such location is the Palo Verde Nuclear Generating Station, about 50 miles west of Phoenix, Arizona. Western's CRSP Management Center has access to this trading hub and often buys energy there to supplement its deliveries of Federal hydropower to its customers. Because of their widespread use in the western United States power markets, Palo Verde futures prices were used in this analysis. It is important to note that unlike energy, capacity generally cannot be purchased at these trading hubs.

The GTMax model that Western uses to analyze and plan its operations is programmed to have Glen Canyon powerplant generate as much electrical energy and capacity as possible (within operating constraints) during the hours when prices input into the model are highest. The model is designed to maximize the value of the energy produced by releasing water through powerplant turbines at the dam that spin generators to produce electricity. One of the inputs to the model is a set of energy prices that are more expensive during high-load hours relative to prices during low-load hours. Prices follow a pattern that is similar to Western's customers' loads. When the load increases during a low load hour by a small amount, for example one MW, the corresponding increase in price is relatively small. On the other hand, during times of high demand, the same one-MW increase in load will result in a much larger price increase. Therefore, although prices and loads have the same general pattern, the price pattern over time tends to be comparatively flat at night while exhibiting a relatively higher spike during the peak load hours.

The following are steps Western took to prepare energy price data for input into the GTMax model:

On and off-peak futures prices at Palo Verde on April 11, 2011, were obtained from IVG Energy[5]. Western decided for the purposes of this analysis to use a price level of 2016, or halfway through the 10-year analysis period.

IVG futures prices for the year 2016 are specified monthly. To update these prices it was necessary to scale the April 11, 2011, Palo Verde futures prices using a scaling factor. The futures price for natural gas was selected for scaling since natural gas futures prices[6] are available for many years into the future and are available for the past. Also, fuel prices typically account for about 90% of the cost of electricity generation and therefore, there is a close correlation between the price of natural gas and the market price of electricity.
Using the NYMEX gas futures price for April 11, 2011, monthly prices were scaled by about 4.0 to 4.5 percent depending on the month.

Finally, the 2016 monthly on-peak and off-peak prices were increased or decreased from the base value based on historical Western customer loads for that hour. This creates a series of power prices that are scaled to resemble the way that customers typically schedule their power allocations from Western. In that way, power prices enable the GTMax model to allocate more available water for power generation during those hours when it has the highest value to customers, and less water in those hours when it is less valuable.

The result of the above approach is a set of 168 hourly prices (one week long) for each of 12 months of the year at a 2016 price level. That information was then loaded into the GTMax model.

Table 2 documents the on-peak and off-peak energy futures prices by month that were used to scale to hourly prices.

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5 IVG Energy http://www.ivgenergy.com/ provides subscribers with news, information, and power prices that are updated daily.
6 Information on natural gas futures prices was obtained from the CME Group website: http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html

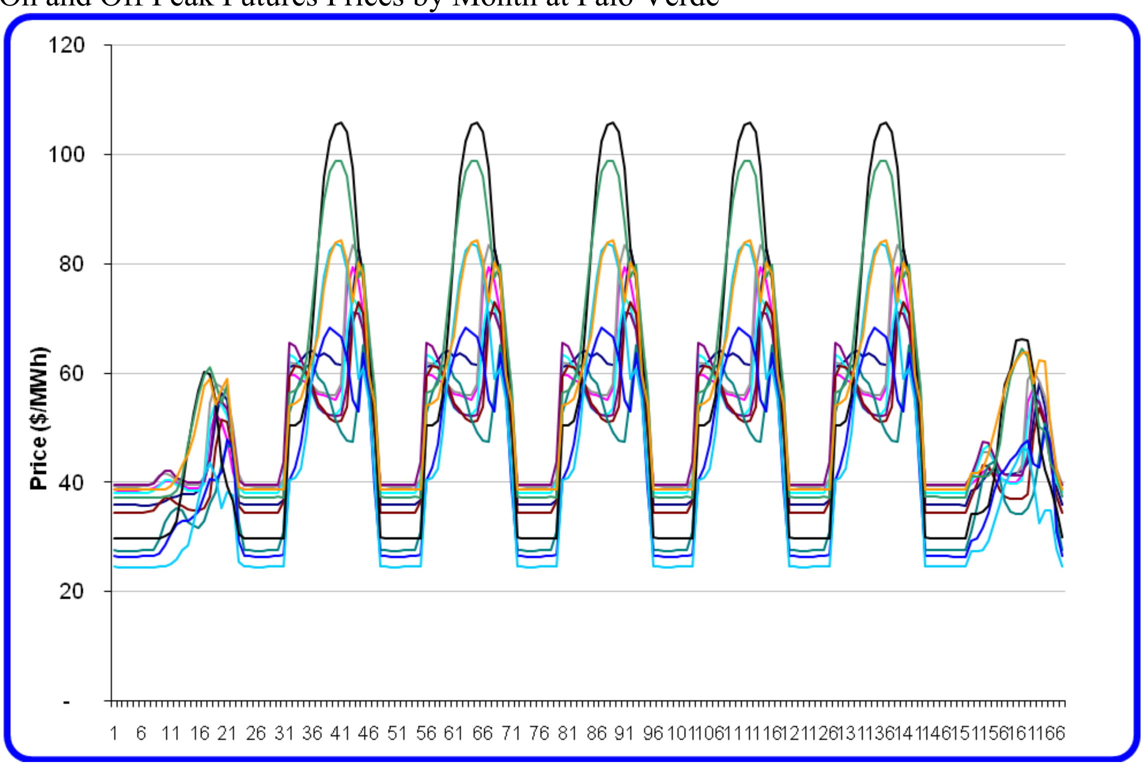
Table 2

2016 On and Off Peak Energy Futures Prices by Month at Palo Verde

| | On-Peak Scaled | Off-Peak Scaled |
|---|---|---|
| Jan | $ 57.31 | $ 39.35 |
| Feb | $ 57.04 | $ 40.79 |
| Mar | $ 54.97 | $ 36.53 |
| Apr | $ 51.77 | $ 30.36 |
| May | $ 53.16 | $ 29.35 |
| Jun | $ 56.87 | $ 27.43 |
| Jul | $ 71.78 | $ 34.12 |
| Aug | $ 71.82 | $ 41.01 |
| Sep | $ 65.52 | $ 41.73 |
| Oct | $ 60.49 | $ 38.43 |
| Nov | $ 58.99 | $ 39.57 |
| Dec | $ 61.53 | $ 40.65 |
| Ave | $ 60.10 | $ 36.61 |

Figure 1 shows the results of this scaling process in $/MWH for a typical week (Sunday through Saturday).

On and Off Peak Futures Prices by Month at Palo Verde




Hours of the Week

The prices shown in Figure 1 were used by GTMax for each of the 10-years of the study period.

CAPACITY: Electrical capacity is defined as the maximum amount of generation that is available from a power plant at any given period of time. Electrical capacity is important because it is necessary for the power system to have sufficient capacity to meet the peak demand, or the result will be problems such as blackouts and brownouts. The changes in operations at GCD from HFEs not only reduce energy production but also reduce the electrical capacity produced by the plant. In addition to the cost of purchasing electrical energy, there is also a cost for electrical capacity. Capacity costs are more related to the cost of constructing a power plant, while energy costs are more related to the cost of operating and maintaining the power plant. Because of this distinction, energy costs tend to change more often, owing to changes in the cost of fuel and personnel, while the cost of electrical capacity tends to remain more constant. Electrical capacity is often specified and priced as a separate product from electrical energy in bulk power purchase and sale transactions. Western, for example, has an energy price and a capacity price as components of its rate for power sales to customers. For this analysis a price of $106.70/kW-year, or about $8.90/kW-month for any changes to capacity has been used. The capacity cost is based on an Advance Combustion Turbine 2011 construction cost.

Under some conditions, an electrical generator must be constructed to replace lost GCD generation as a result of an HFE or series of HFEs. Some uncertainties that must be considered include:

The HFE protocol is proposed as 10-year action. HFEs would be scheduled for October/November and/or March/April. This means water may be added to these months from other months in the year. If implementing the protocol results in a reduction by Western of a capacity commitment to GCD electrical contractors, those contractors will need to add capacity resources as a result.

While Western's contracts for Federal hydropower are based on the capacity of the powerplant and the average electrical energy produced, Western often purchases small amounts of energy from electrical energy exchanges to meet its hourly contractual commitments. When capacity is in short supply in the region in which Western purchases power, or when transmission constraints require additional purchases, the prices Western pays for electrical energy include a capacity premium.

Western's power customers are uncertain as to the stability and availability of the GCD resource under their long-term purchase contracts. Since the planning horizon for the construction of new electrical generators is long (10 – 20 years), utilities that have contracts for Federal power from the Colorado River Storage Project (CRSP) dams may "overbuild" when they undertake new generating capacity construction due to the uncertainty of the GCD resource.

This analysis did not attempt to measure whether new capacity would need to be constructed to replace capacity lost as a result of the HFE protocol. Instead, the difference in available capacity between the No Action and the Proposed Action case for the peak month for each of the hydrologic and sediment cases has been calculated. Having identified those capacity losses, a capacity cost has been applied based on the annualized construction costs of an electrical generator that would be a likely replacement for GCD power.

THE MODELING: Monthly GCD Release Volumes for the No Action and Proposed Action Alternatives

Reclamation used its Riverware reservoir operations model to develop the GCD monthly water release volumes used in this analysis. Twelve 10-year periods of 120 monthly releases, were developed to include all the potential conditions that Reclamation wanted to study. A hydrological condition, with a sand condition, over a 10-year period, is called a trace. Of the 12 traces, three are base case or No Action Alternatives for dry, median, and wet hydrological conditions. These do not have any HFE releases included. The remaining nine traces include three change cases or Proposed Action Alternative traces for dry, median, and wet hydrological conditions. These have HFE releases. Western's GTMax analysis modeled each of the 12 traces for the entire 10-year period.

Monthly Lake Powell Elevations

The three No Action Alternative traces provided by Reclamation included the Lake Powell reservoir elevation associated with each monthly release volume from GCD. The nine Proposed Action Alternative traces provided by Reclamation did not include Lake Powell elevations. Lake elevation is used by the GTMax model in its computations to determine the efficiency at which the hydroelectric generators convert water releases through turbines into electrical power. It was therefore necessary to compute lake elevations associated with each of the 12 traces, not just the three base case traces[7]. Calculations of reservoir elevations are based on an equation that estimates elevations based on the amount of water it holds.

HFE Hourly Release Profiles

For each of the 13 HFEs Reclamation included in the EA, an hourly release profile was constructed in an Excel spreadsheet. Each HFE includes hourly releases in cubic feet per second (cfs) and acre-feet for the entire month in which the HFE occurs. According to the

[7] Calculation method for lake elevations for the Proposed Action traces: 1. Using an equation that relates the water storage volume in Lake Powell to the lake elevation, the base case elevations were converted to equivalent water volumes. 2. For each change case trace associated with that base case trace, the volume of water was increased or decreased each month by that amount that the change case releases differed from the base case releases, resulting in an adjusted storage volume for each month of the change case trace. 3. Using the same equation as in step one above, the adjusted storage volumes for the change cases were converted back to lake elevations, yielding a lake elevation value corresponding to the water releases in each change case trace.

proposed HFE experimental protocol, HFEs would only occur in March/April or October/November.

The water release in the HFE month was broken down into three parts:

A base flow release amount was calculated for the month, consisting of a minimum release from GCD of 5,000 cfs during the 7 pm to 7 am period, and 8,000 cfs during the 7 am to 7 pm period, each day. Cfs values were converted to acre-feet per hour.

The hourly ramp up (4,000 cfs) period, peak flow period, and hourly ramp down (1,500 cfs) period were then added to the base flow amount. The above release constraints are defined in the GCD Record of Decision (ROD) and are used in the GTMax modeling calculations.

The maximum water release through the powerplant is dependent on a number of factors including the number of turbines in operation, turbine maximum generation capability, and the reservoir forebay elevation. When this elevation drops below the top of the penstock (i.e., 3,490 feet), the plant generation is assumed to be zero. Any water releases during the HFE in excess of the maximum level were assumed to bypass the powerplant.

The hourly releases during experimental hours were summed so that, for each of the 13 HFEs, there is a base flow release through the powerplant, an HFE release through the powerplant, and a bypassed water release, all in acre feet. Knowing the amount of water released each hour of the HFE enables calculation of each hour's energy generation in MWh and so enables the calculation of the total dollar cost of the generation based on the prices described above.

Adjusting Monthly Releases

The monthly release values from the Riverware model that Reclamation provided for each of the 12 traces is a total release volume that includes the base flow release volume and HFE release volume. For the GTMax modeling process, it is necessary to remove the HFE release volumes from the total release volume to leave only the base flow release volumes in those months where an HFE was scheduled. The entire release during the days when the HFE test occurred was removed from the total (using the same method described in the paragraph above), and the remaining water volume was used to compute the actual base flow release for the month. This actual base flow was used by the GTMax model for computations.

Running Typical Weeks in GTMax
Having adjusted base flow quantities enabled the GTMax program to pattern the water over the typical week restricted by GCD ROD powerplant constraints. GTMax patterns the generation releases that result in the greatest possible value of the resulting hydropower generation in dollars, using the energy prices described previously.

The results from the typical week are then scaled up by the model to become monthly values. The output of the GTMax run is the value of the generation in each month excluding the value of the generation associated with an HFE. To get the complete result, the dollar value of the base flow generation is then added to the value of the generation associated with the HFE water releases described in the section above.