RECLAMATION

Managing Water in the West

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
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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 experimental protocol builds on, and was developed, following analysis of a series of high flow experimental releases, particularly those conducted in 1996, 2004, and 2008. This experimental protocol is the next logical scientific investigation as part of the Department's efforts to improve conservation of limited sediment resources in the Colorado River below Glen Canyon Dam. The information gained through this experimental protocol cannot be developed in any other manner, and is essential to informing future decisions in an adaptive management setting. In the past fifteen years of scientific research and monitoring, scientists have learned much regarding the use of high flow releases from Glen Canyon Dam. This proposed protocol is based on that science and targets future monitoring and research so as to refine our ability to predict the outcomes of future management actions intended to benefit the Colorado River ecosystem.

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 is 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.

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 information will be used to inform high-flow experiments over the course of the protocol.

This action is needed to take advantage of future sediment-enriched conditions in the Colorado River with experimental high-flow tests. This action will improve the understanding of the relationships between high dam releases of up to 45,000 cfs and sediment conservation, and it is expected to have long-term benefits for these resources. 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. Reclamation will ensure that other resources would not be unduly or unacceptably impacted or that any such impacts could be sufficiently mitigated.

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 will continue to follow the Modified Low Fluctuating Flow (MLFF) preferred alternative as adopted by the Secretary of the Interior and described in the 1996 Record of Decision for the Operation of Glen Canyon Dam (Interior 1996), with the added refinement of steady flows in 2012 as identified in Reclamation's 2008 decision on the operations of Glen Canyon Dam (2008-2012)(Reclamation 2008), and as addressed in relevant U.S. Fish and Wildlife Service biological opinions on the operation of Glen Canyon Dam [2008 Opinion and the 2009 supplemental biological opinion (2009 Supplement)]. The timing of high-flow releases would be March-April and October-November, 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 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 – 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

[1] A water year is the 12-month period from October 1 through September 30. 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."

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 is not expected to affect the long-term water quality of the reservoir or the Colorado River downstream of Glen Canyon Dam.

Air Quality.—Energy generated from coal or gas-fired powerplants likely 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 0.002 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, it is not expected to be substantial because the effects to air quality would likely 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 less certain, 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. Negative impacts of HFEs likely would be greater in Glen Canyon (above the Paria River) because there is no substantial input of sand and fine sediment to that reach.

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.

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 (organic material suspended by river flows) downstream due to increased suspension from higher volume releases. Spring releases would likely stimulate aquatic foodbase production with full biomass recovery taking from less than 4 months to more than a year for some taxa based on 1996 and 2008 experiences, respectively. 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 (as well as in the relevant non-native fish control actions and science plan described in the non-native fish control EA). 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. The USFWS has determined that incidental take of razorback sucker is not reasonably certain to occur because razorback suckers are in very low numbers in the action area.

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.—It is likely that some trout eggs, fry, and young would be destroyed or lost downstream during HFEs. There is also some short-term risk that the aquatic foodbase would be reduced, subsequently affecting adult trout for a period following a high-flow release. However, research shows that spring HFEs are followed by higher drift rates, increased production, and improvement in foodbase nutritional quality. The impact of a fall HFE on the trout population is less certain due to a lack of data on trout response to the one fall HFE conducted in November 2004. 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, has been developed by Reclamation to identify actions proposed to mitigate or counteract the effects of increased numbers of trout dispersing from the Lees Ferry reach. Proposed actions to address potential impacts to endangered fish, particularly the humpback chub, are further detailed in the non-native fish control biological assessment, which is an appendix to the non-native fish control environmental assessment, and a supplement to both biological assessments, included as part of Appendix C to this document.

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 could 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 the specific period of release of high flows from Glen Canyon Dam, 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 with the volume of releases greater than can be passed through the powerplant to produce the high flows and replacement power for the bypassed water 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.

1.0 Introduction

1.1 Background

The Department of the Interior (Interior), acting through the Bureau of Reclamation (Reclamation), is proposing to develop and implement a protocol for high-flow experimental releases from Glen Canyon Dam to better determine whether and how sand conservation can be improved in the Colorado River corridor downstream from Glen Canyon Dam, with emphasis on the reach below the Paria River and within Grand Canyon National Park (GCNP).

This experimental protocol builds on, and was developed following analysis of, a series of high flow experimental releases, particularly those conducted in 1996, 2004, and 2008. This experimental protocol is the next logical scientific investigation as part of the Department's efforts to improve conservation of limited sediment resources in the Colorado River below Glen Canyon Dam. The information gained through this experimental protocol cannot be developed in any other manner, and is essential to informing future decisions in an adaptive management setting. In the past fifteen years of scientific research and monitoring, scientists have learned much regarding the use of high flow releases from Glen Canyon Dam. This proposed protocol is based on that science and targets future monitoring and research so as to refine our ability to predict the outcomes of future management actions intended to benefit the Colorado River ecosystem. See further discussion at Sec. 1.7.

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 Glen Canyon National Recreation Area (GCNRA) and Colorado River in GCNP.

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

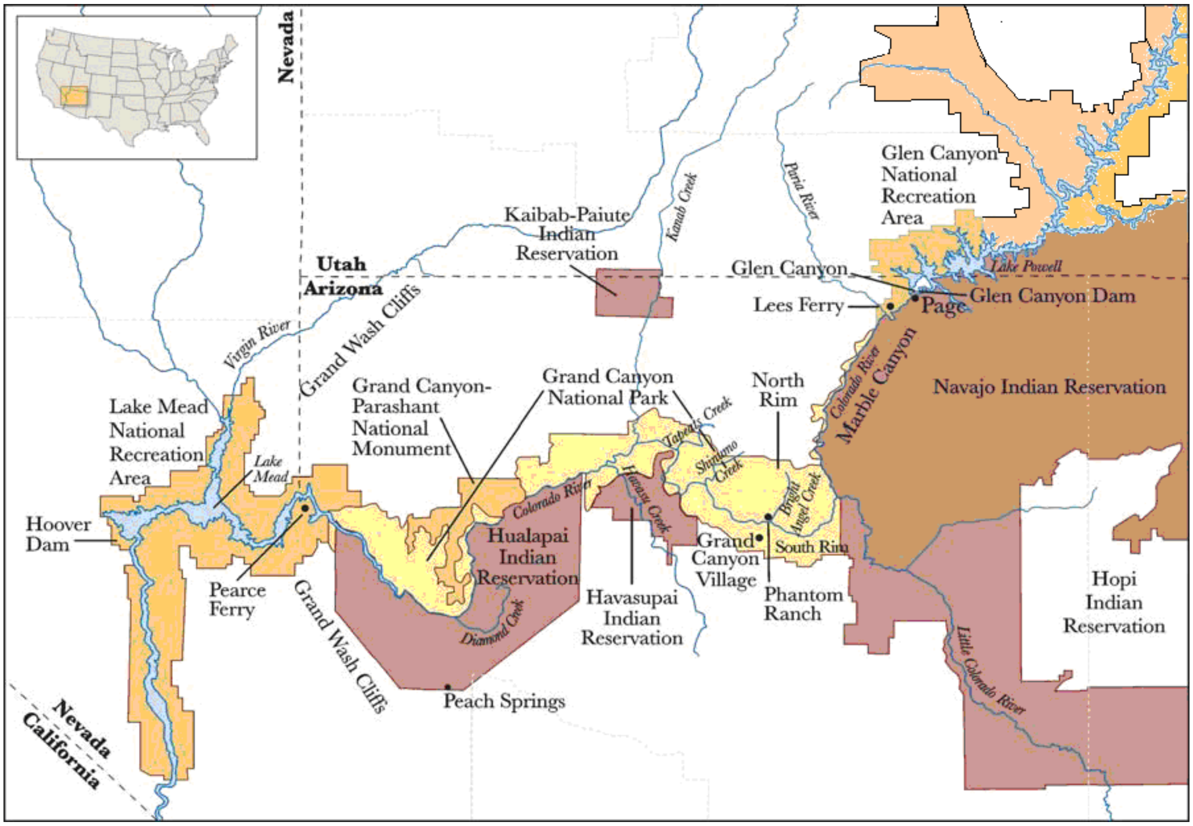


Figure 1. Geographic scope of the proposed action, showing places referenced in the text. Map courtesy of U.S. Geological Survey.

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, cultural, 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 and provides further direction to the Secretary to address 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 (1995 EIS; Reclamation 1995) with the preferred alternative, called the Modified Low Fluctuating Flow Alternative (MLFF), selected by the Secretary of the Interior as the required operating regime for Glen Canyon Dam. 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 1.7 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, (AMWG, 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. This statutorily-required monitoring and research was used to develop the HFE Protocol addressed in this EA and the science plan that accompanies this analysis.

The Colorado River Basin has experienced prolonged and historic drought conditions. In response to several years of below-normal runoff and declining reservoir conditions beginning in 1999 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 has prepared 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, particularly in the reach below the Paria River within GCNP.

The Non-native Fish Control EA is designed to research and 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 HFE 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 prey upon native, endangered humpback chub.

Reclamation reviewed and considered these comments and has added this discussion to this updated EA 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. Both EAs consider the information and analysis conducted in the other EA.

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 non-native 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 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 experiment 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 non-native 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 an issue, given the post-2008 monitoring results, it is clear that both warm-water 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 non-native 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 (geomorphic protection and enhancement of riparian (e.g. sandbars) 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 experimental 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 decision makers 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 experimental 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 C.F.R. 1500-1508) and the Department of the Interior regulations implementing NEPA (43 C.F.R. 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; 76 FR 39435-46, July 6, 2011). 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 developed through the HFE Protocol as well as 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 (NPS). 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 was published in the *Federal Register* on July 6, 2011, and the public scoping process is open through January 31, 2012.

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. Such information on the effect of sequential high-flow releases would not be available absent implementation of the HFE Protocol. 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.

Reclamation anticipates that the LTEMP process will incorporate knowledge gained from implementation of the HFE Protocol and that the protocol will be updated accordingly, as appropriate. The LTEMP Record of Decision will then be the mechanism for implementing future high-flow experiments.

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. Some of 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 conduct experimental releases (and associated research and monitoring) designed 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. This information will be used to inform high-flow experiments over the course of the protocol.

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. Reclamation believes this experimental action will lead to improved management and conservation of the sediment resource. 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 to improve the management and conservation of the sediment resource, 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 2.2.3) to better inform future decision making regarding dam operations and other related management actions. Interior will conduct scientific monitoring and analysis with all experimental high-flow tests and will integrate the results of those investigations into 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.” While no modification is proposed or anticipated at this time, any future potential modification of the

[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, see Section 2.2.1) 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.

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 powerplant 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 monthly, daily, and hourly time increments. The 2007 Record of Decision governs annual water year releases from Lake Powell in coordination with the operation of Lake Mead.

A past NEPA analysis that overlaps with the first calendar 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.

Reclamation is developing an EA for non-native fish control downstream from Glen Canyon Dam concurrent with this EA (see Section 1.2 for additional details). As discussed above, 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; non-native fish control was addressed 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 (Valdez and Ryel 1995; Marsh and Douglas 1997; Yard et al. 2011). 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 and in a supplement and in a 2009 supplement to the 2008 opinion. 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 and Supplement (see Appendix C) that accompanies this EA. Progress on those conservation measures is identified in the 2010 BA (Reclamation 2010a) and the 2011 biological opinion (USFWS 2011b).

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. Translocations to Shinumo Creek and Havasu Creek were made in 2011. This translocation action is part of a Reclamation conservation measure contained in the 2008 Opinion and 2009 Supplement.

Mechanical removal of non-native fish, primarily rainbow trout from Shinumo Creek and brown 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 Reclamation conservation measure related to the 2008 Opinion and 2009 Supplement.

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.

GCNP 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 emigrating 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, has undergone Intra-Service consultation. Of particular interest to Reclamation's proposed 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 previous records of decision, operating criteria, and 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 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 ESA conservation and associated consultation and recovery leadership with various agencies, tribes and 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). Western markets at wholesale to utilities who provide retail electric service to over 5 million consumers in the CRSP region. These resources are provided by eleven powerplants 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 powerplant 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 powerplant 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; Hazel et al. 1999; Schmidt 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 (RM = river miles upstream or downstream from Lees Ferry; negative values are miles upstream). 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 (Webb et al. 1999; e.g. Gloss et al. 2005; Makinster et al. 2010a; 2010b; Ralston 2010; Rosi-Marshall et al. 2010; Korman et al. 2011) to assist in the development and design of the HFE Protocol and to determine the relevant resources and issues for analysis in this environmental assessment. Prior high-flow experiments (HFEs) were conducted in 1996, 2004, and 2008. Table 1 presents the list of relevant resources analyzed in this EA.

Table 1. List of resources and issues evaluated.

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	
Terrestrial Invertebrates and Herptofauna	
Aquatic Foodbase	
Fish	
• Humpback Chub	
• Razorback Sucker	
• Non-Listed Native Fishes	
• Trout	
• Other Non-native Fishes	
• Fish Habitat	
Birds	
Mammals	

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. Management of Colorado River fishes rests with the National Park Service, the federal agency responsible for managing natural and cultural resources within GCNP and GCNRA, and the Arizona Game and Fish Department, the state agency responsible for managing sport fish in the state. Because the two park units are not under exclusive federal jurisdiction, state law applies to the management of fish within their boundaries, but only to the extent that it has not been preempted by federal statute, federal regulation, or lawful federal administrative action. In accordance with 43 C.F.R. part 24 the NPS must consult with the Arizona Game and Fish Department before taking certain administrative actions to manage fish within the park units. No other permits are known to be required at this time.

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 projected to be completed in 2015. 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 2015. The five-year schedule currently shows no major maintenance beyond the spring of 2015. 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
Power-plant 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
Power-plant plus River Bypass Capacity	35 to 42 Kcfs	35 to 42 Kcfs	38 to 42 Kcfs	35 to 42 Kcfs	25 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 in advance of the implementation of the experiment. Reclamation recognizes the need to ensure that implementation of the HFE Protocol does not result in significant impacts to resources such as endangered humpback chub and will closely monitor both trout and chub populations to ensure that potential changes are monitored, detected and analyzed 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 the monitoring program of the GCDAMP and fully 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 (such as those identified in Section 1.5), a short-term priority arising from one of those actions or their effects could preclude an HFE.

2.0 Description of Alternatives

This section describes the alternatives considered in this EA. 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.

A no action alternative and a proposed action alternative are evaluated in this EA. There are two major reasons why no additional alternatives were evaluated. First, the preponderance of scientific evidence gained through the 15 years of GCDAMP investigations indicates that the proposed action is most likely to have desired effects in conserving resources and advancing learning. These investigations include advanced modeling of potential methods for sand conservation in sediment-limited rivers that has resulted in peer-reviewed publication in scientific journals (Wright et al. 2008; 2010; Wright and Grams 2010). The results of this modeling were first presented by USGS scientists in a workshop conducted in June 2010 attended by both scientists and resource managers, so it contains perspectives from research and management. A modification of the USGS approach was later provided by one of the cooperating agencies, and it was integrated into the proposed action. Second, no other competing alternatives were put forward by the public during the scoping period of this environmental assessment.

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 through 2012 under 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. Under the no action alternative, no high-flow experiments would be conducted and resource benefits would not accrue.

The MLFF flow regime was the Secretary of the Interior's 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 for the first time under enhanced sediment conditions and to provide steady flows in the fall to evaluate the ability of such flows 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 adopted by the Secretary of the Interior in the 1996 ROD and the 2007 ROD.

The 2008 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 with a 2009 Supplement (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 Age-Structured Mark-Recapture (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 No Action	Restricted Fluctuating Flows Moderate Low Fluctuating
Minimum releases (cfs)[1]	1,000 Labor Day–Easter 3,000 Easter–Labor Day[2]	8,000 between 7 a.m. and 7 p.m. 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 28,500 Easter–Labor Day	5,000; 6,000; or 8,000[4]
Ramp rates (cfs/hour)	Unrestricted	4,000 up; 1,500 down
Common elements		Adaptive management (including long-term monitoring and research) Monitoring and protecting cultural resources Flood frequency reduction measures Beach-habitat building flows New population of humpback chub Further study of selective withdrawal Emergency exception criteria

[1] In high volume release months, the allowable daily change would require 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.

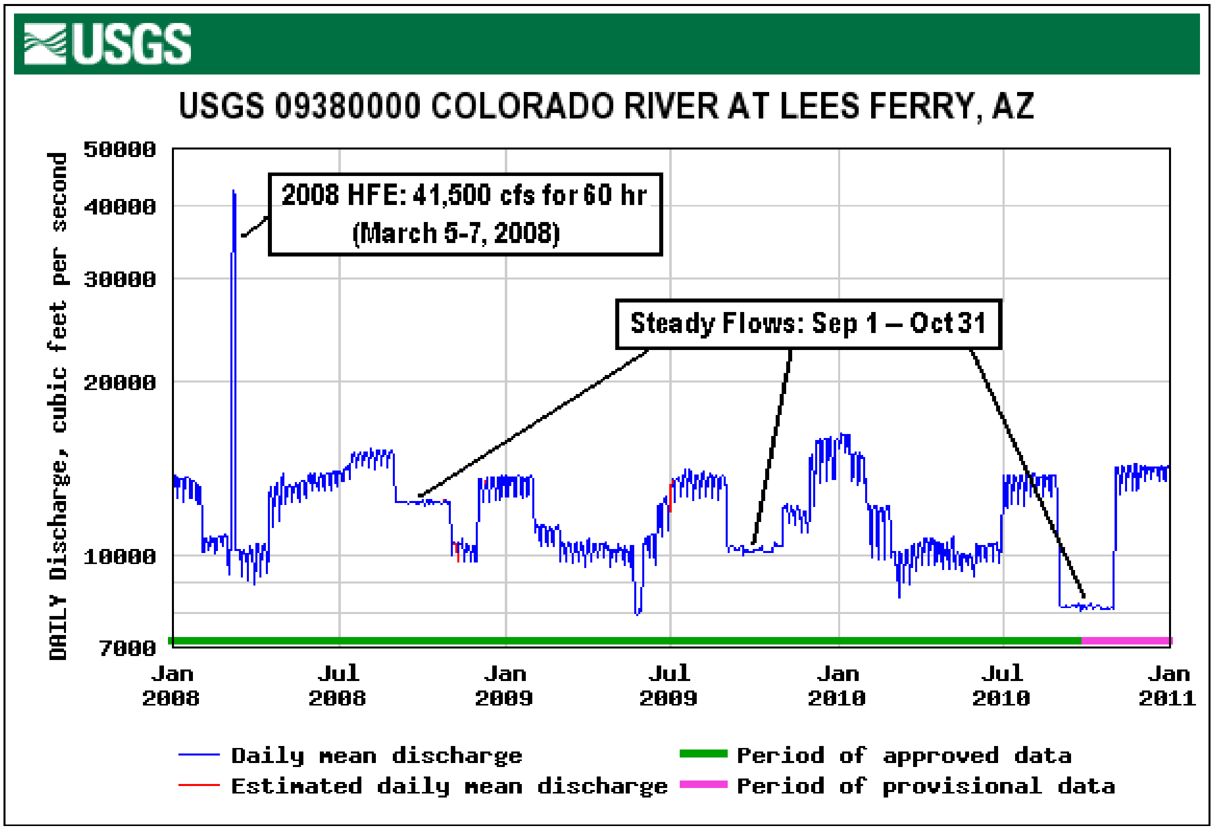


Figure 2. Mean daily discharge of the Colorado River at Lees Ferry from January 1, 2008 to December 31, 2010, showing the 2008 HFE, the September-October steady flows, and the intervening releases under modified low fluctuating flows (MLFF).

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 adopted by the Secretary of the Interior in the 1996 ROD with the added refinement of steady flows through 2012 as identified in the 2008 Opinion and the 2009 Supplement and the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. 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 changes are required as an outcome of future decisions. 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 resource reviews to provide information that will help 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 since finer particles largely are transported downstream during the sand storage period. Conversely, the rapid response approach focuses on both sand and finer particles. 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 (March-April and October-November) 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 2012 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 release 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 2014 if that is the outcome of the steps identified above and 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 sand 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 sand 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 estimated from the Paria River streamflow 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 applicable legal or operational requirements (including applicable 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 and Reclamation considers this approach to be the best method of evaluating the proposed action.

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 that 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 2.2.4).

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 conducted in the early part of each calendar year prior to a decision on a spring HFE would evaluate the information on the status and trends of key resources. Any criteria set forth in biological opinions for ESA-listed species would be utilized as would the Desired Future Conditions objectives and metrics presently in development through the GCDAMP. This information would be provided to Interior to assist with the decision and implementation component of this protocol. Funding for previous HFEs was provided through the GCDAMP budget process and from Reclamation appropriations. The Adaptive Management Work Group (AMWG) federal advisory committee makes recommendations to Interior on allocation of these funds. Reclamation would be prepared to conduct an HFE if funding is provided, resource conditions are suitable, there is sufficient sediment input to trigger an HFE, and Interior determines all conditions are suitable for proceeding.

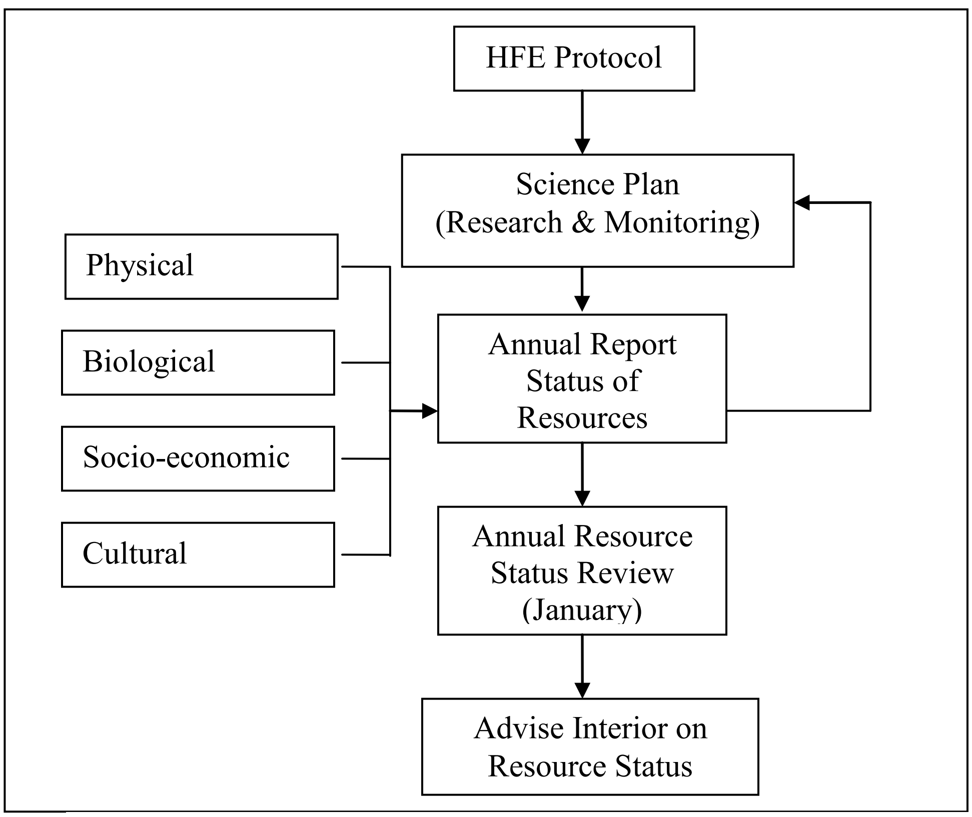


Figure 3. Planning and budgeting component for the HFE protocol.

The details of the resource evaluation process have not been finalized, but it likely would be based on criteria similar to those proposed earlier for beach/habitat building flows, as initiated by Ralston et al. (1998) (Table 7). The criteria would be refined by GCMRC with input from the GCDAMP Technical Work Group. Additional key resources would be drawn from those being monitored under the HFE Protocol science plan (see Appendix B). 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 would not be limited to): in-channel sediment storage, sandbar campable area, high-elevation sand deposits, archaeological site condition and stability, sediment flux, aquatic food base, Lees Ferry fish monitoring, Lees Ferry fishery 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 is a key GCDAMP resource that could be adversely affected by HFEs through increases in trout numbers, a trigger has been identified in the 2011 Opinion (USFWS 2011b) that would be used to determine if removal of non-native fish would occur in the LCR reach of the Colorado River. A determination whether the trigger has been reached would be made from monitoring and modeling data gathered through the GCDAMP.

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. Average area of sandbars above 20,000 cfs, by reach and stage Number of suitable backwater habitats by reach at specific river stages between 8,000 cfs and 45,000 cfs 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 Populated KAS habitat (total area) outside impact zone Estimated total KAS population outside impact zone 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) Number of breeding pairs expected to be displaced by BHBF 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. 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). Estimated number of successfully reproducing adult fish (creel catch rate; electrofishing catch rate by size class as an index of population size) Survival of juveniles and subadults Recruitment Growth rate 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.

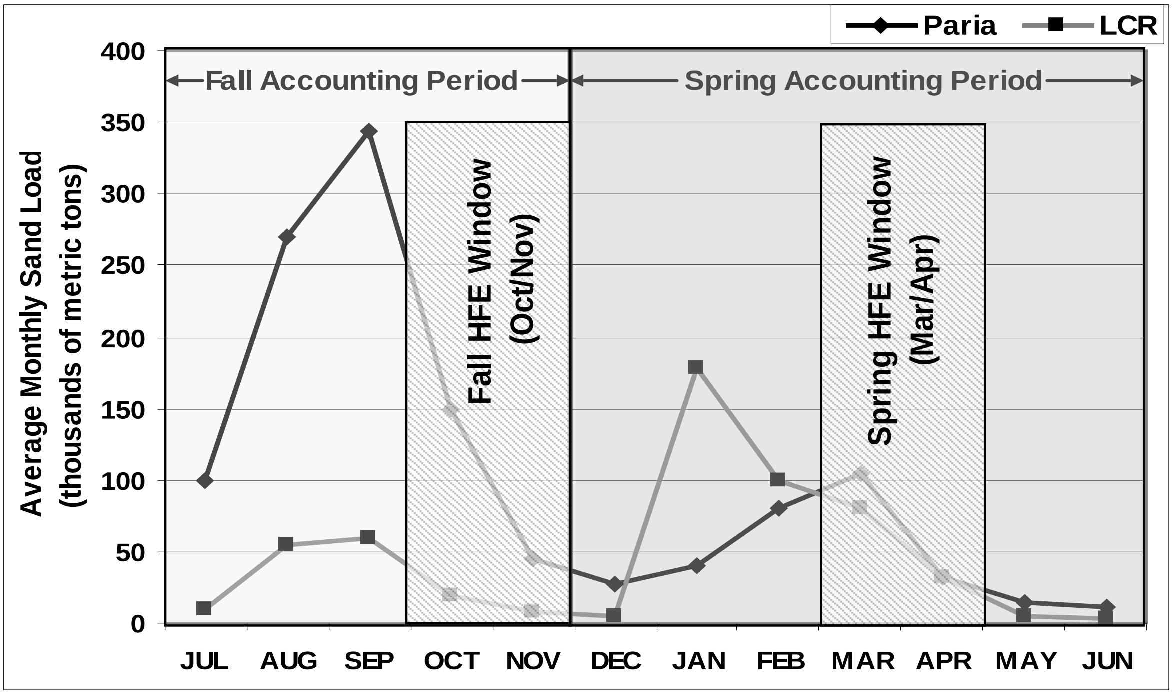


Figure 4. The two sand accounting periods and the two high-release periods with average monthly sand loads for the Paria River and the Little Colorado River (adopted from Scott Wright, U.S. Geological Survey, personal communication, and Wright and Kennedy 2011).

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.

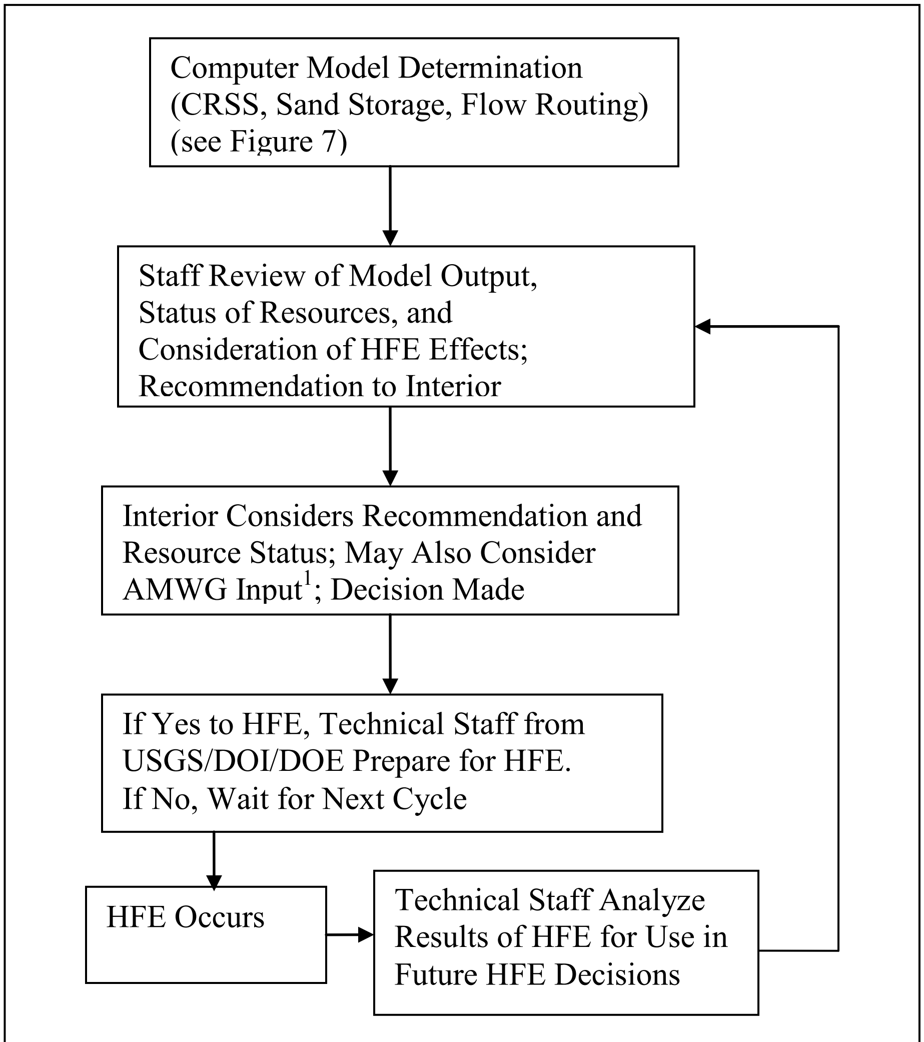
Phase 2 – October-November HFE window. Beginning October 1, sand storage, and forecast hydrology are evaluated using the sediment budget model to determine whether conditions are suitable for an HFE. The model determines what magnitude and duration of the HFE, if any, will produce a positive sand balance 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 below), 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. For example, if the scenario that is identified by the model cannot be implemented because of facility limitation to 42,000 cfs or less (see Section 1.5.2), managers would assess the need to modify the range of magnitude and duration of the HFE. 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 AMWG meetings, 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 for that release, since the decision must be made in advance of the actual HFE release and there is an admitted uncertainty in the modeled forecast for both sediment inputs and dam releases. Caution will 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 and Secretarial decisions 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).

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, following completion of commitments in 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). Consistent with 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 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 2.2.3 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.

The GCDAMP has an extensive research and monitoring program. A HFE science plan, prepared by GCMRC, is attached to this EA for the HFE Protocol (see Appendix B) and will be used to supplement the extensive monitoring already being conducted under the GCDAMP. This plan addresses research and monitoring activities necessary to evaluate HFEs both as individual and 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. Participation by 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 there was a wide range of certainty associated with predicting the direction of response for different resources. Hydropower capacity and replacement costs for a BHBF or HMF were very certain, whereas predicting response direction for physical variables (i.e., sediment and water temperature) was relatively certain to uncertain. The assessment also concluded that response directions for the aquatic foodbase and fish were uncertain or highly uncertain. A subsequent knowledge assessment has not been published, 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 have been identified for four major resource areas: (1) the Colorado River ecosystem (CRE) which encompasses the Colorado River from the forebay of Glen Canyon Dam to its inflow into Lake Mead, and lies between the pre-dam high water zone terraces. The ecosystem also includes relevant additional habitats needed to sustain the CRE or that may be useful as scientific monitoring controls. The CRE includes aquatic and riparian processes and components (e.g., species) as well as terrestrial components that are influenced by riverine processes; (2) hydropower; (3) cultural resources; and (4) recreation. When completed, 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 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 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: How can an HFE Protocol be implemented without causing significant impacts to other resources?

Key research questions are tiered from the over-arching questions and addressed in greater detail in the final HFE science plan. These research questions include, but are 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 from 4 to 15 months of biomass 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; Makinster et al. 2010a; 2010b; Ralston 2010; Rosi-Marshall et al. 2010; Korman et al. 2011; 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 the development of the HFE Protocol and in the analysis contained in this EA. Feedback from the public was received during the course of two review periods, from January 14 to March 18, 2011, and from July 5 to July 19, 2011. Each of these public reviews was preceded by cooperating agency reviews.

3.0 Affected Environment and Environmental Consequences

This chapter describes the environmental consequences of developing and implementing a protocol for high-flow experimental releases from Glen Canyon Dam, and compares these releases to taking no further action for the period 2011 through 2020. The action area or geographic scope of this EA is the Colorado River corridor from Glen Canyon Dam downstream to the Lake Mead inflow near Pearce Ferry. Detailed information on resources affected by the proposed action is provided below. This chapter is organized by resource categories, including physical, biological, cultural, and socio-economic. Each of these categories is further divided into specific resources for the impact analysis, as identified in Table 1 of this EA. 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 the 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 Council on Environmental Quality and Interior guidelines and regulations, which are summarized for single and multiple HFEs in Tables 17 and 18. Each impact topic or issue is analyzed for the no action and proposed action alternatives, and in consideration of related actions, projects, plans, and documents (see Section 1.5). Impacts are described in terms of context (site specific, local or regional), duration (short- or long-term), timing (direct or indirect), and type (adverse or beneficial). Any cumulative effects that may be present are discussed in their respective resource areas and not in a stand-alone cumulative effects section. A biological assessment was also conducted to address the effects of the proposed action on five threatened and endangered species. That assessment subsequently was supplemented and both are included in this document (see Appendix C).

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 added 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. Potential impacts for all combinations and sequences of HFEs within the approved range for the full 10-year period of this proposed action could not be precisely assessed. However, the HFE Protocol process is specifically designed to ensure that any given HFE will be analyzed for its potential impacts. Furthermore, the 15-year history of scientific investigations under the GCDAMP has produced a body of knowledge upon which the protocol is based. The HFE Protocol is designed to facilitate experiments that will improve learning during this period. That learning will help to further ensure undesirable impacts will not occur. The HFE protocol process, with a strong commitment to resource evaluation during each iteration and the input of both scientists and resource managers to the Interior decision process, ensures that implementation of HFEs will not have significant negative impacts.

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, including results from lower magnitude habitat maintenance flows in 1997 and 2000, and of the synthesis of results from the 1996, 2004, and 2008 high-flow experiments (Melis et al. 2011).

The six HFEs that have been conducted in Grand Canyon have been independent single events. Their impacts were evaluated, documented, and used to provide baseline information for the impact analysis of this EA (see Table 8). Study results of HFEs varied and were more complete for some events and resources than others. Four the latter 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 know whether short duration (relative to pre-dam) 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 8. 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.

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 (3-4 mo.) reduction in abundance/ biomass [3,4,23,24]	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 persisting up to 15 mo, enhanced drift and production of some taxa, improved fish food quality[20, 21].
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. 2011
[22] Sorenson 2005
[23] Shannon et al. 2001
[24] Valdez et al. 1999

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 biological opinions (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 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.

Reclamation's conclusion is that the no action alternative will not 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 in a given month 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 would adjust the projected monthly release volumes as necessary for the following December through March period or May through August period, respectively. More detail on how this would be accomplished is provided in Section 2.2.4 of this EA.

The timing, magnitude, and duration of HFEs will not affect annual water year volumes because Reclamation would only reallocate water within or among months within a given water year to achieve the necessary volumes. 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 would reallocate water within or among months to achieve the necessary volume, dam operations would 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 largely 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 the Lees Ferry trout 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 temporary slight increase in salinity. During the year following a single HFE, release 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, GCNP is a Class I Area, with the most stringent requirements for air quality, while GCNRA 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 powerplants.

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 good, 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 for ease of analysis, 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 9 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 0.002 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 to the Environmental Protection Agency. 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 be minor due to the low volume of emissions.

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

Table 9. Megawatt hours of lost electrical generation and subsequent additions of CO_2 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

Nearly 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. In the project area, the first major sediment-producing tributary is the Paria River which enters the mainstream approximately 16 river miles below the dam. 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. Since the first major sediment-bearing tributary is the Paria River, 16 miles below the dam, the positive effects of the HFE Protocol on sand conservation and beach building are expected to occur below the tributary mouth. There is some sand input from ungauged ephemeral tributaries above the Paria and some of these deposits may accrue on beaches in the Glen Canyon reach above that tributary. It is likely, however, that implementation of the HFE Protocol will have some negative impacts on sand deposits in that reach. Monitoring of these impacts would be accomplished under the HFE Science Plan and an evaluation of the sand resource condition would be done as part of the resource status assessment preceding a decision on an HFE.

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 10; 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 10. 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.

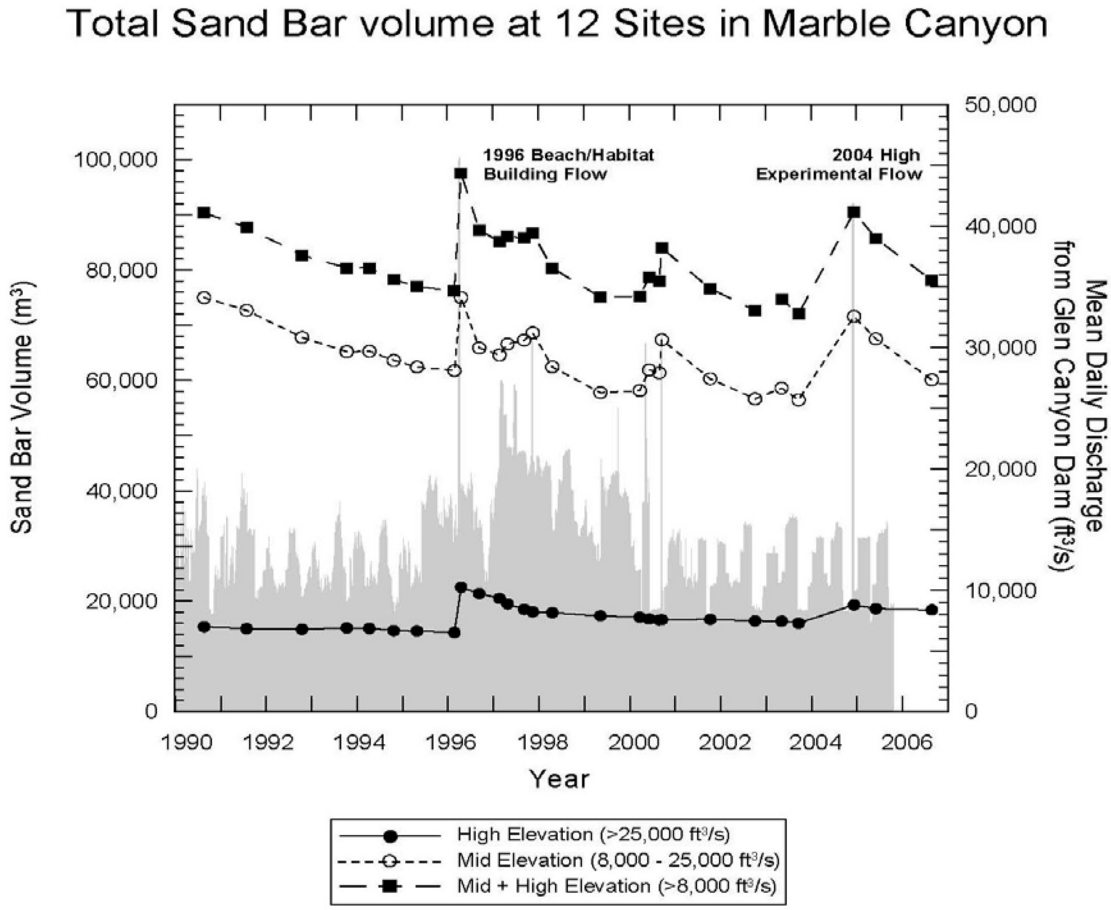


Figure 6. Total sandbar volume at 12 sites in Marble Canyon. ***Source:*** **J. Hazel, preliminary data courtesy of Northern Arizona University.**

High-volume MLFF releases from Glen Canyon Dam that followed the 1996, 2004, and 2008 HFEs have been associated with 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. 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.

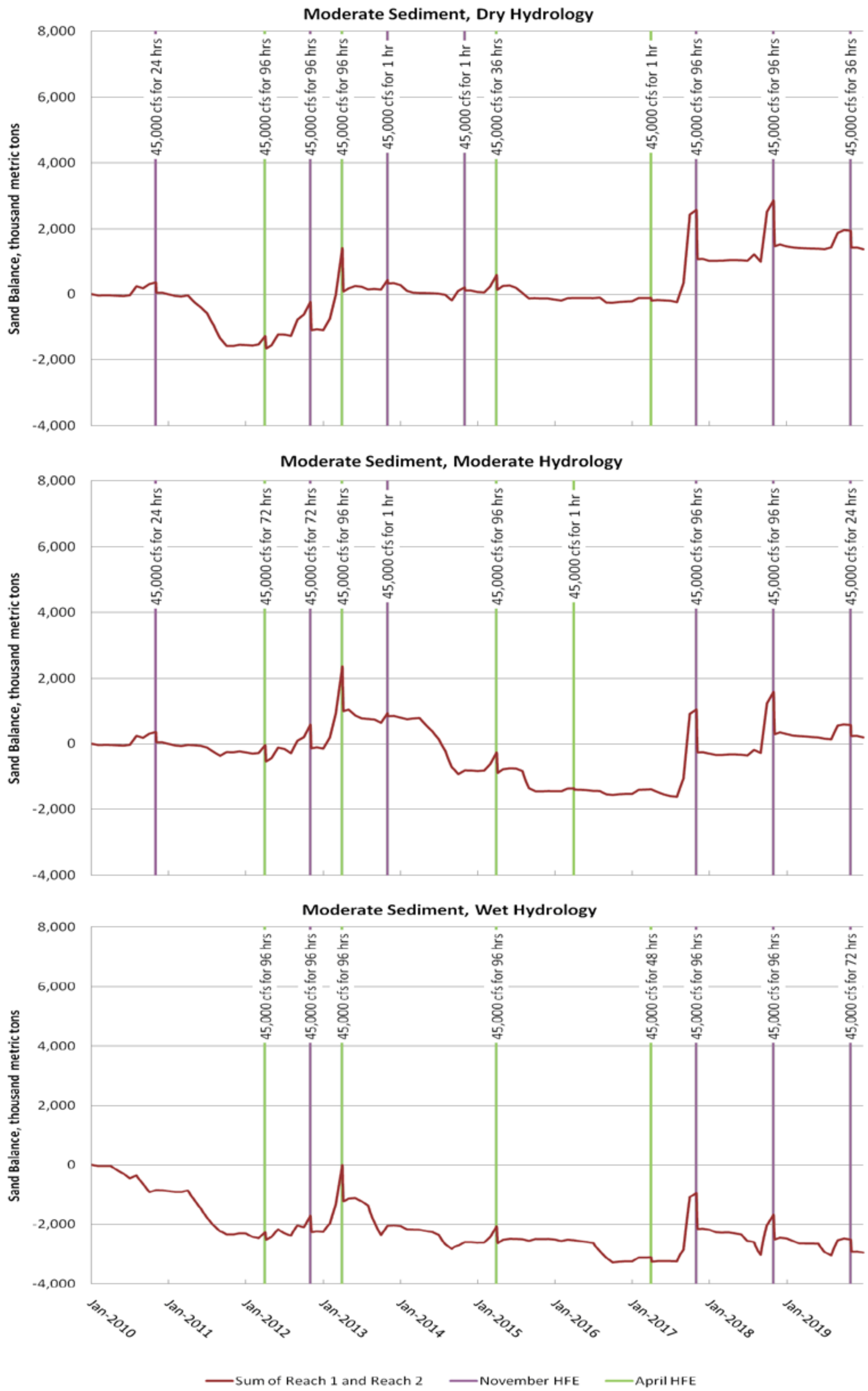


Figure 7. Occurrence of described HFEs from model runs for moderate sediment with dry, moderate, and wet hydrology in reaches 1 and 2 (Russell and Huang 2010).

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 less certain 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 less certain. 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 (Schmidt and Graf 1990).

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 consistent with the 2008 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 (Parnell et al. 1997; Brouder et al. 1999; Hazel et al. 1999). 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 (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 and other native fish.

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 (produced by plants in the river) 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 less certain. 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). These river reaches are seasonally warmed; however, and not as 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 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 biological opinions (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 (Stromberg et al. 1996; Shafroth et al. 1998). 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 accumulate 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 (Ladenburger et al. 2006). 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 2.5×10^8 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 and temporary diminishment of avian, beaver, and other riparian wildlife habitats. A large increase in beetle biomass, at least in the short term, 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, provided 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 (Porter 2002; Kearsley et al. 2006). 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 during the period of the proposed action, but in the long run more sand would likely be deposited on sandbars and beaches upstream rather than transported to the reservoir. 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 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 GCNP (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 GCNP (NPS 2009a) also lists the northern leopard frog as extirpated.

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, including 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 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 at flows from 20,000 to 25,000 cfs (MLFF allows flows up to 25,000 cfs), one patch of snail habitat is much affected, and a second patch to a lesser extent at flows above 23,000 cfs. Very few Kanab ambersnails have been found in these patches 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.

Based on estimates calculated in August 2004, a flow of 45,000 cfs would scour approximately 17 percent (1,285 $ft^{2)}$ 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 in 2008, 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).

The HFE protocol would likely impact the snails to a greater degree than previously conducted single HFEs because the increased frequency will reduce the time available for habitat and population recovery. Snails and snail habitat are expected to be scoured and displaced downstream. If HFEs are conducted frequently under the protocol, the habitat and the population of the Kanab ambersnail are expected to reestablish at a higher elevation. The USFWS has analyzed this impact and determined that this level of take of snails and snail habitat will not be detrimental to the Kanab ambersnail habitat at Vaseys Paradise because the amount of habitat and snails not affected by HFEs and MLFF operations is anticipated to be sufficient to maintain a healthy population (USFWS 2011b).

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.

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; whereas 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 majority of foodbase taxa are expected to largely 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), although some taxa may recover more slowly (Cross et al. 2011). A post-flood increase in production and drift of midges and black flies is expected following spring HFEs (Cross et al. 2011). 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 fish by making more digestible items available, particularly to tailwater trout; 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 45,000 cfs 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 less certain 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 less certain 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. The following spring HFE following a fall HFE could then 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 more rapid 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. Although there are differences between the River Spöl and the Colorado River, this experiment provides a useful comparison for assessing impacts of multiple floods on the flora and fauna of a perennially cold river. As in Grand Canyon, the Swiss floods reduced periphyton biomass substantially and transiently shifted ecosystem metabolism towards autotrophy (increased photosynthesis). However, 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 less certain.

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 less certain. 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.

Reclamation's conclusion is that there will be short-term scouring of the aquatic food base that will occur and increase with the magnitude and duration 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 (Table 11). Only five of the original eight fish species native to the Colorado River in Grand Canyon definitely have persisted, including humpback chub, razorback sucker, 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 11. 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 (SWCA 2008). X = absent , P = present in small numbers, C = common, A = abundant.

Common Name	Scientific Name	Lees Ferry	Marble Canyon	Grand Canyon
Non-native 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	C	C
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	*Xyrauchen 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; USFWS 2011a). 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). Mainstem spawning is known to occur in 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 whether downstream fish originated from the Little Colorado River or from local reproduction.

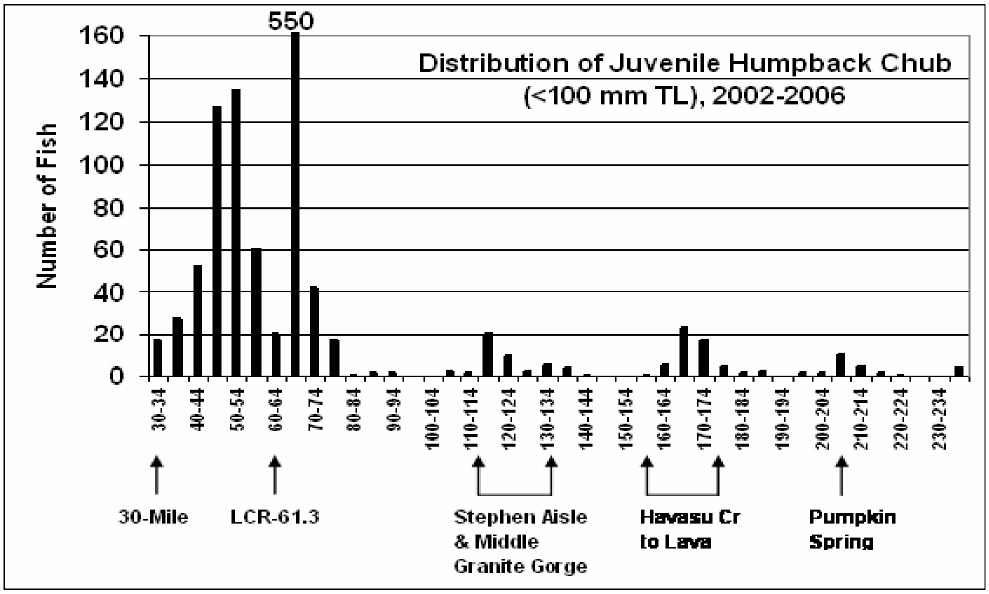


Figure 8. Distribution of juvenile humpback chub < 100 mm TL during 2002-2006 by 5-mile increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from SWCA 2008).

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.

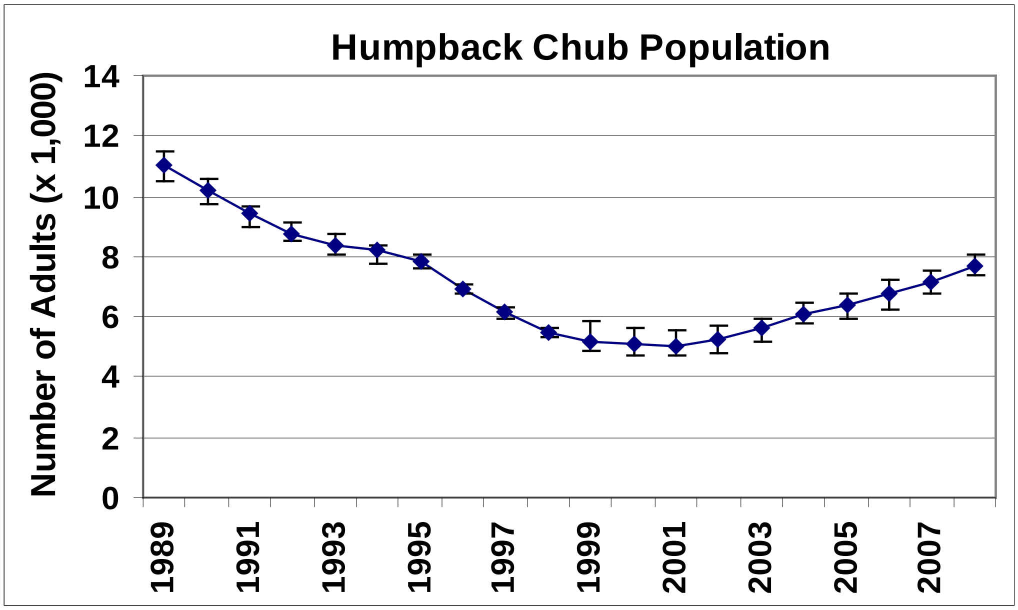


Figure 9. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials. All 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, including fulfillment of the ongoing conservation measures required by existing biological opinions, would not negatively impact humpback chub.

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 currently are 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; McIvor and Thieme 1999; McKinney et al. 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 non-native fish control as identified in the 2010 biological opinion (USFWS 2010). 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) and they are occasionally collected as far upstream as the Lees Ferry reach. Although lower in abundance than rainbow trout, predation rates of brown trout on native fish typically are 7-20X those of rainbow trout (Valdez and Ryel 1995; Yard et al. 2011).

The rainbow trout population in the Lees Ferry reach was 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) increased, reflecting a strongly density-dependent fish population where growth and condition are inversely related to fish abundance (McKinney et al. 2001; McKinney and Speas 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 Sections 2.2 and 2.3 in the Non-native Fish Control EA (Reclamation 2011b), for additional discussion of previous non-native fish control efforts.

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.

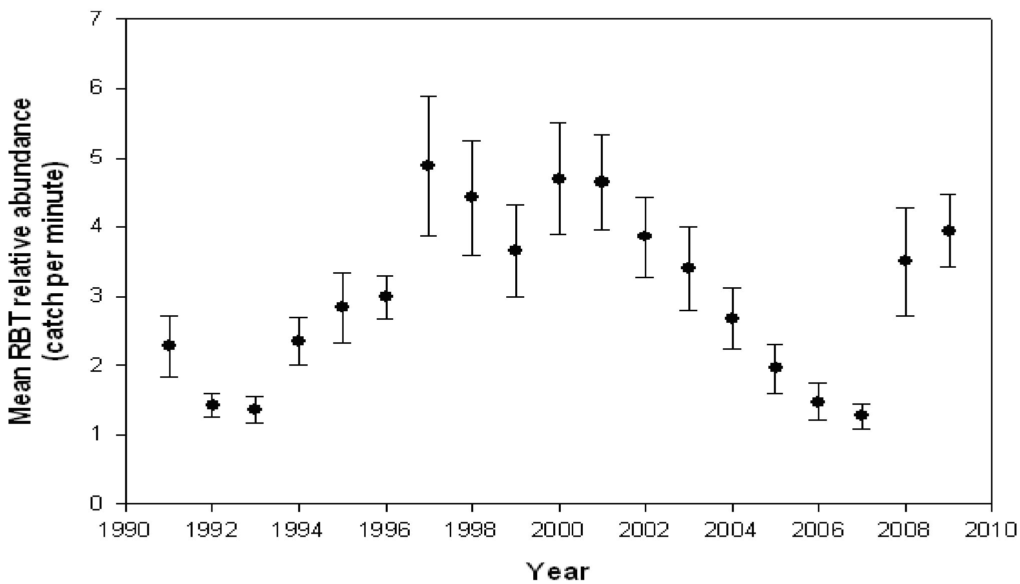


Figure 10. Average annual electrofishing catch rate of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991-2010 (Makinster et al. 2010a).

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; Stevens and Ayers 2002; Hilwig et al. 2010). 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 non-native fish population in Marble Canyon is dominated by rainbow trout and carp with small numbers of seven other species. In Grand

Canyon, the dominant non-native 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 increased from 11 species 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. Results for non-native fish were similar (4,500 to about 2,800 m^2), although less habitat was available over debris fan substrates (Figure 11).

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 Canyon 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.

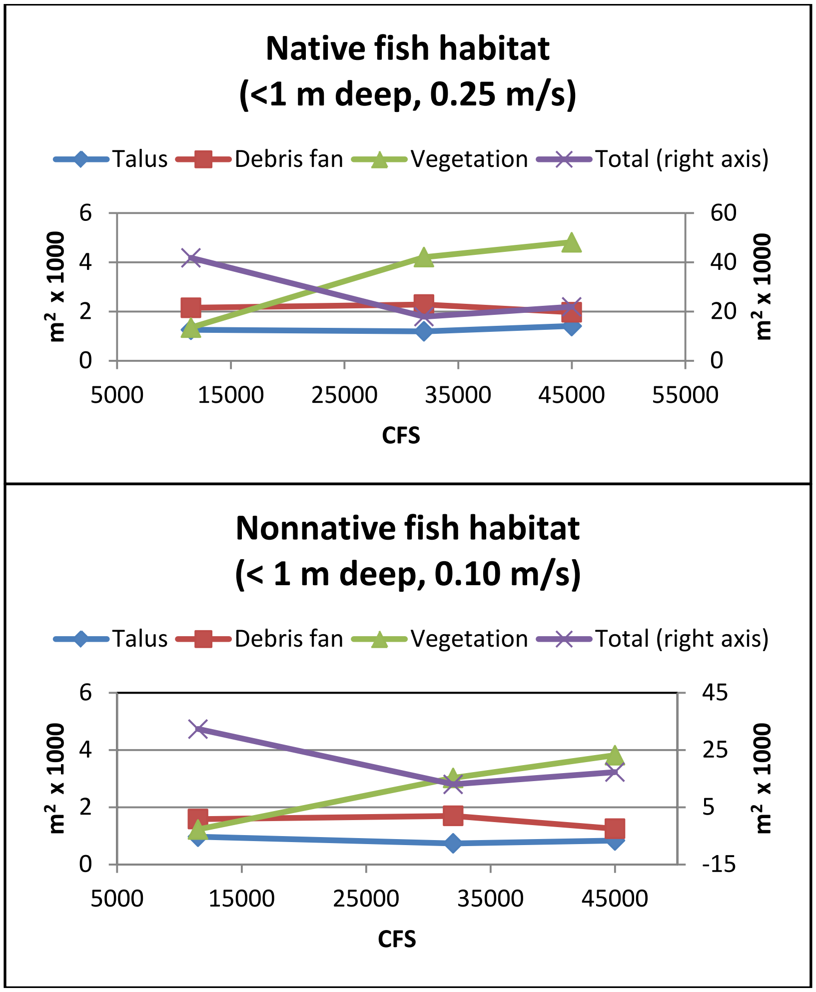


Figure 11. Total suitable habitat (purple line, right axis) and breakdown by shoreline types (left axis) used by native fish (top; approximated by humpback chub parameters) and non-native fish (bottom). Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transect. Habitat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

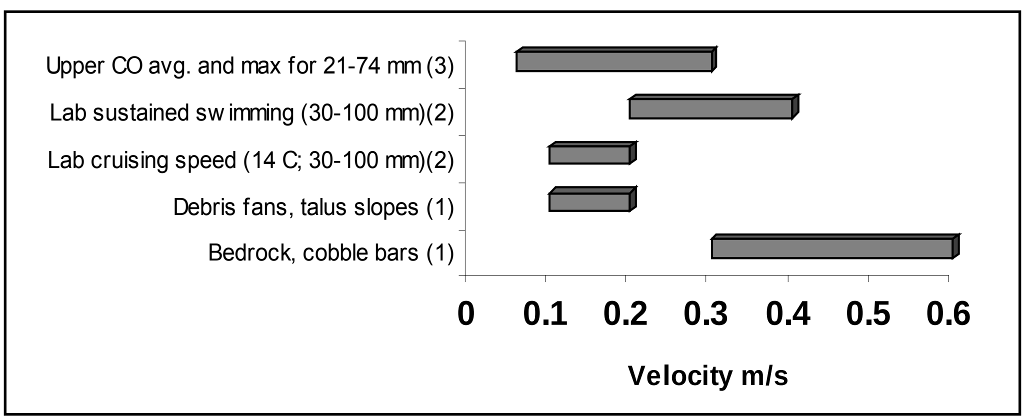


Figure 12. Velocity preference criteria for humpback chub in the Colorado River, Grand Canyon. Sources include: (1) Converse et al. 1998; (2) Bulkley and Pimentel 1983; and (3) Valdez et al. 1990.

3.2.14 Fish under Proposed Action

Impacts from the proposed action on resources considered in this EA, including fish, are summarized in Tables 17 and 18. 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 less certain 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 less certain, 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 (Appendix B).

Downstream Displacement
Humpback chub have high site fidelity (remain in a localized area) so displacement out of preferred habitat 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 (Kaeding and Zimmerman 1983; Tyus and Karp 1989; Kaeding et al. 1990; Valdez and Ryel 1995), 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 to 12 °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 30 to 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 biological opinion (USFWS 1995).

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 65.5 to RM 68 with electrofishing and minnow traps, and backwaters with seines before, during, and after the 7-day late-March, early-April 1996 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 1996 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 most 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; however, this analysis applies mainly to the young-of-year 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 (Bulkley et al. 1982; Valdez et al. 1990; Converse et al 1998; Korman et al. 2004a), 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.

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 (Makinster et al. 2010b; Korman et al. 2011). 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 without mitigation. 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 (ear bones used to measure growth) 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 HFEs 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. Conversely, 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 are 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 the unknown frequency of future HFEs and the actual response by the trout population. Reclamation is proposing to implement non-native control during 2011–2020 through the Non-native Fish Control EA (Reclamation 2011b) that has been developed concurrent with this HFE Protocol 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 is 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 (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.

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 (Lauretta and Serrato 2006; Coggins 2007; SWCA 2008; Coggins and Walters 2009) showed that numbers of humpback chub have been stable or increasing since well before 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 previous independent HFEs 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, diminishment 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.

Non-native fish control measures were first identified as part of a proposed action, including modified dam operations and mechanical removal, by Reclamation in a 2002 EA (Reclamation 2002) and included in the ensuing biological opinion (USFWS 2002c). Later biological opinions have expanded the commitments for non-native fish control, including removal of non-native fish from tributaries in conjunction with translocation of endangered fish. Section 2.3 of the Non-native Fish Control EA (Reclamation 2011b) provides ongoing and additional mitigation and monitoring measures for non-native fish identified by Reclamation to offset any negative impacts from dam operations, including impacts from implementation of the HFE Protocol EA. These measures have further been identified in the 2011 USFWS biological opinion on the operation of Glen Canyon Dam (USFWS 2011b).

Reclamation's conclusion on the proposed action for HBC is summarized in Tables 17 and 18, 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 (M. McKinstry, Bureau of Reclamation, personal communication).

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 less certain. 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.

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 less certain, 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.

3.2.17 Non-listed Native Fishes under the Proposed Action

Impacts of a March-April HFE on non-listed native fish are 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, so 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 a 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 (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 cannot move between the tributary and mainstem.

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

Reclamation does 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 larger trout. 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 were 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 HFE, so downstream dispersal of trout as an effect of high flows could not be evaluated directly.

Reclamation 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. There may be different effects from spring HFEs depending on the timing within the HFE window. Only further experiments that differ in timing will reveal these differences. 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, but as previously discussed in Section 3.0, the HFE Protocol contains provisions to address uncertainty.

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. Their major reproductive effort occurs in Bright Angel and a small number of other spring-fed tributaries in Grand Canyon. Continued Reclamation and NPS conservation measure efforts to control brown trout in Bright Angel Creek, in conjunction with measures contained in the 2011 biological opinion (USFWS 2011b), 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; McKinney et al. 1999; Valdez and Hoffnagle 1999; Makinster et al. 2007; Korman et al. 2011).

Reclamation expects 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 12). During flood, 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 (Bulkley and Pimentel 1983; Valdez et al. 1990; Converse et al. 1998; Korman et al. 2004), whereas 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.

Table 12. 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	

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 affected as much as 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.

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 (Stevens et al. 1997b; Spence 2004). 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 et al. 1989; Brown and Stevens 1991; 1992; Brown 1992). 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 separated the tributary mouth from the Colorado River, so 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, multi-storied 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 (Unit 1987; Sogge et al. 1995b; Tibbitts and Johnson 1999).

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 and later HFEs (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).

March-April or October-November HFEs would probably have no negative effect on the bald eagle because wintering and migrant bald eagles largely are not present in Grand Canyon region during these times (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 effect reproduction or survival to any measurable extent. Multiple HFEs could extend the length of this effect, 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 and they do not 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; Warren and Schwable 1985; Frey 2003; Kearsley et al. 2006). 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. They 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 beavers or their signs 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 non-native 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 because they would be able to leave their dens and swim to safety.

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

Historic Properties

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. The area measures approximately 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.

Under no action, no HFEs would be released, thus there would be no adverse effect to sacred sites from the high flows.

Sacred Sites

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.

Under no action, both Reclamation and the NPS, as the executive branch agencies with statutory or administrative responsibility for the management of the Indian sacred sites, have continuing obligations under EO 13007 to ensure that, where practicable and appropriate, reasonable notice is provided of any proposed actions that might restrict future access to the site or adversely affect its physical integrity. Under no action, no HFEs would be released, thus there would be no effect to sacred sites from the high flows.

3.3.2 Cultural Resources under Proposed Action

Historic Properties

Reclamation is in the process of completing 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 and redeposited 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. There is the potential for direct deposition of sand on archeological sites by HFEs, however, and research conducted under the GCDAMP has identified some locations where sand deposited during HFEs is redeposited by the wind and can contribute to covering of archeological sites (Draut and Rubin 2008; Draut et al. 2010).

Appendix G contains the July 1, 2011, response from the Arizona State Historic Preservation Officer to Reclamation's June 27, 2011, determination of eligibility and effect on historic properties from the proposed action. Identical letters were sent to other consulting parties.

Sacred Sites

At least five federally-recognized tribes consider the Colorado River and Grand Canyon as a sacred site. Following EO 13007, the HFEs could 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.

Mitigating measures are being discussed to offset the direct, indirect, and cumulative impacts of the proposed action with the tribes per 36 CFR 800.6. Reclamation is committed to completing the process of resolving adverse effects with the tribes and other interested parties prior to implementation of the proposed action.

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" (43 U.S.C. 620f). The 1996 ROD on Glen Canyon Dam operations constrained hydropower production to meet electrical demand as a means of reducing environmental impacts. A post-ROD study has been completed that reevaluates ROD power economic impacts and compares these results to the economic analysis performed for the 1995 EIS (Veselka et al. 2010). The 1995 EIS analysis predicted a range in annual economic impacts from $22.4 million to $65.5 million (in $2009). The 2010 study, which considered years 1997 through 2005, found the average annual economic impact in both capacity and energy costs for the nine year period to be $39 million (in $2009). In a subsequent study (Veselka et al. 2011), it was estimated that the cost of experimental flows for the same period varied from a positive $2.73 million to a negative $26.5 million, with the total cost for the nine year period being $23.02 million (in nominal dollars).

Glen Canyon Dam is one component of a larger hydropower system, and it is included along with other powerplants for marketing purposes. Capacity and energy from the CRSP, the Seedskadee Project, 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 powerplants 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).

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 powerplants 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.

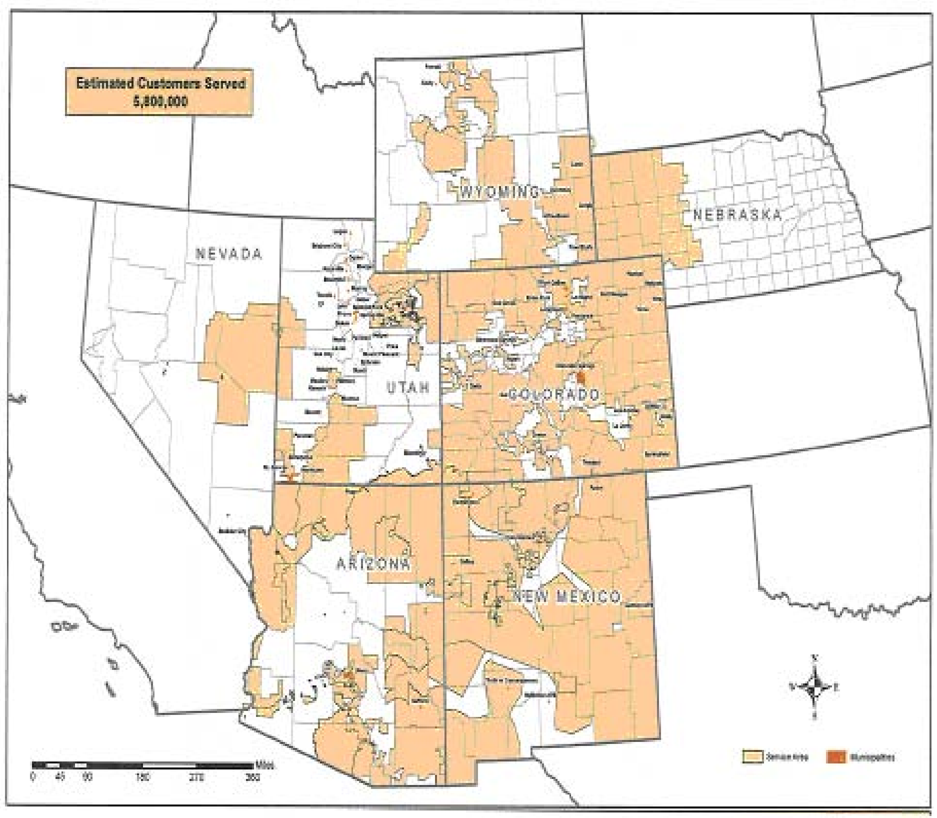


Figure 13. Colorado River Storage Project management center service territory. Map courtesy of Western Area Power Administration.

The maximum amount of electric energy that 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 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a). The description of the preferred alternative in that EIS (to which this EA is tiered) 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 times 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, the Glen Canyon powerplant provides 40 MW of system regulation and up to 98 MW of reserves to support electrical system reliability. 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 MW (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 98 MW. These "ancillary services" are important in maintaining the reliability of the electrical and transmission grid.

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 powerplant 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 of this EA).

HFEs at GCD could affect power generation in five 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 water that bypasses the powerplant 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 powerplants at a higher price, and causes additional carbon-dioxide emissions. There may also be an increase in water consumption at these thermal powerplants. The economic impacts associated with increased powerplant water consumption were not accounted for in this analysis, but presumably would be included in the cost of operation of these power plants and reflected in replacement power costs.

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.

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 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 powerplant at any point in 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 available at 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 powerplant, while energy costs are more related to the cost of operating and maintaining the powerplant. Electrical capacity is often specified and priced as a separate product from electrical energy in bulk power purchase and sale transactions.

Under some conditions, additional capacity may need to be acquired to replace lost GCD generation as a result of a series of HFEs. For example:

- Although dam operations under the HFE Protocol are implemented to reduce the need to do so, water to satisfy high magnitude, long duration HFEs may need to be transferred from other months of the year. 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 need to 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 CRSP electrical contractors and customers, those entities will need to look at different options 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 and they will need to take that into consideration.

Impacts to both capacity and energy generation have been calculated. In the foreseeable future, capacity replacement, if needed, and replacement energy would most likely be from existing natural gas or coal fired plants.

Results

Tables 13 through 15 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 in this EA)[3]. These are expressed in terms of differences from the no action trace in millions of 2010 dollars. The impacts described in Table 13 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 and the use of market prices observed in recent years would result in higher dollar impacts.

[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 (see Table 4), 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.

The impacts identified in Table 13 represent the cost to purchase replacement power, whether incurred by Western or passed on to customers in the form of a reduced contract commitment. 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.

Likelihood of Events

The nine conditions described in Table 13 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 percent of the time. The median hydrological case is a condition in which during 50 percent of the time hydrological conditions are wetter and during 50 percent 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 inputs from the Paria River. 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.

Table 13. 10-year GCD Electrical Energy Cost for the Proposed Action Alternative.

Hydrologic Condition	Sand Condition	Difference from No Action – Total over the 10-year study period (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 14 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. The impacts identified in Table 14 represent an industry estimate to replace capacity needed to meet demand, if necessary.

Table 14. 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 14 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 15 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 15 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 15. GCD Total Cost of the Proposed Action Alternatives.

Hydrologic Condition	Sand Condition	Difference from No Action over the 10-year period (2010 $M)
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 scenario 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 large 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 large 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 percent of cases).While the median and interquartile range of impacts for each hydrological condition are 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.

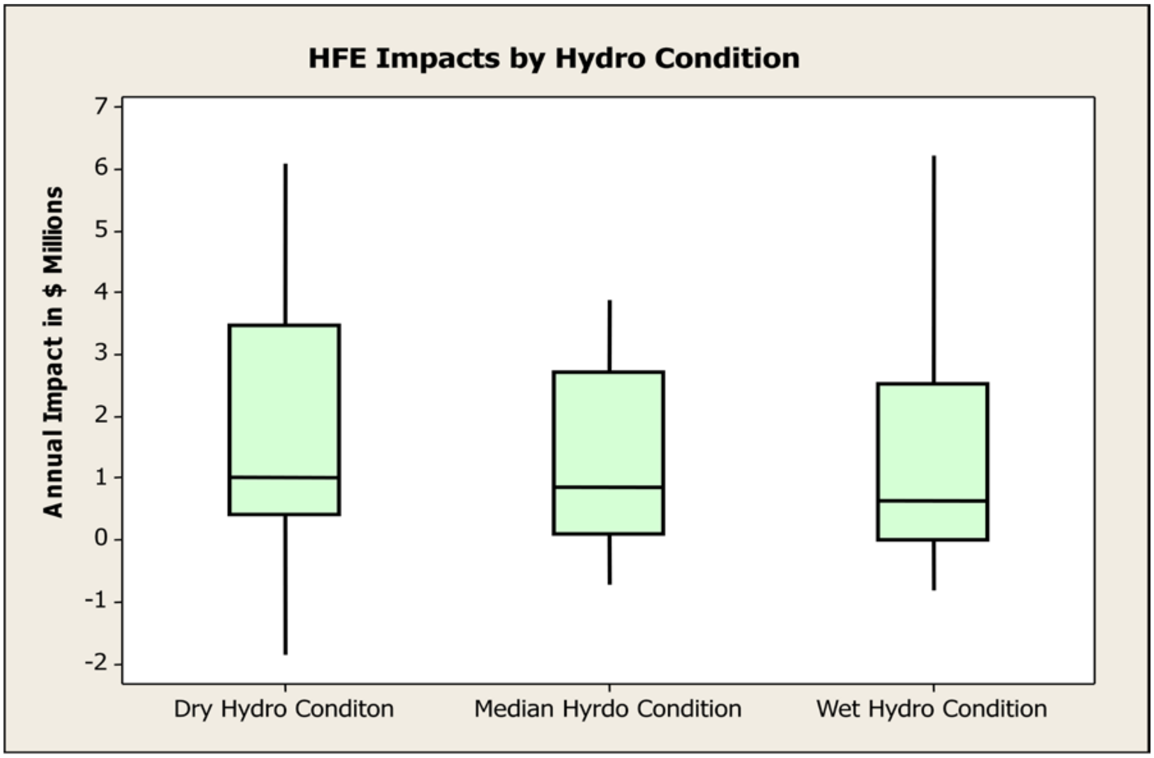


Figure 14. Annual impacts in millions of dollars of HFEs during three different hydrological conditions.

In Figure 15, impacts to capacity are added to impacts to energy. When capacity impacts are added and hydrological conditions are aggregated, the range of impacts no longer includes benefits as described above for individual years.

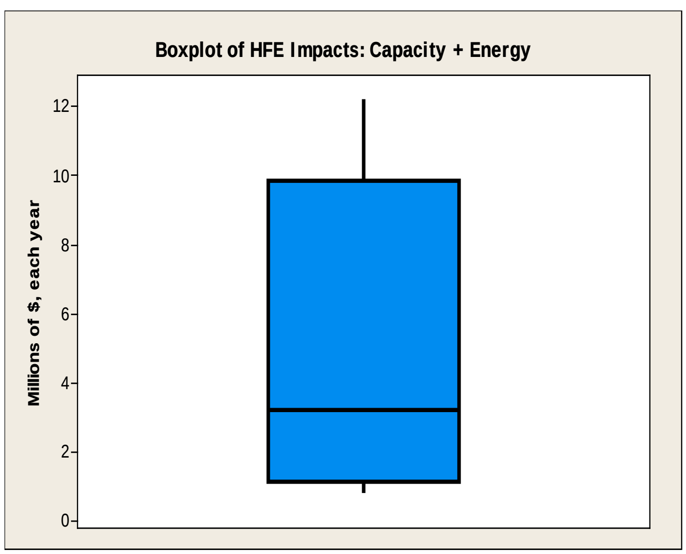


Figure 15. An illustration of the variability of impacts of the proposed action on both energy and capacity. The blue box illustrates the interquartile range, the whiskers illustrate the range of impacts, from minimum to maximum.

Uncertainties

Despite the sophistication of the water and power models used for the hydropower analysis in this EA, 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 (kayaking, rafting, canoeing, etc.) from Glen Canyon Dam to Lees Ferry, boating through Grand Canyon, and the Hualapai Indian tribe's rafting enterprise at the western end of Grand Canyon and into Lake Mead (Lichtkoppler 2011). NPS divides the Colorado River into three reaches for river management. After the Lees Ferry Reach, the upper reach starts at Lees Ferry (river mile [RM] 0) and continues to Diamond Creek (RM 226) and is known as the Marble/Grand Canyon reach or upper river. The lower reach or lower river, starts at Diamond Creek (RM 226) at the Hualapai Reservation and goes to Lake Mead (RM 277).

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 (a user day is one person on the river for any portion of a day) 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).

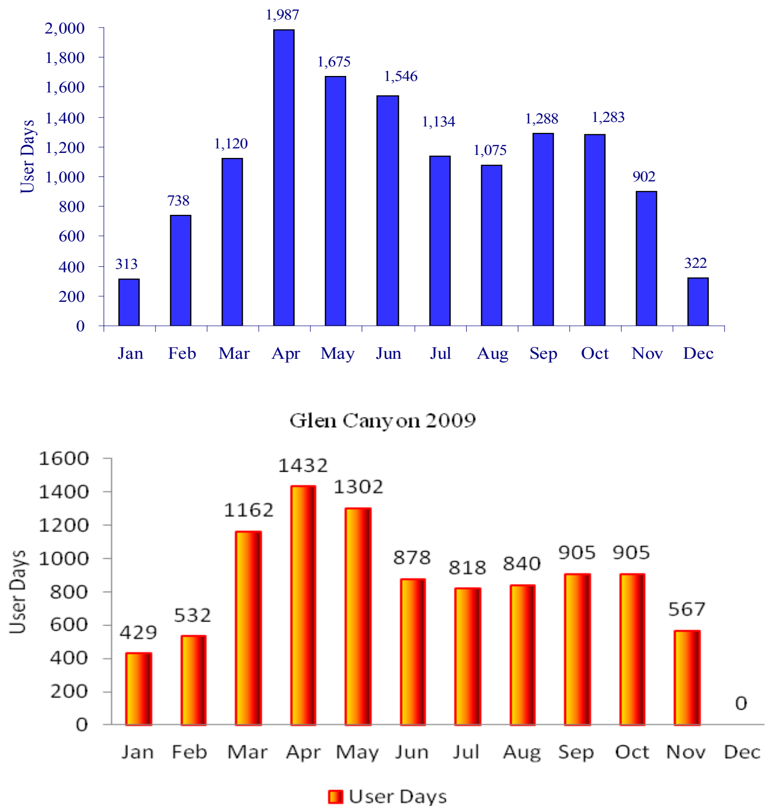


Figure 16. Fishing user days by month in the Lees Ferry reach for 2006 (top) and 2009 (bottom). User days for December 2009, listed as 0, were not measured because the vehicle counter was broken.

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 there is limited use in winter and the majority of trips are concentrated in the summer (Table 16). 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 16. 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

Boating below Lees Ferry under No Action

Boating 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; NPS 2006) with a lottery system.

The CRMP for boating through Grand Canyon National Park (NPS 2006) governs use in both the reach from Lees Ferry to Diamond Creek and the reach from Diamond Creek down to Lake Mead. Under this plan, total boating use was increased and the distribution of that use during the year was altered. 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 shows the expected maximum amount of use allowed by the CRMP as measured in user days. These estimates are based upon the number of launches allowed per day each month, the allowable group size per launch, and the expected total number of user-days per month. Experience has shown that not all of the available noncommercial trips in the winter and shoulder seasons have been filled. This is probably because colder temperatures and shorter hours of available sunlight make these trips less desirable.

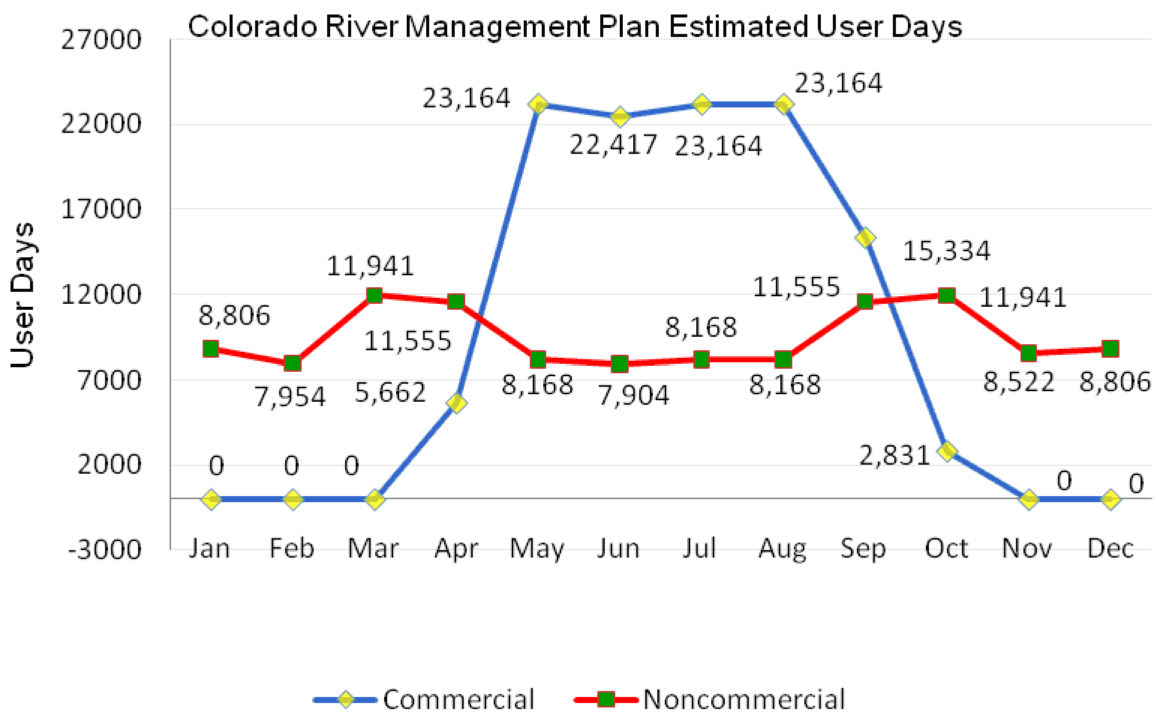


Figure 17. Boating in the Grand Canyon, anticipated annual use by month (CRMP; NPS 2006).

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 (Sullivan 2008; 2010). 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 private recreational 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 opens on March 15 and runs until October 31. 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 has been reported in the past at 45,000 cfs flows.

Recreational use below Diamond Creek is managed in accordance with the CRMP (NPS 2006). Figure 18 illustrates the maximum rafting use below Diamond Creek by the HRR as allowed by the CRMP (NPS 2006). Months of highest allowable use are June through September, with moderate use from March through May and in October. There is no allowable use for commercial boating from November through February.

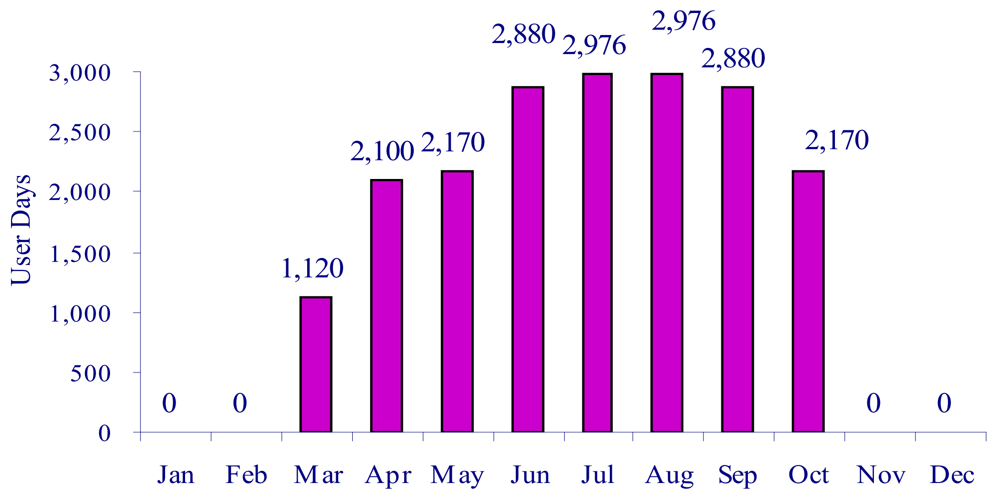


Figure 18. Commercial boating recreation use below Diamond Creek (HRR maximum possible).

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.

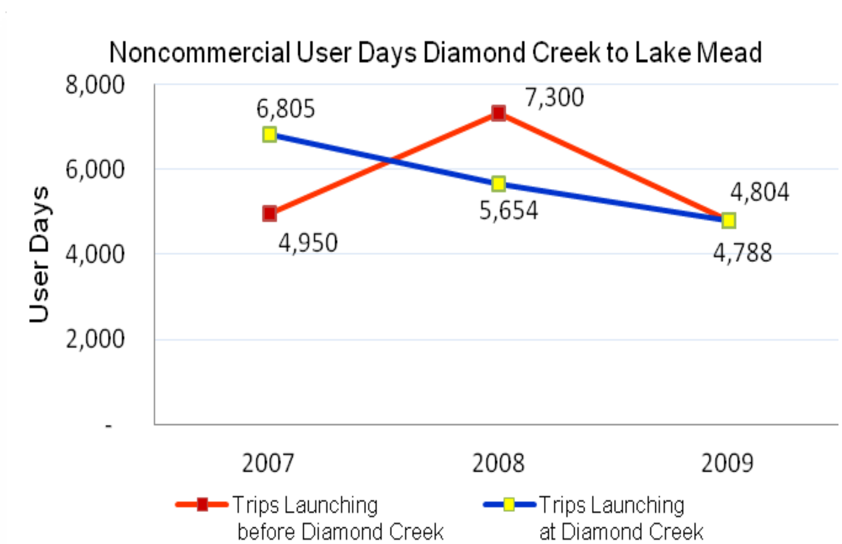


Figure 19. Noncommercial user days – Diamond Creek to Lake Mead (NPS 2009b).

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 can be served 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 boating. No control actions would be implemented.

Regional Economic Activity under No Action
Visitors to Lees Ferry and the Grand Canyon spend large sums of money in the region purchasing gas, food and drink, lodging, guide services, and outdoor equipment while visiting the region. These expenditures impact the regional economy through direct effects, indirect effects, and induced effects. Direct effects represent a change in final demand for the affected industries caused by the change in spending. Indirect effects are the changes in inter-industry purchases as industries respond to the new demands of the directly affected industries. Induced effects are the changes in spending from households as their income increases or decreases due to the changes in production.

The annual regional economic activity that results from nonresident anglers, boaters, and rafters who visit Glen and Grand Canyons was estimated for the 1995 EIS at approximately $25.7 million (Reclamation 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). A more recent study by Hjerpe and Kim (2003) found that approximately 394 jobs were supported in Coconino County alone.

The no action alternative is not expected to change regional recreation-related economic activity as a result of continuing current operations of Glen Canyon Dam.

Nonuse Economic Value under No Action
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). No subsequent non-use studies have been completed, so it cannot be determined whether or not these values would be repeated in an updated study.

3.4.4 Recreation under Proposed Action

Fishing under Proposed Action

Even with the highest flow magnitude of 45,000 cfs, access to Glen Canyon would be open for fishing. GCNRA has never closed Glen Canyon to fishing during one of Reclamation's high flows (personal communication, J. Seay, GCNRA ranger, 2010). The recreation area has never had any reported incidents due to high flows. 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 most macroinvertebrates and filamentous algae recovered within 3 months. More recent studies have shown that recovery rates are longer for some taxa (Cross et al. 2011). 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 and onsite warnings provided by management agencies on the timing, magnitude, and duration of the high flows 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 for several days. HFEs within this range of magnitudes occurred in 95% of all events using the sand mass balance model and historical data (see Table 5). Day use rafting trips were not restricted from Lees Ferry access and boats could move upstream under NPS 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.

Boating in Grand Canyon under Proposed Action

The effects of high flows above powerplant capacity on navigability are 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 choose 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 BHBF, 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 (maximum 96 hours) relative to the length of a typical non-motorized trip (18 days) and the advisement of boaters by NPS that high flows will occur suggests effects on boaters would be limited.

Wilderness characteristics of Grand Canyon 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). Boating visitation use has been unaffected by river flows.

High flows of 45,000 cfs for periods of up to 96 hours (four days) in March, April, October, or November would not keep very experienced boaters from floating the river. Other, less experienced, river runners may choose to cancel their trips or make other arrangements (perhaps to trade dates), resulting in a reduced use of the river during the experiment. 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.

Regional Economic Activity under Proposed Action

The net effect of HFEs on regional economic activity in Coconino and Mohave, Arizona, under the proposed action was estimated for recreational fishing and day-use boating in 2010 dollars 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 direct, indirect, and induced effects combined for recreational fishing in the Lees Ferry reach from a 45,000 cfs, 96-hour duration HFE ranged from approximately \$22,000 in November to \$58,000 in April. Day use boating regional impacts for the same magnitude and duration HFE 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 also included the Hualapai concessionaire downstream at Quartermaster Canyon. For a low magnitude, short duration HFE of 31,500 cfs and one hour, both recreational fishing and day-use boating impacts were estimated to have little to no measurable impact (Lichtkoppler 2011) assuming appropriate advance warnings were implemented by the action agencies.

Table 17. 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. Expected impact duration identified as days, months, or years.

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 impact (months), 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 (months), 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 (months), 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 (months), 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 (months), 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 (months), 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 photic period 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; biomass recovery expected in ~4-15 months for different taxa.	

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[4]	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-\$25,000.	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.

[4] Estimated cost of replacement power from Western Area Power Administration, Colorado River Storage Project Management Center, Salt Lake City

Table 18. 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.

Resource	Spring HFE Followed by Fall HFE	Fall HFE Followed by Spring HFE	More Than Two Consecutive HFEs
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 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.

Resource	Spring HFE Followed by Fall HFE	Fall HFE Followed by Spring HFE	More Than Two Consecutive HFEs
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-native Fish	Moderate short-term impact from changes in foodbase and displacement of small-bodied fish; short-term reduction in populations of fathead minnow, red shiner, plains killifish, other small-bodied fish expected.		Major long-term impact expected from changes 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 as identified in Table 17. Both HFE release windows are in periods of lower electrical demand.		Moderate to high impact, linear increase in replacement costs (capacity and energy) for number, magnitude, duration of HFEs.

Resource	Spring HFE Followed by Fall HFE	Fall HFE Followed by Spring HFE	More Than Two Consecutive 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 affects 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. 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 allowed months for a high-release are during low to moderate power demand, the amount of power needed for replacement is relatively small, 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 a variety of customers including: (1) small and medium-sized towns that operate publicly owned electrical systems, (2) irrigation cooperatives and water conservation districts, (3) rural electrical associations or generation and transmission co-operatives who are wholesalers to these associations, (4) federal facilities such as Air Force Bases, (5) universities and other state agencies, and (6) Native American tribes. 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. GCNP (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.

4.0 Consultation and Coordination

4.1 Tribal Consultation

Consultation with American Indian Tribes on a government-to-government basis is being conducted and results have been incorporated into this assessment and the Non-native Fish Control EA. In addition, the Pueblo of Zuni, Hopi, and Hualapai tribes are cooperating agencies on the HFE Protocol EA. 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
Paiute Indian Tribe of Utah
Las Vegas Paiute Tribe
Moapa Band of Paiutes
Havasupai Tribe
Navajo Nation, Arizona, New Mexico, and Utah
Yavapai-Apache Nation of the Camp Verde Reservation, Arizona
Zuni Tribe of the Zuni Reservation, New Mexico

Consultation has occurred through meetings with tribal officials, the exchange of letters and memoranda, telephone calls, and meetings of the GCDAMP, which include members of the Hopi Tribe, Hualapai Indian Tribe, and Kaibab Band of Paiute Indians, Navajo Nation, and the Pueblo of Zuni Tribe. The following meetings and conference calls have been conducted to observe the commitment for tribal consultation:

- Government-to-government tribal consultation meetings were held with the Zuni Tribe at the Pueblo of Zuni at Zuni, New Mexico, on September 15, 2009, March 24 and June 4, 2010, and on January 25 and March 16, 2011;

- Government-to-government tribal consultation meetings also were held with the Hopi Tribe (March 4 and April 22, 2010, and January 27, 2011), Navajo Nation (June 9, 2010, and January 26, 2011), Hualapai Tribe (March 6, 2010, and January 8, 2011), Havasupai Tribe (March 15, 2010 and February 28, 2011), Kaibab Paiute Tribe (March 18, 2010, and January 20, 2011), and the Paiute Indian Tribe of Utah (December 13, 2010);

- The Assistant Secretary for Water and Science and other representatives from Interior met with the Governor of the Pueblo of Zuni, the Zuni Tribal Council, Zuni Cultural Resource Advisory Team, and the Zuni public at Zuni, New Mexico, on August 5, 2010;

- A cooperating agency and tribal meeting was held in Flagstaff on August 20, 2010;

- Cooperating agency conference calls were conducted on September 2, 9, 16, 23, 30, and November 4 and 21, 2010, and on January 5, 2011, and March 24, 2011.

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 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. At the request of interested parties, a second public review commenced on July 5, 2011, and closed on July 19, 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 the draft EAs by cooperating agencies proceeded the two public reviews identified above.

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

Sub-basin:
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.

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

BILLING CODE 4310–MN–P

Appendix B: Science Plan

General Science Plan for Monitoring and Research of a High-Flow Experiment Protocol at Glen Canyon Dam

December 22, 2011

Grand Canyon Monitoring and Research Center
Southwest Biological Science Center
U. S. Geological Survey
Flagstaff, Arizona

Introduction

This general science plan describes a program of monitoring and research activities that support ongoing information needs associated with implementation of the proposed action described in the **Environmental Assessment for Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, 2011 through 2020** (hereafter referred to as the HFE EA). These high flows are proposed to repeatedly occur during a ten-year period.

This document represents an initial plan for science activities that will be implemented in FY2012. In response to the Grand Canyon Monitoring and Research Center's (GCMRC) initial 2011 proposal for studying flows under the HFE EA, these tasks were recommended by the Glen Canyon Dam Adaptive Management Program (GCDAMP) as part of the **Glen Canyon Dam Adaptive Management Program Biennial Budget and Work Plan—Fiscal Years 2011-12** (hereafter referred to as the FY 2011-12 BWP.

The proposed action of the HFE EA is based on the best available knowledge of sediment transport and geomorphic processes of the Colorado River downstream from Glen Canyon Dam. Previous research demonstrates that high-magnitude dam releases have beneficial geomorphic effects on the Colorado River ecosystem only if there is a large amount of antecedent fine sediment stored on the channel bed or being delivered to the Colorado River at the time of large dam releases (Melis, 2011). Measurement of antecedent fine sediment storage requires continuation of GCMRC's sediment-transport monitoring programs. This science plan recognizes a need to inform future decisions about implementation of high flows and the appropriateness of trigger criteria. Thus, this science plan will be adaptively revised so as to inform the adaptive management of the Colorado River.

The proposed action of the HFE EA has as its goal the retention of fine sediment within the Colorado River ecosystem. Retention of fine sediment – those sizes of sediment < 2 mm and classified as sand and mud – as eddy sandbars and channel-margin deposits fulfills many ecological objectives for the management of the Colorado River in Grand Canyon National Park. Retention of fine sediment is hereafter referred to as "fine-sediment conservation." Most of the FY2012 tasks described in this plan focus on flow and suspended-sediment transport monitoring, conducted in combination with measurements of sand-bar topography. The resulting data are intended to document changes in the amount of sand and mud temporarily stored in and near the channel, as well as documenting the characteristics of riparian and aquatic habitats associated with fine-sediment deposits.

Although the HFE EA is focused on issues of sediment transport and geomorphology, the HFE EA also notes that high flow releases have the potential to directly affect biological and cultural resources. Thus, other tasks scheduled for the initial year (FY2012) of this science plan are intended to document biotic, economic, and recreational responses associated with the timing and frequency of repeated high flow experiments (HFEs).

The tasks identified in this general science plan have only been approved for FY2012, and other science planning activities associated with the GCDAMP are ongoing and not yet completed for 2013 and thereafter. As such, this plan is not comprehensive or inclusive of all science activities that may eventually be needed to evaluate the proposed ten-year period of high-flow experiments under the recommended action of the HFE EA (hereafter referred to as the HFE Protocol).

Need for Experimental Project

Previous HFEs released from Glen Canyon Dam were conducted in 1996, 1997, 2000, 2004, and 2008. These previous releases varied from 2.5 to 7 days in length and had peak flows ranging from power-plant capacity of about 31,500 to 45,000 cubic feet per second (ft^3/s). From these experiments, sediment scientists generally concluded that the only presently available tool for rebuilding sand bars is to release short duration, high flows after tributary floods have deposited new sand and mud into the main channel of the Colorado River. The HFE EA takes advantage of the knowledge gained in the previous experiments (Melis, 2011) and proposes to implement HFEs on a more regular basis following tributary fine sediment inputs. A brief summary of some elements the HFE Protocol, as described in the HFE EA follows:

> "The timing of high-flow releases would be March/April or October/November; the magnitude would be from 31,500 [ft^3/s] to 45,000 [ft^3/s]. 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 will initially evaluate the effectiveness of high-flow releases under the HFE Protocol starting in 2012. These tasks are described in more detail in the FY 2011-12 BWP. Revisions to this science plan in years beyond 2012 will very likely be needed based on availability of funds. Additionally, knowledge gained from the initial scientific studies will inform future HFEs within an adaptive management framework. Revisions may also be required to address additional experimental activities identified in the **Long Term Experimental and Management Plan** (LTEMP) environmental impact statement (EIS) for Glen Canyon Dam operations that was initiated by the U. S. Department of the Interior in 2011.

The approach described in this science plan relies on existing quality-of-water, sediment, aquatic biology, and other resource monitoring projects funded in the FY 2011-12 BWP. No new studies are proposed, however, some existing 2012 monitoring and research efforts are expanded or adjusted to provide information that is directly relevant to the evaluation of a high flow experiment in 2012 should one occur.

This initial science plan is focused on assessing only the effects of the "store and release approach" described in the HFE EA. A separate science plan will be developed to assess the effects of the "rapid response approach" that is also described in the HFE EA. The details of this alternative approach have not yet been extensively described.

It is expected that many of the studies described below will inform both approaches to releasing high flows under the HFE Protocol, but more specific short-term investigations may be needed to evaluate the efficacy of the rapid response approach. This alternative release strategy may need to be adapted during periods when upper Colorado River basin hydrology is average or wetter and dam releases need to be increased to meet downstream water transfers or for dam safety purposes. In response to above-average runoff from the upper basin in 2011, Glen Canyon Dam releases during Water Year 2012 are predicted to be above-average to achieve equalization requirements for water storage between Lake Powell and Lake Mead. Owing to these required releases, ongoing science planning associated with a rapid response strategy is expected to occur during 2012. Science tasks that may be needed beyond the scope of this initial plan will be developed in coordination with the GCDAMP as part of the FY2013-14 biennial work plan as well as the next 5-year monitoring and research plan (FY2013-17).

Experimental Project Goals

The primary goal of HFE EA is to test the hypothesis that a series of tributary sand-enriched high flows will be an effective strategy for rebuilding and maintaining sand bars using dam operations. A secondary scientific goal will be to evaluate the effects of implementation of the HFE Protocol on other priority GCDAMP resources including the aquatic food base, riparian vegetation and spring habitats, camping beaches, archaeological sites, and hydropower economics.

Strategic Science Questions

A major task of the GCMRC in 2010 was the synthesis of the results of the 1996, 2004 and 2008 high flow experiments (Melis, 2011). In this report Wright and Kennedy (2011) provided direction that is relevant to the primary focus of HFE Protocol 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."

Thus, in addition to the fundamental strategic science questions related to sediment resources, other science tasks will need to focus on assessing the effects of HFEs on other priority GCDAMP resources including aquatic food base, riparian vegetation and springs habitat, recreational camping beaches, archaeological sites, and hydropower economics. Science questions and tasks pertaining to HFEs and effects on native fish (especially humpback chub) and Lees Ferry rainbow trout (including recreational angling satisfaction) will also be addressed by the GCMRC and its cooperators, and are described within a separate general science plan associated with the U.S. Department of Interior, Bureau of Reclamation's **Environmental Assessment of Non-Native Fish Control Downstream from Glen Canyon Dam** (NNFC EA).

Scientists emphasize that there is substantial uncertainty about some of the resource outcomes 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 HFE Protocol in response to sandbar monitoring may also be required, and a different HFE strategy may be justified during average-to-wet versus dry runoff periods in the upper Colorado River basin. Because of these uncertainties, the annual "status check" outlined in the HFE EA will be a critical component of an adaptive strategy for future high flows from the dam. This status check would involve reviewing recent monitoring data for sand budgets, sandbar size and other resource responses. Based on the findings of these reviews, the HFE Protocol may also need to be adapted to address undesirable resource responses. Likewise, HFE science tasks may need to be adapted annually based on new knowledge and learning and to address new or evolving science questions.

Methods and Tasks

Initial HFE Protocol monitoring and research tasks are summarized below. Reference should be made 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 FY 2011-12 BWP, and (b) additional funding is not available to provide expanded research and monitoring of the effects of the HFE Protocol in 2012, should a high flow be released.

Additional funding or reprogramming of existing FY 2011-12 BWP funds would be required to expand the scope of the initial work described here for year-1 of HFE Protocol implementation. 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 Protocol on priority GCDAMP resources (also, see general science plan associated with the NNFC EA).

The priority focus of this general science plan in 2012 will be to address and answer, to the extent possible, the following HFE Protocol science questions:

<u>Sandbars, Camping Beaches, and Archaeological Sites</u>

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 that comes from 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 along the Colorado River?
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?

<u>Aquatic Food Base</u>

5. What is the effect of a fall HFE on the aquatic food base of the Lees Ferry reach, defined as the Glen Canyon Dam tailwater reach extending approximately 15 miles downstream from the dam?

<u>Riparian Vegetation and Spring Habitats</u>

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

<u>Water Quality</u>

9. How do high flow experiments affect water quality (especially dissolved oxygen and temperature) in the forebay of Lake Powell and in the Colorado River between Glen Canyon Dam and Lees Ferry?

<u>Hydropower</u>

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

Additional studies aimed at addressing the effects of dam operations on native and nonnative fisheries in Glen, Marble, and Grand Canyons, either under the HFE Protocol or other proposed flow experiments, are described within the general science plan accompanying the NNFC EA.

Task 1. Monitoring Within-Channel and High-Elevation Sediment Storage

This task involves monitoring the topography of fine sediment deposits. The ultimate measure of whether or not fine sediment is conserved along the Colorado River is whether or not fine sediment deposits increase or decrease in volume and area. For purposes of informing dam management, it is also important to distinguish between changes in the volume and area of fine sediment that occur below the water surface and changes that occur at higher elevations. Measurement of such changes in the mass of fine sediment requires a mix of direct field measurement and extrapolation throughout the 255 miles of the Colorado River ecosystem between Glen Canyon Dam and River Mile 240, which is the upstream end of Lake Mead. To meet this objective of measuring changes in fine sediment in response to the HFE protocol, the results of four currently funded programs will be integrated.

Project a (infrequent measurement of entire segments of the river corridor):

This project involves measuring changes in the area and volume of sandbars. The ***SedTrend*** channel-mapping project is designed to monitor the cumulative effects of multiple high flows. 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 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 of the FY 2011-12 BWP. Because the approach of this project is to monitor average sandbar size in a "typical" condition, the channel mapping associated with ***SedTrend*** will occur six months or more following each HFE. Thus, in some years that have high flows, channel mapping may be postponed or deferred depending on HFE timing.

Project b (frequent measurement of sandbar monitoring sites):

Additionally, changes in sandbar area and volume above the 8,000 ft^3/s water surface will be measured at long-term sandbar monitoring sites. While the focus of measurements described in *Project a* is comprehensive monitoring of total changes in sand storage - including sandbars - at infrequent measurement intervals, measurements at long-term measurement sites will be used to describe changes at a subset of sandbars at more frequent intervals. Reference should be made to the project descriptions of Goal 8 of the FY 2011-12 BWP for a summary of the methods. To enable comparison with historical conditions, it is essential that this task monitor the same set of 50 study sites that have been monitored in the past. The data collected here and in *Project c* will be used to address the issues related to the use of this small set of monitoring sites relative to the large number of sandbars that are in Grand Canyon. Sediment scientists believe that only by collecting and analyzing the more spatially robust data outlined in this project and in

Project d, 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 sandbars gradually erode. For this reason, this 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 to this monitoring effort. Instead, the GCMRC proposes to perform a survey approximately six 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 alternate year. In that case, an additional monitoring trip would be required. This sandbar monitoring was conducted in FY 2011, so FY 2012 is the first year that this activity would 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 digital remote cameras. The GCMRC plans to install cameras at up to 20 additional sites before the next high flow, should one occur in fall 2012. Reference should be made to the FY 11-12 BWP for more details on this project.

Project c (campsite monitoring):

Measurement of the high elevation parts of sandbars is critical to estimating the impact of the HFE Protocol on the availability of campsites. Monitoring is currently scheduled to occur every two years unless a high flow occurs. Reference should be made to the Goal 9 project description for a summary of the planned campsite-monitoring component in the FY 2011-12 BWP. 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 along the Colorado River ecosystem 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, the GCMRC proposes to perform a campable area survey approximately six months following each high flow in conjunction with the proposed sandbar-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. Sandbar monitoring occurred in FY 2011, so FY 2013 is the first year that this need for supplementary funding would occur should an HFE be released in fall 2012.

Project d (remote sensing):

This project is needed to supplement other measurements to fully track changes in sandbar area above the stage of 8,000 ft^3/s. 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 ft^3/s). Collection and processing of these data will provide 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 Project b are representative of sandbar trends throughout the Colorado River ecosystem. 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 along shorelines used by fish. Reference should be made to Goal 8 and Goal 12 for more detailed project descriptions within the FY 2011-12 BWP. This activity is part of the regular monitoring program for terrestrial resources along shorelines of the Colorado River below Glen Canyon Dam to address high-flow responses and does not require additional funding when high flows occur. Remote sensing data collection is scheduled to occur every 4 years, with the last imagery data set collected in May 2009 and the next over flight scheduled for May 2013.

Task 2. Monitoring Suspended-Sediment Flux

This project addresses the fundamental premises of the HFE Protocol by tracking tributary sand inputs and main channel export. Monitoring of sand and mud flux during future high flows will be conducted as part of the regular Goal 7 monitoring activities. The methods, monitoring sites, and planned products are described in the Goal 7 project description found in the FY 2011-12 BWP should an HFE occur in 2012. This task requires 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 3. Monitor Archaeological Site Condition and Stability in Response to Repeated HFEs

Monitoring protocols are under development by the GCMRC that are specifically intended to be applicable for evaluating physical changes at archaeological sites tied to changes in sediment supply under a variety of dam operations. The initial 2012 HFE monitoring program for archaeological sites will continue with a limited phase of research and development while also evaluating use of 2009 remote imagery data intended to support ongoing National Park Service monitoring efforts in Grand Canyon National Park. In 2012, this task will consist of combining use of remotely sensed imagery with ongoing site monitoring methods conducted by National Park Service. At the same time, other site monitoring techniques will continue to be piloted in Glen Canyon National Recreation Area and evaluated for possible ongoing use to meet management information needs as HFEs are repeated between 2013 and 2020 under the HFE Protocol. Existing remote imagery data from 2002, 2005, and 2009 are also being evaluated by GCMRC and the National Park Service in 2012 to determine how aerial imagery might be used throughout the Colorado River ecosystem to track changes in sandbar area resulting from repeated high flows and other dam operations.

Task 4. Monitoring the Aquatic Food Base

The presently funded aquatic food base (AFB) project has been focused since 2006 on establishing 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 Lees Ferry and Diamond Creek (located 240 miles downstream of Glen Canyon Dam) is included in the final FY 2011-12 BWP. Monthly sampling is planned during FY 2012. The GCMRC suggests that monthly sampling of AFB beyond FY 2012 is also needed to support evaluation of the future HFEs between 2013 and 2020. 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. Reference should be made to the FY2011-12 BWP for a more detailed description of this project.

Task 5. Riparian Vegetation Monitoring

Together with its cooperators, the GCMRC has been monitoring the riparian vegetation community since 2000. Because of the distribution and extent of the vegetation community, the 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 proposed ongoing 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 an HFE. Vegetation monitoring using transects is scheduled to take place in 2012 and over a biennial schedule thereafter. Supplemental monitoring of vegetation in 2013 would be needed if a controlled flood occurred in fall of 2012 or spring 2013 and subsequently every other year thereafter. Monitoring vegetation in years with a high flow release allows for assessment of both short and long-term impacts of HFEs to riparian vegetation. The FY 2011-12 BWP approved budget covers the cost of field transect monitoring in 2012, and details of this monitoring are described in the biennial work plan.

Task 6. Kanab Ambersnail Monitoring

As described in the US Fish and Wildlife Service's 2011 Final Biological Opinion related to the NNFC EA, information related to changes in Kanab ambersnail habitat at Vaseys Paradise, located 47 miles downstream from Glen Canyon Dam, will be provided through annual monitoring, as described in the FY 2011-12 BWP (p. 107). No additional work will be programmed during FY 2012 in association with an HFE unless further information needs are identified through the GCDAMP planning process as part of the FY 2013-14 biennial work plan.

Task 7. Lake Powell and Lees Ferry Water Quality Monitoring

Monitoring of the water quality in Lake Powell provides an important perspective in the assessment of any high-flow release impacts to the reservoir itself or to downstream resources that respond to the quality of water released from the dam. 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.

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 FY 2011-12 BWP, 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.

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.

Task 8. Evaluate Effects to Hydropower from Repeated HFEs

As part of the FY 2011-12 BWP, the GCMRC convened an expert workshop in 2011 to evaluate Western Area Power Administration’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. As economic studies continue to be developed as part of the GCDAMP during 2012, the GTMax model, as well as other models, may start to be used by GCMRC and its cooperators to assess potential costs and benefits to hydropower from implementing repeated HFEs, as well as for evaluating other alternative experimental operational scenarios in the future. During early 2012, the GCMRC is also adding an economist to its staff who will continue to work with the GCDAMP to develop studies intended to evaluate HFEs, as well as other related dam operation and resource topics.

Science Products/Reports on HFE Protocol

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) with updated information also posted at the GCMRC’s web site (http://www.gcmrc.gov/). In addition, a summary of relevant results and findings specific to an individual HFE should one occur in 2012 will be provided by the GCMRC in fiscal year 2013 and beyond as HFEs continue to be released under the protocol.

Budget

The GCMRC anticipates that the HFE Protocol science tasks described above will be funded as part of ongoing monitoring and research projects included in the approved FY 2011-12 BWP, including use of experimental funds as described in that work plan. Continuation of the tasks described here, or the addition of any other tasks that may be needed to provide information about repeated high flows released beyond 2012, will be developed through ongoing planning efforts between the GCMRC and the GCDAMP, starting with development of the draft FY 2013-14 Biennial Work Plan during 2012.

References Cited

Melis, T. S., ed., 2011, Effects of three high-flow experiments on the Colorado River ecosystem downstream from Glen Canyon Dam, Arizona: U. S. Geological Survey 1366, 147 p.

Wright, S. A., and Kennedy, T. A., 2011, Science-based strategies for future high-flow experiments at Glen Canyon Dam, ***in*** Melis, T. S., ed., 2011, Effects of three high-flow experiments on the Colorado River ecosystem downstream from Glen Canyon Dam, Arizona: U. S. Geological Survey 1366,, p. 127-147.

Appendix C: Biological Assessment and Supplement

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

IN REPLY REFER TO:
UC-700
ENV-7.0

JAN 14 2011

MEMORANDUM

To: Field Supervisor, Mr. Steve Spangle, U.S. Fish and Wildlife Service, 2321 West Royal Palm Road, Suite 103, Phoenix, Arizona 85021

From: Larry Walkoviak
Regional Director ACTING FOR

Subject: Transmittal of Bureau of Reclamation Biological Assessment Regarding the Development and Implementation of a Protocol for High-Flow Experimental Releases From Glen Canyon Dam, Arizona, 2011 through 2020

Pursuant to Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.c. § 1531 et seq. and the implementing regulations at 50 C.F.R. 402.16, Reclamation is requesting initiation of formal consultation with the U.S. Fish and Wildlife Service (Service) regarding Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020.

This request is to analyze the effects of development and implementation of a protocol for high flow experimental releases from Glen Canyon Dam that may affect listed species including Kanab ambersnail (*Oxyloma haydeni kanabensis*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), southwestern willow flycatcher (*Empidonax traillii extimus*) and California condor (*Gymnogyps californianus*) or designated critical habitat for humpback chub and razorback sucker. Our effects analysis is described in detail in the attached Biological Assessment.

The attached Biological Assessment was prepared by Reclamation staff and contractors as described in 50 C.F.R 402.12. The biological assessment incorporates results of onsite inspections, updated information on listed species and designated critical habitats based on the views of recognized experts, reviews of the literature, and reaches findings about the effects of the proposed action on listed species and critical habitat in the action area below the dam. The findings are that the proposed action, as described in the attached Biological Assessment:

- May affect, and is likely to adversely affect, the Kanab ambersnail, due to scouring of snail habitat and transport of animals downstream during the high flow experiments.

- May affect, and is likely to adversely affect the humpback chub, due to increased production of rainbow trout, which prey upon the endangered fish, short-term adverse effects on habitat and foodbase from high flows, and potential downstream displacement of young-of-year and juveniles from the high flows.

- May affect, and is likely to adversely affect the razorback sucker, due to potential short-term effects of high flow on early life stages in spawning and rearing habitats in the Lake Mead inflow.

- May affect, but is not likely to adversely affect the southwestern willow flycatcher, because birds will not be present during high flow test periods, but birds could be present and foraging and there could be some indirect effect to their food supply.

- We have determined that the proposed action will not affect the California condor because the proposed action will not result in direct or indirect effects to this species, and thus will not affect the numbers, distribution, or breeding, feeding, or shelter of this species.

In assessing effects on designated critical habitats below the dam, the proposed action:

- Is likely to result in adverse effect to critical habitat for the endangered humpback chub from short-term reductions in nearshore habitat, short-term reductions in food supply, and increased numbers of predators.

- Is likely to result in adverse effect to critical habitat for the endangered razorback sucker due to deposition of fine sediments on spawning and rearing habitats.

We appreciate your expedited consideration of this request for initiation of consultation. If you have any questions regarding the Biological Assessment, please contact Mr. Glen Knowles at 801-524-3781.

Attachment

cc: UC-413, UC-438, UC-600, UC-720, UC-730 (each w/att)

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).

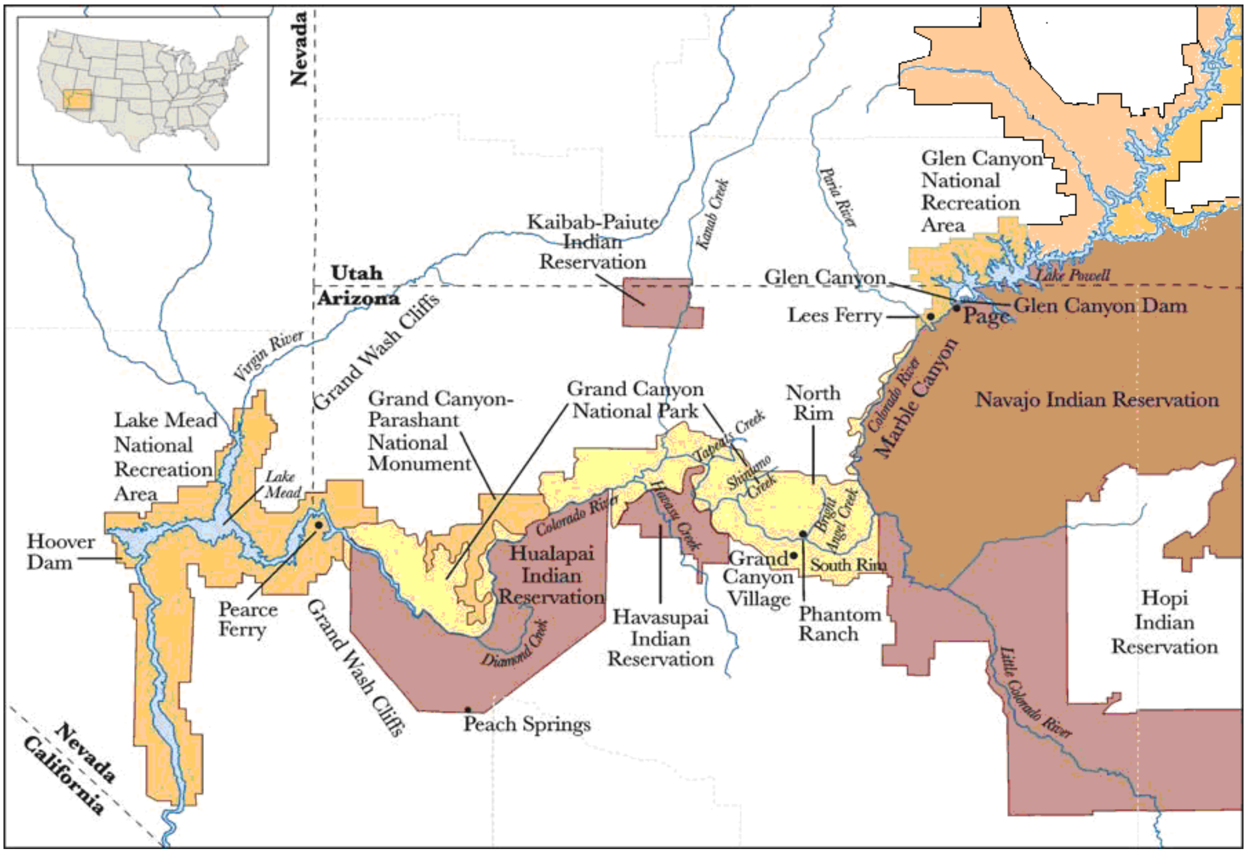

Figure 1. Action area from Glen Canyon Dam to Pearce Ferry, Arizona.

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.

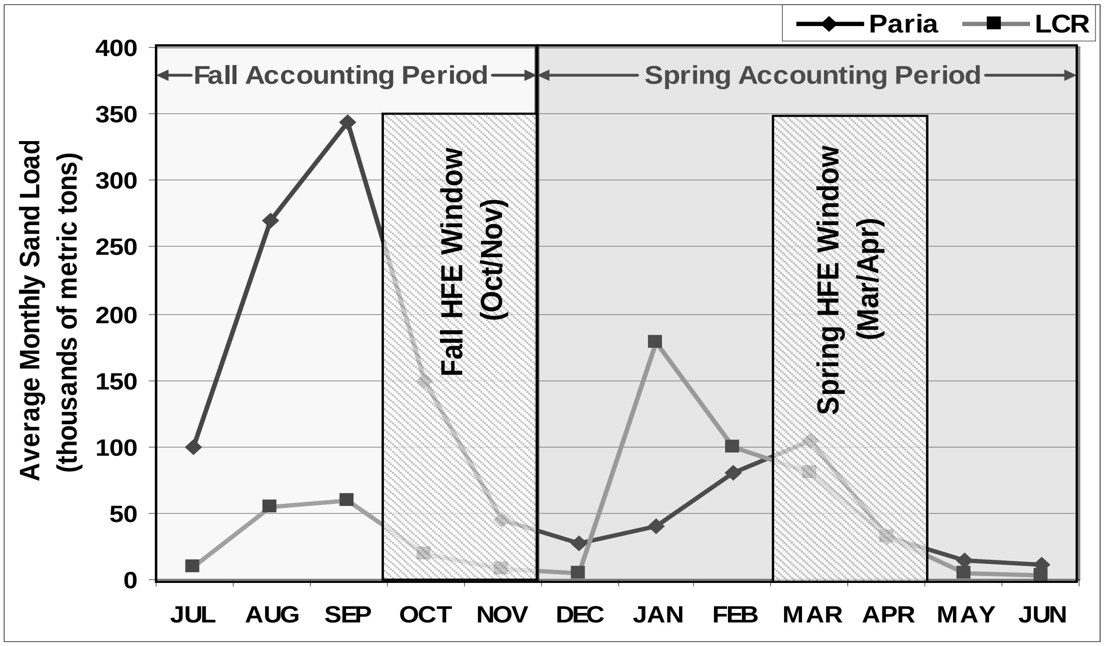

Figure 2. The two sand accounting periods and the two high-release periods with average monthly sand loads for the Paria River and the Little Colorado River. Note that although average monthly sand load from the Paria River for the fall accounting period is August and September, greatest accumulation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

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[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).

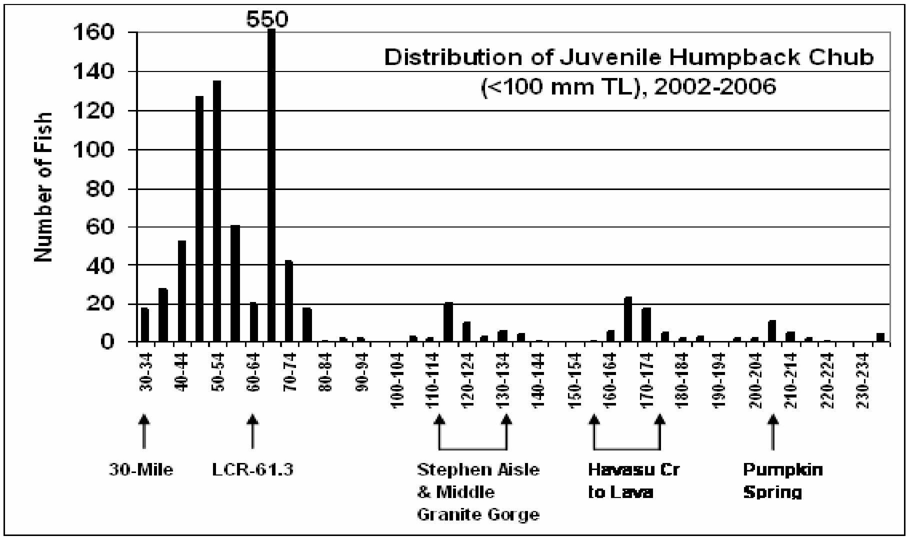

Figure 3. Distribution of juvenile humpback chub < 100 mm TL during 2002-2006 by 5-miles increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from Ackerman and Valdez 2008)

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.

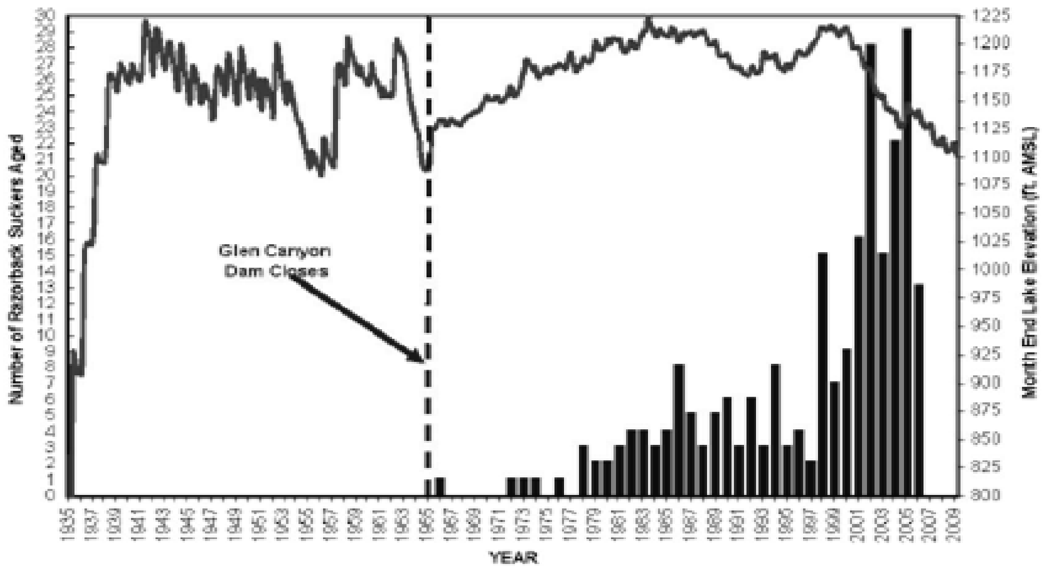

Figure 4. Lake Mead elevation from January 1935 to June 2009 with the number of razorback sucker that were born each year lake-wide, based on ages of fish captured during 2005-2008 (figure from Kegerries et al. 2009). Note that the historic decline in numbers of fish is not necessarily a measure of spawning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

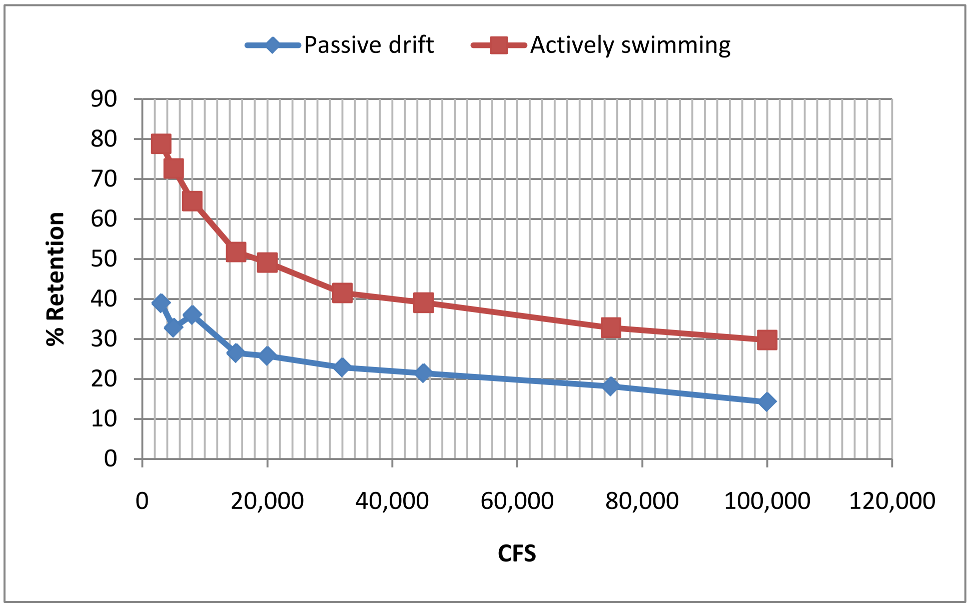

Figure 5. Average percent of simulated young-of-year fish retained within a given river reach over a range of river flows and swimming behavior assumptions. Legend refers to swimming performance assumptions (see text). Data are from Korman et al. 2004.

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).

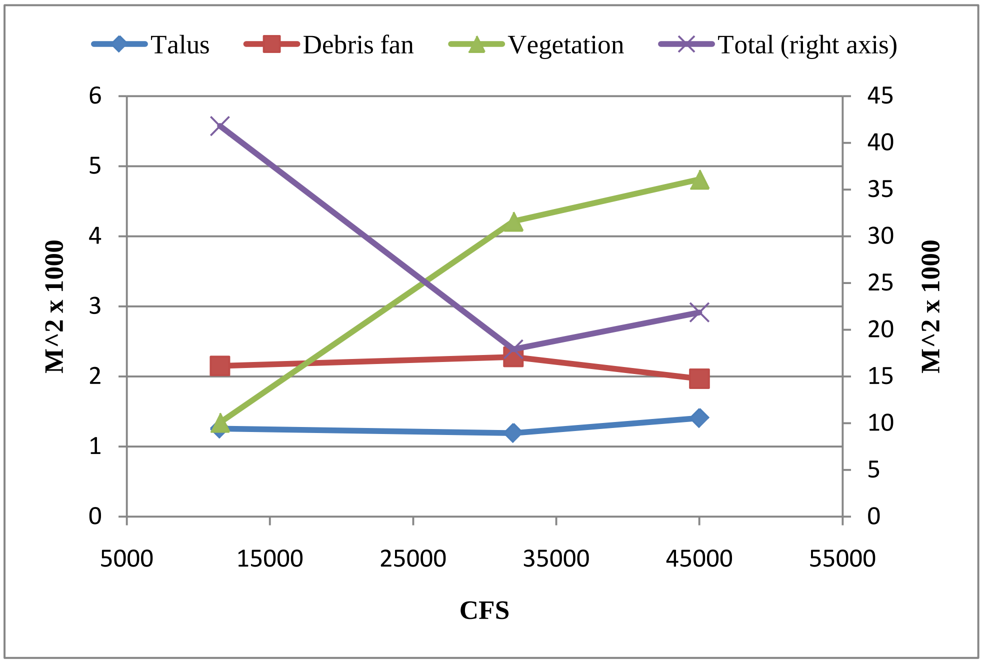

Figure 6. Total suitable shoreline habitats of humpback chub by river flow. Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transect.

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.

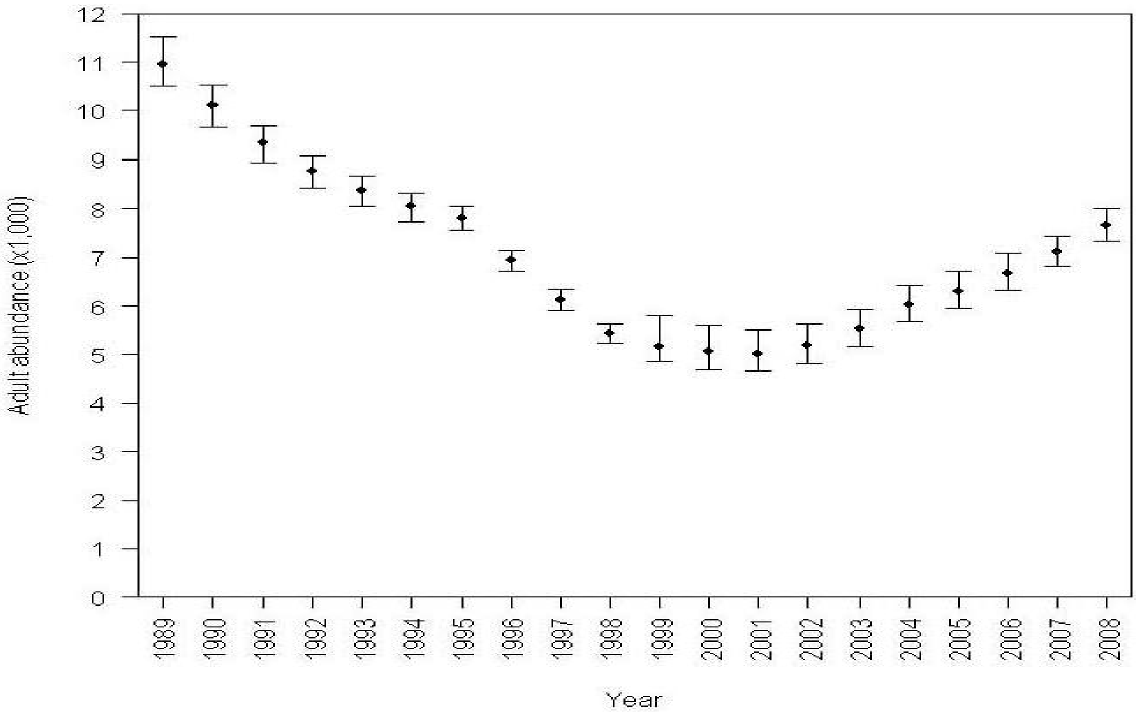

Figure 7. Estimated adult humpback chub abundance (age 4+). Point estimates are average values and error bars represent maximum and minimum 95 percent confidence intervals. From Coggins and Walters (2009).

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.

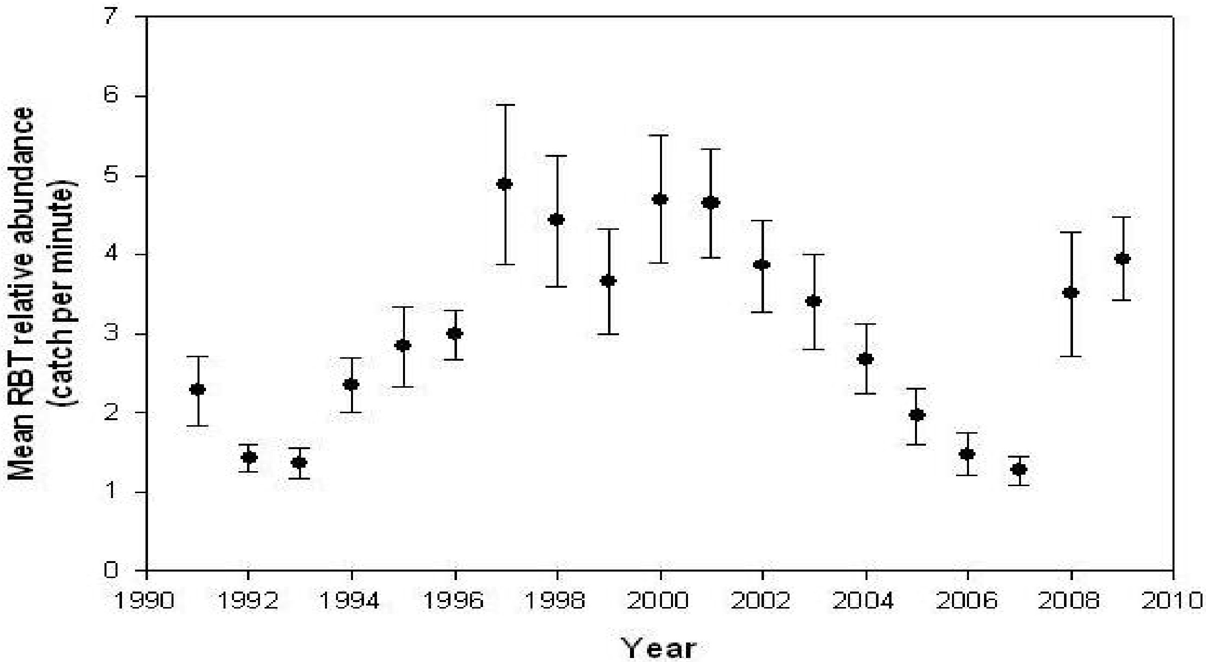

Figure 8. Rainbow trout mean relative abundance (catch per minute) in the Lees Ferry tailwater fishery, 1991-2009. Figure represents data from all size classes in both fixed and random transects. Points represent the average among sites and seasons while bars represent ± 2 standard errors of the average, 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. • 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.
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. • Short-term beneficial effect from inundated vegetation and increased turbidity as protective cover from predators. • 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. • 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. • Proportionally less habitat area scoured and fewer numbers of snails would be displaced by lower magnitude HFEs. • 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. • 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 safeguarded 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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United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

IN REPLY REFER TO:
UC-700
ENV-7.0

JUL 13 2011

MEMORANDUM

To: Field Supervisor, U.S. Fish and Wildlife Service, 2321 West Royal Palm Road, Suite 103, Phoenix, Arizona 85021
Attn: Steve Spangle

From: Larry Walkoviak
Regional Director Anamarie Gold

Subject: Supplement to Biological Assessments for Development and Implementation of a Protocol for High-Flow Experimental Releases and Non-native Fish Control Downstream from Glen Canyon Dam, Arizona, 2011 through 2020

Pursuant to Section 7(a)(2) of the Endangered Species Act (ESA), 16 U.S.C. § 1531 et seq. and the implementing regulations at 50 C.F.R. 402.16, the Bureau of Reclamation is providing additional information to you for formal consultation with the U.S. Fish and Wildlife Service regarding Development and Implementation of a Protocol for Conducting High Flow Experimental Releases from Glen Canyon Dam, and Non-native Fish Control Downstream from Glen Canyon Dam in Coconino County, Arizona.

Reclamation has recently provided biological assessments (BAs) and draft Environmental Assessments (EAs) to the USFWS for these proposed federal actions:

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

- Non-Native Fish Control Downstream from Glen Canyon Dam.

As part of the protocol for high-flow experimental releases (HFEs), the numbers of rainbow trout (*Oncorhynchus mykiss*) in the Lees Ferry reach are expected to increase as an unintended consequence of the action. An increase in this population could result in greater downstream dispersal of trout into reaches of the Colorado River that are occupied critical habitat of the humpback chub (*Gila cypha*) where the trout prey upon and compete with this endangered species.

Predation by rainbow trout and brown trout (*Salmo trutta*) has been identified as a source of mortality for juvenile humpback chub that potentially reduces recruitment and possibly the overall size of the population of humpback chub. The purpose of this memorandum and the attached BA supplement is to identify and clarify actions being undertaken and proposed by

Reclamation to offset and mitigate unanticipated effects of the proposed HFE protocol, which could include increased rainbow trout production and hence negative effects to the humpback chub in Grand Canyon. Additional analysis that supplements the two BAs you have already received is provided in the attached BA supplement, as well as a summary of the anticipated effectiveness of actions to mitigate these effects.

In addition, we are also including in this supplement an analysis of the effects to ESA-listed species of implementing the modified low fluctuating flow (MLFF) for 10 years through 2020. As identified in our previous BAs, the underlying dam operations for these proposed actions would be the MLFF as defined in the 1995 Environmental Impact Statement and 1996 Record of Decision on the operation of Glen Canyon Dam. We are clarifying that our proposed action will include implementation of the MLFF through 2020, and request your biological opinion on the implementation of these actions with regard to the effects to listed species, in particular, the humpback chub, the razorback sucker (*Xyrauchen texanus*) and their critical habitat, the Kanab ambersnail (*Oxyloma kanabensis haydenii)*, and the southwestern willow flycatcher (*Empidonax traillii extimus*). All other aspects of the proposed action remain the same as described in the previously released BAs, and updated proposed actions in the July 5, 2011 drafts of the Non-native Fish Control EA and HFE Protocol EA.

Please also note that, in compliance with section 9 of the ESA, as previously explained in our January 28, 2011, request for consultation, Reclamation anticipates the potential take of individual humpback chub from implementation of non-native fish control and other aspects of the proposed actions. The form of take is expected to be from potential harm and harassment to humpback chub resulting from electrofishing and handling stress and other science-related activities. However, we request that this take be covered separately through ESA section 10(a)(l)(A) recovery permits.

We appreciate your expedited consideration of this request for consultation in light of the proposal to implement the HFE Protocol and undertake non-native fish control this calendar year. We look forward to working with the USFWS and Glen Canyon Dam Adaptive Management Program partners in reaching a balance among American Indian tribes' concerns, non-native fish control, sediment conservation, and conservation of the endangered humpback chub in Grand Canyon. If you have any questions regarding this request, please contact Glen Knowles at 801-524-3781.

Attachment

cc: UC-413, UC-438, UC-600, UC-720, UC-731
(each w/att)

RECLAMATION
Managing Water in the West

Supplement to Biological Assessments for Development and Implementation of a Protocol for High-Flow Experimental Releases and Non-native Fish Control Downstream from Glen Canyon Dam, Arizona, 2011 through 2020

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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

July 8, 2011

Introduction

The Bureau of Reclamation (Reclamation) is in the process of completing NEPA compliance for two separate but related actions: Development and Implementation of a Protocol for High-Flow Experimental Releases (HFEs) from Glen Canyon Dam, Arizona, 2011 through 2020 (HFE Protocol); and Non-native Fish Control Downstream from Glen Canyon Dam, Arizona (Non-native Fish Control). Reclamation completed biological assessments (BAs) on these actions and submitted them to U.S. Fish and Wildlife Service (USFWS) with requests for Endangered Species Act (ESA) section 7 consultation on effects of these actions on listed species. These requests were submitted to USFWS on January 21, 2011 (HFE Protocol) and January 28, 2011 (Non-native Fish Control).

A recent finding of HFE analysis is that HFEs, and particularly those conducted in the spring, result in increases in the numbers of rainbow trout (*Oncorhynchus mykiss*) in the Lees Ferry reach (Korman et al. 2011). These increases, and in particular those resulting from the March 2008 HFE, also result in increases in downstream dispersal of rainbow trout into reaches of the Colorado River that are occupied critical habitat of the humpback chub (*Gila cypha*), where the trout prey upon and compete with this endangered species. A more detailed description of the relationship of high flows to trout and humpback chub is provided in Appendix A, as well as the Non-native Fish Control and HFE Protocol EAs and BAs (Bureau of Reclamation 2011a, 2011b, 2011c, 2011d).

Predation by rainbow trout and brown trout (*Salmo trutta*) has been identified as a source of mortality for juvenile humpback chub (Yard et al. 2011) that potentially reduces recruitment and possibly the overall size of the population of humpback chub (Coggins 2008, Coggins et al. 2011). The purpose of this BA supplement is to identify and clarify actions being undertaken and proposed by Reclamation including those to offset and mitigate unanticipated effects of the proposed HFE protocol, which could include increased rainbow trout production and hence negative effects to the humpback chub in Grand Canyon. Additional analysis that supplements the two BAs you have already received is provided, as well as a summary of the anticipated effectiveness of actions to mitigate these effects.

In addition, we are also including in this supplement an analysis of the effects to ESA-listed species of implementing the modified low fluctuating flow (MLFF) for 10 years through 2020. As identified in our previous biological assessments, the underlying dam operations for these proposed actions would be MLFF as defined in the 1995 Environmental Impact Statement (1995 EIS) and 1996 Record of Decision (1996 ROD) on the operation of Glen Canyon Dam (Bureau of Reclamation 1995, 1996). We are hereby clarifying our proposed actions to include implementation of the MLFF through 2020, and provide here an analysis of the implementation of MLFF in combination with these actions with regard to the effects to listed species and their critical habitat in the action area: the humpback chub, the razorback sucker (*Xyrauchen texanus*), the Kanab ambersnail (*Oxyloma kanabensis haydenii)*, and the southwestern willow flycatcher (*Empidonax traillii extimus*). All other aspects of the proposed actions remain the same as described in the prior EAs and BAs.

Changes to the Proposed Actions

The Modified Low Fluctuating Flow

The proposed action in the BAs includes MLFF as the background Glen Canyon Dam operation through 2020, as well as steady flows previously scheduled (and consulted upon) for September and October 2011 and 2012. The MLFF is a set of dam operations defined in the 1995 EIS and 1996 ROD, and we hereby incorporate those documents by reference. Under the MLFF, minimum daily flow releases are limited to a minimum of 5,000 cubic feet per second (cfs) and maximum to 25,000 cfs (although this can be exceeded for emergencies or during extreme hydrological conditions). Minimum flow during the day from 7:00 am to 7:00 pm is further limited to 8,000 cfs. Daily fluctuation limit is 5,000 cubic feet per second (cfs) for months with release volumes less than 0.6 million acre feet (maf), 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf, and 8,000 cfs for monthly volumes over 0.8 maf. Ramp rates must not exceed 4,000 cfs per hour ascending and 1,500 cfs per hour descending (Table 1). Operations under the MLFF are typically structured to generate hydropower in response to electricity demand, with higher monthly volume releases in the winter and summer months, and daily fluctuations in release volume.

Table 1. Glen Canyon Dam release constraints as defined by Reclamation in the 1996 Record of Decision (U.S. Bureau of Reclamation 1996).

Glen Canyon Dam Release Constraints		
Parameter	**Release Volume (cfs)**	**Conditions**
Maximum Flow[1]	25,000	
Minimum Flow	5,000	Nighttime
	8,000	7:00 a.m. to 7:00 p.m.
Ramp Rates		
Ascending	4,000	Per hour
Descending	1,500	Per hour
Daily Fluctuations[2]	5,000 to 8,000	

1 May be exceeded for emergencies and during extreme hydrological conditions.

2 Daily fluctuation limit is 5,000 cubic feet per second (cfs) for months with release volumes less than 0.6 maf; 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf; and 8,000 cfs for monthly volumes over 0.8 maf.

Non-Native Fish Control

Mechanical removal of trout from the Colorado River has been shown to be effective at reducing abundance of trout in areas occupied by humpback chub (Coggins et al. 2011).

The proposed action has been modified with regard to non-native fish control as follows for the 10-year period (2011-2020) of the two proposed federal actions identified above:

1. Paria River to Badger Creek (PBR) reach (RM 0-8; Figure 1): Up to 10 removal trips per year.

2. Little Colorado River (LCR) reach (RM 56.3-65.7; Figure 1): Up to six removal trips per year **only** if adult (age 4 years or more) humpback chub abundance drops below 7,000 adults as determined using the Age Structured Mark Recapture Model (ASMR; Coggins and Walters 2009).

All non-native fish removed would be removed live, transported, and stocked into areas with approved stocking plans, or would be euthanized for later beneficial use such as human consumption or as food for wildlife at wildlife rehabilitation facilities.

Proposed Non-Native Fish Research Activities

The following specific research and monitoring activities are proposed in the initial years of the proposed action. In future years, implementation of these actions will be based on the outcome of these research activities. These activities include:

1. Lees Ferry reach (RM +15-0): One rainbow trout marking trip in October.

2. Paria to Badger reach (RM 0-8): Two monitoring/live removal trips during November-January period.

3. Marble Canyon (RM 0 – 62): Three monitoring trips (no trout removal), one each in July, August, and September to detect downstream movement of rainbow trout and conduct nearshore ecology work on juvenile humpback chub at the LCR confluence.

4. Conduct research, through a continuation of the Nearshore Ecology Study to develop triggers for juvenile humpback chub abundance and survivorship to consider in implementing LCR reach removal, to investigate the relative importance of habitats in the LCR and mainstem Colorado River in humpback chub recruitment, and to investigate the effect of high flows on displacement loss of young-of-year and/or juvenile humpback chub.

5. Reclamation will undertake development, with stakeholder involvement, of additional non-native fish suppression options for implementation in the first two years of the proposed action to reduce recruitment of non-native rainbow trout at, and emigration of those fish from, Lees Ferry. Both flow and non-flow experiments focused on the Lees Ferry reach may be conducted in order to experiment with actions that would reduce the recruitment of trout in Lees Ferry, lowering emigration of trout. These actions may also serve to improve conditions

of the recreational trout fishery in Lees Ferry. Additional environmental compliance may be necessary for these experiments.

6. Undertake a review in 2014 of the first two years of implementation of the two proposed actions through a workshop with scientists to assess what has been learned. Based on the results of this workshop, the proposed action may be altered in coordination with the FWS to better meet the intent of the conservation measure.

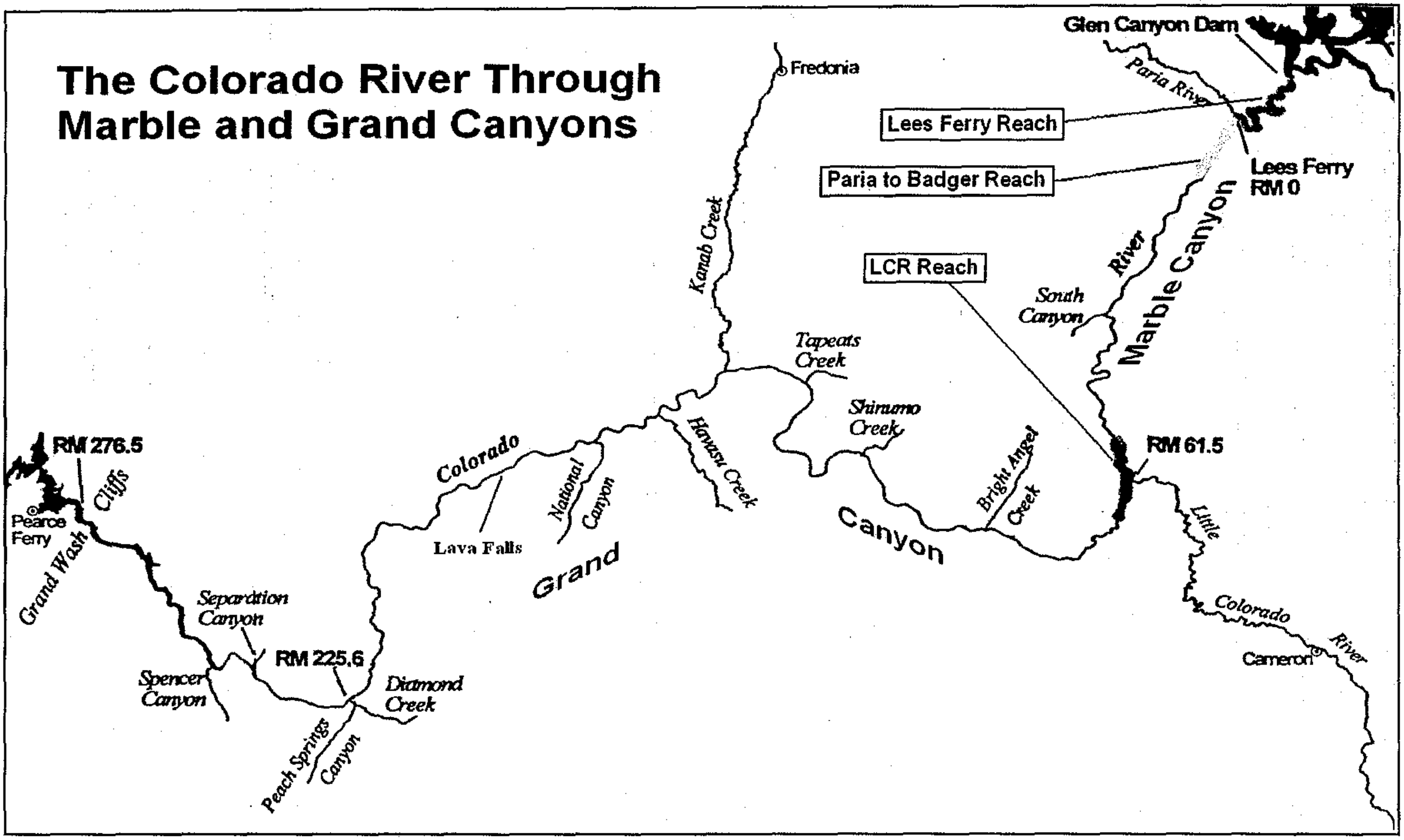

Figure 1. Map of the Colorado River from Glen Canyon Dam to Pearce Ferry in upper Lake Mead. The Lees Ferry, Paria to Badger reach (PBR), and Little Colorado River (LCR) reach are identified.

Rationale for Proposed Action

The focus of the proposed action is to explore new methods of non-native fish control that alleviate concerns of the American Indian tribes within the Glen Canyon Dam Adaptive Management Program (GCDAMP) regarding the taking of life in an area of cultural importance to the tribes, and to incorporate research to better understand the effect of predation by non-native fish on humpback chub, but to do so in a way that also does not result in undue adverse effects to the humpback chub. The 10-year period of the non-native fish control action is appropriate to establish and extend a long-term and important conservation measure for non-native fish control in a manner that is consistent with several USFWS biological opinions and with ongoing consultation on the prospective operation of Glen Canyon Dam. USFWS ESA section 10(a)(1)(A) scientific collecting permits would be obtained to cover incidental take of listed species resulting from implementation of non-native fish control actions.

The High Flow Experimental Protocol is a related EA that contains a concurrent 10-year proposed federal action, and non-native fish control is needed as a means to offset the possible effects of increased trout abundance that has been shown to accompany spring HFEs (Wright and Kennedy 2011). Some of these control activities have already been implemented as conservation measures outlined in the 2007 and 2008 Biological Opinions and the 2009 Supplement (e.g., fish research and monitoring, and limited mechanical removal in the Colorado River and its tributaries including Shinumo and Bright Angel creeks; USFWS 2007, 2008, 2009, 2010). HFEs also may have the potential to displace young-of-year and/or juvenile humpback chub or other native fish. The proposed action includes research that builds on the Nearshore Ecology Study to, in part, assess the potential for displacement of these age classes by HFEs, which will serve as important information for consideration in the HFE decision-making process.

The following provides a rationale for each of the non-native fish removal and research activities identified above:

Paria to Badger Reach (PBR) Removal.—Reclamation is proposing to test the ability to reduce the source of fish preying on humpback chub by intercepting and removing rainbow trout migrating downstream from Lees Ferry through the PBR reach. Removal of trout from the PBR would be tested starting in 2011 with up to 10 removal trips per year. Boat electrofishing has been shown to be the most effective means of removing these fish (Coggins 2008), although other methods may be considered and employed. The goal of this removal is to better understand: (1) the degree to which rainbow trout emigrating from the Lees Ferry reach result in increased trout abundance in the LCR reach (leading to humpback chub predation), and (2) the efficacy of removing rainbow trout in the PBR reach (if emigration is occurring on a large scale) to reduce the number of trout preying on or competing with humpback chub in the LCR reach. PBR removal would utilize rainbow trout tagging trips in the Lees Ferry reach in the fall to help detect and quantify downstream movement of trout from Lees Ferry. To alleviate the tribal concerns, in FY 2012, fish would be removed alive and stocked into waters with approved stocking plans to test the efficacy of live removal.

PBR Monitoring/Removal.—Two monitoring/removal trips would be conducted during the November-January period to determine the extent of emigration of trout from the Lees Ferry reach, based on marked fish from that reach, and evaluate the efficacy of PBR reach removal.

LCR Reach Removal.—Up to six removal trips would be conducted per year in the LCR reach if adult humpback chub abundance drops below 7,000 adults based on the ASMR. In addition, Reclamation will conduct research to develop other triggers, such as abundance of juvenile humpback chub (discussed below). Reclamation would coordinate with the USFWS to determine the need to implement LCR reach removal. Fish removed would be removed alive and stocked into offsite waters with approved stocking plans or would be euthanized for later beneficial use.

Marking of Trout in Lees Ferry.—Marking of rainbow trout with PIT tags in the Lees Ferry reach would begin in fall 2011 to start to track emigration from the Lees Ferry reach downstream through Marble Canyon and to answer questions on natal origins of trout that occupy the LCR reach.

Marble Canyon Monitoring.—Monitoring trips would be conducted in the initial years of the proposed action through Marble Canyon in July, August, and September to detect downstream movement of rainbow trout, to better understand the degree to which rainbow trout emigrating from the Lees Ferry reach result in increased trout abundance in the LCR reach, and to help evaluate the efficacy of removing rainbow trout in the PBR reach. Trout would not be removed during these trips. These monitoring trips would also stop at the LCR reach and conduct research and monitoring as an extension of the Nearshore Ecology Study to better understand habitat use by juvenile humpback chub in the LCR and in the mainstem and improve estimates of abundance of juvenile humpback.

Research to Develop Triggers.—Because of the sensitivity to American Indian tribes, removal of trout from the LCR reach would be implemented only when necessary to alleviate losses of humpback chub to trout predation. The proposed criteria for implementing trout removal in the LCR reach is the "HBC Trigger," such that when the estimated abundance of humpback chub falls below 7,000 adults based on the ASMR, removal of trout from the LCR reach would be triggered and implemented. The age-structured mark-recapture model (ASMR; Coggins and Walters 2009) would be used to assess adult humpback chub abundance periodically. If the estimate drops below 7,000 adults, removal of trout from the LCR reach could be implemented. Additionally, research would be implemented to refine and further develop triggers based on juvenile humpback chub abundance and survivorship. This research would seek to identify and quantify the different sources of mortality for young humpback chub, including but not limited to thermal shock, diseases/parasites, downstream displacement, stranding, food starvation, and fish predation.

Feasibility of Flow Releases.—Reclamation will begin working with stakeholders to develop and assess the feasibility of possible flow and non-flow actions to reduce Lees

Ferry rainbow trout recruitment for potential implementation in the next 1-2 years. Some flow-related actions have been tested and evaluated as possible control methods for trout in the Lees Ferry reach (Korman et al. 2011). Flow releases may be proposed, pending additional NEPA and ESA compliance, to provide for additional means to control recruitment of rainbow trout in Lees Ferry, both to reduce predation on native fishes downstream and to improve aspects of the Lees Ferry fishery.

Continuance of Assessing Young-of-Year and Juvenile Humpback Chub. Reclamation will provide sufficient funding to continue monitoring of young-of-year and juvenile humpback chub in the area downstream of the LCR-mainstem confluence so that managing agencies can assess recruitment after high flow events. This will be used to assist managing agencies in determining future high flows by providing indirect information as to recruitment over multiple years of high flows.

Scientific Review.—Reclamation will also undertake a thorough scientific review in 2014 through a workshop with scientists and managers to assess what has been learned through implementation of non-native fish control as proposed here, in particular, on the ultimate effect of trout predation on adult humpback chub abundance. If results indicate that rainbow trout are causing substantial unanticipated impacts to humpback chub, Reclamation will reinitiate consultation with the FWS.

Relationship to Existing Biological Opinions.—Reclamation believes that the proposed action satisfies its responsibilities under the existing biological opinions while also addressing the concerns of American Indian tribes. The proposed action was refined from that identified in the Draft Non-Native Fish Control EA to further balance implementation of non-native fish control measures with minimization of actions that have generated American Indian tribal concerns. To mitigate the adverse affects of the MLFF and the HFE Protocol, Reclamation also intends to continue conservation measures identified in previous biological opinions (U.S. Fish and Wildlife Service 2008, 2009) through 2020 as warranted, based on continued consultation and coordination between Reclamation and USFWS.

Removal of trout from the LCR reach will be based on humpback chub status, as described above. The decision to implement LCR reach trout removal will be based on evidence from monitoring and the ASMR that humpback chub are declining, and that implementing LCR reach removal is necessary to avoid exceeding levels of incidental take defined in previous biological opinions (U.S. Fish and Wildlife Service 2010a). To address tribal concerns and to insure beneficial use of removed fish, Reclamation will either remove fish live for translocation and stocking into waters with approved stocking plans, or the fish will be euthanized for later beneficial uses, such as food for human consumption or to feed wildlife.

Relationship of Proposed Action to Incidental Take

The current incidental take statement for the humpback chub in Grand Canyon is based on the September 1, 2010 Reissuance of the 2009 Supplement to the 2008 Final

Biological Opinion for the Operation of Glen Canyon Dam (USFWS 2010a). According to that reissuance, incidental take is exceeded if the humpback chub population drops below 6,000 adults within the 95% confidence interval based on the ASMR. The proposed non-native fish control action is also designed to minimize the chances of violating this incidental take. Additionally, information gathered from removal activities, scientific research, and the scheduled 2014 workshop will help to better inform and possibly refine the anticipated level of take for the humpback chub in Grand Canyon.

The proposed non-native fish removal action described in this BA supplement is designed to reduce losses of young humpback chub due to trout predation. The estimated number of young humpback chub lost to predation can be gauged from an existing incidental take statement that anticipates between 1,000 and 24,000 y-o-y or juvenile humpback chub would be lost to predation by trout as a result of cancelling non-native fish removal from the LCR reach for a 13-month period (USFWS 2010b). The adopted incidental take of 10,817 humpback chub (mostly age-0 and age-1) for this 13-month period is the estimate provided in the April 2010 BA (Reclamation 2010), based on minimum and maximum predation rates calculated by Yard et al. (2008) (1.7 and 7.1 prey/rainbow trout/year, and 18.2 to 106 prey/brown trout/year). Since the issuance of the BA and BO, these rates of piscivory have been revised by Yard et al. (2011) and the new values range from 4 to 10 fish/rainbow trout/year, and 90 to 112 fish/brown trout/year. The estimated prey fish consumed (27.3% were humpback chub) remained the same. Using the new predation rates, the estimated take of humpback chub is revised to 16,215 fish, which is still within the anticipated range of take of 1,000 to 24,000 fish.

Changes to Effects Analysis

The effects determinations for both the HFE Protocol and Non-native Fish Control actions remain the same as determined in the previous biological assessments (Table 2), and we hereby incorporate by reference those documents (Bureau of Reclamation 2011a, 2011b). We provide here additional analysis to support these effects determinations in consideration of implementation of MLFF through 2020 and to further evaluate the combined effects of these actions.

Table 2. Effects determinations to ESA-listed species for the implementation of MLFF through 2020 in conjunction with implementation of the HFE Protocol and Non-Native Fish Control actions through 2020.

Species	Effects 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. • 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. • Non-native fish control actions would provide a beneficial effect to the species and its critical habitat. • MLFF would affect the species and its critical habitat through physical habitat manipulation; releases have a cooling effect on water temperatures and may result in reduced quality of sediment-formed habitats such as backwaters through erosion and daily fluctuations of MLFF may disrupt nearshore habitats, reducing food base and increasing energetic requirements or predation risk of young humpback chub. • MLFF would result in colder temperatures that could result in reduced growth rate and survival of young humpback chub, although results of recent research are contradictory, indicating relatively high survivorship and growth rates that are at times relatively high. • The cooling effect of MLFF on mainstem fish habitat likely inhibits non-native fish in the same ways it inhibits native fish. This is likely a benefit to humpback chub by disadvantaging non-native predators and competitors with the species.
Razorback Sucker	May affect, likely to adversely affect species and critical habitat	• In general, HFEs, non-native fish control, and the MLFF are unlikely to affect the species because it apparently no longer occurs in the action area, although a small reproducing population occurs downstream in Lake Mead, but possible effects include: • Short-term beneficial impacts to food supply from large influx of organic material during HFEs. • Short-term beneficial effect from inundated vegetation and increased turbidity as protective cover from predators. • 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. • Potential short-term burial of spawning bars and other habitats by fine sediment during HFEs. • Non-native fish control actions would provide a beneficial effect to the species and its critical habitat. • MLFF would affect the species critical habitat through physical habitat manipulation; releases have a cooling effect on water temperatures and result in reduced quality of sediment-formed habitats such as backwaters through erosion. • Cooling effect of MLFF on mainstem fish habitat likely inhibits non-native fish in the same ways it inhibits native fish. This likely benefits razorback

		sucker through reduced numbers of non-native fish predators and competitors with the species.
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. • Proportionally less habitat area scoured and fewer numbers of snails would be displaced by lower magnitude HFEs. • Sequential HFEs could reinundate and scour primary habitat prior to full recovery from previous HFE. • Non-native fish control actions would not affect this species. • MLFF at high releases of over 17,000 cfs can inundate and scour up to 10 percent of available habitat, but the habitat is of low quality and contains few snails. • Critical habitat has not been designated for the species.
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. • Birds will be off nests by Sept-Oct, but birds will be foraging and there could be some indirect effect to their food supply. • Non-native fish control actions would not affect this species. • MLFF would have only limited effects of southwestern willow flycatcher. Nesting habitat occurs at stage elevations above 45,000 cfs, and normal operations below 25,000 cfs are unlikely to affect habitat for the species. Southwestern willow flycatcher critical habitat does not occur in the action area.

Effects of MLFF through 2020 on Humpback Chub and its Critical Habitat

The MLFF is a set of dam operations that results in hourly, daily, and monthly variations in flow from Glen Canyon Dam. The MLFF is implemented by Reclamation through the GCDAMP as defined in the 1995 EIS and 1996 ROD (Bureau of Reclamation 1995, 1996). The variations in flow resulting from MLFF affect many aspects of the ecosystem below Glen Canyon Dam downstream some 250 miles or so to Lake Mead. Effects are on the abiotic aspects of the ecosystem (e.g., water temperature, turbidity, sediment transport, riverine habitat formation) and on the biotic aspects (e.g. food base dynamics, fish species abundance and composition, fish growth, fish predation rates, prevalence of disease or parasites). Many of these effects are poorly understood at best, and adding to the complexity is the fact that few if any affects can be analyzed separately because they interact.

Water temperature is an important aspect of the physical ecosystem for humpback chub that is affected by dam operations. Humpback chub require temperatures of 16-22 °C for successful spawning, egg incubation, and survival of young (Hamman 1982, Valdez and

Ryel 1995). Since closure of the dam and filling of Lake Powell, water temperatures in the mainstem Colorado River at the LCR inflow have been about 8-10 °C on average (Valdez and Ryel 1995). Water temperature of downstream releases from Glen Canyon Dam is affected by release temperature, which is a function of reservoir elevation, temperature and volume of inflow, and air temperature. Downstream warming of the river is a function of Glen Canyon Dam release temperatures, release volumes, and volume fluctuations, and warming is also along a longitudinal gradient that varies with air temperature, such that warming increases as water moves downstream and more so in the hotter months than in cooler months (Wright et al. 2008a).

Water releases under MLFF are designed to produce hydropower during months when power demand is greatest, releasing more water in the winter months of December-February and summer months of June-August. Increasing releases in the winter months has little effect on warming of the river because air temperatures and release water temperatures are cold. In summer, however, the effect of increasing monthly releases to meet electricity demand (within the constraints of MLFF) has a measurable effect on water temperature. Lower release volume results in greater downstream warming (Wright et al. 2008a). This is most evident from the 2000 low summer steady flow. Releases during the summer months (June 1 – September 1) were limited to 8,000 cfs, and mainstem temperatures warmed somewhat more than at higher releases. The mainstem water temperature at the LCR inflow in June 2000 was 13.3 °C; release temperature at the dam was 9.5 °C, so releases had warmed 3.8 °C; June temperatures for the previous six years at the LCR inflow ranged from 10.3 °C to 11.8 °C and had warmed an average of 2.3 °C (Vernieu 2000). Structuring monthly release volumes to generate hydropower under a fluctuating regime has a cooling effect on downstream water temperature, which likely results in, or contributes to, mortality to humpback chub eggs and juvenile fish due to cold temperatures (Hamman 1982, Marsh 1985), or death of juvenile humpback chub from cold shock or increased predation due to cold shock (Berry 1988, Berry and Pimentel 1985, Lupher and Clarkson 1994, Valdez and Ryel 1995, Marsh and Douglas 1997, Robinson et al. 1998, Clarkson and Childs 2000, Ward et al. 2002).

MLFF also modifies the hydrograph (the timing of water delivery in the river). Monthly flows under MLFF produce a hyrdrograph with the highest flows in the winter and summer months. Humpback chub evolved with a historically variable hydrograph in Grand and Marble Canyons, but with consistently high flows in the spring following snow melt and low flows in the summer (Topping et al. 2003). Muth et al. (2000) recommend releases from Flaming Gorge Dam mimic this natural pattern in the Green River to benefit humpback chub by providing high flows in the spring and base flows in other seasons. But at Glen Canyon Dam, the maximum release at powerplant capacity (31,500 cfs) is likely too low to provide any benefit to native fishes (Valdez and Ryel 1995), but flows that utilize the outlet works such as the March 2008 high flow test do provide some of these positive benefits to humpback chub, such as by rearranging sand deposits in recirculating eddies, effectively reshaping reattachment bars and eddy return current channels. The proposed action also includes September and October steady flow releases through 2012 to determine if these flows benefit humpback chub without undue risk from benefiting non-native species. In 2013, flows in September and October will be determined by annual hydrological conditions, the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead and related legal mandates, and the MLFF restrictions (U.S. Department of the Interior 1996, 2007).

Fluctuating daily volume to meet power demand may have direct and indirect effects to humpback chub, and in particular to juvenile humpback chub, because this life stage prefers nearshore habitats where the effects of fluctuations are concentrated (Valdez and Ryel 1995, Robinson et al. 1998, Stone and Gorman 2006, Korman and Campana 2009). Daily variation in discharge can result in a variety of adverse affects due to lateral movement of the shoreline, such as the direct effect of stranding juvenile fish (Cushman 1985). Ongoing research referred to as the Nearshore Ecology study (NSE) into the use of nearshore habitats in the Colorado River mainstem near the LCR has provided some interesting insight into these effects. Juvenile humpback chub appear to have relatively high survival rates in these mainstem habitats based on mark-recapture monitoring. Also, juvenile humpback chub in the mainstem at times exhibit higher growth rates than fish in the LCR, indicating potentially better food availability, higher water temperatures, or both (B. Pine, Univ. of Florida, pers. comm., 2011).

Fluctuations also result in a cooling effect to nearshore habitats such as backwaters, which may be important nursery areas for juvenile humpback chub. Daily fluctuations cause mixing of warm waters contained in backwaters with cold mainchannel water (Arizona Game and Fish Department 1996, Grand et al. 2006). Hoffnagle (1996) found that mean, minimum, maximum and diel temperature range of backwaters were higher under steady versus daily fluctuating flows, with mean daily temperatures (14.5 °C) under steady flows about 2.5 °C greater than those under fluctuating flows. Differences in the mainchannel temperatures during steady and fluctuating flows were also statistically significant, but mean temperatures differed by only 0.5 °C. Trammell et al. (2002) found backwater temperatures during the 2000 low steady summer flow experiment to be 2-4 °C above those during 1991-1994 under fluctuating flows. Korman et al. (2006) found warmer backwater temperatures under steady flow conditions, concluding that backwaters were cooler during fluctuations because of the daily influx of cold main channel water. Although fluctuations would thus likely be expected to result in some increased mortality to humpback chub eggs and juvenile fish due to colder temperatures (Hamman 1982, Marsh 1985), recent work through the NSE on use of these habitats appears to contradict this, with juvenile humpback chub exhibiting relatively high survival rates in these habitats, and humpback chub growth rates appeared to be higher in the mainstem in some months (B. Pine, Univ. of Florida, pers. comm., 2011).

Daily variation in discharge can also result in a variety of adverse sub-lethal effects due to colder water and lateral movement of the shoreline and potential displacement effect as fluctuations dewater these habitats daily, which can result in reduced growth rates, increased stress levels, predation risk, energy expenditure, or reduced feeding opportunities (Cushman 1985). Korman et al. (2006) hypothesized that fluctuation effects on nearshore habitats pose an ecological trade-off for fish utilizing these areas;

fish may choose to exploit the warmer temperatures of the fluctuating zone on a daily basis and simply sustain any bioenergetic disadvantages of acclimating to rapidly changing discharge, or they may choose to remain in permanently wetted zones that are always wetted, but colder than the immediate nearshore margin. Korman et al (2005) found that young rainbow trout in the Lees Ferry maintained their position as flows fluctuated rather than follow the stream margin up slope, indicating that the bioenergetic cost of changing stream position with fluctuations in discharge perhaps outweighs the benefits of exploiting the slightly warmer stream margins. If humpback chub chose to utilize warmer backwaters, movement into and out of these habitats as stage changes with fluctuation will be required. Korman and Campana (2009) found that, for rainbow trout in Lees Ferry, growth appeared to increase during stable flows, based on evidence of a distinctive line on the ototlith (inner ear bone) representing increased growth that corresponded to juvenile trout's increased use of immediate shoreline areas on Sundays (the only day of the week with steady flows), where higher water temperatures and lower velocities provided better growing conditions. If humpback chub are similarly affected, fluctuating flows could result in lower growth rates, or perhaps death of juvenile humpback chub from cold shock or increased predation due to cold shock, as well as increased predation risk due to increased movement (Berry 1988, Berry and Pimentel 1985, Lupher and Clarkson 1994, Valdez and Ryel 1995, Marsh and Douglas 1997, Robinson et al. 1998, Clarkson and Childs 2000, Ward et al. 2002). Results of the NSE seem to contradict these expected findings; juvenile humpback chub survival rates appear high in the mainstem, and growth rates can exceed those in the LCR.

Structuring releases (within the MLFF constraints) to meet electricity demand also increases erosion of sandbars and backwaters, which could result in a reduction in habitat quality for juvenile humpback chub. Lovich and Melis (2007) hypothesized that the MLFF's annual pattern of monthly volumes released from the dam (with the greatest peak daily flows during the summer sediment input months of July and August) is a key factor in preventing accumulation of new sand inputs from tributaries over multi-year time scales. Also, the amount of sand exported is dependent on antecedent conditions, but if the supply of sand is sufficient, the amount transported by the river is exponentially proportional to flow volume (i.e., the rate of increase in sand load is much greater than the rate of increase in flow). As a result, daily flow fluctuations will transport more sediment than steady flows of the same daily average volume because the fluctuating flows are at a higher volume flow than steady flows during part of each day (U.S. Bureau of Reclamation 1995). Wright et al. (2008b) evaluated Glen Canyon Dam releases relative to existing sediment supply from tributary inputs to determine if any operational regime could rebuild and maintain sandbars, and found that a "best case" scenario for Glen Canyon Dam operations to build and retain sandbars would be to utilize high flow tests followed by equalized monthly volumes, at the lowest volume allowable under the Law of the River, with a constant steady flow, because export increases with both volume and fluctuations. And Wright et al. (2008b) acknowledged that "The question remains open as to the viability of operations that deviate from the best-case scenario that we have defined." Thus varying flow seasonally and daily to meet electricity demand is not optimal for retaining sand in the system for use in maintaining sand bars and backwaters because it results in increased erosion. However, the degree to which dam operations may be able to deviate from this best case and still retain enough sediment to meet resource needs using high flow tests remains a research question (Wright et al. 2008b) which is currently being evaluated by research and monitoring of the effects of the 2008 high flow test, and would be further tested through the implementation of the HFE Protocol.

Fluctuations and seasonal variation in flow volume to meet electricity demand also affects the food base available for fishes. As flow volume increases, Valdez and Ryel (1995) documented increasing densities of chironomids and simuliids in the drift on the descending limb of the diurnal hydrograph, and McKinney et al. (1999) documented a similar response for *G. lacustris*. Chironomids and simulids are important food items for adult humpback chub (Valdez and Ryel 1995), thus flow fluctuations may make these prey items more available in the drift. Flow fluctuations may have a negative effect on food availability in nearshore habitats, reducing food base of juvenile humpback chub. In a study conducted in the upper Colorado River basin (middle Green River, Utah), Grand et al. (2006) found that the most important biological effect of fluctuating flows in backwaters is reduced availability of invertebrate prey caused by dewatered substrates (see also Blinn et al. 1995), exchange of water (and invertebrates) between the mainchannel and backwaters, and (to a lesser extent) reduced temperature. As the magnitude of within-day fluctuations increases, so does the proportion of backwater water volume influx, which results in a net reduction in as much as 30 percent of daily invertebrate production (Grand et al. 2006). Early results of the NSE suggest that there may be little effect on food base in nearshore mainstem habitats near the LCR based on high juvenile humpback chub survivorship and relatively high growth rates at times in these habitats (B. Pine, Univ. of Florida, pers. comm., 2011).

The effect of flows in Grand Canyon on non-native fishes is not well understood, but in general, effects are similar to those described for humpback chub. The most relevant effect of dam operations on non-native fishes for humpback chub conservation is how operations benefit or disadvantage non-native fishes. This presents a tradeoff to managers that has been recognized since the 1970s (U.S. Fish and Wildlife Service 1978) and was discussed briefly in the 1995 USFWS biological opinion on the operation of Glen Canyon Dam: operations that benefit humpback chub are likely to also benefit non-native fishes that prey on and compete with humpback chub. Because predation and competition from non-native fishes is such a serious threat to humpback chub, any operations that disadvantage non-native fishes could potentially be an advantage to humpback chub. For example, the 2000 low summer steady flow appeared to benefit all fish species as abundances for size classes < 100 mm TL (3.9 inches) of all species increased during the steady flow period compared to previous years (Trammell et al. 2002, Speas et al. 2004). There is also evidence that non-native fish including fathead minnow and largemouth bass spawned in the mainstem above Diamond Creek during the low summer steady flow, and there was no record of largemouth bass reproducing above Diamond Creek prior to this (Trammel et al. 2002). Changes in hydrology likely benefitted non-native species in the Yampa River, and this appears to have led to increased predation on humpback chub and the collapse of that humpback chub population. A similar scenario occurred in Desolation and Gray canyons (Jackson and Hudson 2005, Finney 2006, Fuller 2008, R. Valdez, pers. comm., 2009).

The MLFF affects humpback chub critical habitat in many of the same ways it affects the species itself as described above. Critical habitat for humpback chub in the action area consists of the lowermost 8 miles (13 km) of the LCR to its mouth with the Colorado River, and a 173-mile reach of the Colorado River in Marble and Grand Canyons from Nautiloid Canyon (RM 34) to Granite Park (RM 208). The primary constituent elements of critical habitat are: Water of sufficient quality (i.e., temperature, dissolved oxygen, lack of contaminants, nutrients, turbidity, etc) that is delivered to a specific location in accordance with a hydrologic regime that is required for the particular life stage for each species; Physical Habitat, areas for use in spawning, nursery, feeding, and movement corridors between these areas; and Biological Environment, food supply, predation, and competition (Maddux et al. 1993a, 1993b, U.S. Fish and Wildlife Service 1994).

The MLFF directly affects water temperature, a primary constituent element (PCE) of humpback chub critical habitat (U.S. Fish and Wildlife Service 1994) by cooling mainstem water temperatures. The MLFF does this by increasing the monthly volume of releases in the winter and summer months to meet increased electricity demand. By releasing greater volumes in the summer, when air temperatures and solar insolation could warm lower volume releases, the MLFF cools the mainstem (Wright et al. 2008a). Operations under the MLFF also cool the water temperature of nearshore habitats because release volume often fluctuates over the course of the day to meet electricity demand. This significantly cools mainstem nearshore habitats by alternately flooding and dewatering nearshore habitats, especially during warm seasons, when warm air temperatures and solar insolation greatly warm these habitats (Arizona Game and Fish Department 1996, Korman et al. 2006, Wright et al. 2008a). This cooling effect is additive to the already cold temperatures of the hypolimnetic releases coming out of Glen Canyon Dam, and limits the suitability of the mainstem to provide for successful spawning and rearing of humpback chub in the mainstem (Valdez and Ryel 1995), although as discussed previously, there is evidence of mainstem spawning and recruitment (Ackerman et al. 2008, Andersen et al. 2009, 2010), and new evidence of survival and growth of early life stages of humpback chub in the mainstem (B. Pine, University of Florida, pers. comm., 2011).

The MLFF also affects the timing and volume of water delivery, directly affecting PCEs of critical habitat, and specifically, the quantity of water that is delivered to a specific location in accordance with a hydrologic regime that is required for the particular life stage for each species. Operations under MLFF alter the hydrograph to deliver more water during months with higher electricity demand in the winter and summer. Historically, humpback chub evolved with a variable hydrograph in Grand and Marble canyons, but with consistently high flows in the spring following snow melt and low flows in the summer (Topping et al. 2003). As discussed earlier, the maximum release from Glen Canyon Dam at powerplant capacity (31,500 cfs) is likely too low to provide any benefit to humpback chub in terms of providing high spring flows to clean spawning substrates and rework sediment-formed habitats (Valdez and Ryel 1995). But flows that utilize the outlet works, such as HFEs of 40,000 cfs or more, do provide some of these positive benefits to humpback chub, such as rearranging sand deposits in recirculating eddies, effectively reshaping reattachment bars and eddy return channels, creating and enlarging backwaters. The post-dam hydrograph also likely no longer provide sufficiently high flows to constitute a physical spawning cue (Valdez and Ryel 1995); despite this, humpback chub continue to spawn in the mainstem based on the persistence of mainstem aggregations and presence of juvenile and young of year humpback chub at mainstem aggregations (Andersen, M., GCMRC, pers. comm., 2007, Ackerman et al. 2008). Valdez and Ryel (1995) hypothesized that humpback chub in the mainstem now rely on photoperiod as a physical cue for spawning, noting that gonadal maturation appears normal and timed to correspond to either suitable LCR conditions (March-May) or historic mainstem conditions (May-July).

Critical habitat for humpback chub also includes PCEs for Physical Habitat, including areas for use in spawning, nursery, feeding, or corridors between these areas, such as river channels, bottomlands, side channels, secondary channels, oxbows, backwaters, and other areas in the 100-year floodplain, which when inundated provide spawning, nursery, feeding and rearing habitats, or access to these habitats. The MLFF primarily affects the quality of nursery and feeding habitats. Backwaters may be important nursery habitat for native fish due to low water velocity, warm water and high levels of biological productivity. There is a strong need for additional research on the relationship between backwaters and fish habitat suitability and humpback chub survival and recruitment. Converse et al. (1998) identified shoreline habitats used by subadult humpback chub and related spatial habitat variability with flow regulation. Most juvenile humpback chub utilized talus, debris fans or vegetated shorelines in shallow areas of low current velocity, and backwaters were a relatively rare, and rarely used, habitat type.

The MLFF affects the formation of physical habitat and has an adverse affect of eroding sediment out of the system, which results in a continual loss of sediment downstream to Lake Mead (Lovich and Melis 2007, Wright et al. 2008b). Continual erosion and a lack of flood flows may not affect the total number of backwater habitats available as much as the flow volume at any given time, but likely does reduce the size and quality of sediment-formed habitats such as backwaters (Stevens and Hoffnagle 1999, Goeking et al. 2003) that may be important rearing habitat for young humpback chub (Arizona Game and Fish Department 1996). High flow tests, timed to utilize tributary sediment inputs, can reset the system, creating sand bars and sediment formed habitat, but the degree to which this is effective in counterbalancing the erosion loss of MLFF is unclear (Wright et al. 2008b); implementation of the HFE Protocol will provide a long-term test of this hypothesis.

The MLFF's fluctuations also dewater nearshore habitats daily. Because juvenile humpback chub prefer nearshore habitats (Valdez and Ryel 1995, Robinson et al. 1998, Stone and Gorman 2006), they are especially susceptible to the adverse effects that fluctuating flows have on these habitats. Daily fluctuations in discharge can result in a variety of adverse affects due to lateral movement of the shoreline, such as stranding of juvenile fish, or sub-lethal effects related to increased stress levels, predation risk, energy expenditure, or reduced feeding opportunities (Cushman 1985) as well as decreased growth rates (Korman and Campana 2009). MLFF may likely adversely affect PCEs from the displacement effect of fluctuations, but this is not known with certainty.

The biological environment PCEs of food base, predation and, competition are also affected by the MLFF, although in complex ways that are not fully understood. As described earlier, as flow volume increases, Valdez and Ryel (1995) documented increasing densities of chironomids and simuliids on the descending limb of the diurnal hydrograph, and McKinney et al. (1999) documented a similar response for G. lacustris. Chironomids and simulids are important food items for adult humpback chub (Valdez and Ryel 1995), thus flow fluctuations may make these prey items more available in the drift, and this seems supported by data provided by Hoffnagle (2000) that found adult humpback chub condition factor was higher in the mainstem than in the LCR.

Flow fluctuations may have a negative effect on food availability in nearshore habitats, reducing food base of juvenile humpback chub. In a study conducted in the upper Colorado River basin (middle Green River, Utah), Grand et al. (2006) found that the most important biological effect of fluctuating flows in backwaters was reduced availability of invertebrate prey caused by dewatered substrates (see also Blinn et al. 1995), exchange of water (and invertebrates) between the mainchannel and backwaters, and (to a lesser extent) reduced temperature. As the magnitude of within-day fluctuations increases, so does the proportion of backwater water volume influx, which results in a net reduction in as much as 30 percent of daily invertebrate production (Grand et al. 2006). However, preliminary results of the NSE study indicate that survivorship of juvenile humpback chub in mainstem nearshore habitats is high, and growth rates in these habitats can at times be higher than LCR growth rates (B. Pine, Univ. of Florida, pers. comm., 2011).

The MLFF likely negatively affects the abundance and distribution of non-native fish species, an aspect of the biological PCEs for humpback chub, because MLFF results in a net cooling effect on mainstem river temperatures and mainstem nearshore habitats (Trammel et al. 2002, Korman et al. 2005, Valdez and Speas 2007, Wright et al. 2008a). Lower and steady mainstem flows, such as the seasonally adjusted steady flow (SASF) (see U.S. Bureau of Reclamation 1995) would lead to an increase in water temperatures that may promote spawning and minimize exposure of incubating and early larval stages of fishes, which appears to benefit non-native fishes as well as native fish species (Trammell et al. 2002). Because MLFF has the effect of cooling mainstem waters, it may benefit humpback chub by disadvantaging non-native fish species that prey on, and compete with, humpback chub including common species such as channel catfish, common carp, rainbow trout, and brown trout, as well as potential invaders, such as largemouth bass, smallmouth bass, and green sunfish (Valdez and Speas 2007). This is likely also true for small-bodied non-native fishes; for example, Trammel et al. (2002) found a significant increase in fathead minnow abundance during the 2000 Low Summer Steady Flow experiment, apparently due to the habitat stability and increases in water temperatures resulting from the flow experiment. Climatologists predict that the southwest will experience extended drought due to global climate change, and lower Lake Powell Reservoir elevations and warmer release temperatures are predicted (Seager et al. 2007, U.S. Climate Change Science Program 2008a, b). Warmer water conditions will benefit warm-water non-native fishes, result in invasions of new species, and cause greater proliferation of existing non-native fish species (Rahel et al. 2008). Thus operations that disadvantage warm-water non-native fish species may become an increasingly important tool in conservation of humpback chub.

In summary, operations under the MLFF manipulate the Colorado River hydrograph in Marble and Grand Canyons on a daily and monthly scale that has important effects to humpback chub and its critical habitat. MLFF results in a cooling effect to the mainstem Colorado River and to nearshore areas. This negatively affects water temperature PCEs, and likely results in some loss of humpback chub spawning and rearing habitat. The MLFF hydrograph also no longer provides seasonal flooding and its benefits, although Glen Canyon Dam has only a limited capability to flood the system relative to pre-dam conditions. The daily fluctuations of the MLFF may result in stranding of juvenile humpback chub, as well as sub-lethal effects from displacement, although these effects are poorly understood. The MLFF may have both beneficial and adverse effects on food base, but may adversely affect food base in nearshore habitats. The MLFF erodes sediment-formed habitats such as backwaters that may be important to juvenile humpback chub; high flow tests can offset this, but the degree to which erosion effects can be offset, and the importance of sediment-formed habitats to humpback chub, are research questions. Steady flows likely improve spawning and rearing habitat for both non-native fishes as well as native fish species, thus MLFF may have an important beneficial effect in suppressing non-native fishes. The status of the Grand Canyon population of humpback chub, in terms of both recruitment and adult abundance, has improved since the implementation of MLFF (Coggins and Walters 2009), an indication that the MLFF, originally designed to benefit native fishes, may have improved conditions for humpback chub relative to pre-MLFF flows.

Effects of MLFF through 2020 on Razorback Sucker and its Critical Habitat

The MLFF would affect razorback sucker in much the same ways as it affects humpback chub. The MLFF modifies physical habitat by cooling the water temperatures of downstream releases, particularly in the summer months. Physical habitats, backwaters formed by fine sediment in particular, are eroded by MLFF. The cooling effect of MLFF likely provides a benefit in disadvantaging non-native fish species and fish parasites such as Asian fish tapeworm. However, because razorback sucker appear to be extirpated from the action area, although they do still occur as a small reproducing population downstream in Lake Mead (Albrecht et al. 2007), none of these effects would likely actually occur to the species. Razorback sucker critical habitat does occur in the action area and 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. Razorback sucker critical habitat PCEs are exactly the same as those for humpback chub and would be affected in essentially the same ways as described above. In general, MLFF impacts critical habitat primarily through a cooling effect on water temperature, with some likely additional affects from shoreline erosion, and physical habitat manipulation through daily fluctuation. The

MLFF may benefit the biological PCEs of razorback sucker critical habitat because its cooling effect on water temperatures disadvantages non-native fishes that prey on and compete with the species.

Effects of MLFF through 2020 on Kanab Ambersnail

Kanab ambersnail habitat can be adversely affected by scouring at Colorado River flows exceeding 17,000 cfs. MLFF has been implemented since 1991, and flows have consistently scoured Kanab ambersnail habitat, removing habitat and snails below about the 25,000 cfs flow level. The MLFF includes flows up to 25,000 cfs (and beyond in emergency situations; up to 33,200 cfs may be released at power plant capacity, plus 15,000 cfs from the river outlet works, and 208,000 cfs from the spillways). Flows in excess of 25,000 cfs rarely occur, only in wettest years, although if the HFE Protocol is implemented, could occur as often as twice a year if conditions are met (up to 45,000 cfs). Nevertheless some loss of habitat and snails would occur as MLFF flows in excess of about 17,000 cfs scour the vegetation at Vaseys Paradise and carry the snails downstream. But the amount of habitat that is subjected to this effect, which is usually incremental and continuous (as opposed to the high magnitude, short duration, and relatively instantaneous effect of a HFE), is a small proportion of habitat available to Kanab ambersnail at Vaseys Paradise. Meretsky and Wegner (2000) found that at flows from 20,000 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). The largest these patches have been recently was in July 1998 when the area of both patches was 28.68 m^2 (308.7 ft^2) (Meretsky and Wegner 2000). Total habitat available in July 1998 (minus two patches that were not included in the total measurement) was 276.82 m^2 (2,979.7 ft^2). Thus patches 11 and 12, even in a good year, constitute less than 10 percent of total habitat available. Also, very few Kanab ambersnail have been found in patches 11 and 12 historically, and these patches are of low habitat quality for Kanab ambersnail (Sorensen 2009). Currently the amount of habitat loss at the 25,000 cfs flow level due to scour would be low, and is estimated to be about 300-350 ft^2 (27.9-32.5 m^2) or less (Meretsky and Wegner 2000). Thus the scouring effect of MLFF is predicted to have little effect on the overall population of Kanab ambersnail at Vaseys Paradise because scouring would occur infrequently, would affect only a small proportion of overall habitat available, habitat lost would be of low quality, and is expected to contain few snails.

The proposed action will have no effect on the water flow from the side canyon spring that maintains wetland and aquatic habitat at Vaseys Paradise. Kanab ambersnail at Elves Chasm would be unaffected by MLFF because the snails and their habitat are located up the chasm well above the Colorado River and the influence of dam operations on flow. No critical habitat has been designated for Kanab ambersnail, thus none would be affected.

Effects of MLFF through 2020 on Southwestern Willow Flycatcher

The southwestern willow flycatcher can be adversely affected by high flows through scouring and destruction of willow-tamarisk shrub nesting habitat or wetland foraging habitat, or conversely, through a reduction in flows that desiccate riparian and marsh vegetation. However, willow flycatcher nests in Grand Canyon are typically above the 45,000 cfs stage, and thus would not be affected by the highest typical Glen Canyon Dam releases (Holmes et al. 2005). Flycatchers nest primarily in tamarisk shrub in the lower Grand Canyon (Sogge et al. 1997), which is quite common, and can tolerate very dry and saline soil conditions, and thus is capable of surviving lowered water levels (Glenn and Nagler 2005). Therefore, maximum flows of the MLFF of 25,000 cfs and minimum flows of 5,000 cfs are neither expected to scour or significantly dewater habitats enough to kill or remove tamarisk, and no loss of southwestern willow flycatcher nesting habitat from flooding or desiccation is anticipated.

An important element of flycatcher nesting habitat is the presence of moist surface soil conditions (U.S. Fish and Wildlife Service 2002d). Moist surface soil conditions are maintained by overbank flow or high groundwater elevations supported by river stage, and provide nesting habitat of riparian trees, and habitat for insects that contribute to the food base for flycatchers. The MLFF flows have been implemented since 1991, and given the typical range of daily fluctuations, groundwater elevations adjacent to the channel are not expected to decline enough to significantly desiccate nesting habitat. Thus the proposed action will likely have little effect on the abundance or distribution of southwestern willow flycatcher in the action area or regionally.

Ability of Non-native Fish Control Actions to Offset Increases in Non-native Fish

Non-native fish control may be an important conservation measure in offsetting and mitigating adverse effects of dam operations, both the MLFF and HFEs. As explained previously, the proposed non-native fish control actions are designed to utilize research to improve the fundamental understanding of the effect of predation and competition on native fish, in particular humpback chub, but to do so in a way that minimizes impacts to cultural resources, and protects the humpback chub from excessive losses of individuals from non-native fish predation. The effectiveness of the proposed non-native fish control activities over the 10-year period of the proposed action, including implementation of MLFF and the HFE Protocol, was evaluated predicatively with a model (Coggins and Korman, unpublished). The model was originally designed and used to help evaluate various alternatives of non-native fish control through a structured decision-making process (Runge et al. 2011). The model contains three submodels: (1) Submodel 1 estimates the numbers of age-0 trout emigrating downstream from Lees Ferry based on a specified proportion of recruits; (2) Submodel 2 tracks the monthly numbers of age-0 trout emigrating downstream through Marble Canyon, together with specified numbers already in the main channel, and incorporates specified levels of removal in the PBR and LCR reaches, and includes incorporation of a "HBC Trigger" to implement removal in LCR reach only when the humpback chub population drops below 7,000 adults; and (3) Submodel 3 is an age-structured stock recruitment model ("HBC Shell") that evaluates the effect of different trout numbers resulting from Submodel 2 on annual modeled estimates of adult humpback chub abundance in the LCR reach.

Five scenarios were used to determine the probability that, under predation from various trout numbers, the population of humpback chub would remain greater than 5,000; 6,000; 7,000; or 10,000 adults (Figure 2; Tables 1, 2, and 3). The range of 5,000 to 10,000 adults represents a range of possible humpback chub population size. The level of 6,000 adults corresponds to the previous incidental take statement for humpback chub, and the level of 7,000 adults corresponds to the "HBC Trigger" that would cause removal of trout in the LCR to be implemented.

The five scenarios are based on the number of age-0 rainbow trout recruits in Lees Ferry; i.e., 10,000; 25,000; 50,000; 75,000; and 100,000. These numbers represent a range of possible recruitment numbers based on the best available scientific information (Korman et al. 2010). Each of these five scenarios was evaluated for three levels of existing trout numbers in the 62-mile reach between Lees Ferry and the LCR; i.e., 4,500; 45,000; and 75,000. These numbers are within the range of estimated population estimates from a low of 2,131 rainbow trout (July 2006) to a high of 10,571 rainbow trout (March 2003) reported from an 8.1-mi "control reach" (RM 44-52.1) by Coggins (2008). Assuming uniform distribution, these numbers of trout expand to a range of 16,311 to 80,914 trout for the 62-mile reach.

Three levels of trout removal were evaluated for each of the five scenarios; no removal, PBR only removal, and PBR and LCR removal. PBR only removal means that mechanical removal of trout would occur only in the 8-mi reach from the Paria River to Badger Creek Rapid. Removal in the LCR reach would be implemented in the 9.4-mi reach of the Colorado River (RM 56.3-65.7) used for removal during 2003-2006 (Coggins 2008). Removal in the LCR reach was triggered and implemented in the model only when the humpback chub population dropped below 7,000 adults. The model also always implements removal in the LCR in combination with removal in the PBR reach. The proposed action differs from the model in that removal could be implemented in either reach based on extant conditions.

The computed probabilities are based on annual estimates of adult humpback chub determined from monthly abundances of trout for 100 years, each simulated 100 times.

Scenario 1: 10,000 Rainbow Trout in Lees Ferry

Scenario 1 evaluates a base Lees Ferry recruitment of 10,000 age-0 trout, with 550 emigrating downstream. For a main-channel population equilibrium of 4,500 trout (Table 1, Figure 2), there is a 0.89, 0.92, and 0.93 probability that the adult population of humpback chub will remain above 6,000 adults (incidental take level) for no removal, PBR only removal, and PBR and LCR removal, respectively. For a main-channel population equilibrium of 45,000 trout (Table 2), the probability that the adult population of humpback chub will remain above 6,000 adults is 0.86, 0.91, and 0.89, respectively. These results show that at a low Lees Ferry recruitment level of 10,000 age-0 trout, the probability of maintaining a humpback chub population of above 6,000 adults is better than 0.90 with or without trout removal. As a comparison, the probability of maintaining the adult humpback chub population above 6,000 with no trout present is 0.93. At much higher main-channel numbers of 75,000 trout, the probability of maintaining the humpback chub population above 6,000 adults is 0.66, 0.70, and 0.67 for no removal, PBR only removal, and PBR and LCR removal, respectively. This drop in probability indicates that the numbers of trout present in the main channel strongly affects the ability of trout removal to maintain the population above 6,000 adults.

Scenario 2: 25,000 Rainbow Trout in Lees Ferry

Scenario 2 increases the number of Lees Ferry recruits to 25,000 age-0, with 1,080 emigrating downstream. At a low main-channel population equilibrium of 4,500 trout (Table 1, Figure 2), the probability of the humpback chub population remaining above 6,000 adults is 0.84, 0.93, and 0.92 for no removal, PBR only removal, and PBR and LCR removal, respectively. For a main-channel population equilibrium of 45,000 trout, the probability of >6,000 adults is 0.77, 0.88, and 0.90, respectively. This scenario reveals little difference in the probability of maintaining the humpback chub population above 6,000 adults for PBR only removal compared to PBR and LCR removal. As with the scenario 1, removal of trout at the PBR keeps the probability for more than 6,000 adult humpback chub at about 90%. At much higher main-channel numbers of 75,000 trout, removal at the PBR and LCR reaches provides a probability of about 0.70, confirming that the numbers of trout already in the main channel strongly affects the ability of trout removal to maintain the humpback chub population above 6,000 adults.

Scenario 3: 50,000 Rainbow Trout in Lees Ferry

Scenario 3 tests a greater number of Lees Ferry recruits of 50,000 age-0 trout, with 1,950 emigrating downstream. This is the first scenario that shows a marked difference between no trout removal and trout removal. With no trout removal, the probability of maintaining more than 6,000 adult humpback chub is 0.57 and 0.00 for 4,500 and 45,000 trout in the main channel. Furthermore, the probability for more than 6,000 adults does not differ by more than 0.01 between PBR-only removal and PBR and LCR removal for 4,500 main-channel trout (0.91 and 0.89) and 45,000 main-channel trout (0.88 and 0.89). In other words, if the number of Lees Ferry recruits is 50,000 age-0 trout, removal at PBR is sufficient to maintain more than 6,000 adult humpback chub at a probability of about 0.90. At the much higher main-channel numbers of 75,000 trout, however, removal at the PBR and LCR reaches provides a probability of only up to about 0.67.

Scenario 4: 75,000 Rainbow Trout in Lees Ferry

Scenario 4 tests a number of Lees Ferry recruits of 75,000 age-0 trout, with 2,830 emigrating downstream. As with Scenario 3, the difference between no removal and removal of trout is dramatic for the probability of maintaining the humpback chub population above 6,000 adults. For no removal, PBR removal, and PBR and LCR removal, the respective probabilities are 0.23, 0.82, and 0.81 for 4,500 main-channel trout and 0.00, 0.89, and 0.87 for 45,000 trout. This scenario illustrates the effect of trout removal on maintaining the humpback chub population at higher main-channel trout abundances, and also indicates that LCR removal does not appear to improve humpback chub survival beyond the PBR-only removal. At higher main-channel numbers of 75,000 trout and 75,000 Lees Ferry recruits, removal at the PBR and LCR reaches provides a probability for >6,000 adults of only up to about 0.66.

Scenario 5: 100,000 Rainbow Trout in Lees Ferry

Scenario 5 tests a number of Lees Ferry recruits of 100,000 age-0 trout, with 3,700 emigrating downstream. As with Scenarios 3 and 4, the difference between no removal and removal of trout is dramatic for the probability of maintaining the humpback chub population above 6,000 adults. For no removal, PBR removal, and PBR and LCR removal, the respective probabilities are 0.01, 0.69, and 0.68 for 4,500 main-channel trout and 0.00, 0.88, and 0.89 for 45,000 trout. This scenario also illustrates the effect of trout removal on maintaining the humpback chub population, and also indicates that LCR removal does not appear to improve humpback chub survival beyond the PBR-only removal. At higher main-channel numbers of 75,000 trout and 100,000 Lees Ferry recruits, removal at PBR and LCR provides a probability for >6,000 adults of up to about 0.70.

Trout Removal and HBC Trigger

The average number of trout removed per month (1 trip of 4 passes) was estimated with the model for the PBR and LCR reach, as well as the percentage of months in which the HBC Trigger for LCR reach removal occurred (Tables 1, 2, and 3). For a rainbow trout population equilibrium of 4,500, the estimated average number of trout removed at the PBR per month ranged from 634 to 1,988. At a main-channel equilibrium of 45,000 trout, estimated numbers removed ranged from 993 to 3,568, and at an equilibrium of 75,000 trout, monthly removal ranged from 1,001 to 3,876. Coggins (2008) reported a range of 66 to 3,605 rainbow trout captured with electrofishing from the LCR mechanical removal reach in March 2006 (4 passes) and January 2003 (5 passes), respectively. The striking similarity between the maximum number of fish captured monthly by Coggins (i.e., 3,605 when the expanded Marble Canyon trout population was 80,914) and the highest monthly PBR removal estimate by the model (i.e., 3,876 with an Marble Canyon population of 75,000) provides confidence in the model estimates.

The HBC Trigger for LCR reach removal (adult humpback chub <7,000) occurred in 10-28% of months for 4,500 main-channel trout; 12-13% for 45,000 trout; and 28-29% for 75,000 trout. When the trigger occurred, estimated monthly removal in the LCR reach was 205-880 for 4,500; 19-22 for 45,000; and 32-35 for 75,000 trout. These low removal numbers in the LCR reach reflect an estimated capture probability in the PBR that intercepts most of the trout moving downstream. The model shows that removal can keep up with emigration of large numbers of trout from the Lees Ferry reach, as long as the number of trout in Marble Canyon is low to moderate (i.e., 4,500-45,000).

Unknowns and Uncertainties

The model results described above and provided in Tables 1-3 and Figure 2 reflect estimated system responses based on model parameters with different levels of uncertainty. Many of the parameters used in the model have not been thoroughly evaluated and validated. The research activities described above are designed to provide a better understanding of the relationship of trout and humpback chub and to better inform these model parameters, as well as other uncertainties.

Caution is advised in the use of the model and interpretation of results beyond general relationships and approximate responses because of the uncertainty associated with some model parameters. The model is a valuable tool in providing insight into likely probabilities of maintaining the humpback chub population above certain levels under different trout abundances. More importantly, the model helps to identify the most sensitive parameters and those that need further investigation.

The following is a list of unknowns and uncertainties associated with the proposed non-native fish activities and with the model used to evaluate mechanical removal:

1. The current size and trend of the rainbow trout population in the Lees Ferry reach, as well as in Marble Canyon, are not known with certainty; from 2001 to 2007, the population in Lees Ferry showed a continued decline (see Figure A-3), but abundance in 2008 and 2009 increased dramatically to a level similar to the highest abundance reported by Coggins (2008) (i.e., 10,571 rainbow trout in the 8.1-mi "control reach" in March 2003).

2. The anticipated positive response of the Lees Ferry trout population to an HFE is based primarily on information derived from a fall (2004) and spring (2008) event; different investigations of the spring 1996 HFE indicate a similar beneficial response by trout to the 2008 HFE, and no response from the 2004 HFE.

3. The proportion of trout recruitment in the Lees Ferry reach that emigrates downstream to the LCR reach is not known with certainty.

4. The effectiveness of trout removal in the PBR reach has not been implemented and evaluated.

5. The distribution of trout in Marble Canyon is assumed in the model to be uniform, but preliminary data indicate decreasing numbers downstream of Lees Ferry.

6. The extent of trout reproduction in Marble Canyon is not known, although length data indicate no young trout are hatched downstream of Lees Ferry.

7. Emigration of trout downstream of Lees Ferry is not known with respect to timing, fish size, or numbers of fish.

8. Movement of trout in Marble Canyon is not known; the model assumes uniform downstream movement and no upstream movement.

9. Various sources of mortality to humpback chub are not identified and segregated, and the role of trout predation in total mortality is not known.

Summary of Anticipated Effects of Actions

Model results indicate that mechanical removal in the 8-mi Paria River to Badger Creek reach (PBR) is a viable approach to reducing the abundance of trout in Marble Canyon and for maintaining the population of humpback chub above the 6,000-adult level of incidental take. The model also shows that at low to moderate numbers of trout in Marble Canyon (i.e., 4,500-45,000), removal in the PBR reach alone may be sufficient and may not necessitate removal in the LCR reach.

Removal of trout from the PBR reach has several advantages: (1) trout are intercepted before they move downstream to the LCR reach, (2) PBR removal could reduce the source of trout to the LCR reach and lead to continued and long-term downstream trout reduction (assuming little or no trout production in Marble Canyon), (3) crews could be based at Lees Ferry where fish could be processed or further transported, and (4) labor and cost are greatly reduced with PBR removal when compared to trips through the entire 225-mi reach to Diamond Creek or further downstream to Pearce Ferry.

At higher Marble Canyon trout abundances (i.e., 45,000+ trout), it may be necessary to implement removal in both the PBR and LCR reaches. Trout abundance indices for the Lees Ferry reach for 2008-2009 show a similar abundance level to 2003 (see Figure A-3) when Coggins (2008) reported the highest estimated abundance of 10,571 rainbow trout for the 8.1-mi "control reach." This equates to about 81,000 fish for the 62-mile Marble Canyon reach, assuming uniform distribution, and represent the current condition of rainbow trout abundance in Marble Canyon. At this higher Marble Canyon trout abundance, 10 monthly PBR removal trips and 6 monthly LCR removal trips provide a probability of about 0.60 of maintaining the humpback chub population above 6,000 adults. It may be necessary, at the higher Marble Canyon trout abundances, to implement a short-term removal effort in the LCR reach in order to bring main-channel numbers down to a level where PBR removal only can control trout numbers. However, LCR removal would only occur if adult humpback chub numbers drop below 7,000 fish based on the ASMR.

The model shows that removal can keep up with emigration of large numbers of trout from the Lees Ferry reach (up to 100,000), but it is necessary to first reduce the Marble Canyon trout abundance. The model suggests that if trout abundance is high in the mainstem through Marble Canyon, maintaining a humpback chub population of >6,000 adults with a probability >0.60 will likely require more than 10 PBR removal trips, and could also require more than 6 LCR removal trips.

The unknowns and uncertainties listed above help to identify those elements of non-native fish control activities and model parameters that need to be addressed. The investigations identified in this BA supplement, together with ongoing investigations, and monitoring and evaluation being conducted in compliance with conservation measures and biological opinions will help to provide a sound scientific basis for this need. The workshop scheduled for 2014 will help to bring scientists and managers together to assess and evaluate available information and proceed with reasonable and prudent actions.

Conclusions

The proposed action will implement 10 years worth of the MLFF, multiple HFEs, and experimentation and implementation of non-native fish control to mitigate the adverse effects of these dam operatoins. There is uncertainty about how these actions will interact over the 10-year period. Reclamation is proposing to implement these actions in such a way that adaptive management principles will be utilized to both learn as much as possible about these resource management actions, but also to learn in a way that poses the least possible risk to the suite of resources identified in the Grand Canyon Protection Act that are under the GCDAMP's authority.

MLFF tends to cool mainstem habitat for humpback chub and erode sediment-formed habitats such as backwaters. The cooling effect likely adversely affects humpback chub through inhibited growth and cold shock, but also benefits humpback chub by helping to suppress non-native fish predators. Recent findings by the NSE study indicate survival and growth of humpback chub in mainstem nearshore habitats is much better than expected, and effects to the species in the mainstem from MLFF may not be as adverse as previously thought. Humpback chub status has improved in the 20-years since the MLFF was implemented, which is perhaps not surprising, because it was intended to improve conditions for native fish.

HFEs would potentially be conducted twice a year for the 10-year period of the proposed action. Although the existing information indicates that this will likely benefit sediment conservation in the action area, as well as related resources such as camping beaches, and sediment-formed habitats that may be important for native fish, there is also the potential that biological resources such as humpback chub could be adversely affected by increases in the trout population resulting from HFE implementation (Wright and Kennedy 2011).

Model predictions for the effectiveness for using rainbow trout removal in the PBR and LCR reaches to offset increases in trout that result from HFEs indicate that the success of this approach in maintaining the humpback chub population depends on the numbers of trout already in the mainstem in Marble Canyon and the number of trout emigrating from Lees Ferry. Korman et al. (2010) documented numbers of age-0 rainbow trout in Lees Ferry and found that abundance of age-0 trout in the Lees Ferry reach increased in spring as fish emerged from the gravel and recruited to the sampled population, peaking by mid-July, and then declined as losses owing to mortality and possibly downstream dispersal or movement to offshore habitat in the Lees Ferry reach that was not sampled. The rate of decline in abundance decreased in fall, and abundance was generally stable through winter. Most of this decrease is thought to be from mortality, as opposed to emigration to other habitats or downstream, but emigration is thought to occur, and likely occurs in the fall (J. Korman, Ecometric, pers. comm., 2011). Given this, and numbers of age-0 trout documented in past years by Korman et al. (2010), the scenarios of 10,000 to 50,000 rainbow trout recruits seems more likely than 75,000 or 100,000. Although the numbers of rainbow trout currently in Marble Canyon could be about 80,000 based on past results (Coggins et al. 2011), this assumes uniform distribution, which is unlikely. Also, Coggins et al. (2011) found that, even at these densities, mechanical removal in the LCR reach was successful in reducing abundances back down to the 4,500 level for the Marble Canyon reach. In other words, under any conditions, based on prior LCR reach removal results, LCR reach removal can, if necessary, create the 4,500 mainstem trout condition in the LCR reach. Given these assumptions and monitoring results, the proposed action seems likely to be able to maintain the humpback chub population above 6,000 adults for the duration of the proposed action. In other words, the moderate recruitment and adult trout abundance scenarios evaluated with the model seem like the most probable, and under these conditions probability of maintaining the adult humpback chub population above 6,000 adults is relatively high, although enough uncertainty exists that only testing these assumptions will reduce existing uncertainty.

The proposed action is expected to have both beneficial and adverse effects to humpback chub and to humpback chub and razorback sucker critical habitat, but Reclamation believes the net result will be positive for these species. This is because non-native fish control would be conducted potentially in both the PBR and LCR reaches, augmenting ongoing removal projects by the NPS in Bright Angel and Shinumo Creeks. Abundance of non-native fish species, especially trout, would be expected to decline. The potential adverse effect of HFEs resulting in increases in rainbow trout would potentially be mitigated by removal efforts. Decreases in non-native fish species would lead to decreased predation and competition on endangered humpback chub, resulting in increases in young humpback chub and potentially increased recruitment, and increases in adult abundance. The value of critical habitat for humpback chub and razorback sucker would also be improved. Reclamation has reviewed the best available science, and, using our technical expertise to interpret the science, our conclusion is that the proposed action represents the best option to implement the non-native fish control conservation measure in a way that satisfies our legal commitments and responsibilities under the ESA, is protective of the humpback chub, and is least damaging to cultural and other resources.

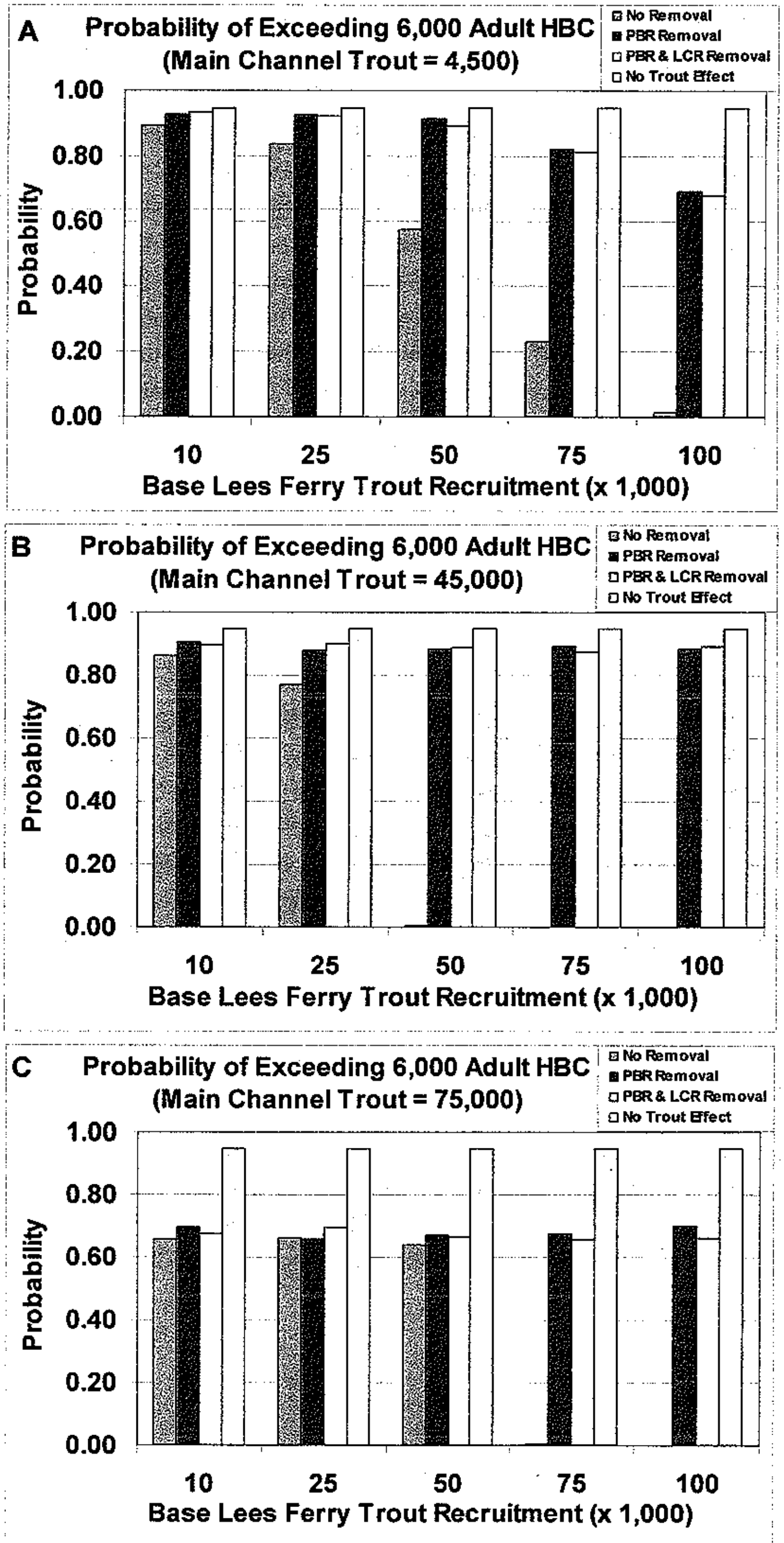

Figure 2. Probability of exceeding 6,000 adult humpback chub with main channel trout equilibriums of (A) 4,500, (B) 45,000, and (C) 75,000. Comparisons are made for no removal of trout, PBR removal only, PBR and LCR removal, and no trout effect (i.e., no trout present in the system).

Table 1. Probabilities of exceeding 5,000; 6,000; 7,000; and 10,000 adult humpback chub for combinations of (A) base recruitment of rainbow trout at Lees Ferry, (B) recruitment/emigration rate, (C) main-channel rainbow trout population equilibrium of 4,500, (D) PBR removal, and (E) LCR removal. Estimated numbers of trout removed per month and percentage of months in which the HBC Trigg occurred are also provided. Probabilities are based on 100 model simulations for 100 years each. Model parameters are described in table footnotes.

Model Parameters	No Trout Effect	Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
A. Base LF Recruit (1,000s age-0 RBT)	0	10	10	10	25	25	25	50	50	50	75	75	75	100	100	100
B. Recruit/Emigration Rate	0	0.55	0.55	0.55	1.08	1.08	1.08	1.95	1.95	1.95	2.83	2.83	2.83	3.7	3.7	3.7
C. MC RBT Pop Equilibrium	0	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500	4,500
D. PBR Removal Sched (trips, 4 passes)	0	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10
E. LCR Removal Sched (trips, 4 passes)	0	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Probability of Exceeding Adult HBC Numbers																
>5,000	0.99	0.96	0.98	0.98	0.93	0.96	0.98	0.85	0.96	0.96	0.48	0.94	0.93	0.08	0.88	0.87
>6,000 (Incidental Take)	0.93	0.89	0.92	0.93	0.84	0.93	0.92	0.57	0.91	0.89	0.23	0.82	0.81	0.01	0.69	0.68
>7,000 (HBC Trigger)	0.90	0.72	0.81	0.82	0.64	0.75	0.80	0.39	0.72	0.71	0.07	0.61	0.61	0.01	0.43	0.43
>10,000	0.48	0.19	0.30	0.33	0.14	0.26	0.29	0.04	0.19	0.19	0.00	0.11	0.12	0.00	0.03	0.04
Trout Removed and HBC Trigger																
Ave No. Trout Removed/Month (PBR)	--	--	634	634	--	832	834	--	1,192	1,192	--	1,587	1,590	--	1,987	1,988
Ave No. Trout Removed/Month (LCR)	--	--	0	205	--	0	311	--	0	500	--	0	690	--	0	880
% of Months HBC Trigger Occurred	--	--	0	10%	--	0	10%	--	0	15%	--	0	21%	--	0	28%

A. Base LF Recruit (1,000s age-0 RBT: The number of age-0 rainbow trout recruiting at Lees Ferry; 10,000; 25,000; 50,000; 75,000; and 100,000 (see Figure A-2.

B. Recruit/Emigration Rate: The model provides three "Recruitment-Emigration Relationships" (WLR, WLR0.4, NoLR). The output on this table is from WLR only (i.e., with specified trout recruitment from Lees Ferry); the number 1.95 means that for age-0 trout recruitment of 50,000, a total of 1,950 emigrate downstream. The other models are not relevant to these scenarios.

C. MC RBT Pop Equilibrium: This sets the numbers of trout already in the main channel downstream from Lees Ferry, set proportional to seven river reaches from Lees Ferry (RM 0) to the LCR (RM 62). Specified numbers of 4,5 45,000; and 75,000 are equivalent to a range of trout numbers in a "control reach" of 690 RBT/mi (July 2006) to 3,424 RBT/mi (March 2003) (Coggins 2008).

D. PBR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the PBR or any specified number of removal trips and passes; table output is based on 4 passes in each of 10 monthly removal trips

E. LCR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the LCR or any specified number of removal trips and passes if the HBC population drops below 7,000 adults (i.e., "HBC Trigger"); ta output is based on 4 passes in each of 6 monthly removal trips.

Table 2. Probabilities of exceeding 5,000; 6,000; 7,000; and 10,000 adult humpback chub for combinations of (A) base recruitment of rainbow trout at Lees Ferry, (B) recruitment/emigration rate, (C) main-channel rainbow trout population equilibrium of 45,000, (D) PBR removal, and (E) LCR removal. Estimated numbers of trout removed per month and percentage of months in which the HBC Trigger occurred are also provided. Probabilities are based on 100 model simulations for 100 years each. Model parameters are described in table footnotes.

Model Parameters	No Trout Effect	Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
A. Base LF Recruit (1,000s age-0 RBT)	0	10	10	10	25	25	25	50	50	50	75	75	75	100	100	100
B. Recruit/Emigration Rate	0	0.55	0.55	0.55	1.08	1.08	1.08	1.95	1.95	1.95	2.83	2.83	2.83	3.7	3.7	3.7
C. MC RBT Pop Equilibrium	0	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000	45,000
D. PBR Removal Sched (trips, 4 passes)	0	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10
E. LCR Removal Sched (trips, 4 passes)	0	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Probability of Exceeding Adult HBC Numbers																
>5,000	0.99	0.97	0.97	0.96	0.91	0.96	0.96	0.01	0.97	0.97	0.01	0.97	0.96	0.00	0.97	0.96
>6,000 (Incidental Take)	0.93	0.86	0.91	0.89	0.77	0.88	0.90	0.00	0.88	0.89	0.00	0.89	0.87	0.00	0.88	0.89
>7,000 (HBC Trigger)	0.90	0.74	0.74	0.73	0.58	0.72	0.73	0.00	0.73	0.74	0.00	0.75	0.75	0.00	0.77	0.73
>10,000	0.48	0.20	0.23	0.21	0.12	0.21	0.21	0.00	0.22	0.21	0.00	0.22	0.23	0.00	0.23	0.21
Trout Removed and HBC Trigger																
Ave No. Trout Removed/Month (PBR)	--	--	999	993	--	1,379	1,384	--	2,118	2,111	--	2,855	2,854	--	3,570	3,568
Ave No. Trout Removed/Month (LCR)	--	--	0	22	--	0	20	--	0	22	--	0	19	--	0	21
% of Months HBC Trigger Occurred	--	--	0	13%	--	0	12%	--	0	13%	--	0	11%	--	0	12%

A. Base LF Recruit (1,000s age-0 RBT: The number of age-0 rainbow trout recruiting at Lees Ferry; 10,000; 25,000; 50,000; 75,000; and 100,000 (see Figure A-2.

B. Recruit/Emigration Rate: The model provides three "Recruitment-Emigration Relationships" (WLR, WLR0.4, NoLR). The output on this table is from WLR only (i.e., with specified trout recruitment from Lees Ferry); the number 1.95 means that for age-0 trout recruitment of 50,000, a total of 1,950 emigrate downstream. The other models are not relevant to these scenarios.

C. MC RBT Pop Equilibrium: This sets the numbers of trout already in the main channel downstream from Lees Ferry, set proportional to seven river reaches from Lees Ferry (RM 0) to the LCR (RM 62). Specified numbers of 4,500; 45,000; and 75,000 are equivalent to a range of trout numbers in a "control reach" of 690 RBT/mi (July 2006) to 3,424 RBT/mi (March 2003) (Coggins 2008).

D. PBR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the PBR or any specified number of removal trips and passes; table output is based on 4 passes in each of 10 monthly removal trips.

E. LCR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the LCR or any specified number of removal trips and passes if the HBC population drops below 7,000 adults (i.e., "HBC Trigger"); table output is based on 4 passes in each of 6 monthly removal trips.

Table 3. Probabilities of exceeding 5,000; 6,000; 7,000; and 10,000 adult humpback chub for combinations of (A) base recruitment of rainbow trout at Lees Ferry, (B) recruitment/emigration rate, (C) main-channel rainbow trout population equilibrium of 75,000, (D) PBR removal, and (E) LCR removal. Estimated numbers of trout removed per month and percentage of months in which the HBC Trigger occurred are also provided. Probabilities are based on 100 model simulations for 100 years each. Model parameters are described in table footnotes.

Model Parameters	No Trout Effect	Scenario 1			Scenario 2			Scenario 3			Scenario 4			Scenario 5		
A. Base LF Recruit (1,000s age-0 RBT)	0	10	10	10	25	25	25	50	50	50	75	75	75	100	100	100
B. Recruit/Emigration Rate	0	0.55	0.55	0.55	1.08	1.08	1.08	1.95	1.95	1.95	2.83	2.83	2.83	3.7	3.7	3.7
C. MC RBT Pop Equilibrium	0	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000	75,000
D. PBR Removal Sched (trips, 4 passes)	0	0	10	10	0	10	10	0	10	10	0	10	10	0	10	10
E. LCR Removal Sched (trips, 4 passes)	0	0	0	6	0	0	6	0	0	6	0	0	6	0	0	6
Probability of Exceeding Adult HBC Numbers																
>5,000	0.99	0.86	0.90	0.88	0.87	0.86	0.89	0.86	0.87	0.87	0.01	0.87	0.87	0.00	0.90	0.87
>6,000 (Incidental Take)	0.93	0.66	0.70	0.67	0.66	0.66	0.70	0.64	0.67	0.67	0.00	0.68	0.66	0.00	0.70	0.66
>7,000 (HBC Trigger)	0.90	0.40	0.44	0.43	0.41	0.42	0.45	0.39	0.43	0.41	0.00	0.42	0.41	0.00	0.43	0.41
>10,000	0.48	0.02	0.03	0.04	0.03	0.04	0.04	0.02	0.04	0.03	0.00	0.03	0.04	0.00	0.03	0.03
Trout Removed and HBC Trigger																
Ave No. Trout Removed/Month (PBR)	--	--	1,001	1,003	--	1,393	1,396	--	2,168	2,173	--	3,025	3,025	--	3,876	3,874
Ave No. Trout Removed/Month (LCR)	--	--	0	35	--	0	34	--	0	36	--	0	32	--	0	35
% of Months HBC Trigger Occurred	--	--	0	29%	--	0	30%	--	0	30%	--	0	30%	--	0	28%

A. Base LF Recruit (1,000s age-0 RBT: The number of age-0 rainbow trout recruiting at Lees Ferry; 10,000; 25,000; 50,000; 75,000; and 100,000 (see Figure A-2.

B. Recruit/Emigration Rate: The model provides three "Recruitment-Emigration Relationships" (WLR, WLR0.4, NoLR). The output on this table is from WLR only (i.e., with specified trout recruitment from Lees Ferry); the number 1.95 means that for age-0 trout recruitment of 50,000, a total of 1,950 emigrate downstream. The other models are not relevant to these scenarios.

C. MC RBT Pop Equilibrium: This sets the numbers of trout already in the main channel downstream from Lees Ferry, set proportional to seven river reaches from Lees Ferry (RM 0) to the LCR (RM 62). Specified numbers of 4,500 45,000; and 75,000 are equivalent to a range of trout numbers in a "control reach" of 690 RBT/mi (July 2006) to 3,424 RBT/mi (March 2003) (Coggins 2008).

D. PBR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the PBR or any specified number of removal trips and passes; table output is based on 4 passes in each of 10 monthly removal trips.

E. LCR Removal Sched (trips, 4 passes): This parameter provides the option of no removal at the LCR or any specified number of removal trips and passes if the HBC population drops below 7,000 adults (i.e., "HBC Trigger"); table output is based on 4 passes in each of 6 monthly removal trips.

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APPENDIX A: Relationship of High Flows to Trout and Humpback Chub

High releases from Glen Canyon Dam, especially in the spring, are expected to increase survival and recruitment of young rainbow trout in the Lees Ferry reach and increase their abundance (Korman et al. 2010). Figure A-1 illustrates the relationship of high-flow releases to rainbow trout and humpback chub. The increase in trout abundance is expected to result in emigration of some young trout downstream into designated critical habitat occupied by the endangered humpback chub near the LCR confluence.

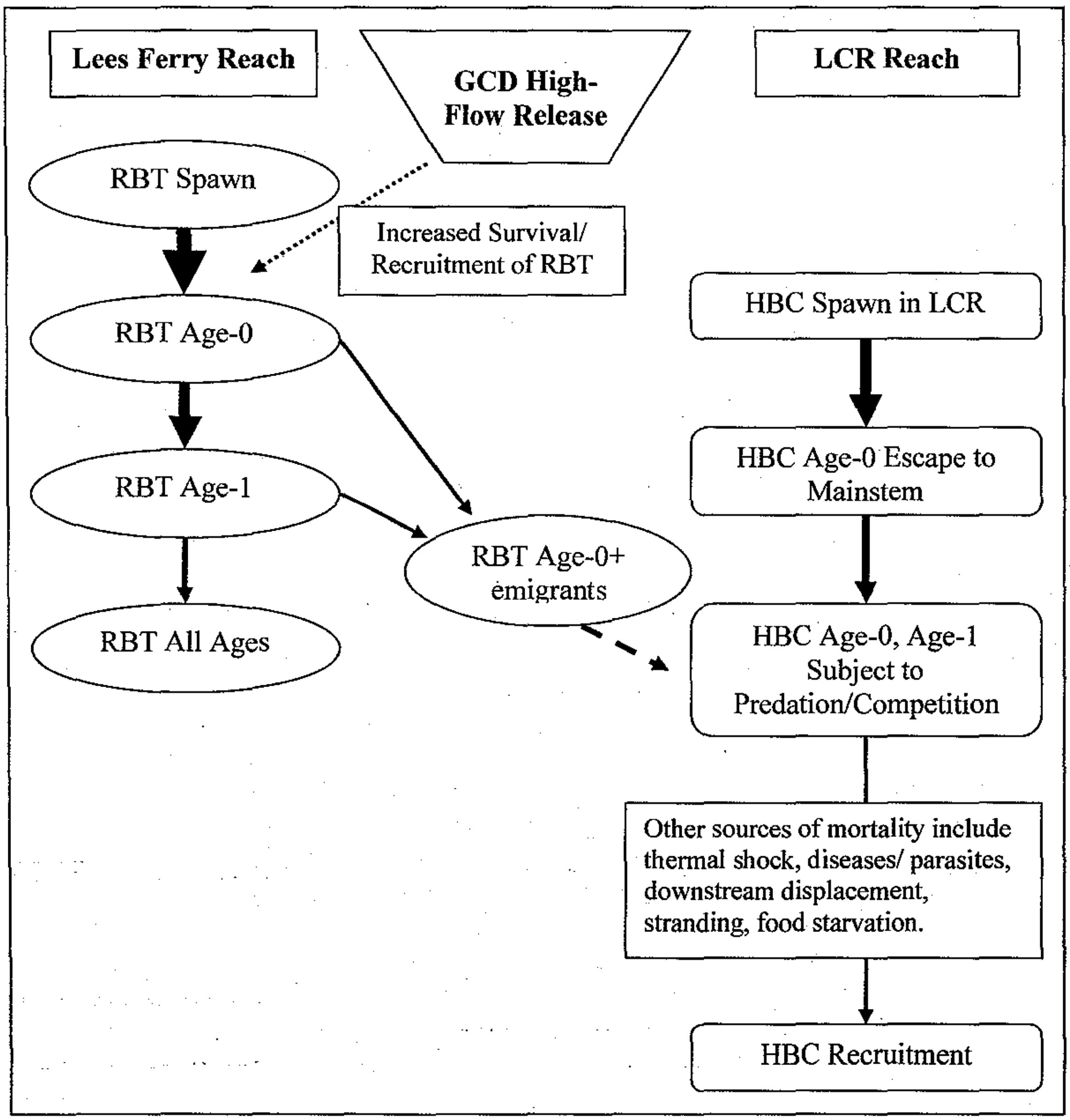

Figure A-1. Relationship of a high-flow release to rainbow trout and humpback chub.

Humpback chub in their first and second years of life use nearshore habitats as nursery areas (Converse et al. 1998), where they are susceptible to predation by rainbow trout and brown trout. Rates of piscivory ranged from 4 to 10 fish/rainbow trout/year, and 90 to 112 fish/brown trout/year (Yard et al. 2011). Of prey fish consumed, an estimated 27.3% were humpback chub.

The greatest concentration of young humpback chub occurs in the LCR reach, about 70-80 mi downstream from Glen Canyon Dam. This reach 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; SWCA 2008), where there is evidence of overwinter survival in some years (Andersen et al. 2010).

Evidence of Trout Response to a High-Flow Release

Evidence for a potential increase in abundance of rainbow trout from a high-flow release is based on measured survival rates of young trout in the Lees Ferry reach before and after high-flow releases (HFEs) in November 2004 and April 2008 (Figure A-2, Korman et al. 2010). A stock-recruitment analysis showed that survival rates of early life stages increased more than fourfold following the March 2008 HFE compared to survival rates before the experiment. Fry abundance in 2009 was more than twofold higher than expected, given the estimated number of viable eggs deposited that year, but fry abundance in 2010 was similar to levels between 2003 and 2007.

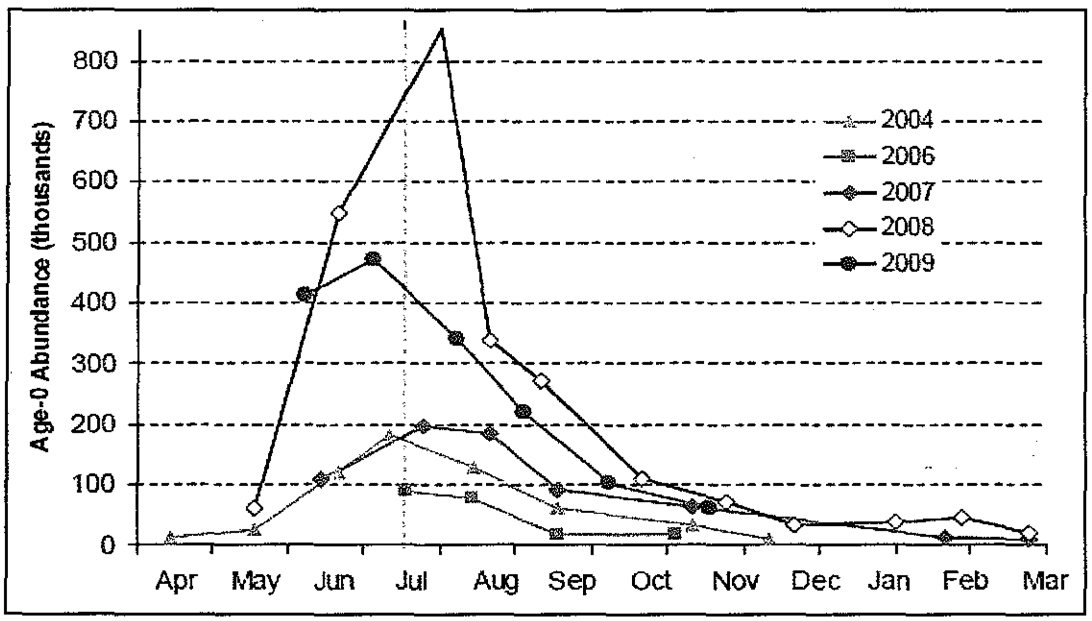

Figure A-2. Trends in the abundance of age-0 rainbow trout in the Lees Ferry reach through the year for several different brood years (years in which the eggs that produced the fish were fertilized). The vertical dashed line represents July 15, the date used as a standard time for the annual recruitment values in the stock-recruitment analysis (from Korman et al. 2010).

This pattern indicates that the effect of an HFE on early life stages of trout declines through time, with increased survival rates lasting for as long as 2 years (Korman and Melis 2011). Increased abundance of fry in 2008 eventually led to increased abundance of 1-year-old trout in 2009 in the Lees Ferry reach, and some of these fish likely moved downstream to the area near the confluence with the Little Colorado River (Makinster et al. 2010a) used by humpback chub. In contrast, the November 2004 HFE resulted in lower apparent survival of rainbow trout compared to that observed during more typical dam operations. Although the cause of this effect was not clear, it may be that spring HFEs benefit trout by increasing egg and fry survival, whereas fall HFEs may scour overwinter food sources and detrimentally affect trout survival.

The rainbow trout population in the Lees Ferry reach underwent a dramatic increase from 1991 to 1997 most likely because of increased minimum flows and reduced daily discharge fluctuations (Figure A-3). After 2001, there was a steady decline in the Lees Ferry population until 2007; a similar decline occurred below the Paria River (Makinster et al. 2010a). The 2001–2007 decline is attributed less to increased daily fluctuations (trout suppression flows) during 2003-2005 and more to increased water temperatures (associated with low reservoir elevations) and increased trout metabolic demands coupled with a static or declining foodbase, periodic oxygen deficiencies and nuisance aquatic invertebrates; e.g., New Zealand mudsnail (*Potamopyrgus antipodarum*) (Behn et al. 2010). The dramatic increase in 2008, as previously discussed is attributed to the April 2008 HFE.

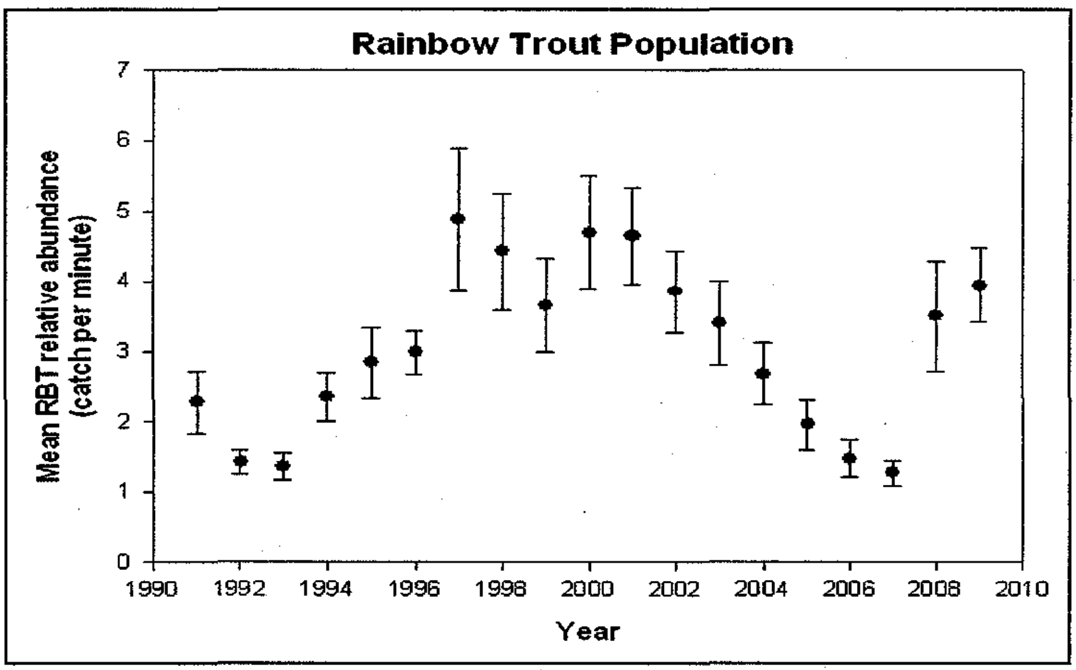

Figure A-3. Average annual electrofishing catch rates of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991–2010 (from Makinster et al. 2010a).

The population of humpback chub for the period 1991 to 2007 (Figure A-4) appears to be inversely related to the abundance of rainbow trout. The chub population was lowest in 2000 and 2001 when the rainbow trout density was highest.

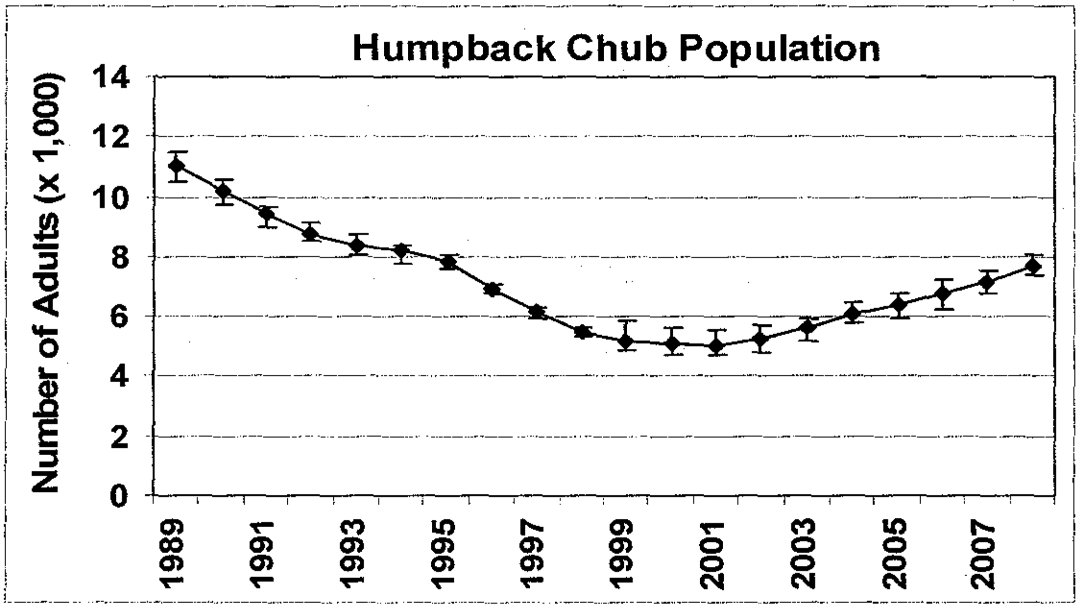

Figure A-4. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials. 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 (from Coggins and Walters 2009).

Effects of Past Removal Activities

From 2003 through 2006, over 36,500 non-native fish of 15 species were removed from a 9.4-mi reach of the Colorado River (RM 56.3-65.7) in the vicinity of the LCR; 82% were rainbow trout and 1% was brown trout (Coggins 2008). The estimated abundance of rainbow trout in the entire removal reach ranged from a high of 6,446 (95% credible interval (CI) 5,819-7,392) in January 2003 to a low 617 (95% CI 371-1,034) in February 2006; a 90% reduction over this time period. Between February 2006 and the final removal effort in August 2006, the estimated abundance increased by approximately 700 fish to 1,297 (95% CI 481-2,825).

An average of 1,765 rainbow trout and 36 brown trout were captured during each trip (2-5 passes per trip; 2 nights per pass) from the LCR reach when the trout population was highest in 2003 (Table A-1). Assuming that these numbers of fish can be removed in a single trip from the LCR reach during each of six proposed trips, a total of 10,590 (1,765 x 6) rainbow trout and 216 (36 x 6) brown trout could be removed in one year. It is recognized that fewer fish would be removed with lower numbers of trout. In a given year, therefore, with these levels of mechanical removal and high levels of trout abundance we would expect to save 11,564—28,911 chub from predation by rainbow trout (i.e., numbers removed times HBC/predator/year) and between 5,307 and 6,604 chub from predation by brown trout. These numbers were derived from rates of piscivory of 4 to 10 fish/rainbow trout/year, and 90 to 112 fish/brown trout/year, and the estimation that 27.3% of prey fish consumed were humpback chub (Yard et al. 2011).

Table A-1. Average numbers of rainbow trout (RBT) and brown trout (BNT) captured in the LCR reach each year from 2003 through 2006. Data from Coggins (2008).

Year	Trips	Passes	Average per Trip	
			RBT	BNT
2003	6	2-5	1,765	36
2004	6	4-6	908	32
2005	6	4	364	6
2006	5	4	160	5

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 90th percentile (9.6% exceedance to 10.4% exceedance probability), moderate traces the 50th percentile and dry traces, the 10th percentile.

The 15 corresponding traces were pulled from CRSS output to gather the Lake Powell outflow for the years 2010 to 2019. Each of the wet ten-year outflow time series was plotted and the 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.

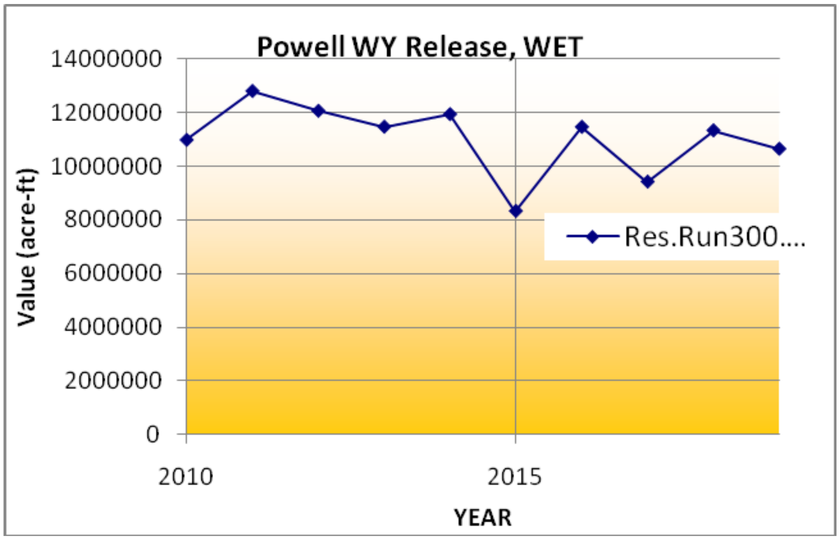

Figure 1. Lake Powell water year releases, wet trace.

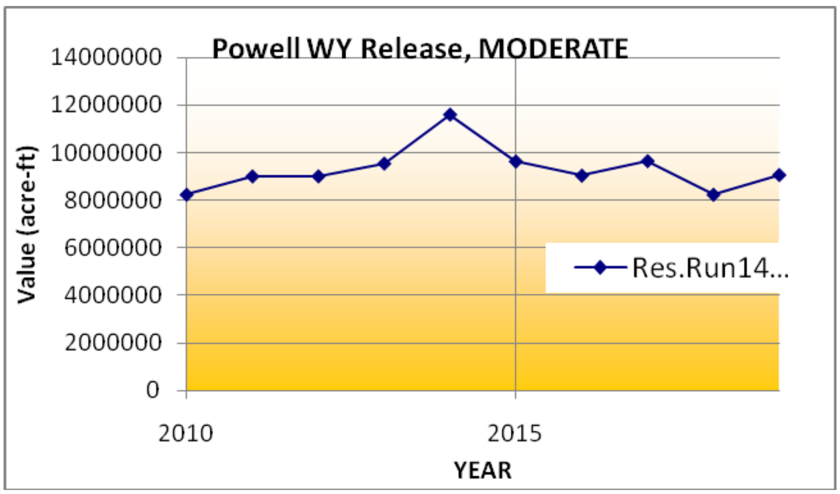

Figure 2. Lake Powell water year releases, moderate trace.

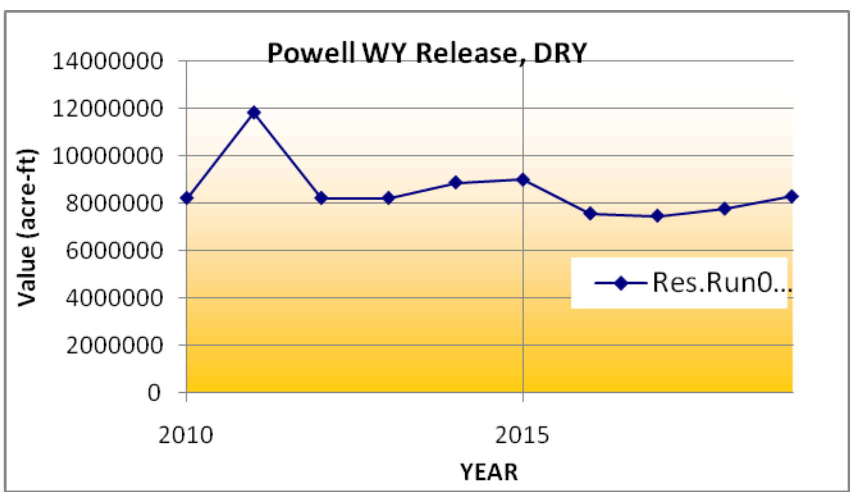

Figure 3. Lake Powell water year releases, dry trace.

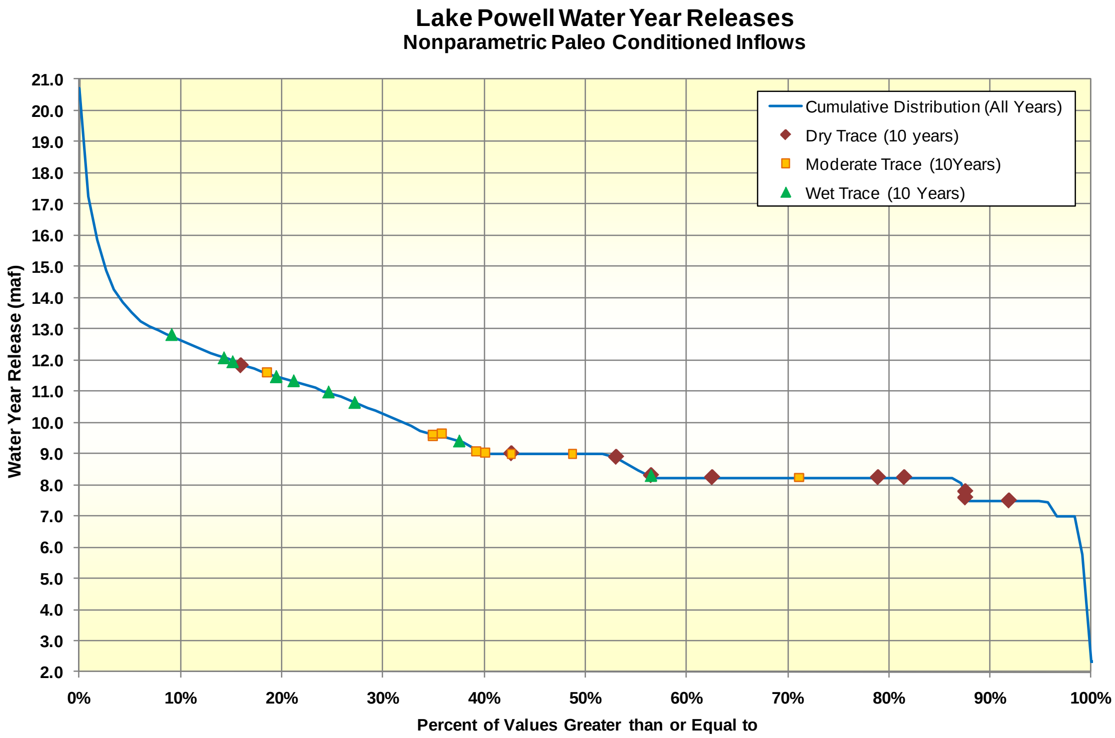

Figure 4. Lake Powell water year releases, all CRSS runs with values from selected dry, moderate, and wet traces highlighted.

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

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

Appendix E 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.

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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.

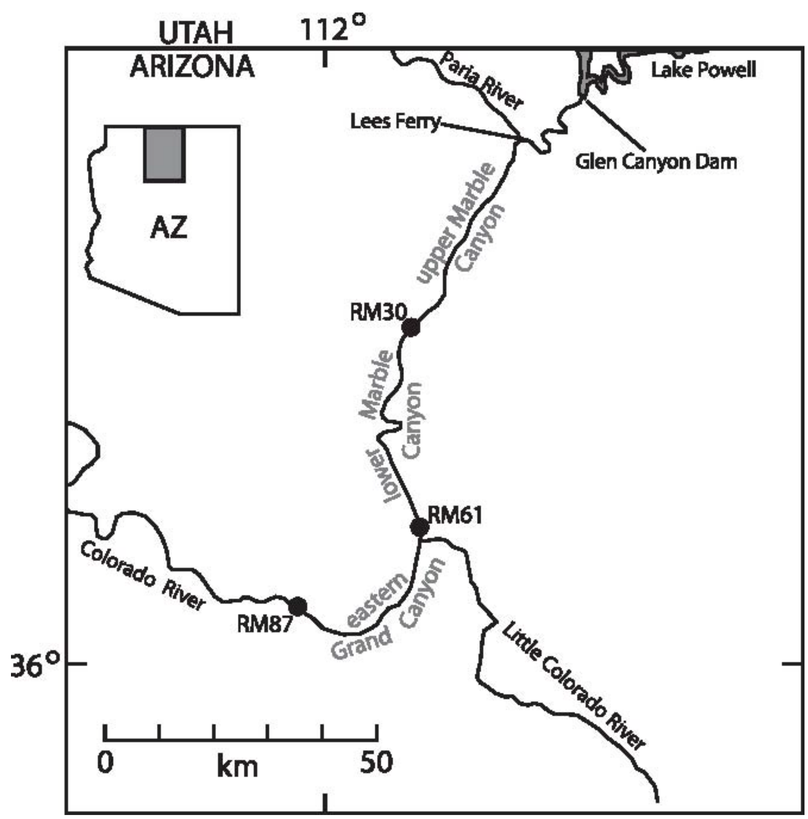


Figure 1. Sand budget model reaches (from Wright et al. 2010)

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.

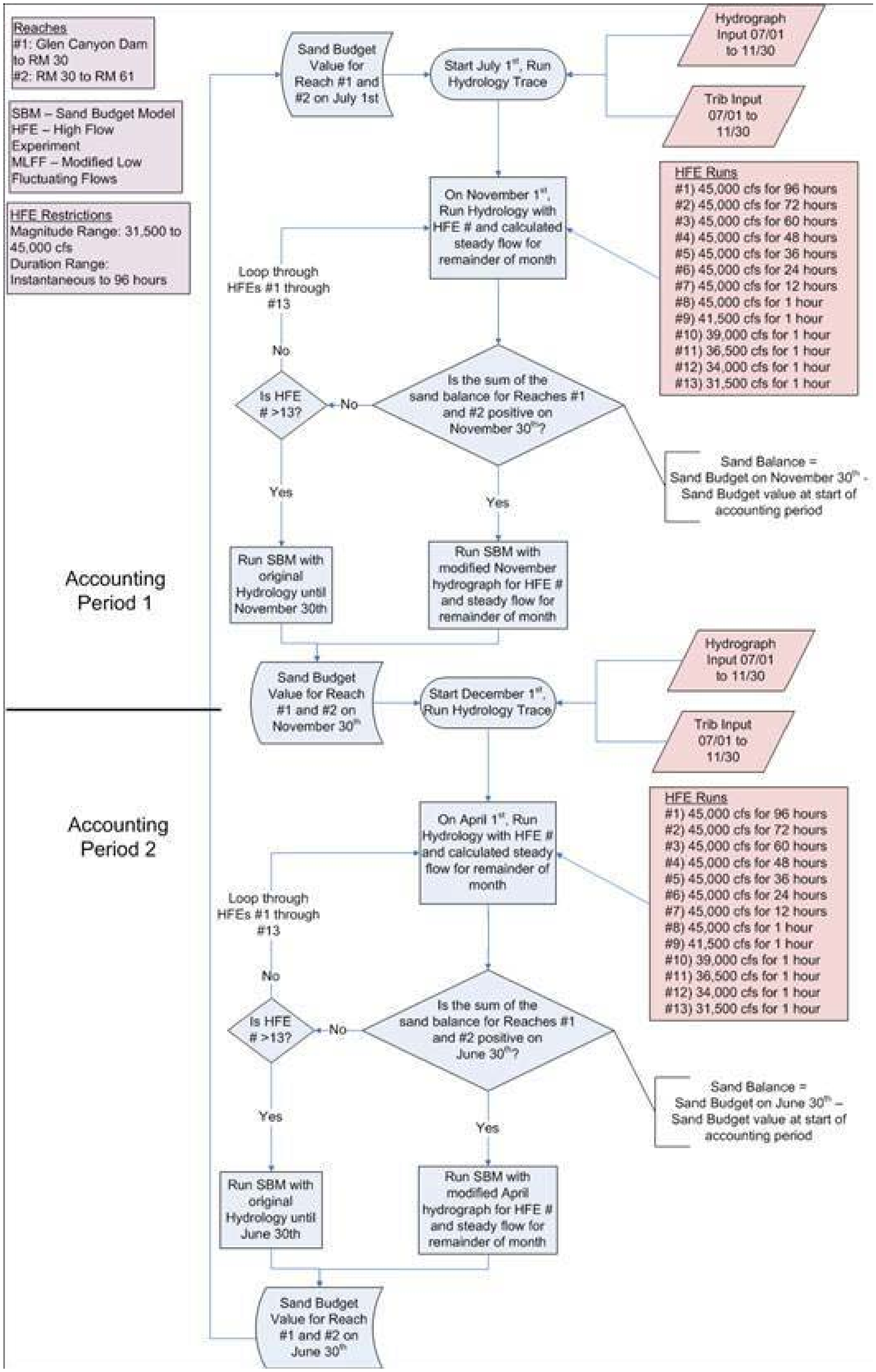


Figure 2. Detailed flow chart of modified sand budget model framework.

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.

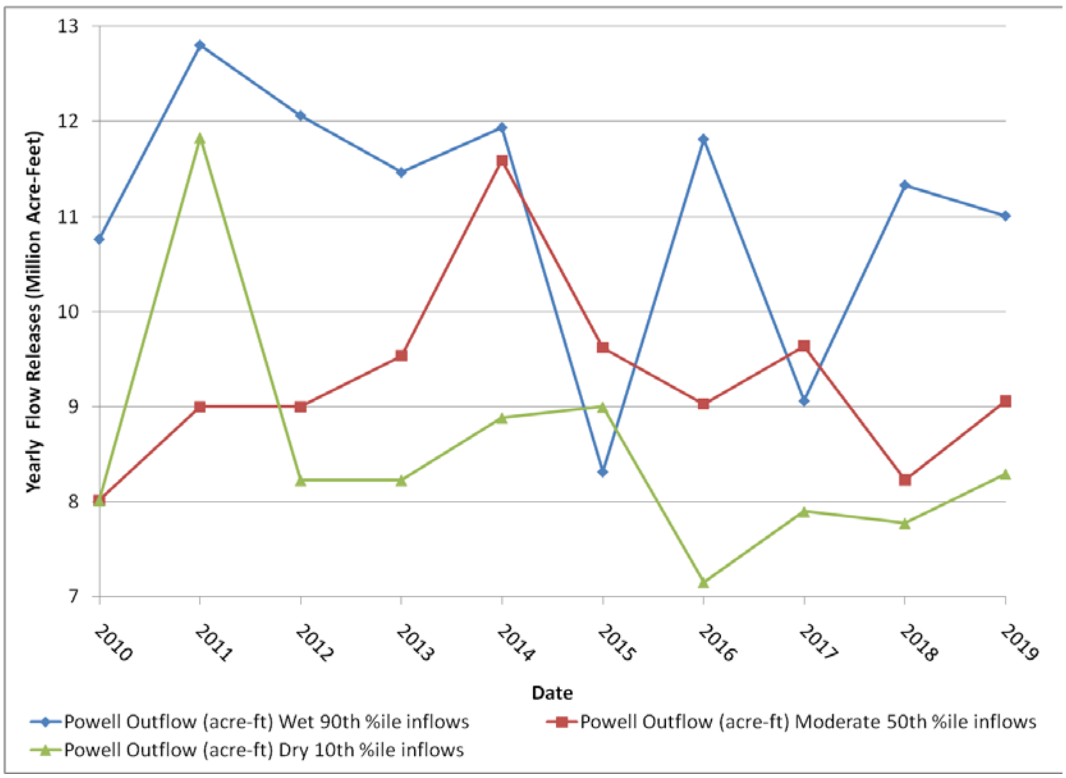


Figure 3. Yearly volumes for three Glen Canyon Dam release traces.

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.

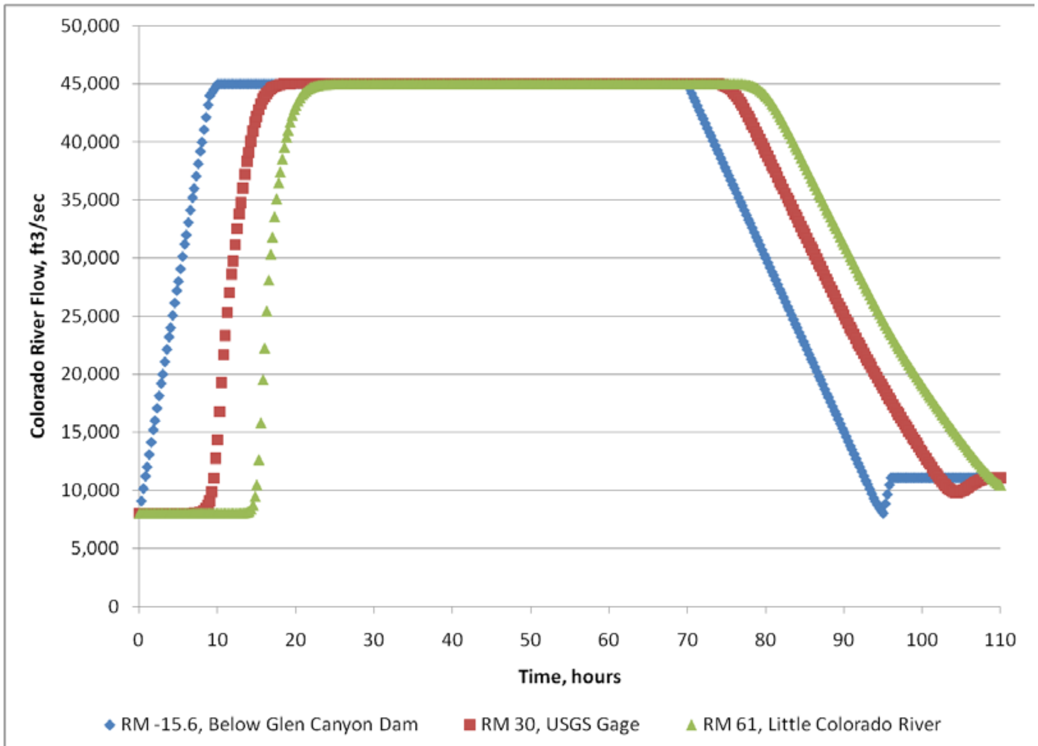


Figure 4. Flow hydrographs for HFE 3 (45,000 ft^3/sec for 60 hours) at RM -15.6, RM 30, and RM 61.

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.

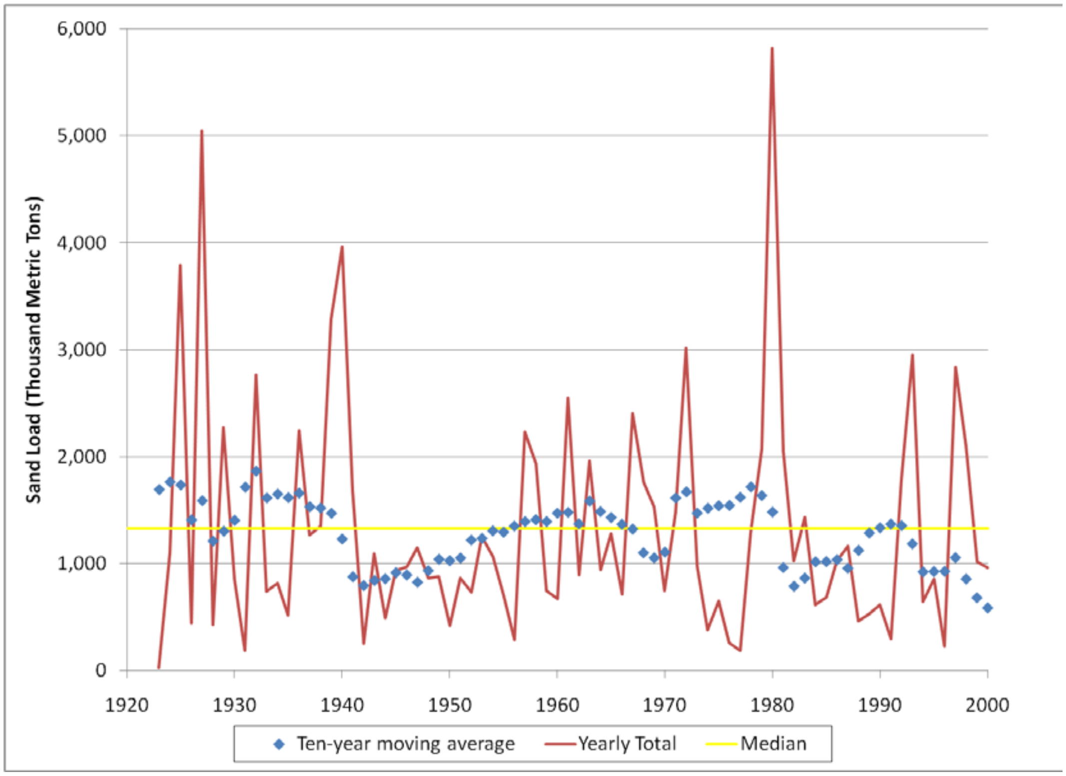


Figure 5. Yearly Paria River sand loads with calculated ten-year moving average.

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.

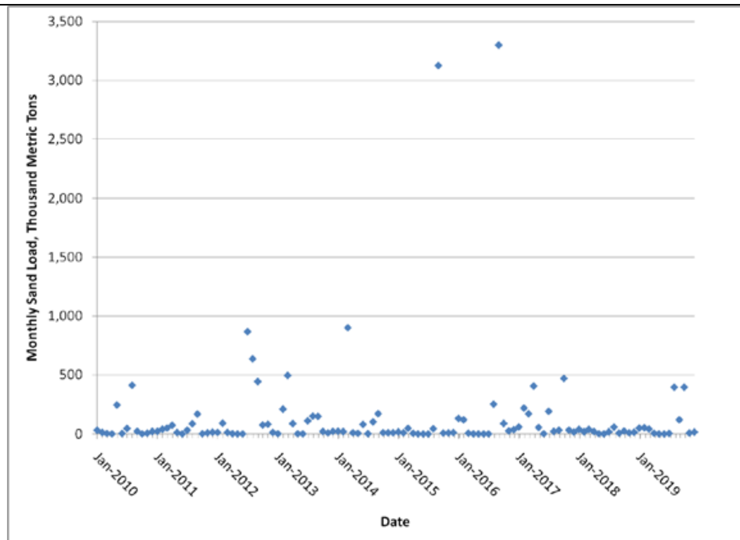
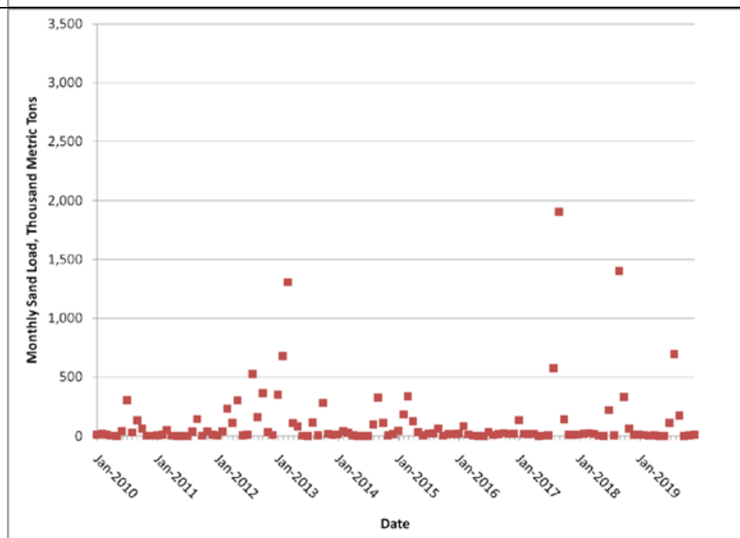
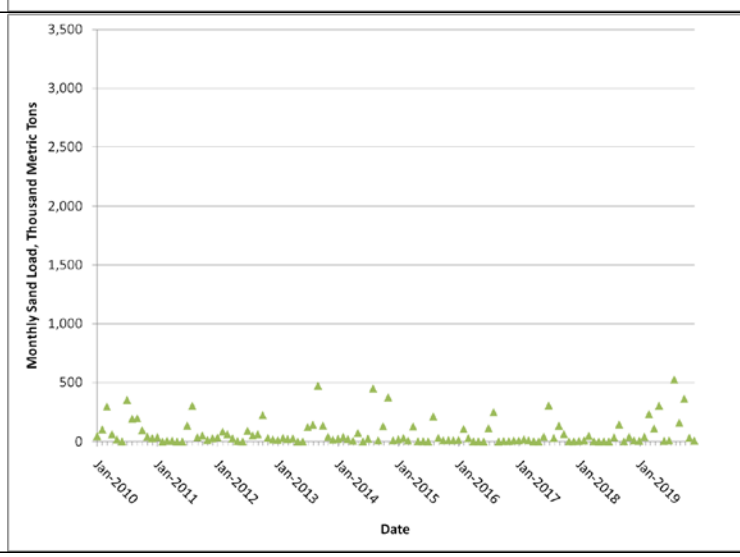
a) High Sediment Monthly Load Trace	
b) Moderate Sediment Monthly Load Trace	
c) Low Sediment Monthly Load Trace	

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 50% tributary sand supply 90% tributary sand supply
50% hydrology trace	10% tributary sand supply 50% tributary sand supply 90% tributary sand supply
90% hydrology trace	10% tributary sand supply 50% tributary sand supply 90% tributary sand supply

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.

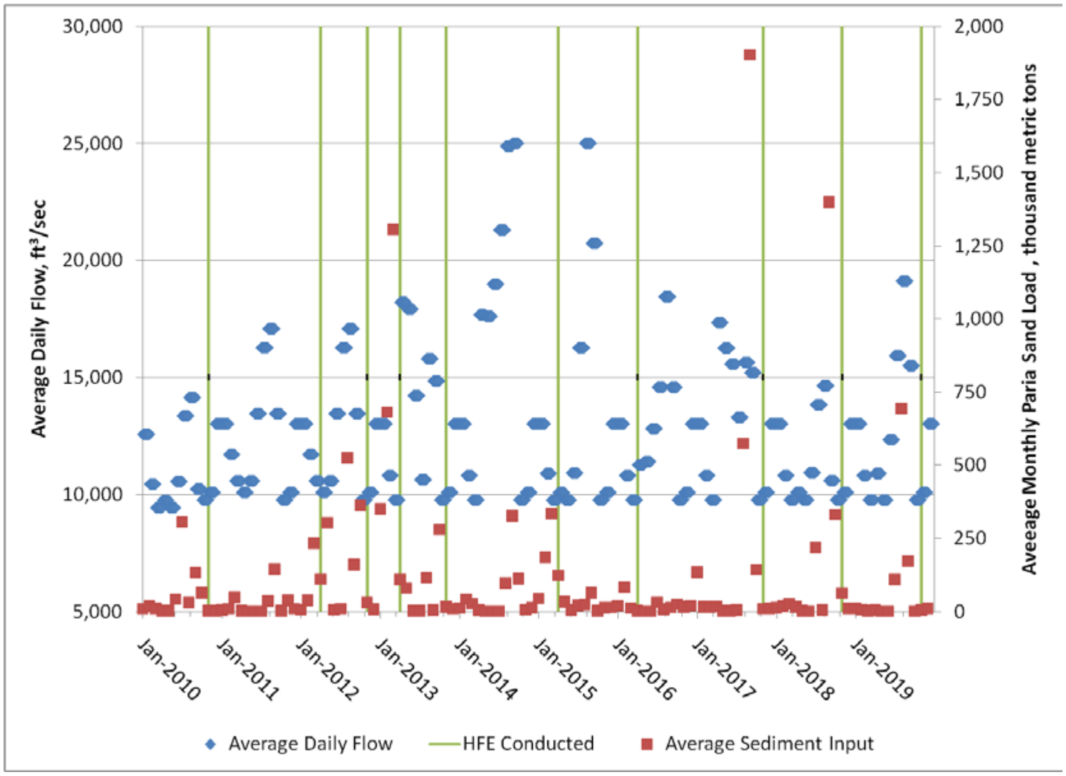


Figure 7. Average daily flow and average monthly sand loads for the moderate hydrology, moderate sediment trace with the HFEs resulting from the modified sand budget model.

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.

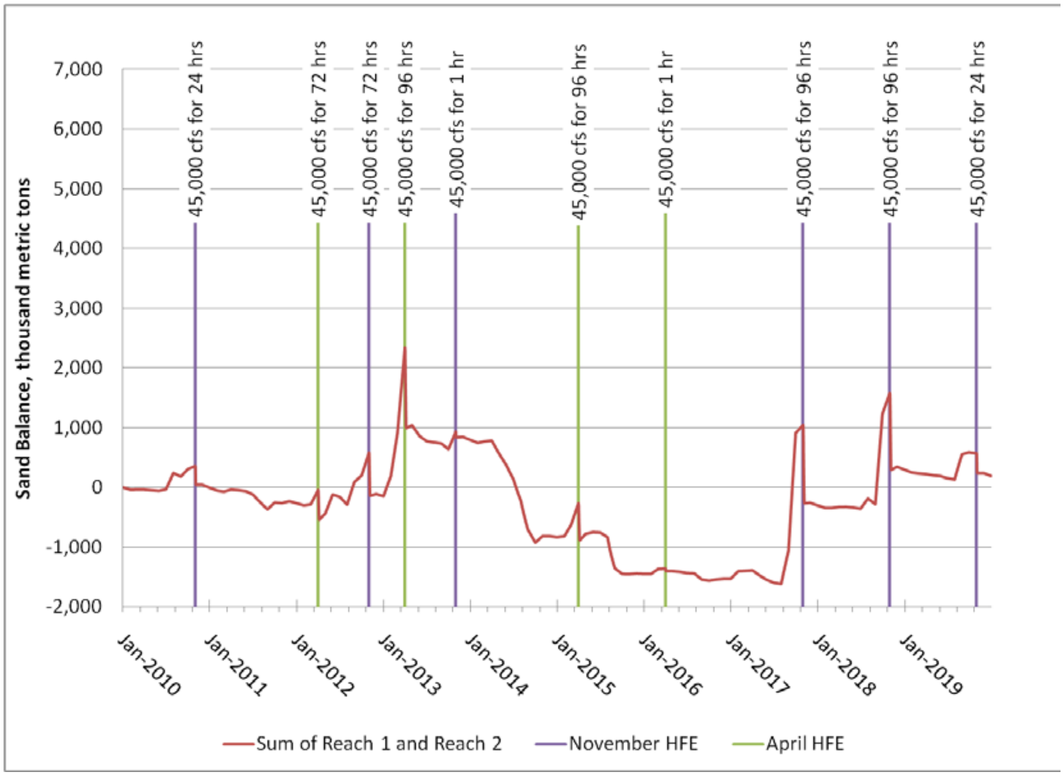


Figure 8. The cumulative sand balance (sum of Reach 1 and Reach 2) for the moderate hydrology, moderate sediment trace with the HFEs resulting from the modified sand budget model.

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

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[5]: 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 difficult

[5] The analysis for this EA was completed by Western Area Power Administration, CRSP Management Center in Salt Lake City.

and costly, and so it is not done except in a few special circumstances. Since electricity cannot be stored easily 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[6]. 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[7] 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.

6 IVG Energy http://www.ivgenergy.com/ provides subscribers with news, information, and power prices that are updated daily.
7 Information on natural gas futures prices was obtained from the CME Group website: http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html

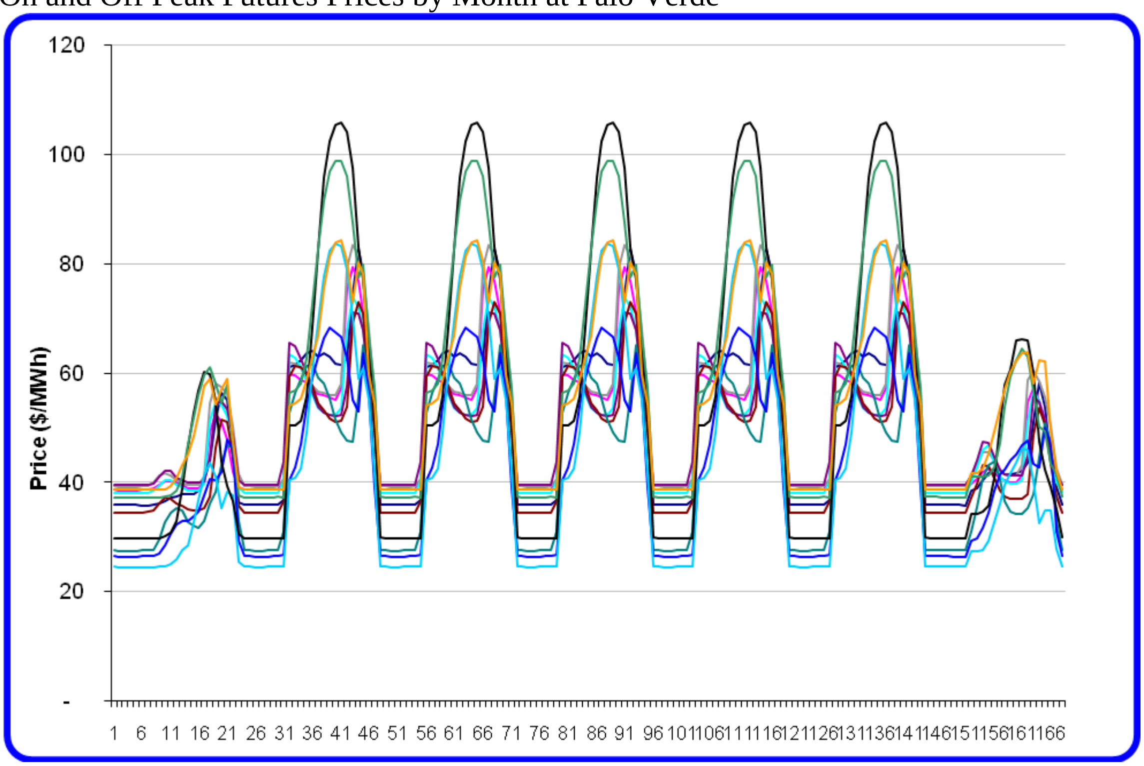
Table 2

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 powerplant 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 powerplant, while energy costs are more related to the cost of operating and maintaining the powerplant. 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 traces8. 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 proposed HFE experimental protocol, HFEs would only occur in March-April or October-November.

[8] 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.

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. 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.

Appendix G: Letter of Concurrence from Arizona State Historic Preservation Office on Reclamation's Determination of Eligibility and Effect on Historic Properties Regarding Proposed Adoption of a High-Flow Protocol for Glen Canyon Dam, Coconino and Mohave Counties, Arizona

SHPO-2011-0844(92776)
AE

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, UT 84138-1102

IN REPLY REFER TO:
ENV-3.00
UC-720

JUN 27 2011

RECEIVED
JUL 01 2011
JC

Mr. James Garrison
State Historic Preservation Officer
Arizona State Parks
1300 West Washington
Phoenix, AZ 85007

Subject: Determination of Eligibility and Effect on Historic Properties Regarding Proposed Adoption of a High Flow Protocol for Glen Canyon Dam, Coconino and Mohave Counties, AZ

Dear Mr. Garrison:

As agency official for purposes of compliance with Section 106 of the National Historic Preservation Act of 1966, I wish to consult your office regarding the Bureau of Reclamation, Upper Colorado Region's proposed undertaking, which is consideration and adoption of a high flow protocol for experimental releases from Glen Canyon Dam (Dam) with the potential to affect the Colorado River in both Glen Canyon National Recreation Area (GCNRA) and Grand Canyon National Park (GCNP). While a programmatic agreement (PA) has been in effect since 1994 for operations of the Dam, concerns of the Pueblo of Zuni and other Indian tribes regarding the proposed undertaking are such that I have elected to follow the 36 CFR 800 process.

The proposed undertaking is to develop and implement a protocol for high flow experimental releases (HFEs) from the Dam to better determine whether and how sand conservation can be improved in the Colorado River corridor within GCNP. This protocol would evaluate short-duration, high volume Dam releases during sediment-enriched conditions for a 10-year period of experimentation, 2011–2020, to determine how multiple HFEs 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, rebuilding these features that are continually lost from erosion. These sand features and associated backwater habitats can provide key wildlife habitat, potentially reduce erosion of archaeological sites, enhance riparian vegetation, and provide camping opportunities along the Colorado River in GCNP.

For this undertaking, the area of potential effects (APE) within which historic properties might be affected is defined in lineal distance as following the Colorado River from below the Dam downstream as far as Pearce Ferry. The lateral extent is defined by the high water mark of the Colorado River at 45,000 cubic feet per second. The area measures about 10 square miles.

In compliance with 36 CFR 800.2 and 800.4, Reclamation has reviewed existing information on historic properties within this APE and has sought new information from consulting parties, including the National Park Service, the federal agency that administers GCNRA and GCNP, and has consulted with Indian tribes likely to have knowledge of, or concerns with, historic properties in the APE. Based on NPS review of relevant documentation, the APE includes all or portions of approximately 19 sites listed in Table 1.

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 for listing on the National Register through a consensus determination.

Table 1. Sites and districts potentially affected by the action. The sites labeled "GLCA" are located on lands managed by GCNRA. Those labeled NN are on Navajo Nation lands. Those labeled "GRCA" are on lands managed by GCNP. These Grand Canyon properties are considered contributing elements in an historic district previously determined eligible by the AZ SHPO. The tribal names indicate which tribe has identified the site as a contributing element in their traditional cultural property.

Site#	*Stage, Date*	*Type*	*Hopi*	*Hualapai*	*Paiute*	*Navajo*	*Zuni*	*Eligibility* *
AZ B:15:124 (GRCA)	Historic	Inscription						E
AZ B:16:262 (GRCA)	Historic	USGS Gauging Station						E
AZ C:2:11 (GLCA/NN)	Historic	District	x				x	L
AZ C:2:32 (GLCA)	unknown	Feature	x				x	E
AZ C:2:35 (GLCA)	PII	Campsite	x				x	E
AZ C:2:58 (GLCA/NN)	1920's-1930's	Cableways & associated materials						E
AZ C:2:59 (GLCA/NN)	1930's	USGS gauging station						E
AZ C:2:75 (GLCA)	unknown	lithic scatter				x	x	E
AZ C:2:77 (GLCA)	unknown	lithic scatter				x	x	E
AZ C:2:98 (GRCA)	Archaic – Historic	Campsite					x	E
AZ C:6:2 (GRCA)	1889	Inscription						E
AZ C:6:4 (GRCA)	1923	Inscription						E
AZ C:6:5 (GRCA)	unknown	Petroglyph	x			x	x	E

AZ C:9:88 (GRCA)	1950's	Dam site					E
AZ C:13:9 (GRCA)	PII	Masonry rooms	x			x	E
AZ C:13:10 (GRCA)	PI-III	Masonry rooms	x		x	x	E
AZ C:13:291 (GRCA)	PII	Masonry rooms	x			x	E
AZ C:13:347 (GRCA)	PII	Feature			x	x	E
AZ C:13:371 (GRCA)	PII	Masonry rooms	x			x	E

*E=Eligible for purposes of Reclamation's 106 compliance with this undertaking; NE=Not Eligible; L-Listed.

In addition, Reclamation has been consulting with Indian tribes that may attach traditional religious or cultural significance to the Colorado River and adjacent properties below Glen Canyon Dam as traditional cultural properties. While these identification efforts are not yet complete, as documented in the enclosed site forms and reports, I have determined that the National Register Criteria for Evaluation are met as follows:

Site	**Criteria for Evaluation**	**Eligibility**
Hopi traditional cultural property	a,b,c,d	Eligible
Hualapai traditional cultural property	a,b,c,d	Eligible
Navajo traditional cultural property	a,b,c,d	Eligible
Zuni traditional cultural property	a,b,c,d	Eligible
Southern Paiute	a,b,c,d	Eligible

Historic properties that could be affected by 45,000 cfs flows were considered prior to the 1996, 2004, and 2008 high flow experiments conducted by Reclamation in coordination with Glen Canyon Adaptive Management Program participants. Based on these prior undertakings, I believe 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." 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). Reclamation's finding is therefore adverse effect for the proposed undertaking.

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.

Conversely, there is the possibility of some benefit to individual sites as a result of the undertaking. There is potential benefit in protecting some sites eligible under criterion d due to stabilization of terrain through sediment deposits and potential improvements to riparian vegetation, for example. Nevertheless, because of the uncertainties discussed above, we believe that an overall determination of adverse effect is appropriate for this undertaking.

As indicated above, Reclamation has coordinated with the NPS in determining eligibility and effects information for this undertaking, and we are continuing to consult with them. I understand that they will correspond with your office directly in the next few days.

I am seeking your concurrence on these determinations of eligibility and effect for Reclamation's section 106 compliance purposes. If I do not hear from you within 30 days, I shall assume your concurrence and proceed to the next step in the section 106 process which is resolution of effects pursuant to 36 CFR 800.6. If you have any questions, please contact Beverley Heffernan at 801-524-3712 or by email, bheffernan@usbr.gov.

CONCUR
Ann E. Howard
fa
ARIZONA STATE HISTORIC PRESERVATION OFFICER
ARIZONA STATE PARKS BOARD
7-28-11

Sincerely,

Larry Walkoviak

Larry Walkoviak
Regional Director

Enclosure (CD containing 5 files)

IDENTICAL LETTER TO:

Dr. Alan Downer
Navajo Tribal Historic Preservation Officer
P.O. Box 4950
Window Rock, AZ 86515

Mr. David Uberuaga, Superintendent
Grand Canyon National Park
PO Box 129
Grand Canyon, AZ 86023

Mr. Todd Brindle, Superintendent
Glen Canyon National Recreation Area
P.O. Box 1507
691 Scenic View Dr.
Page, AZ 86040-1507

Appendix H: Biological Opinion

United States Department of the Interior

U.S. Fish and Wildlife Service
Arizona Ecological Services Office
2321 West Royal Palm Road, Suite 103
Phoenix, Arizona 85021-4951
Telephone: (602) 242-0210 FAX: (602) 242-2513

In Reply Refer To:
AESO/SE
22410-2011-F-0100
22410-2011-F-0112

December 23, 2011

Memorandum

To: Regional Director, Bureau of Reclamation, Salt Lake City, Utah

From: Field Supervisor

Subject: Final Biological Opinion on the Operation of Glen Canyon Dam including High Flow Experiments and Non-Native Fish Control

Thank you for your request for formal consultation with the U.S. Fish and Wildlife Service (FWS) pursuant to section 7 of the Endangered Species Act of 1973 (16 U.S.C. 1531-1544), as amended (ESA). Your January 2011 request was supplemented with Biological Assessment (BA) dated July 13, 2011, and received by us on July 15, with supplements provided as described in the Consultation History section of this document. At issue are impacts that may result from the proposed 10-year continued operation of Glen Canyon Dam under the Modified Low Fluctuating Flows (MLFF) alternative along with High Flow Experimental (HFE) Releases and Non-Native Fish (NNFC) Control downstream from Glen Canyon Dam (GCD), Coconino County, Arizona.

The Bureau of Reclamation (Reclamation) concluded that the proposed action "may affect, and is likely to adversely affect" the humpback chub (*Gila cypha*) and its critical habitat, the razorback sucker (*Xyrauchen texanus*) and its critical habitat, and the Kanab ambersnail (*Oxyloma kanabensis haydenii).* You also concluded that the proposed action "may affect, but is not likely to adversely affect" the southwestern willow flycatcher (*Empidonax traillii extimus*). We concur with your determination on the flycatcher and provide our rationale in Appendix A.

This biological opinion (Opinion) replaces the 2008 Final Biological Opinion on the Operation of Glen Canyon Dam (USFWS 2008a, consultation number 22410-1993-F-R1 and the court ordered supplements to that opinion). This Opinion is based on information provided in Reclamation's January and July BAs biological assessments on HFE Releases and NNFC, the draft environmental assessment on HFE Releases and NNFC, telephone conversations and meetings between our staff, and other sources of information found in the administrative record supporting this Opinion. All other aspects of the proposed action remain the same as described in the Environmental Assessments (EA) and BAs. Literature cited in this biological opinion is not a complete bibliography of all literature available on the species of concern. A complete administrative record of this consultation is on file at this office. The proposed action is the continued operation of Glen Canyon Dam under MLFF with the inclusion of a protocol for high-flow experimental releases from Glen Canyon Dam and non-native fish control for the 10-year period, 2011 through 2020. It is the FWS's biological opinion that the action, as proposed, is not likely to jeopardize the continued existence of the humpback chub, razorback sucker, or Kanab ambersnail and is not likely to destroy or adversely modify designated critical habitat for razorback sucker or humpback chub. A Table of Contents is provided below.

Table of Contents

Consultation history

January 14, 2011

Reclamation submitted a BA and requested initiation of formal consultation on the Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011-2020.

January 28, 2011

Reclamation submitted a BA, Draft EA, and requested informal consultation on implementation of Non-native Fish Control downstream from Glen Canyon Dam, Arizona, 2011-2020.

March 17, 2011

FWS submitted separate comments for the following: Draft EA for Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam (HFE Protocol), Arizona, 2011-2020; and Draft EA for Non-native Fish Control Downstream from Glen Canyon Dam (Non-native Fish Control). These reviews provided input on biological analysis and conservation needs for humpback chub, non-listed native species, and other fish and wildlife resources.

June 6, 2011

The FWS provided additional comments (email memorandum) for continuing issues to be addressed.

July 18, 2011

Reclamation submitted a Supplement to the BA responding to input received from, among others, FWS (as described above), and requested that the proposed action be modified to include:

1. A fuller description clarifying baseline operations that would form the basis for HFE implementation (the MLFF alternative as described in the 1995 Environmental Impact Statement and adopted in the 1996 ROD) for the 10-year period from 2011-2020.

2. Non-native fish control in the Little Colorado River (LCR) reach only when the number of adult humpback chub falls below 7,000.

3. A request that the proposed HFE protocol, non-native fish control (two separate BAs), and continued ROD operations (2011-2020) be evaluated in a single biological opinion. July 26, 2011 - FWS sent a memo to Reclamation acknowledging the request for the modified proposed action (re: non-native fish control), and the request for a single biological opinion and expedited consultation.

August 24, 2011 and
August 25, 2011

Informal meetings between Reclamation and the FWS in Phoenix, Arizona concerning the BAs for Non-native Control and High Flow Experiment. Notes compiled by Reclamation staff.

August 31, 2011

Conference call between Reclamation and FWS with notes by Reclamation staff.

September 2, 2011

Conference call between Reclamation, FWS, National Park Service (NPS), and Grand Canyon Monitoring and Research Center (GCMRC) to discuss the scientific merits of some potential changes to the proposed action.

September 6 - 8, 2011

FWS participated in the National Historic Preservation Act Section 106 Meeting in Phoenix along with Federal, State, Tribal, and private partners. FWS staffs discuss with meeting attendees the ongoing section 7 consultation.

October 4, 2011

Reclamation and FWS agree to general conservation measures for the draft biological opinion. Reclamation requests final Opinion by the end of November.

October 27, 2011

Reclamation sent revised Conservation Measures to FWS.

November 8, 2011 and
November 18, 2011

Conference calls with DOI, Reclamation, and FWS to review status of draft Opinion. Some revisions of conservation measures were provided.

November 25, 2011

FWS sent draft biological opinion to Reclamation for agency review.

November 30, 2011

Reclamation provides comments on the draft Opinion and requests review of a second draft.

December 6, 2011

Second revised draft Opinion provided to Reclamation for review.

December 8, 2011

Reclamation responded to second draft Opinion.

December 14, 2011
Third draft Opinion provided to Reclamation for review.

December 20, 2011
Conference call between FWS and Reclamation. Reclamation provides comments on the third draft document.

December 21, 2011 and
December 22, 2011
Reclamation and FWS discuss final draft biological opinion.

BIOLOGICAL OPINION

DESCRIPTION OF THE PROPOSED ACTION

The proposed action is the continued operation of Glen Canyon Dam under MLFF with the inclusion of a protocol for high-flow experimental releases from Glen Canyon Dam and non-native fish control for the 10-year period, 2011 through 2020. The 10-year period for the proposed action is based on the experimental development of the high-flow protocol, allowing a sufficient period of time to assess the long-term effects of repeated high-flow releases as a potential action to benefit downstream resources. The Department is also undertaking an Environmental Impact Statement (EIS) process to evaluate the Long-Term Experimental and Management Plan (LTEMP) which will be addressed as a separate Federal action.

HFEs

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. HFEs restore sand bars in Grand Canyon which are thought to provide backwaters that are beneficial to humpback chub. Annual and monthly releases would follow prior decisions, including the MLFF flow regime adopted in the 1996 Record of Decision on Glen Canyon Dam Operations, and the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Reservoir Operations (Interim Guidelines). Fall steady flows as identified in the 2008 Opinion and the 2009 Supplemental Opinion[1] are also scheduled for September and October 2012 as part of the proposed action.

---

[1] On February 27, 2008, the Service issued to Reclamation a biological opinion on the operation of Glen Canyon Dam for the period 2008-2012 (2008 Opinion). On May 26, 2009, the District Court of Arizona, in response to a lawsuit brought by the Grand Canyon Trust, ordered the Service to reevaluate the conclusion in the 2008 Opinion that the Modified Low Fluctuating Flow (MLFF) does not violate the Endangered Species Act (Case number CV-07-8164-PHX-DGC). The Court ordered the Service 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. The court noted that other portions of the biological opinion, the two components analyzing Reclamation's proposed action for steady flow releases in September and October 2008-2012 and the 2008 experimental high flow test, were adequate and would remain in effect. The court further ordered that "Reclamation may continue operating the Dam in accordance with the 2008 Experimental Plan" in the interim. The Service published a supplement to the 2008 Opinion (2009 Supplemental Opinion) in response to the Court Order. It provided a revised analysis of the effects of MLFF on endangered humpback chub and its critical habitat, and the endangered Kanab ambersnail. It also provides an explanation for why MLFF does not destroy or adversely modify humpback chub critical habitat and addressed whether MLFF will advance or impede chub recovery. On June 29,

The timing of HFE releases from Glen Canyon Dam would be March-April (spring) and October-November (fall); the magnitude would be between 31,500 cubic feet per second (cfs) and 45,000 cfs; and the duration would be from less than one hour to 96 hours. The precise 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.

A complete description of the proposed HFE protocol is provided in Reclamation's HFE Protocol EA (Reclamation 2011a) which we summarize here. Also, an expanded discussion of the past experimental actions regarding high flow testing is provided in the Environmental Baseline section below. With respect to the proposed action, the HFE protocol will consist of three components: (1) planning and budgeting, (2) modeling, and (3) decision and implementation. An annual report will assimilate and synthesize the information on the effects of HFEs, including the status and trends of key resources in the action area. This information will be used by the Department of the Interior to assist with the decision on whether to pursue one or more HFEs in any given year.

The HFE Protocol modeling component uses real-time sediment accounting/monitoring data to evaluate conditions of sediment in the Colorado River in Marble and Grand Canyons. Sediment is accounted for during two accounting periods. The fall accounting period is July 1 through November 30, and the spring accounting period is December 1 through June 30. Based on the amount of sand input during the accounting periods and analysis results of the three HFE Protocol components, HFEs may be scheduled in one of two release windows, March-April and October-November. HFE release volume and magnitude will be based on available information including model recommendations.

Because the hydrology and sediment conditions are unpredictable, the magnitude, duration, and frequency of HFEs will not be prescribed in advance. Sediment conditions depend on periodic and unpredictable tributary floods in the Paria River, and annual releases from GCD also vary considerably based on Colorado River inflows into Lake Powell. Colorado River inflows into Lake Powell can be modeled using Reclamation's Colorado River Simulation System (CRSS). The CRSS uses the last 100 years of Colorado River hydrology to establish dry conditions (10th percentile of the last 100 years of annual river flows), moderate conditions (50th percentile), and wet conditions (90th percentile). Reclamation analyzed nine traces of hydrology and sediment conditions by combining three hydrology settings based on the CRSS (dry, moderate, and wet conditions of the Colorado River) with three sediment input settings from the Paria River: low sediment input (i.e. 1983, 862,000 metric tons), moderate sediment input (i.e. 1990, 1,334,000 metric tons), and high sediment input (1934, 1,649,000 metric tons). Using these nine possible combinations, the model simulates random sediment input and hydrology for a 10-year period. The simulation is not predictive of future events, but provides an example of how HFEs might be conducted under a maximum 10-year experimental period. The above-mentioned LTEMP is

2010, the District Court issued an order remanding the 2009 Incidental Take Statement to the Service for further consideration. On March 30, 2011, the District Court issued a final order upholding the Service's court ordered revision to the 2009 Incidental Take Statement and terminating the case. On October 18, 2011, Plaintiff filed its opening appellate brief with the 9th Circuit Court of Appeals. The portions of the 2008 Opinion and 2009 Supplemental Opinion that have been upheld by the District Court are incorporated by reference in this opinion.

anticipated to provide an updated analysis of flow and non-flow actions prior to the completion of the maximum 10-year experimental period for the HFE protocol.

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. 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 over the 10-year period. Of these HFEs, 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 release window or accounting periods (i.e. 80 percent of HFEs were also consecutive).

<u>Non-native fish control</u>

The HFE proposes a program of high-flow releases that may increase the numbers of rainbow trout (*Oncorhynchus mykiss*) in the Lees Ferry reach (Wright and Kennedy 2011). An increase in trout population, as discussed in detail below, followed the 2008 HFE. The potential for increasing the numbers of trout by HFE's is an unintended consequence of the HFE. An increase 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. Thus, Reclamation proposes to implement non-native fish control measures as described in the Non-native Fish Control Downstream from Glen Canyon Dam, 2011–2020 BA (Reclamation 2011b) and supplemental information provided by Reclamation staff. This portion of the proposed action could under limited circumstances remove trout from the LCR and tests the removal of rainbow trout in the Paria-Badger reach (PBR) to reduce the emigration of rainbow trout from Lees Ferry downstream to the LCR reach. The non-native fish control elements of the proposed action are designed to advance scientific understanding of non-native fish and the risks they pose to native fish in the Grand Canyon through targeted monitoring and research.

Boat-mounted electrofishing equipment will be used to remove non-native fish. The electrofishing equipment is not intended to result in mortality of any endangered fish species, although some small number of endangered fish may be injured or killed from being caught and handled. One to six removal passes would be conducted in each trip. Up to 10 PBR removal trips could be conducted in any one year for the ten-year period 2011-2020. Up to six non-native control trips could occur in the LCR reach in any one year, according to a defined trigger. Reclamation has committed to working with FWS to further define the triggering criteria over the life of the proposed action based on continuing research and related analyses. However, they may otherwise take action, such as moving to immediate removal of non-native fish in either the PBR or LCR reach, in the event of new information. For example, there is currently a very large cohort of rainbow trout in Lees Ferry, described in detail below, and should monitoring data indicate that these trout are moving downstream to the LCR, immediate control actions may be implemented.

The trigger to determine when LCR control would take place is as follows:
Removal of non-native fish at the LCR reach would only occur if 1) rainbow trout abundance estimates in the portion of the reach from RM 63.0-64.5 exceeds 760 fish, and 2) if the brown trout (*Salmo trutta*) abundance estimate for this reach exceeds 50 fish (evaluated each calendar year in January); and 3) the abundance of adult humpback chub declines below 7,000 adult fish

based on the Age-Structured Mark Recapture Model (ASMR) this model estimate will be conducted every 3 years, and each year the latest ASMR results will be evaluated with the other elements of the trigger (i.e. numbers of trout) each calendar year in January.

OR

The above conditions 1 and 2 for trout abundance are met, and all of the following three conditions are also met:

1. In any 3 of 5 years during the proposed action using data extending retrospectively to 2008, the abundance estimate of humpback chub in the LCR between 150-199 millimeters (mm) [5.9- 7.8 inches] total length within the 95 percent confidence interval drops below 910 fish (evaluated each calendar year in January); and

2. Temperatures in the mainstem Colorado River at the LCR confluence do not exceed 12 degrees Celsius (ºC) in two consecutive years (evaluated each calendar year in January); and

3. Annual survival of young humpback chub (40-99 mm total length (TL)) in the mainstem in the LCR Reach drops 25 percent from the preceding year (evaluated each calendar year in January)[2] .

One goal of the non-native fish control program will be to assess and mitigate the effects of the increased predation on and competition with humpback chub by reducing the numbers of trout in areas from which the trout may disperse and in reaches that they occupy together with humpback chub. Another goal of the non-native fish control program is to assess and mitigate the effects of the increased predation and competition, caused by implementation of the HFE protocol, by reducing the numbers of trout which may disperse into reaches occupied by humpback chub. An increase in trout population, as discussed in detail below, followed the 2008 HFE.

Predation and competition by rainbow trout and brown trout have been identified as sources of mortality for juvenile humpback chub (Valdez and Ryel 1995, Marsh and Douglas 1997, Yard et al. 2011). This added mortality reduces recruitment and possibly the overall size of the population of adult humpback chub (Coggins 2008a). Reclamation, in cooperation with the NPS, has also implemented a conservation measure to support the brown trout removal effort at Bright Angel Creek. Bright Angel Creek is a known source of brown trout to the LCR reach. Reclamation has committed to continuing and expanding this effort as discussed below.

All non-native fish will be removed alive, transported, and stocked into areas with approved stocking plans, or euthanized for future beneficial use. PBR reach removal is expected to be cost-efficient because boats used in the removal effort can travel to the Badger Creek confluence at River Mile (RM) 8 and return to Lees Ferry the same day and reduce program costs. Stocking

[2] As a result of the NSE study and other monitoring associated with the GCDAMP, we now have estimates of survival rates of y-o-y humpback chub in the LCR confluence area. The results are discussed in other sections of this opinion. These techniques were not available when the 2009 Opinion was prepared.

live trout removed from the Colorado River into other waters is not evaluated in this proposed action but stocking would only occur into areas with approved stocking plans. During the collection of non-native fishes, there is a potential for capture of listed fish. Reclamation has requested that any adverse effects to listed fish from implementation of non-native fish control and other aspects of the proposed actions be evaluated under their ESA section 10(a)(1)(A) recovery permit. This request will be addressed in a separate process.

Modified Low Fluctuating Flows

This portion of the proposed action includes the continuation of the MLFF alternative as described in the 1995 Environmental Impact Statement and adopted in the 1996 ROD on Glen Canyon Dam operations for the 10-year period for fiscal years 2011-2020. MLFF is also considered in the Environmental Baseline section of this opinion because MLFF has been in effect since 1996. Previously scheduled steady flows will continue in September and October 2012 as part of the proposed action that is subject of this consultation. Under the MLFF, daily flow releases are limited to a minimum of 5,000 cfs and maximum of 25,000 cfs (although this can be exceeded for emergencies or during extreme hydrological conditions). Minimum flow during the day from 7:00 am to 7:00 pm is further limited to 8,000 cfs. Daily fluctuation limit is 5,000 cfs for months with release volumes less than 0.6 million acre feet (maf), 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf, and 8,000 cfs for monthly volumes over 0.8 maf. Ramp rates must not exceed 4,000 cfs per hour ascending and 1,500 cfs per hour descending (Table 1). Operations under the MLFF are typically structured to generate hydropower in response to electricity demand, with higher monthly volume releases in the winter and summer months, and daily fluctuations in release volume.

Table 1. Glen Canyon Dam release constraints as defined by Reclamation in the 1996 Record of Decision (Reclamation 1996).

Glen Canyon Dam Release Constraints		
Parameter	**Release Volume (cfs)**	**Conditions**
Maximum Flow[1]	**25,000**	
Minimum Flow	**5,000**	**Nighttime**
	8,000	**7:00 a.m. to 7:00 p.m.**
Ramp Rates		
Ascending	**4,000**	**Per hour**
Descending	**1,500**	**Per hour**
Daily Fluctuations[2]	**5,000 to 8,000**	

1 May be exceeded for emergencies and during extreme hydrological conditions.

2 Daily fluctuation limit is 5,000 cubic feet per second (cfs) for months with release volumes less than 0.6 maf; 6,000 cfs for monthly release volumes of 0.6 maf to 0.8 maf; and 8,000 cfs for monthly volumes over 0.8 maf.

Conservation Measures

As explained in the 2008 Opinion and 2009 Supplemental Opinion, we are confident that Reclamation will implement the following conservation measures because of their continued demonstration of effectiveness in implementing past and ongoing conservation measures. Essentially all of the ongoing conservation measures are currently being implemented by Reclamation. It is important to note that Reclamation's continuing implementation of these measures is in marked contrast to conditions at the time of the 1995 jeopardy biological opinion when none of these elements were funded and implemented at that time, although some had been identified as potential actions. Based on new information, Reclamation in coordination with Glen Canyon Dam Adaptive Management Program (GCDAMP) has updated some of the conservation measures as described below.

Re-Evaluation Points – Pursuant to 50 CFR § 402.16 (c), reinitiation of formal consultation is required and shall be requested by the Federal agency or by the FWS where discretionary Federal involvement or control over the action has been retained or is authorized by law and if new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered. Reclamation and FWS agree to meet at least once every 3 years to specifically review the need for reinitiation based on humpback chub status and other current and relevant information. Reclamation will undertake a review in 2014 of the first two years of implementation of the proposed action through a workshop with scientists to assess what has been learned, which will also serve as the first re-evaluation point. Reclamation will also produce a written report of each evaluation and either FWS or Reclamation may require reinitiation of formal consultation on the proposed action to reevaluate the effects of the action.

Humpback Chub Translocation – Reclamation will continue to assist the NPS and the GCDAMP in funding and implementation of translocating humpback chub in the LCR and into tributaries of the Colorado River in Marble and Grand canyons, and in monitoring the results of these translocations. Non-native fish control in these tributaries will be an essential element to translocation, so Reclamation will help fund control of both cold water and warm water non-native fish in tributaries, as well as efforts to translocate humpback chub into these tributaries. Havasu, Shinumo, and Bright Angel creeks will continue to be the focus of translocation efforts, although other tributaries may be considered.

Humpback Chub Nearshore Ecology Study – Through the Natal Origins Study, in coordination with other GCDAMP participants and through the GCDAMP, Reclamation will continue research efforts on nearshore ecology of the LCR reach to better understand the importance of mainstem nearshore habitats in humpback chub recruitment and the effect of non-native fish predation on humpback chub recruitment, and to monitor the trend in annual survival of young humpback chub in the mainstem for use in determining the need for non-native fish control.

Humpback Chub Refuge – Reclamation will continue to assist FWS in maintenance of a humpback chub refuge population at a Federal hatchery (Reclamation has assisted the FWS in creating a humpback chub refuge at Dexter National Fish Hatchery and Technology Center) (DNFHTC) or other appropriate facility by providing funding to assist in annual maintenance (including the collection of additional humpback chub from the Little Colorado River for this purpose). In the unlikely event of a catastrophic loss of the Grand Canyon population of humpback chub, a humpback chub refuge will provide a permanent source of sufficient numbers of genetically representative stock for repatriating the species.

Humpback Chub Monitoring and Mainstem Aggregation Monitoring – Reclamation will, through the GCDAMP, continue to conduct annual monitoring of humpback chub and, every 3 years, conduct the ASMR. Reclamation will also monitor the abundance of humpback chub and species composition at the eight mainstem aggregations of humpback chub in Marble and Grand Canyon annually.

Bright Angel Creek Brown Trout Control – Reclamation will continue to fund efforts of the NPS to remove brown trout from Bright Angel Creek and will work with GCMRC and NPS to expand this effort to be more effective at controlling brown trout in Grand Canyon. This issue has been prioritized based on emerging information on the particular risk that brown trout pose to native fish.

High Flow Experiment Assessments – Reclamation will conduct pre- and post-HFE assessments of existing data on humpback chub status and other factors to both determine if a HFE should be conducted and to inform decisions to conduct future HFEs. Consideration will be given to minimize effects to humpback chub in defining the timing, duration, and magnitude of each HFE conducted within the framework established by the HFE protocol.

Dexter National Fish Hatchery Genetic Study – Reclamation will fund an investigation of the genetic structure of the humpback chub refuge housed at the DNFHTC that will include: 1) a genotype of the refuge population using microsatellites; 2) an estimate of humpback chub effective population size; and 3) a calculation of pairwise relatedness of all individuals in the DNFHTC Refuge population.

Kanab Ambersnail – Reclamation implemented conservation measures for the HFEs conducted in 2004 and 2008 to protect habitat for the Kanab ambersnail at Vasey's Paradise. However, due to the pending taxonomic evaluation (discussed below), the FWS and Reclamation have agreed to forgo this conservation measure for future HFEs and to study the effect of the HFE Protocol on the population of Kanab ambersnail at Vasey's Paradise through continued monitoring. FWS has analyzed the effect of the potential loss of habitat over the life of the proposed action and concluded that the conservation measure is not necessary to maintain a healthy population of Kanab ambersnail at Vasey's Paradise because the amount of habitat and snails that will be unaffected by the proposed action is sufficient to maintain the population. Reclamation will continue, through the GCDAMP, to monitor the population on a periodic basis to assess the health of the population over the life of the proposed action.

Conservation of Mainstem Aggregations - Reclamation will also, as part of its proposed action, work within its authority through the GCDAMP to ensure that a stable or upward trend of humpback chub mainstem aggregations can be achieved. Ongoing and additional efforts will be coordinated to: 1) explore and potentially implement flow and non-flow measures to increase the amount of suitable humpback chub spawning habitat in the mainstem Colorado River (additional environmental compliance may be required); 2) secure numbers of humpback chub in a wider distribution in the mainstem Colorado River by supporting the number of young-of-year (y-o-y) recruiting to aggregations; 3) expand the role of tributaries and their ability to contribute to the growth and expansion of mainstem aggregations; and 4) develop and implement a protocol for "maintenance control" of rainbow trout through appropriate means to ensure low levels of trout in the LCR Reach, for example, by implementing PBR control every year, in coordination with the FWS and other partners.

Ongoing Research

The GCDAMP established in 1997 to implement the Grand Canyon Protection Act will continue. The Program provides a process for assessing the effects of current operations of Glen Canyon Dam on downstream resources and develops recommendations for modifying dam operations and other resource management actions, including monitoring listed species. Several of the conservation measures from the 2008 and 2009 Opinions have been completed such as the Monthly Transition Flow Study; other measures are ongoing such as supporting a refuge for humpback chub at DNFHTC, and translocation into Shinumo and Havasu Creeks, and above Chute Falls. Reclamation has also agreed to assist in implementing the Humpback Chub Comprehensive Plan.

Reclamation will undertake development, with stakeholder involvement, of additional non-native fish suppression options for implementation, and Reclamation will complete development of such options within the first two years of the proposed action to assist efforts to reduce recruitment of non-native rainbow trout at, and emigration of those fish from, Lees Ferry. Options will include both flow and non-flow non-native fish suppression experiments focused on the Lees Ferry reach, which would reduce the recruitment of trout in Lees Ferry, lowering emigration of trout. Additional environmental compliance may be necessary for implementation of these experiments. In full cooperation with the NPS, as co-lead for the LTEMP Process, Reclamation will assess whether and how the LTEMP may provide a mechanism for analysis and implementation of future experimental suppression flows.

The Natal Origins Study will also be a key research component to the proposed action. This new research effort is designed to determine the natal origins of rainbow trout in Marble Canyon and more specifically in the LCR reach. The study will also continue the mainstem juvenile humpback chub assessment conducted through the Nearshore Ecology Study described in the conservation measures and will provide information on rainbow trout emigration rates out of the Lees Ferry Reach.

Action Area

The action area for this proposed action is the Colorado River corridor from Glen Canyon Dam in Coconino County, Arizona, downstream to Pearce Ferry, Mohave County, Arizona including the confluence area of major tributaries in this reach: the Paria River, the LCR, Bright Angel Creek, Tapeats Creek, Kanab Creek, Shinumo Creek, and Havasu Creek. Below Pearce Ferry, ESA compliance is addressed within the Lower Colorado River Multi-Species Conservation Program (LCR MSCP 2005). The LCR MSCP addresses Section 7 and Section 9 responsibilities for areas up to and including the full-pool elevation of Lake Mead, and downstream areas along the Colorado River within the U.S.

STATUS OF THE SPECIES AND CRITICAL HABITAT

Humpback chub

The humpback chub was listed as endangered on March 11, 1967 (32 FR 4001). Critical habitat for humpback chub was designated in 1994. Seven reaches of the Colorado River system were designated as critical habitat for humpback chub for a total river length of 379 miles in the Yampa, Green, Colorado, and Little Colorado rivers in Arizona, Colorado, and Utah. Known constituent elements include water, physical habitat, and biological environment as required for each life stage (59 FR 13374; USFWS 1994). Water includes a quantity of sufficient quality (i.e., temperature, dissolved oxygen, lack of contaminants, nutrients, and turbidity) that is delivered to a specific location in accordance with a hydrologic regime that is required for the particular life stage. Physical habitat includes areas of the Colorado River for use in spawning, nursery, feeding, and rearing, or corridors to these areas. The biological environment includes food supply and habitats with levels of non-native predators and competitors that are low enough to allow for spawning, feeding, and rearing.

The humpback chub is a medium-sized freshwater fish of the minnow family, Cyprinidae. The adults have a pronounced dorsal hump, a narrow flattened head, a fleshy snout with an inferior-subterminal mouth, and small eyes. It has silvery sides with a brown or olive-colored back. The humpback chub is endemic to the Colorado River Basin and is part of a native fish fauna traced to the Miocene epoch in fossil records (Miller 1955, Minckley et al. 1981). Humpback chub remains have been dated to about 4000 B.C., but the fish was not described as a species until the 1940s (Miller 1946), presumably because of its restricted distribution in remote whitewater canyons (USFWS 1990). Because of this, its original distribution is not known.

Adult humpback chub occupy swift, deep, canyon reaches of river (Valdez and Clemmer 1982, Archer et al. 1985, Valdez and Ryel 1995), with microhabitat use varying among age-groups (Valdez et al. 1990). Within Grand Canyon, adults demonstrate high microsite fidelity and occupy main channel eddies, while subadults use nearshore habitats (Valdez and Ryel 1995, Robinson et al. 1998, Stone and Gorman 2006). Young humpback chub use shoreline talus, vegetation, and backwaters typically formed by eddy return current channels (Arizona Game and Fish Department (AGFD) 1996). These habitats are usually warmer than the main channel especially if they persist for a long time and are not inundated or desiccated by fluctuating flows (Stevens and Hoffnagle 1999). Subadults also use shallow, sheltered shoreline habitats but with greater depth and velocity (Valdez and Ryel 1995, Childs et al. 1998).

Valdez and Ryel (1995, 1997) reported on adult humpback chub habitat use in the Colorado River in Grand Canyon. They found that adults used primarily large recirculating eddies, occupying areas of low velocity adjacent to high-velocity currents that deliver food items. Adults also congregated at tributary mouths and flooded side canyons during high flows. Adults were found primarily in large recirculating eddies disproportionate to their availability, with lesser numbers found in runs, pools, and backwaters. Hoffnagle et al. (1999) reported that juveniles in Grand Canyon used talus shorelines at all discharges and apparently were not displaced by a controlled high flow test of 45,000 cfs in late March and early April, 1996. Valdez et al. (1999) also reported no displacement of radiotagged adults, with local shifts in habitat use to remain in low-velocity polygons within large recirculating eddies.

As young humpback chub grow, they exhibit an ontogenic shift toward deeper and swifter offshore habitats that usually begins at age 1 (about 100 mm [3.94 in] TL) and ends with maturity at age 4 (≥200 mm [7.87 in] TL; Valdez and Ryel 1995, 1997, Stone and Gorman 2006). Valdez and Ryel (1995, 1997) found that young humpback chub (21–74 mm [0.83-2.91 in] TL) remain along shallow shoreline habitats throughout their first summer, at low water velocities and depths less than 1 m (3.3 feet), and shift as they grow larger (75–259 mm [2.95-10.20 in] TL) by fall and winter into deeper habitat with higher water velocities and depths up to 1.5 m (4.9 ft). Stone and Gorman (2006) found similar results in the Little Colorado River, finding that humpback chub undergo an ontogenesis from diurnally active, vulnerable, nearshore-reliant y-o-y (30–90 mm [1.81-3.54 in] TL) into nocturnally active, large-bodied adults (180 mm [7.09 in] TL), that primarily reside in deep midchannel pools during the day, and move inshore at night.

Movement of adult humpback chub is substantially limited compared to other native Colorado River fishes (Valdez and Ryel 1995). Adults have a high fidelity for site-specific habitats in the Colorado River and generally remain within a 1-km (0.6 mi) area, except during spawning ascents of the Little Colorado River in spring. Adult radio-tagged humpback chub demonstrated a consistent pattern of greater near-surface activity during the spawning season and at night, and day-night differences decreased during moderate to high turbidity.

The humpback chub is an obligate warm-water species that requires temperatures of about 16-22 °C (61-72 °F) for spawning, egg incubation, and optimal survival of young. Spawning is usually initiated at about 16 °C (61 °F) (Hamman 1982). Highest hatching success is at 19–20 °C (66-68 °F) with an incubation time of 3 days; and highest larval survival is slightly warmer at 21–22 °C (70-72 °F)(Marsh 1985). Hatching success under laboratory conditions was 12 percent, 62 percent, 84 percent, and 79 percent in 12–13 °C (54-54 °F), 16–17 °C (61-63 °F), 19–20 °C (66-

68 °F), and 21–22 °C (70-72 °F), respectively, whereas survival of larvae was 15 percent, 91 percent, 95 percent, and 99 percent, at the same respective temperatures (Hamman 1982). Time from fertilization to hatching ranged from 465 hours at 10 °C (50 °F) to 72 hours at 26 °C (79 °F), and time from hatching to swim-up varied from 372 hours at 15 °C (59 °F) to 72 hours at 21–22 °C (70-72 °F). The proportion of abnormal fry varied with temperature and was highest at 15 °C (59 °F) (33 percent) dropping to 17 percent at 25 °C (77 °F). Marsh (1995) also found total mortality of embryos at 5, 10, and 30 °C (41, 50, 86 °F). Bulkley et al. (1981) estimated a final thermal preference of 24ºC (75 °F) for humpback chub during their first year of life (80–120 mm [3.2-4.72 in]).

Humpback chub are broadcast spawners with a relatively low fecundity rate compared to cyprinids of similar size (Carlander 1969). Eight humpback chub (355–406 mm [14.0-16.0 in] TL), injected with carp (*Cyprinus carpio*) pituitary and stripped in a hatchery, produced an average of 2,523 eggs/female, or about 5,262 eggs/kg of body weight (Hamman 1982). Eleven humpback chub from the Little Colorado River (LCR) yielded 4,831 eggs/female following variable injections of carp pituitary and field stripping (Clarkson et al. 1993).

Humpback chub in Grand Canyon spawn primarily during March–May in the lower 13 km of the Little Colorado River (Kaeding and Zimmerman 1983, Minckley 1996, Gorman and Stone 1999, Stone 1999) and during April–June in the upper basin (Kaeding et al. 1990, Valdez 1990, Karp and Tyus 1990). Most fish mature at about 4 years of age. Gonadal development is rapid between December and February to April, at which time somatic indices reached highest levels (Kaeding and Zimmerman 1983). Adults stage for spawning runs in large eddies near the confluence of the Little Colorado River in February and March and move into the tributary from March through May, depending on temperature, flow, and turbidity (Valdez and Ryel 1995). Ripe males have been seen aggregating in areas of complex habitat structure (boulders, travertine masses, and other sources of angular variation) associated with deposits of clean gravel, and it is thought that ripe females move to these aggregations to spawn (Gorman and Stone 1999). Habitats where ripe humpback chub have been collected are typically deep, swift, and turbid. Likely as a result, spawning in the wild has not been directly observed. Abrasions on anal and lower caudal fins of males and females in the LCR and in Cataract Canyon (Valdez 1990) suggest that spawning involves rigorous contact with gravel substrates.

At hatching, larvae have nonfunctional mouths and small yolk sacs (Muth 1990). Robinson et al. (1998) found larvae drifting in the LCR from April through June, and evidence suggesting that larvae actively disperse to find suitable nearshore habitats. Robinson et al. (1998) quantified numbers of larval humpback chub that are transported by LCR flows into the mainstem, and Robinson et al. (1998) and Stone and Gorman (2006) suggested that daily fluctuations in the mainstem river may reduce the quality of nearshore habitat for y-o-y and juvenile humpback chub, which may be particularly important during the monsoon period (July to November) when storms cause floods in the LCR, displacing large numbers of young humpback chub into the mainstem (GCMRC unpublished data). Pre-dam annual peak Colorado River flows (April–July) ponded canyon-bound tributary mouths (Howard and Dolan 1981), including the LCR. Robinson et al. (1998) theorized that because ponding probably retained drifting larvae or slowed their passage, it probably allowed greater time for development in a warm, low-velocity environment. Without this ponding effect, presumably more y-o-y and juvenile humpback chub are likely transported into a now-harsher mainstem river while still at a size that is more vulnerable to thermal shock and predation.

Humpback chub attain a maximum size of about 480 mm (18.9 in) TL and 1.2 kg (2.6 lbs.) in weight (Valdez and Ryel 1997) and can live to be 20-30 years old (Hendrickson 1993). Humpback chub grow relatively quickly at warm temperatures until maturity at about 4 years of age, and then growth rate slows substantially. Humpback chub larvae are approximately 7 mm (0.30 in) long at hatching (Muth 1990). In a laboratory, post-larvae grew at a rate of 10.63 mm (0.419 in)/30 days at 20 °C (68 °F), but only 2.30 mm (0.090 in)/30 days at 10 °C (50 °F) (Lupher and Clarkson 1994). Similar growth rates were reported from back-calculations of scale growth rings in wild juveniles at similar water temperatures from the Little Colorado River (10.30 mm (0.406 in)/30 days at 18–25 °C (64-77 °F)) and the mainstem Colorado River in Grand Canyon (3.50– 4.00 mm (0.138-0.157 in)/30 days at 10–12 °C (50-54 °F); Valdez and Ryel 1995). Clarkson and Childs (2000) found that lengths, weights, and specific growth rates of humpback chub were significantly lower at 10 °C and 14 °C (50-57 °F; similar to hypolimnetic dam releases) than at 20 °C (68 °F; i.e., more characteristic of Little Colorado River temperatures during summer months).

Hendrickson (1993) aged humpback chub from the Little Colorado River and the mainstem Colorado River in Grand Canyon and showed a maximum of 23 annular rings. Based on polynomial regression of average number of annuli from otoliths and opercles, age-3 fish were 157 mm (6.18 in) TL and age-4 fish were 196 mm (7.72 in) TL. Valdez and Ryel (1995) recorded size at first observed maturity (based on expression of gametes, presence of spawning tubercles) of humpback chub in Grand Canyon at 202 mm (7.95 in) TL for males and 200 mm (7.87 in) TL for females; computed length of age-4 fish with a logarithmic growth curve was 201 mm (7.91 in) TL. A temperature dependent growth model has also been developed as described in Coggins and Walters (2010).

Humpback chub are typically omnivores with a diet consisting of insects, crustaceans, plants, seeds, and occasionally small fish and reptiles (Kaeding and Zimmerman 1982, Kubly 1990, Valdez and Ryel 1995). They appear to be opportunistic feeders, capable of switching diet according to available food sources, and ingesting food items from the water's surface, midwater, and river bottom. Valdez and Ryel (1995) examined diets of humpback chub in Grand Canyon. Guts of 158 adults from the mainstem Colorado River, flushed with a nonlethal stomach pump, had 14 invertebrate taxa and nine terrestrial taxa, including simuliids (blackflies, in 77.8 percent of fish), chironomids (midges, 57.6 percent), Gammarus (freshwater shrimp, 50.6 percent), Cladophora (green alga, 23.4 percent), Hymenoptera (wasps, 20.9 percent), and cladocerans (water fleas, 19.6 percent). Seeds and human food remains were found in eight (5.1 percent) and seven (4.4 percent) fish, respectively.

The decline of the humpback chub throughout its range and continued threats to its existence are due to habitat modification and streamflow regulation (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 (USFWS 2002a). Streamflow regulation, in general, eliminates flows and temperatures needed for spawning and successful recruitment, which is exacerbated by predation and competition from non-native fishes. In Grand Canyon, brown trout, channel catfish (*Ictalurus punctatus*), black bullhead (*Ameiurus melas*), and rainbow trout have been identified as principal predators of young humpback chub, with consumption estimates that suggest loss of complete year classes to predation (Marsh and Douglas 1997, Valdez and Ryel 1997). Valdez and Ryel (1997) also suggested that common carp could be a significant predator of incubating humpback chub eggs in the LCR. In the upper basin, channel catfish have been identified as the principal predator of humpback chub in Desolation/Gray Canyons (Chart and Lentsch 2000), and in Yampa Canyon (USFWS 2002a). Smallmouth bass (*Micropterus dolomieu*) have also become a significant predator in the Yampa River (T. Chart, FWS, pers. comm., 2007). Parasitism, hybridization with other native *Gila*, and pesticides and pollutants are also factors in the decline (USFWS 2002a).

There are six populations of humpback chub in the Colorado River basin; five in the upper basin, and one in the lower basin (basins divided by Glen Canyon Dam) (Figure 1). The upper basin populations include three in the Colorado River: at Cataract Canyon, Utah; Black Rocks, Colorado; and Westwater Canyon, Utah; one in the Green River in Desolation and Grey canyons, Utah; and one in the Yampa River in Yampa Canyon in Dinosaur National Monument, Colorado. The lower basin population is found in the Colorado River and tributaries in Grand Canyon. In January 2011, the FWS signed the 5-Year Review on the Humpback Chub, which describes the significant decline noted from the first adult abundance estimate to the most recent estimate for the populations in Black Rocks, Westwater Canyon, and Desolation/Gray Canyons (FWS 2011a) as described below and shown in Figure 2. Populations in Yampa and Cataract Canyons are too small to monitor through mark-recapture analysis and some individuals have been brought into captivity to preserve their genetic uniqueness.

The Lower Basin currently hosts the largest population of humpback chub and is commonly referred to as the Grand Canyon population. Mark-recapture methods have been used since the late 1980s to assess trends in adult abundance and recruitment of the LCR aggregation, the primary aggregation constituting the Grand Canyon population. 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). 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, increased in 2006 to approximately 5,300-6,700, and further increased to 7,650 adults in 2008. Current methods for assessment of humpback chub abundance rely on the ASMR (Coggins et al. 2006b, Coggins and Walters 2009). Although Coggins and Walters (2009) caution that the ASMR has limited capability to provide abundance estimates, the most important finding in their report is that the population trend in humpback chub is increasing. They also concluded that “considering a range of assumed natural mortality-rates and magnitude of ageing error, it is unlikely that there are currently less than 6,000 adults or more than 10,000 adults” and estimate that the current adult (age 4 years or more) Grand Canyon population is approximately 7,650 fish (Coggins and Walters 2009).

Translocation of juvenile humpback chub from near the mouth of the LCR upstream to above Chute Falls was undertaken in 2008 - 2011 as a conservation measure of the 2008 Opinion. The purposes of the conservation measure are to extend the range of the species upstream in the LCR into reaches previously unoccupied (presumably due to the presence of the falls), to improve the survivorship of juvenile humpback chub by moving juveniles to areas of the LCR with better nursery habitats, and to glean information on the life history of the species. Monitoring of this upstream reach was also conducted every year since 2008. Monitoring of humpback chub in the mainstem Colorado River has documented the persistence of small aggregations, although no population estimates are available (W. Persons, USGS, written comm. 2011a). Young-of-year humpback chub were also translocated into Shinumo Creek and Havasu Creek in an effort to broaden the distribution of humpback chub in the action area. Translocation is further discussed in the Environmental Baseline section.

Humpback Chub Critical Habitat

Critical habitat for humpback chub was designated in 1994 (59 FR 13374; USFWS 1994). Seven reaches of the Colorado River system were designated for a total river length of 379 miles in the Yampa, Green, Colorado, and Little Colorado rivers in Arizona, Colorado and Utah. "Critical habitat," as defined in Section 3(5)(A) of the ESA, means: (i) the specific areas within the geographical area occupied by the species at the time it is listed, on which are found those physical and biological features (I) essential to the conservation of the species and (II) which may require special management considerations or protection; and (ii) specific areas outside the geographical area occupied by a species at the time it is listed upon a determination by the Secretary that such areas are essential for the conservation of the species. The term "conservation," as defined in Section 3(3) of the ESA, means: the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this ESA are no longer necessary. Therefore, in the case of critical habitat, conservation represents the areas required to recover a species to the point of delisting (i.e., the species is recovered and is removed from the list of endangered and threatened species). In this context, critical habitat preserves options for a species' eventual recovery.

In our analysis of the effects of the action on critical habitat, we consider whether or not the proposed action will result in the destruction or adverse modification of critical habitat. In doing so, we must determine if the proposed action will result in effects that appreciably diminish the value of critical habitat for the recovery of a listed species (see p. 4-34, U.S. Fish and Wildlife Service and National Marine Fisheries Service 1998). To determine this, we analyze whether the proposed action will 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). PCEs are provided by the final rule designating critical habitat and three supporting documents (USFWS 1994, Maddux et al. 1993a, 1993b. 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, and the PCEs of those units, to determine the overall ability of all designated critical habitat to support recovery. Further, the functional role of each of the critical habitat units in recovery must also be considered, because, collectively, they represent the best available scientific information as to the recovery needs of the species.

Recovery for the humpback chub is defined by the FWS Humpback Chub Recovery Goals (Recovery Goals) (67 FR 55270) (FWS 2002a). In 2006, a U.S. District Court ruling set aside the Recovery Goals, because they lacked time and cost estimates for recovery. The court did not fault the recovery goals as deficient in any other respect, thus the FWS, the GCDAMP, and the Upper Colorado River Endangered Fish Recovery Program (UCRRP), the program that addresses conservation of all of the upper Colorado River basin populations of humpback chub, continue to utilize the underlying science in the Recovery Goals. In our 2009 Supplemental Opinion we referenced the draft 2009 revisions to the Recovery Goals document because that document provided updates on species biology and distribution, and represented the best available scientific information at that time. The draft 2009 revisions to the Recovery Goals included the same demographic criteria found in the 2002 Recovery Goals. Thus, we are using the demographic criteria found in both the 2002 Recovery Goals and 2009 draft recovery goals. The FWS' 2011 Humpback Chub 5-Year Review relies on the information provided in the recovery goals and provides supplemental information on the species' distribution and status. That supplemental information, as well as the demographic criteria found in the Recovery Goals have been considered in this biological opinion and are summarized here**.** The Recovery Goal demographic criteria for downlisting (endangered to threatened) are:

<u>Upper Basin Recovery Unit</u>

1. Each of the five self-sustaining populations is maintained over a 5-year period, starting with the first point estimate acceptable to the FWS, such that:

    a. the trend in adult (age 4+; ≥ 200 mm [7.9 inches] TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (150–199 mm [5.9-7.8 inches] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. One of the five populations (e.g., Black Rocks/Westwater Canyon or Desolation/Grey Canyons) is maintained as a core population such that each point estimate exceeds 2,100 adults (Note: 2,100 is the estimated Minimum Viable Population (MVP) number; see section 3.3.2 of the Recovery Goals).

<u>Lower Basin Recovery Unit</u>

1. The Grand Canyon population is maintained as a core over a 5-year period, starting with the first point estimate acceptable to the FWS, such that:

    a. the trend in adult (age 4+; ≥ 200 mm [7.9 inches] TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (150–199 mm [5.9-7.8 inches] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

    c. each core population point estimate exceeds 2,100 adults (MVP).

The Recovery Goal demographic criteria for delisting are:

<u>Upper Basin Recovery Unit</u>

1. Each of the five self-sustaining populations is maintained over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the FWS, such that:

    a. the trend in adult (age 4+; ≥ 200 mm [7.9 inches] TL) point estimates does not decline significantly, and

b. mean estimated recruitment of age-3 (150–199 mm [5.9-7.8 inches] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

2. Two of the five populations (e.g., Black Rocks/Westwater Canyon and Desolation/Grey Canyons) are maintained as core populations such that each point estimate exceeds 2,100 adults (MVP).

Lower basin Recovery Unit

a. The Grand Canyon population is maintained as a core over a 3-year period beyond downlisting, starting with the first point estimate acceptable to the FWS, such that:

b. the trend in adult (age 4+; ≥ 200 mm [7.9 inches] TL) point estimates does not decline significantly, and

c. mean estimated recruitment of age-3 (150–199 mm [5.9-7.8 inches] TL) naturally produced fish equals or exceeds mean annual adult mortality, and

d. each core population point estimate exceeds 2,100 adults (MVP).

The Recovery Goals consist of actions to improve habitat and minimize threats. The success of those actions is measured by the status and trend (i.e. the demographic criteria) of the population. We have evaluated the contribution of each critical habitat unit to recovery by examining how the PCEs are, or are not, serving to achieve the demographic criteria. In some cases, population-dynamics information is not statistically adequate to evaluate the demographic criteria as defined in the Recovery Goals. In those cases, we rely on existing data to make an informed, evaluation of the PCEs in a critical habitat unit.

Primary Constituent Elements (PCEs)

In accordance with section 3(5)(A)(i) of the ESA and regulations at 50 CFR 424.12, in determining which areas to propose as critical habitat, we are required to base critical habitat determinations on the best scientific data available and to consider those PCEs that are essential to the conservation of the species, and that may require special management considerations and protection. These include, but are not limited to: space for individual and population growth and for normal behavior; food, water, air, light, minerals, or other nutritional or physiological requirements; cover or shelter; sites for breeding, reproduction, and rearing (or development) of offspring; and habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of a species. The general primary constituent elements required of humpback chub critical habitat are listed below, and the current conditions of PCEs in individual critical habitat reaches, the factors responsible for these conditions, and the conservation roles of individual critical habitat reaches are described, based on FWS (1994), Maddux et al. (1993a), and Maddux et al. (1993b), and updated with the most current scientific information.

General PCEs of Critical Habitat

Critical habitat was listed for the four big river fishes (Colorado pikeminnow [*Ptychocheilus lucius*], humpback chub, bonytail [*Gila elegans*], and razorback sucker) concurrently in 1994, and the PCEs were defined for the four species as a group (FWS 1994). However, note that the PCEs vary somewhat for each species on the ground, particularly with regard to physical habitat, because each of the four species has different habitat preferences.

Water--Consists of water of sufficient quality (i.e., temperature, dissolved oxygen, lack of contaminants, nutrients, turbidity, etc.) (W1) that is delivered in sufficient quantity to a specific location in accordance with a hydrologic regime that is required for the particular life stage for each species (W2).

Physical Habitat--This includes areas of the Colorado River system that are inhabited by fish or potentially habitable for use in spawning (P1), nursery (P2), feeding (P3), or corridors between these areas (P4). In addition to river channels, these areas include bottomlands, side channels, secondary channels, oxbows, backwaters, and other areas in the 100-year floodplain, which when inundated provide spawning, nursery, feeding, and rearing habitats, or access to these habitats.

Biological Environment--Food supply (B1), predation (B2), and competition (B3) are important elements of the biological environment and are considered components of this constituent element. Food supply is a function of nutrient supply, productivity, and availability to each life stage of the species. Predation, although considered a normal component of this environment, is out of balance due to introduced fish species in some areas. This is also true of competition from non-native fish species.

The PCEs are all integrally related and must be considered together. For example, the quality and quantity of water (PCEs W1 and W2) affect the food base (PCE B3) directly because changes in water chemistry, turbidity, temperature, and flow volume all affect the type and quantity of organisms that can occur in the habitat that are available for food. Likewise, river flows and the river hydrograph have a significant effect on the types of physical habitat available. Changes in flows and sediment loads caused by dams may have affected the quality of nearshore habitats utilized as nursery areas for young humpback chub. Increasingly the most significant PCE seems to be the biological environment, and in particular PCEs B2 and B3, predation and competition from non-native species. Even in systems like the Yampa River, where the water and physical PCEs are relatively unaltered, non-native species have had a devastating effect on the ability of that critical habitat unit to support conservation (Finney 2006, Fuller 2009). In fact, as we will describe in more detail, the conservation of humpback chub in the future may depend on our ability to control non-native species, and manipulating the water and physical PCEs of critical habitat to disadvantage non-natives may play an important role.

Specific Critical Habitat Reaches and PCEs

Humpback Chub Critical Habitat Reach 1 -Yampa River - Dinosaur National Monument

The most northerly segment of humpback chub critical habitat is a 44-mile (70.8-km) long reach of the Yampa River in Moffat County, Colorado, in Dinosaur National Monument. The boundaries are from T6N, R99W, section 27 (6th Principal Meridian) to the confluence with the Green River in T7N, R103W, section 28 (6th Principal Meridian); land ownership is NPS, with 1 percent private ownership. The reach is dominated by steep canyon walls and low current velocities. Occasional boulder fields create rapids, but the predominant substrate is gravel/cobble with patches of sand. In the lower portion of the canyon the river meanders through soft sandstone cliffs. The Yampa River exits the canyon at Echo Park, where it meets the Green River (Maddux et al. 1993b). This critical habitat unit contains the Yampa population, one of the five populations of humpback chub in the upper basin. This population of humpback chub has declined precipitously in recent years, likely due to increasing predation and competition from non-native fish species (Finney 2006, USFWS 2011a).

As the Yampa River has minimal water development compared to other rivers in the basin, the current hydrograph reflects flows which are usually representative of historical volume and timing, and habitat of the Yampa River has not been as extensively affected by streamflow regulation as in other rivers of the basin (Roehm 2004, Johnson et al. 2008). Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by humpback chub in Yampa Canyon (Roehm 2004). Yampa River flows also have been identified as critical for maintaining native fish habitat in the Green River below the confluence (Roehm 2004, Muth et al. 2000). There are water diversions upstream which can impact flow, especially during very dry years such as 2002-2003 when flows were very low; however, evidence of juvenile humpback chub indicates that successful spawning continues to occur (Finney 2006). Water temperatures in this portion of the Yampa River have not been altered to any significant degree by human activities and remain suitable for native fishes, although temperature is a function of streamflow, and at low flows, temperatures can become more suitable for non-native fishes such as smallmouth bass (Fuller 2009). No chronic problems with water quality have been identified. Although upstream diversions have some impact on the water PCE W2, both the necessary quality and quantity appear to be provided by this unit (Roehm 2004, Modde et al. 1999).

This reach of the Yampa also provides some areas of adequate physical habitat (FWS 1990, Karp and Tyus 1990, Finney 2006). Yampa Canyon within Dinosaur National Monument is typical of the deep canyon habitat preferred by the species (FWS 1990). This reach provides the humpback chub habitat characteristics of fast current, deep pools, shoreline eddies, and runs (Holden and Stalnaker 1975, Tyus and Karp 1989, USFWS 1990). The Yampa reach of critical habitat remains relatively unaltered from pre-development times in terms of hydrology and geomorphology (Roehm 2004, Modde et al. 1999), and we believe that all aspects of appropriate physical habitat (P1, P2, P3 and P4) are available.

Nutrient inputs and food sources for humpback chub are present within the reach. The relatively unmodified nature of the Yampa River system likely results in foods similar to predevelopment, thus PCE B1 continues to be met. The introduction of non-native fishes is probably the greatest alteration to the historical Yampa system. Non-native fish species abundance has increased significantly in recent years (Fuller 2009). From 2001-2003 a rapid increase in numbers of smallmouth bass was followed by a decline in humpback chub (Finney 2006, Johnson et al. 2008). A Strategic Plan for Non-native Fish Control was developed for the Upper Colorado River Basin and implemented by the UCRRP in 1997 (Fuller 2009). The UCRRP identified smallmouth bass (*Micropterus dolomieu*) and channel catfish (*Ictalurus punctatus*) as the principal predators of humpback chub (USFWS 2009a). Efforts to control smallmouth bass and channel catfish have met with mixed success, although efforts to control northern pike (*Esox luscious*) have been successful (Fuller 2009, R. Valdez, pers. comm., 2009).

Channel catfish numbers have actually increased despite non-native removal efforts, although the average size of channel catfish in the Yampa reach has decreased, which may help reduce predation (Fuller 2009). A combination of cold high flows and mechanical removal may have suppressed smallmouth bass production in 2007-2008, and numbers of native fish have increased (Fuller 2009). The ability of this critical habitat unit to fully function in humpback chub conservation in the future will depend on the success of efforts to remove smallmouth bass and channel catfish (Johnson et al. 2008, Fuller 2009). Given the best available information, the predation and competition aspects of the biological environment PCE (B2 and B3) are not currently met for this species, which prevents this unit from providing for recovery at this time.

The Yampa illustrates that if non-native species are abundant (i.e. B2 and B3 are not met), good condition of other aspects of critical habitat (water and physical PCEs) may not be sufficient to provide for the recovery of the species. Water temperatures in the Yampa River during the summer of 2002 were much warmer than typical, and a longer growing season in 2002 appears to have facilitated recruitment of smallmouth bass in 2003 (Fuller 2009), resulting in a precipitous decline in the humpback chub population. In the mid-2000s, cold high flows may have suppressed smallmouth bass production (along with removal efforts), and numbers of y-o-y humpback chub have increased. So not only does flow affect the water PCE of necessary hydrology and water quality for critical habitat for humpback chub, but it is also directly linked to the biological environment PCEs of predation and competition from non-native fish species. Because of this relationship between the physical and biological PCEs, efforts focused on restoring physical attributes of critical habitat, in places such as the Grand Canyon could have the unintended consequence of benefiting non-native species, offsetting any gains from habitat improvement.

Humpback Chub Critical Habitat Reach 2 - Green River - Dinosaur National Monument

This unit is a 38-mile (61.2-km) reach in Uintah County, Utah, and Moffat County, Colorado, from the confluence with the Yampa River in T7N, RI03W, section 28 (6th Principal Meridian) to the southern boundary of Dinosaur National Monument in T6N., R24E, section 30 (Salt Lake Meridian). The land ownership of the unit is predominantly NPS in Dinosaur National Monument, except for about 4.5 percent of privately-owned lands. The Green River enters Echo Park at its confluence with the Yampa River as a wide, deep, and slow moving stream. Substrate is a mixture of sand and silt with some large gravel and cobble riffles. After a short distance, the river passes through Whirlpool Canyon, an area of steep cliffs, large pools, deep eddies, rapids, and large boulders. The substrate in the canyon is boulder/bedrock, but large deposits of sand exist in eddies. After leaving the canyon, the Green River meanders through Island and Rainbow Parks. The river in this area is shallow and side channels are common. Further downstream, the river enters Split Mountain Canyon. This stretch contains large boulder fields, swift waters, and major rapids. Some significant sandbars exist in the slower moving parts of this reach (Maddux et al. 1993b).

Humpback chub have never been common in this reach, despite what appears to be suitable habitat except for the abundance of non-native fishes. Only eight humpback chub were captured in Whirlpool Canyon from 2002 to 2004 (Bestgen et al. 2006), although young of year chub were collected from Island Park which may be humpback chub (T. Jones, FWS, pers. comm., 2009). The area is considered to be part of the Yampa River population along with the Yampa River upstream, but this critical habitat unit does not appear to currently support humpback chub.

Flows in this reach are primarily a product of the flows released from Flaming Gorge Dam and flows from the Yampa River. During an average hydrologic year, a spring peak of at least 13,000 cfs should occur in this reach. Because of the distance between this reach and the dam and unregulated flows of the Yampa River, water temperatures in this reach approach historical levels. However, when releases during summer and fall from the dam are greater than historical, water temperatures may be lower than under normal conditions. Water quantity and quality needs (PCEs W1 and W2) are believed met for the species, and the UCRRP has completed and implemented flow recommendations for the Green River below Flaming Gorge Dam, including specific seasonal flow recommendations, that should serve to meet the needs of humpback chub in this reach of critical habitat (Muth et al. 2000). All four physical variables also appear to be present (PCEs P1-4), and young of year *Gila* found in 2008 may be an indication that spawning is occurring, although at low levels (T. Jones, FWS, pers. comm., 2009).

This portion of the Green River has large numbers of red shiner (*Cyprinella lutrensis*), channel catfish, smallmouth bass, and common carp, all of which are known to compete with and/or prey upon native fishes. The recent invasion of smallmouth bass has likely greatly reduced the value of this PCE for humpback chub (Finney 2006). Because water and physical PCEs appear to be met for humpback chub in this reach of critical habitat, the presence of non-native fishes (PCEs B2 and B3) may be the primary factor limiting the capability of this critical habitat unit to meet recovery needs.

Humpback Chub Critical Habitat Reach 3 - Green River - Desolation and Gray Canyons

The Green River in Desolation and Gray Canyons contains one of the five upper basin populations of humpback chub. The 73-mile (117.4 km) reach of critical habitat in the Green River is in Uintah and Grand Counties, Utah, from Sumners Amphitheater in T12S, R18E, section 5 (Salt Lake Meridian) to Swasey's Rapid in T20S, R16E, section 3 (Salt Lake Meridian). The reach is about 50 percent Tribal ownership, 49 percent Bureau of Land Management (BLM), and 1.0 percent private. Desolation Canyon is a deep canyon of the Green River with many rapids. Habitats include eddies, rapids, and riffles, with some deep pools. Boulders make up the primary substrate within Desolation Canyon. This canyon is followed by Gray Canyon which contains larger and deeper pools than are found in Desolation Canyon. Other habitats within the canyon include eddies, rapids, and riffles, side channels and backwaters. Substrate in Gray Canyon is composed mainly of boulder/rubble with some gravel (Maddux et al. 1993b).

Population estimates for Desolation/Gray Canyon in 2001-2003 show the population was composed of 1,254 individuals in 2001, 2,612 individuals in 2002, and 937 individuals in 2003 (Jackson and Hudson 2005). However, a significant decline has occurred recently; the first adult abundance estimate in Desolation/Gray Canyons in 2001, 1,254 fish declined to a low in 2007 of about 300 fish (Figure 2; USFWS 2011a). Because of water depletions which occur above this reach, historic water levels are seldom if ever obtained, and thus flooding of bottomlands is infrequent (Muth et al. 2000). However, water quantity and quality needs (PCEs W1 and W2) are believed met for the species; and the UCRRP has completed and implemented flow recommendations for the Green River below Flaming Gorge Dam, including specific seasonal flow recommendations, that should serve to meet the needs of humpback chub in this reach of critical habitat (Muth et al. 2000). This canyon reach contains both deep, swift areas and low-velocity eddies that are associated with steep cliffs and large boulders. Spawning habitat is available based on consistent evidence of recruitment and collection of juvenile fish (Jackson and Hudson 2005). Physical habitat parameters (PCEs P1-4) also appear to be sufficient in this reach of critical habitat.

Little is known on the quantity or quality of the food supply in this reach. Sources of input include the river above and washes and side channels. The flooded bottomlands along this reach were probably once sources of food input into the system, but are now not as extensively flooded. Common non-native fishes include red shiner, channel catfish, smallmouth bass, common carp, and fathead minnow (*Pimephales promelas*) (Jackson and Hudson 2005). Similar to the scenario seen in the Yampa River, an increase in smallmouth bass over the 2001-2003 period co-occurred with a decline in humpback chub over the same period, although Jackson and Hudson (2005) felt the decline in humpback chub was likely too soon to have been solely caused by increases in smallmouth bass. Much as in other critical habitat reaches, water and physical PCEs appear met, but biological PCEs B2 and B3 are not, and limit the capability of this critical habitat unit to meet recovery needs.

Humpback Chub Critical Habitat Reach 4 - Colorado River - Black Rocks/Westwater Canyon

The Black Rocks and Westwater populations of humpback chub occur in this 30-mile (48.3-km) reach of critical habitat. The reach extends from Black Rocks (RM 137) in T1S, R104W, section 25 (6th Principal Meridian) in Mesa County, Colorado, downstream to Fish Ford River (RM 106) in T21S, R24E, section 35 (Salt Lake Meridian) in Grand County, Utah. Land ownership is 66.6 percent BLM, 33.4 percent private. Historically, the largest known concentrations of humpback chub in the upper basin have been found at Black Rocks and Westwater Canyons (Valdez and Clemmer 1982, USFWS 2009a), and this is still the case currently.

Population estimates for humpback chub using mark-recapture estimators began in 1998 with the Black Rocks and Westwater Canyon populations, and were conducted during 1998-2000 and 2003-2005. These estimates showed the Black Rocks population between about 1,000 and 2,000 adults in 2000 (age 4+) and the Westwater Canyon population between about 1,800 and 4,700 adults in 2003 (McAda 2006, Hudson and Jackson 2003, Eleverud 2007, Jackson 2010). But levels of both populations have declined as of the most recent estimates in 2008 to a few hundred in Black Rocks and approximately 1,500 in Westwater Canyon (Figure 2; USFWS 2011a). Levels of both populations appear to have declined further since that time, as evidenced by a few hundred reported by Francis and McAda (2011) in 2011. However, while the estimates are low, they fall within the confidence intervals of earlier abundance estimates, so we cannot conclude an additional decline.

Black Rocks occurs near the Colorado-Utah state line where the Colorado River flows through a mile of upthrust black metamorphic gneiss rock. Some five miles downstream the river again flows through upthrust gneiss for 14 miles (22.5-km) through Westwater Canyon. The geology forms narrow, deep, canyon-bound channels with rapids, strong eddies, and turbulent currents. In both canyons, habitat consists of deep runs, eddies, and pools, with few backwaters, although gravel bars, floodplains, and backwaters do occur above and below the canyons (Maddux et al. 1993b). Habitats have been altered by water use that altered the natural flow regime. Annual peak flows of the Colorado River immediately upstream of the Black Rocks and Westwater Canyon populations decreased by 29–38 percent due mainly to the presence of dams upstream (Van Steeter and Pitlick 1998). However, Black Rocks and Westwater Canyon continue to provide deep eddies, pools, runs, and rapids, with strong turbulent currents. The quantity and quality of water in this reach (PCEs W1 and W2) are presently sufficient. This reach provides deep pools, eddies, and runs for feeding and movement corridors, and spawning and rearing habitat are available as evidenced by successful recruitment. Flow recommendations have been developed that specifically consider flow-habitat relationships in habitats occupied by humpback chub in Black Rocks and Westwater Canyon (McAda 2003). All physical habitat PCEs (P1-4) are met based on the stability of the population and evidence of recruitment (McAda 2006, Hudson and Jackson 2003, Eleverud 2007). Red shiner, channel catfish, black bullhead (*Ameiurus melas*), and largemouth bass (*Micropterus salmoides*) all occur here, but because these canyons are very narrow, and large floods are fairly frequent, flooding generally keeps numbers of non-native fishes low (R. Valdez, pers. comm., 2009), and there currently is no non-native fish control effort in this unit. All PCEs are fully functional, and this critical habitat unit is functioning in support of recovery. But, as with other reaches, there appears to be a correlation between low water years and increases in non-native species; climate change and operations under the Interim Guidelines could lead to an increase in low water years and non-native fishes, challenging the ability of this unit to support recovery (Reclamation 2007, Rahel et al. 2008, R. Valdez, pers. comm., 2009).

Humpback Chub Critical Habitat Reach 5 - Colorado River - Cataract Canyon

A 13-mile (20.9 km) reach of critical habitat in Cataract Canyon on the Colorado River upstream of Lake Powell contains the most southerly population of humpback chub occurring in the upper basin. The reach extends along the Colorado River from Brown Betty Rapid in T30S, R18E, section 34 (Salt Lake Meridian) to Imperial Canyon in T31S, R17E, section 28 (Salt Lake Meridian) in Garfield and San Juan counties, Utah. Land ownership is 100 percent NPS. Lake Powell likely eliminated the majority of the habitat that humpback chub utilized in this section of the Colorado River historically, leaving only about 13 miles (20.9 km) of suitable river habitat when Lake Powell is at full pool. Comprehensive surveys for humpback chub did not begin until about 1980, shortly after Lake Powell had filled. Although the population of humpback chub in the Colorado River in Cataract Canyon above the inflow area to Lake Powell has never been large since consistent surveys began in the 1980s, historically it may have been much larger (R. Valdez, SWCA pers. comm., 2009).

The Cataract Canyon population of humpback chub has declined to approximately 100 individuals and currently is too small to monitor through mark-recapture analysis (USFWS 2011a). Badame (2008) estimated the adult population, using closed point estimates, at 126 individuals in 2003, 91 in 2004, and 70 in 2005. Population estimates based on fish density and total amount of available habitat were 468-262 over the period. Evidence of successful spawning has been inferred from several size classes present in past surveys (Valdez 1990), but no juvenile humpback chub were encountered in the 2003-2005 surveys, and the smallest humpback chub encountered was 195 mm TL (7.7 inches). It is not known if juvenile humpback chub are not encountered because they are not present, or because survey techniques do not detect them, but electrofishing is employed, a technique that reliably captures juvenile humpback chub elsewhere (Badame 2008). Young humpback chub may also be lost to some extent to downstream movement into Lake Powell (D. Elverud, Utah Division of Wildlife Resources, pers. comm., 2009).

The Colorado River in Cataract Canyon cuts deeply through steep canyons and talus slopes, and is characterized by deep, swift runs, large eddies and pools, with a few shallow runs, riffles, and backwaters. Large angular rock and steep gradient have created approximately 13 miles (20.9 km) of rapids before the river flows into the upper end of Lake Powell where it resembles a large, deep, slow-flowing river with high sandstone walls (Maddux et al. 1993b). River flows in Cataract Canyon are greater than in other reaches in the Upper Basin because of the numerous upstream tributaries which enter the Colorado River as a result of its location low in the system. While all life stages of humpback chub were captured in this reach in surveys in the late 1980s (Valdez 1990), indicating adequate habitat for successful reproduction, recent surveys have not located any young humpback chub, indicating possible recruitment failure (Badame 2008), although there is no indication this is due to recent changes in water quality or quantity, and PCEs W1 and W2 of humpback chub critical habitat appear to be functional.

Causes of the apparent current lack of recruitment of the population do not appear to be due to changes in the physical habitat PCEs. Valdez (1990) reported humpback chub of all age classes in Cataract Canyon (indicating a reproducing population) and the presence of preferred physical habitats; there appear to be no changes to the physical habitat since that time that would explain the current lack of recruitment. Cataract Canyon has many non-native fish species, with channel catfish, black bullhead, and red shiner being the most common (D. Elverud, Utah Division of Wildlife Resources, pers. comm., 2009, R. Valdez, pers. comm. 2009), and striped bass (*Morone saxatilis*) were captured in past surveys (Valdez 1990). The water and physical PCEs appears to be met, but the presence of Lake Powell likely eliminated much of the historical habitat, and provides a robust population of non-native fish species. It is not clear if the remaining habitat since Lake Powell filled would have sufficient carrying capacity to support a large population of humpback chub, but the high numbers of non-native species has resulted in the lack of the biological environment PCEs B2 and B3 and this is likely the reason this unit is not functioning currently in humpback chub recovery.

Humpback Chub Critical Habitat Reach 6 - Little Colorado River

Critical habitat in the LCR includes the lowermost eight miles from T32N, R6E, section 12 (Salt and Gila River Meridian) to the confluence with the Colorado River in T32N, R5E, section 1 (Salt and Gila River Meridian) Coconino County, Arizona. Land ownership is 81.3 percent Tribal (Navajo Tribe), and 18.8 percent NPS (Grand Canyon National Park). The Grand Canyon population of humpback chub occurs in both critical habitat reaches 6 and 7. The Grand Canyon population is the largest population of humpback chub, the only population in the lower basin, and constitutes the lower basin recovery unit (Coggins and Walters 2009, USFWS 2009a). While the vast majority of spawning of humpback chub in Grand Canyon occurs in the LCR, humpback chub utilize the mainstem Colorado River also, and condition factor[3] of adult humpback chub in the mainstem has been reported to be better than that of adults in the LCR (Hoffnagle et al. 2006). Additionally eight other spawning aggregations occur in the mainstem Colorado River, all of which, including the LCR, constitute what is considered a single reproducing population (Douglas and Douglas 2007).

Perennial flows in the LCR are maintained through a series of springs, the largest of which is Blue Spring approximately 13 miles (20.9 km) upstream from the mouth of the Colorado River.

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[3] A mathematical function which utilizes the length and weight of a fish to assess its overall health.

The LCR above Blue Spring was once perennial, but is now intermittent throughout most of its 356-mile (572.9-km) length, flowing only during floods from spring thaws or summer rain events (Colton 1937, Miller 1961, Valdez and Thomas 2009). Flows during floods can be between 500-2000 cfs. Base flow of the lower reach containing critical habitat is about 225 cfs (Cooley 1976). Water from these springs is high in chloride salts, relatively constant in flow, warm (20°C), highly charged with carbon dioxide, and saturated with calcium carbonate (Gorman and Stone 1999). This water chemistry forms the mineral travertine, layered deposits of hard, dense calcite. Travertine deposition in the LCR is an ongoing process, forming extensive reefs, terraces, and dams throughout the lower 14.5 miles (23.3-km). Large boulders and cobble fallen from canyon walls or transported by debris flows from side canyons are common in the stream channel (Gorman and Stone 1999). The unique geology forms a complex habitat matrix of pools, shallow runs, and races. Uncemented calcium carbonate particles form part of the stream bottom and contribute to the mild turbidity of the river at base flow (Kubly 1990), and flood flows are extremely turbid. Because of the reduced flow levels from Glen Canyon Dam, only the lower portion of the LCR is ponded by flows from the dam, where approximately 10 to 25% of the adult humpback chub are likely to occur (P. Sponholtz, FWS, pers. comm., 2011). The other adults will be in the mainstem Colorado River or in the upper reaches of the Little Colorado River in areas not affected by the operations of Glen Canyon Dam.

Flows in the LCR maintain acceptable habitat for all sizes and age classes of humpback chub. The historical hydrograph has been altered by the reduction in flows coming into the reach from the watershed, but seasonal variations remain (Valdez and Thomas 2009). Fluctuating flows in the Colorado River affect the lowermost portion of the reach by raising and lowering water levels and altering temperatures, but this affects less than a quarter mile (0.40 km) of the reach. Water quality has not been significantly altered by changes in flow from the historical condition; however salinity levels may be higher now during low-flow periods when there are no additional flows in the Little Colorado to dilute the inflow from the springs. Temperatures in the upper portion of the reach may have changed slightly in response to altered seasonal water levels, but water temperature in the LCR is suitable for spawning and egg and larval development (Gorman and Stone 1999). Although flows have changed in the LCR with development throughout the basin (Valdez and Thomas 2009) and the shift to intermittency upstream of Blue Spring, humpback chub continue to occupy and thrive in this reach of critical habitat (Coggins and Walters 2009, Van Haverbeke and Stone 2008, 2009). Thus PCEs W1 and W2 are present, although threats exist, as described in the Environmental Baseline.

Humpback chub utilize a variety of habitat types in the reach. Larval to juvenile humpback chubs have been found in shallow shoreline areas, sand-bottomed runs, and silt-bottomed backwaters with low-current velocities (USFWS 1990, Robinson et al. 1998). Adult humpback chub in the LCR utilize shoreline areas, pools and eddies, quiet waters under rock ledges, areas below travertine dams, and the deeper water at the confluence (Minckley et al. 1981). Spawning humpback chub have been found over rapidly flowing water among large angular boulders and shoreline outcrops or along shoreline eddy habitats of moderate depth with swirling currents and sand and boulder substrates (Gorman and Stone 1999). Although humpback chub larvae are common in midstream drift, larvae do appear to actively seek out calmer nearshore habitats as they age (Robinson et al. 1998). Stone and Gorman (2006) found that humpback chub undergo an ontogenesis from diurnally active (active during the day), vulnerable, nearshore-reliant y-o-y (30–90 mm, 1.2-3.5 inches TL) into nocturnally active, large-bodied adults (>180 mm TL [3.5 inches]). Adult humpback chub reside in deep mid-channel pools during the day, and move inshore at night (Stone and Gorman 2006). All aspects of the physical habitat PCEs (P1, P2, P3, and P4) are present in Reach 6, based upon the current status of the population (Van Haverbeke and Stone 2008, Coggins and Walters 2009).

Information from stomach contents and other observations indicate that food resources utilized by humpback chub in the LCR include bottom-dwelling invertebrates such as *Gammarus lacustris* and chironomid larvae, planktonic crustaceans, terrestrial invertebrates, and algae such as *Cladophora glomerata* (Minckley 1979, Minckley et al. 1981, Valdez and Ryel 1995). Foods utilized in the Little Colorado River are in different proportions than those utilized in the mainstem, reflecting food availability (Kaeding and Zimmerman 1983, Valdez and Ryel 1995). The extent of competition by non-native fishes is unknown, but predation has been documented by rainbow trout, channel catfish, and black bullhead (Marsh and Douglas 1997). Numbers of non-native fish make up a small proportion of the fish community in the LCR, comprising only 7 percent of total catch in 2007 monitoring (Van Haverbeke and Stone 2008). While relatively small proportions of certain non-native species (e.g., channel catfish) could be problematic for humpback chub in the LCR, the most common non-native fish in 2010 was fathead minnow (Van Haverbeke et al. 2011). All of the PCEs are provided for in the Little Colorado Reach of critical habitat, although significant threats exist which are discussed in the Environmental Baseline.

Humpback Chub Critical Habitat Reach 7 - Colorado River - Marble and Grand Canyons

The 173-mile (278.4-km) reach of critical habitat in the Colorado River in Marble and Grand Canyons extends from Nautiloid Canyon (RM 34) in T36N, R5E, section 35 (Salt and Gila River Meridian) to Granite Park (RM 208) in T30N, RI0W, section 25 (Salt and Gila River Meridian). Land ownership is 87.8 percent NPS and 12.2 percent Tribal (Navajo Nation). As discussed above, Reaches 6 and 7 constitute critical habitat occupied by the Grand Canyon population of humpback chub. While the vast majority of adult humpback chub in Grand Canyon occur in the LCR Inflow aggregation (at RM 57.0-65.4), humpback chub also occur at other aggregations in the mainstem Colorado River throughout Marble and Grand canyons, and there is some movement of humpback chub between the aggregations (Paukert et al. 2006). All nine aggregations constitute what is considered a single reproducing population (Douglas and Douglas 2007). According to Paukert et al. 2006, approximately 85% (12,508 of 14,674) of the humpback chub were captured and recaptured in the LCR, whereas only 241 (1.6%) were captured and recaptured in the mainstem Colorado River within the LCR confluence area. In 2006, concurrent estimates of the LCR and LCR inflow population were determined and represented 14,526 fish (or 99.0% of the recaptures) demonstrating the species' disproportionate reliance on the LCR. There is, however, evidence of some fish travelling among and adding to the mainstem aggregations (Paukert et al. 2006, W. Persons, USGS, written communication, 2011b).

The eight other spawning aggregations are (per Valdez and Ryel 1995): 1) 30-mile (RM 29.8 to 31.3); 2) Lava to Hance (RM 65.7-76.3); 3) Bright Angel Creek Inflow (RM 83.8-93.2); 4) Shinumo Creek Inflow (RM 108.1-108.6); 5) Stephen Aisle (RM 114.9-120.1); 6) Middle Granite Gorge (RM 126.1-129.0); 7) Havasu Creek Inflow (RM 155.8-156.7); and 8) Pumpkin Spring (RM 212.5-213.2). As stated in the 2008 and 2009 Supplemental Opinions, monitoring continues to confirm the persistence of these aggregations (Trammell et al. 2002), although few humpback chub have been caught at the Havasu inflow and Pumpkin Spring aggregations since

2000 (Ackerman 2008). Humpback chub have also been caught infrequently downstream of Pumpkin Spring (Valdez and Masslich1999). The LCR Inflow is the largest aggregation, which is in the lower 15 km (9.3 miles) of the LCR and the adjoining 15 km (9.3 miles) of the Colorado River (RM 57.0-65.4) (Valdez and Ryel 1995). The LCR aggregation has been expanded upstream of Chute Falls through translocation (Stone 2009, Van Haverbeke et al. 2011).

The abundances of the other humpback chub mainstem aggregations, other than the LCR inflow aggregation, are not precisely known, but catches of humpback chub in these other aggregations are consistently small compared to the LCR inflow aggregation. Young-of-year are consistently found throughout Grand Canyon, especially associated with aggregations at 30-mile, Middle Granite Gorge, Shinumo, and Randy's Rock, and recruitment may be occurring at low levels given that these aggregations continue to be documented over time (Figure 3) (Valdez and Ryel 1995, Trammel et al. 2002, Ackerman 2008). Monitoring continues to confirm the persistence of these aggregations (Trammell et al. 2002, W. Persons, USGS, written comm., 2011). In 2011, field surveys documented 2 or 3 year old fish in Havasu Creek just downstream of Beaver Falls (P. Sponholtz, FWS, pers. comm. 2011, Smith et. al. 2011). Eight untagged humpback chub were captured prior to humpback chub translocation in Havasu Creek (Smith et al. 2011). Humpback chub have also been caught infrequently downstream of Pumpkin Spring (Valdez 1994), an area warmed by mineral spring flows.

The Colorado River in Grand Canyon has a restricted channel with limited floodplain development. Channel widths vary from 180 to 390 feet (54.9-118.9 meters [m]) (Valdez and Ryel 1995). Gradients are often high, resulting in areas of rapids separated by long pools and runs. Steep, rocky shorelines, talus slopes with alluvial boulder fans, and undercut ledges border the channel. Substrates range from boulders to cobbles, gravels, and sand. Numerous small tributaries enter the Colorado River in the canyon. These are of two types: (1) perennial tributaries such as the LCR, and Bright Angel, Kanab, Shinumo, and Havasu creeks provide varying amounts of base flow to the river that create shallow water habitats for use by native fish with substrates that tend to be more rocky with fewer fine materials; and (2) the ephemeral tributaries which provide flows during flood periods and contribute significant amounts of sediment to the river. Alluvial fans form at the mouth of these ephemeral streams, contributing to the formation of rapids (Maddux et al. 1993b, Valdez and Ryel 1995). Cobble is the most productive habitat for invertebrates (highest biomass and production), perhaps because sediment thickness is lowest there (T. Kennedy, USGS, written comm. 2011).

Water releases from Glen Canyon Dam vary between 5,000 and 25,000 cfs and will continue in this way as described by the MLFF regime adopted by the Secretary of the Interior in 1996. The dam blocks the primary sediment inflow to the river in the canyon, limiting the sediment load to the amount contributed by the tributaries. The HFE protocol is designed to maximize the tributary inputs by producing high flows to deposit sand on beaches and nearshore habitats. Constant scouring of sediment from the canyon has continually eroded beaches and other sand-formed habitats such as backwaters since dam closure. The greatly reduced sediment load of the Colorado River post-dam increased water clarity, which increased primary productivity, especially in Marble Canyon, and algae and associated invertebrates dominate upstream reaches (Maddux et al. 1993b).

Water temperatures were altered significantly by the completion of Glen Canyon Dam and are cold (8.9 °C) year round when the reservoir is full (Reclamation files). Water temperatures downstream warm seasonally and with increasing distance from the dam due to solar insolation. However, fluctuations in water flow and associated stage change carry cold water continually into nearshore habitats extending the range of cold water influence. Between 2003 and 2006 when Lake Powell levels were low, water temperatures were able to warm up to 17 º C, the warmest temperature recorded since Lake Powell filled in 1980 and near the minimum temperature at which successful humpback chub spawning is initiated (Hamman 1982). This along with increased sediment levels from Paria River and other tributaries and mechanical removal of non-native fish contributed to the creation of water temperatures and habitat parameters that allowed overwintering of young-of-year humpback chub (Andersen et al. 2010). Water years since 2006, and in particular in 2011, have also been unusually warm with water temperatures at Lees Ferry at 13.5 ºC and 14.5 ºC at the LCR (Figure 4; USGS unpublished data). As a result of the different water temperatures available to humpback chub, there can be great variability in growth rates of humpback chub depending on the amount of time fish spend in the mainstem versus time spent in the tributaries.

Non-native fish species, most notably rainbow trout, channel catfish, brown trout, and carp, are established in the river in Marble and Grand canyons (Maddux et al. 1993b, Valdez and Ryel 1995) and prey upon and compete with native fish. Of the native fish species that historically occurred in the Grand Canyon, two have been extirpated. Extirpated species include the bonytail and Colorado pikeminnow. Reproducing populations include the humpback chub, bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), and speckled dace (*Rhinichthys osculus*). As discussed later in the document, the razorback sucker still occurs in the lower Grand Canyon but is very rare.

Flow fluctuations occur on daily, weekly, and monthly cycles based on needs for power generation and downstream water deliveries instead of the natural seasonal extreme flows of pre-dam years. Water depths and velocities are altered by the change in flows. The humpback chub in the mainstem is mostly found in backwaters, shoreline areas, and eddies, all areas of low-current velocity (Valdez and Ryel (1995). These areas may expand or contract in response to changes in flows. Existing water quality is adequate to support aquatic communities; however, changes in turbidity and temperature due to existence of Glen Canyon Dam and its operations have had effects on the suitability of the mainstem Colorado River for humpback chub, with resulting effects to reproduction, predation, and foraging behavior (Glen Canyon Dam Adaptive Management Program 2009). The degree to which the water PCEs (W1 and W2) provide for recovery in this reach of critical habitat is an ongoing research question.

The Colorado River in this reach provides a variety of main channel habitats, including eddies, shorelines, and backwaters. The confluence of the Colorado and LCRs is an important habitat area. Access to both systems provides both adult and juvenile humpback chubs with a variety of physical habitat conditions (water depth, velocity, turbidity, temperature, and substrate). Habitats formed by fine substrates such as backwaters that may be important nursery habitats are negatively impacted by the reduction in sediment supply and constant scour caused by periodic changes in flow volume (Glen Canyon Dam Adaptive Management Program 2009). The physical habitat PCEs are at least partially met. In the 2008 and 2009 Supplemental Opinion, we concluded that the suitability of spawning and rearing habitats (PCEs P1 and P2) to fully function in meeting recovery needs was unknown. Converse et al. (1998) documented a preference for vegetated shorelines in subadult (< 200 mm TL [(7.9 inches]) humpback chub in the area below the LCR. The Near Shore Ecology (NSE) study has demonstrated that all PCEs appear to be met in the limited area of the mainstem where their study occurs 1,500 m (0.93 mile), downstream of the LCR confluence. Reclamation has committed to expand the information and understanding of mainstem aggregations through improved monitoring to support humpback chub distribution throughout the action area as a new conservation measure. Monitoring will be expanded beyond the small NSE study area to better understand the population dynamics of the mainstem aggregations of humpback chub, including yearly trips to try and generate population estimates for these aggregations.

Fish production in the mainstem Colorado River is supported by a small array of food resources of potentially limited availability, which may lead to strong competition for food among fishes, including competition with non-native fish species that may constrain production of the remaining native fishes in this river (Donner 2011). Food resources do not appear to be limiting in the reach for adult humpback chub, and in fact Hoffnagle et al. (2000) found that condition factor for humpback chub in the mainstem was better than that of adult fish in the LCR. However, humpback chub collected in the LCR during that same time may have been impacted by parasites (Hoffnagle et al. 2006.) Food resources in near shore areas and in relation to fluctuating flows continue to be an ongoing research question (U.S. Bureau of Reclamation and U.S. Geological Survey 2009) given the low diversity of aquatic insects currently present in the mainstem (T. Kennedy, written communication, USGS 2011).

There are fewer numbers of non-native fish species established in the Colorado River in Reach 7 than in other reaches of critical habitat, due in part to the harsh physical conditions present. The cold mainstem water temperatures in particular have likely limited the invasion and expansion of warm-water species (such as fathead minnows or smallmouth bass). As discussed earlier, providing warmer water through flow manipulations or dam modifications, or warmer water due to climate change and the Interim Guidelines, could improve the W1 PCE for humpback chub, but would need to be carefully monitored so as to not degrade the B2 and B3 PCEs of critical habitat by increasing predation and competition from non-native fish warm water species. All of the PCEs may be provided for in this reach of critical habitat, although significant questions exist about water temperature (W1), spawning habitat (P1), nursery habitat (P2), and non-native fish predation and competition (B2 and B3); these are discussed in detail in the Environmental Baseline.

Previous consultations on humpback chub

Section 7 consultations on humpback chub have evaluated large-scale water-management activities. For the upper basin, UCRRP tracks the effects of such consultations on the species and provides conservation measures to offset the effects somewhat. Several consultations have occurred on the operations of Glen Canyon Dam, including one in 1995 that resulted in a jeopardy and adverse modification opinion. Subsequent consultations in 2008, 2009, and 2010 reached non-jeopardy/non adverse modification conclusions. Finally, a consultation on Sport Fish Restoration Funding evaluated the sport fish stocking program funded by the USFWS (USFWS 2011b). Biological opinions on actions potentially affecting humpback chub in Arizona may be found at our website www.fws.gov/southwest/es/arizona in the Section 7 Biological Opinion page of the Document Library.

Razorback Sucker and its Critical Habitat

The razorback sucker was first proposed for listing under the ESA on April 24, 1978, as a threatened species. The proposed rule was withdrawn on May 27, 1980, due to changes to the listing process included in the 1978 amendments to the ESA. In March 1989, the FWS was petitioned by a consortium of environmental groups to list the razorback sucker as an endangered species. A positive finding on the petition was published in the Federal Register on August 15, 1989. The finding stated that a status review was in progress and provided for submission of additional information through December 15, 1989. The proposed rule to list the species as endangered was published on May 22, 1990, and the final rule published on October 23, 1991, with an effective date of November 22, 1991. The Razorback Sucker Recovery Plan was released in 1998 (USFWS 1998). Recovery Goals were approved in 2002 (USFWS 2002b). Critical habitat was designated in 15 river reaches (Table 2) in the historical range of the razorback sucker on March 21, 1994, with an effective date of April 20, 1994 (USFWS 1994). Critical habitat included portions of the Colorado, Duchesne, Green, Gunnison, San Juan, White, and Yampa rivers in the Upper Colorado River Basin, and the Colorado, Gila, Salt, and Verde rivers in the Lower Colorado River Basin.

The following information is a summary of life history, habitat use, current distribution, threats, and conservation actions for the razorback sucker. This information was taken from the 2002 Recovery Goals (USFWS 2002b), and the Lower Colorado River Multi-Species Conservation Program Species Status documents (LCR MSCP 2005). Information in these documents is incorporated by reference.

The razorback sucker is the only representative of the genus *Xyrauchen* and was described from specimens taken from the "Colorado and New Rivers" (Abbott 1861) and Gila River (Kirsch 1889) in Arizona. This native sucker is distinguished from all others by the sharp-edged, bony keel that rises abruptly behind the head. The body is robust with a short and deep caudal peduncle (Bestgen 1990). The razorback sucker may reach lengths of 3.3 feet (1.0 m) and weigh 11 to 13 pounds (5.0 to 5.9 kilograms [km]) (Minckley 1973). Adult fish in Lake Mohave reached about half this maximum size and weight (Minckley 1983). Razorback suckers are long-lived, reaching the age of at least 40 years (McCarthy and Minckley 1987).

The razorback sucker is adapted to widely fluctuating physical environments characteristic of rivers in the pre-Euro-American-settlement Colorado River Basin. Adults can live 45-50 years and, once reaching maturity between two and seven years of age (Minckley 1983), apparently produce viable gametes even when quite old. The ability of razorback suckers to spawn in a variety of habitats, flows, and over a long season are also survival adaptations. In the event of several consecutive years with little or no recruitment, the demographics of the population might shift, but future reproduction would not be compromised. Average fecundity recorded in studies ranges from 46,740-100,800 eggs per female (Bestgen 1990). With a varying age of maturity and the fecundity of the species, it would be possible to quickly repopulate an area after a catastrophic loss of adults.

Spawning takes place in the late winter to early summer depending upon local water temperatures. Various studies have presented a range of water temperatures at which spawning occurs. In general, temperatures from 10° to 20° C are appropriate (summarized in Bestgen 1990). Adults typically spawn over cobble substrates near shore in water 3-10 feet (0.9 to 3.0 meters] deep (Minckley et al. 1991). There is an increased use of higher velocity waters in the spring, although this is countered by the movements into the warmer, shallower backwaters and inundated bottomlands in early summer (McAda and Wydoski 1980, Tyus and Karp 1989, Osmundson and Kaeding 1989). Spawning habitat is most commonly over mixed cobble and gravel bars on or adjacent to riffles (Minckley et al. 1991).

Razorback sucker diet varies depending on life stage, habitat, and food availability. Larvae feed mostly on phytoplankton and small zooplankton and, in riverine environments, on midge larvae. Diet of adults taken from riverine habitats consisted chiefly of immature mayflies, caddisflies, and midges, along with algae, detritus, and inorganic material (USFWS 1998).

Adult razorback suckers use most of the available riverine habitats, although there may be an avoidance of whitewater type habitats. Main channel habitats used tend to be low velocity ones such as pools, eddies, nearshore runs, and channels associated with sand or gravel bars (Bestgen 1990). Adjacent to the main channel, backwaters, oxbows, sloughs, and flooded bottomlands are also used by this species. From studies conducted in the upper Colorado River basin, habitat selection by adult razorback suckers changes seasonally. They move into pools and slow eddies from November through April, runs and pools from July through October, runs and backwaters during May, and backwaters, eddies, and flooded gravel pits during June. In early spring, adults move into flooded bottomlands. They use relatively shallow water (ca. three feet [0.9 m]) during spring and deeper water (five to six feet [1.5-1.8 m]) during winter (USFWS 2002b).

Data from radio-telemetered razorback suckers in the Verde River showed they used shallower depths and slower velocity waters than in the upper basin. They avoided depths <1.3 feet (0.4), but selected depths between 2.0 and 3.9 feet (0.6 to 1.2 m), which likely reflected a reduced availability of deeper waters compared to the larger upper basin rivers. However, use of slower velocities (mean = 0.1 foot/sec) may have been an influence of rearing in hatchery ponds. Similar to the upper basin, razorback suckers were found most often in pools or run over silt substrates, and avoided substrates of larger material (Clarkson et al. 1993).

Razorback suckers also use reservoir habitat, where the adults may survive for many years. In reservoirs, they use all habitat types, but prefer backwaters and the main impoundment (USFWS 1998). Much of the information on spawning behavior and habitat comes from fishes in reservoirs where observations can readily be made. Habitat needs of larval and juvenile razorback sucker are reasonably well known. In reservoirs, larvae are found in shallow backwater coves or inlets (USFWS 1998). In riverine habitats, captures have occurred in backwaters, creek mouths, and wetlands. These environments provide quiet, warm water where there is a potential for increased food availability. During higher flows, flooded bottomland and tributary mouths may provide these types of habitats.

Razorback suckers are somewhat sedentary; however, considerable movement over a year has been noted in several studies (USFWS 1998). Spawning migrations have been observed or inferred in several locales (Jordan 1891, Minckley 1973, Osmundson and Kaeding 1989, Bestgen 1990, Tyus and Karp 1990). During the spring spawning season, razorbacks may travel long distances in both lacustrine and riverine environments, and exhibit some fidelity to specific spawning areas (USFWS 1998). In the Verde River, radio-tagged and stocked razorback suckers tend to move downstream after release. Larger fish did not move as much from the stocking site as did smaller fish (Clarkson et al. 1993).

The razorback sucker was once abundant in the Colorado River and its major tributaries throughout the Basin, occupying 3,500 miles (5,633 km) of river in the United States and Mexico (Maddux et al. 1993b). Records from the late 1800s and early 1900s indicated the species was abundant in the lower Colorado and Gila river drainages (Kirsch 1889, Gilbert and Scofield 1898, Minckley 1983, Bestgen 1990). It now occurs in portions of the upper Colorado, Duchesne, Green, Gunnison, White, and Yampa rivers in the Upper Basin; and in the lower Colorado River from Grand Canyon down to Imperial Dam. The species is being reintroduced into the Verde River.

The range and abundance of razorback sucker has been severely impacted by water manipulations, habitat degradation, and importation and invasion of non-native species. Construction of dams, reservoirs, and diversions destroyed, altered, and fragmented habitats needed by the sucker. Channel modifications reduced habitat diversity, and degradation of riparian and upland areas altered stream morphology and hydrology. Finally, invasion of these degraded habitats by a host of non-native predacious and competitive species has created a hostile environment for razorback sucker larvae and juveniles. Although the suckers produce large spawns each year and produce viable young, the larvae are largely eaten by the non-native fish species (Minckley et al. 1991).

Populations in the upper Colorado Basin are being maintained through stocking (Nesler et al. 2003, Zelasko et al. 2010) and the lower basin populations are maintained through stocking and grow-out programs managed by the MSCP program (see http://www.lcrmscp.gov/fish/fish_res_mon.html for specific research projects and reports). In the San Juan River there is evidence of spawning and recruitment primarily at the inflow area to Lake Powell (D. Elverud, Utah Division of Wildlife, personal communication). The only known reproducing and recruiting populations in the Colorado River basin are in Lake Mead (where they are primarily found near inflow areas from the Colorado, Virgin, and Muddy rivers) and the Las Vegas Wash (Albrecht et al. 2008, Kegerries and Albrecht 2011). Stocking and other recovery efforts by the Upper Colorado River Basin and San Juan River Recovery Implementation Programs are ongoing and information on those actions is available at their websites (http://www.coloradoriverrecovery.org/index.html; http://www.fws.gov/southwest/sjrip/. The Lower Colorado River Multi-Species Conservation Program is also implementing conservation actions for the species that are described on their website (http://www.lcrmscp.gov/).

Since 1997, significant new information on recruitment to the wild razorback sucker population in Lake Mead has been developed (Albrecht et al. 2008, Kegerries and Albrecht 2011) that indicates some degree of successful recruitment is occurring at three locations in Lake Mead, and another spawning group was documented in 2010 at the Colorado River inflow area of the lake. This degree of recruitment has not been documented elsewhere in the species' remaining populations. As part of their ongoing commitment to conservation for this species, the AGFD is an active participant in implementation of the razorback sucker recovery plan. In the Lower Colorado River Basin, efforts to reintroduce the species to the Gila, Salt, and Verde rivers have not been successful in establishing self-sustaining populations. Reintroduction efforts continue in the Verde River. Very few razorback suckers were recaptured from these efforts (Jahrke and Clark 1999). The Horseshoe-Bartlett Habitat Conservation Plan (HCP) (SRP 2008) contains conservation actions to be implemented in the Verde River for the razorback sucker, including funding for continued stocking of the species.

Recovery for the razorback sucker is currently defined by the FWS Razorback Sucker Recovery Goals (USFWS 2002b). The Recovery Goals define recovery as specific demographic criteria that must be attained, and recovery factors that must be met to achieve downlisting and delisting of razorback sucker. The recovery factors were derived from the five listing threat factors under ESA section 4(a), and state the conditions under which threats are minimized or removed sufficient to achieve recovery; a list of site-specific management actions and tasks (e.g. the development and implementation of non-native fish control programs) is also provided. They include the need to identify, implement, evaluate, and revise (as necessary through adaptive management) flow regimes to benefit razorback sucker for all the rivers in which the species occurs. Essentially, the goals identify actions needed to maintain the habitat features (i.e. the physical and biological features of critical habitat) to accomplish recovery. But the measures of whether or not actions are working with regard to recovery, and the basis for altering management actions through adaptive management, are the demographic criteria. The site-specific recovery actions, as well as the demographic Recovery Goals, are provided in USFWS (2002b). We summarize here the Recovery Goal demographic criteria for downlisting (there are no delisting criteria) as follows (population demographics in both recovery units must be met in order to achieve downlisting):

Upper basin recovery unit

Green River Subbasin

1. A self-sustaining population is maintained over a 5-year period, starting with the first point estimate acceptable to the FWS, such that:

    a. the trend in adult (age 4+; ≥ 400 mm [15.7 inches] TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (300-400 mm [11.8-15.7 inches]TL) naturally produced fish equals or exceeds adult mortality, and

    c. each population point estimate exceeds 5,800 adults (Note: 5,800 is the estimated MVP number).

Upper Colorado River and San Juan River Subbasins

1. A self-sustaining population is maintained in EITHER the upper Colorado River subbasin or the San Juan River subbasin over a 5-year period, starting with the first point estimate acceptable to the Service, such that for either population:

    a. the trend in adult (age 4+; ≥ 400 mm [15.7 inches] TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (300-400 mm [11.8-15.7 inches]TL) naturally produced fish equals or exceeds adult mortality, and

    c. each point estimate exceeds 5,800 adults (MVP).

Lower basin recovery unit

Lake Mohave

1. Genetic variability of razorback sucker in Lake Mohave is identified, and a genetic refuge is maintained over a 5-year period.

Rest of basin

1. Two self-sustaining populations (e.g., mainstem and/or tributaries) are maintained over a 5-year period, starting with the first point estimate acceptable to the FWS, such that for each population:

    a. the trend in adult (age 4+; ≥ 400 mm [15.7 inches] TL) point estimates does not decline significantly, and

    b. mean estimated recruitment of age-3 (300-400 mm [11.8-15.7 inches] TL) naturally produced fish equals or exceeds adult mortality, and

    c. each point estimate exceeds 5,800 adults (MVP).

General PCEs of Critical Habitat

Critical habitat was listed for the four big river fishes (Colorado pikeminnow, humpback chub, bonytail, and razorback sucker) concurrently in 1994, and the PCEs were defined for the four species as a group in two biological support documents and the final rule designating critical habitat (Maddux et al. 1993a, 1993b, USFWS 1994). The general PCEs are the same as these discussed previously for humpback chub and are not repeated here. However, note that the PCEs vary somewhat for each species on the ground, particularly with regard to physical habitat, because each of the four species has different habitat preferences.

Table 2. CRITICAL HABITAT UNITS FOR RAZORBACK SUCKER
(Range wide information by reach with conservation value and habitat issues at designation)

State	**Reach Description/ River**	**Reach Description/ Segment**	**Conservation value**	**Important issues at time of designation**
Arizona/Nevada	Colorado River	Paria River to Hoover Dam	Delisting	Flow alterations, non-native species
Arizona/Nevada	Colorado River	Hoover Dam to Davis Dam	Downlisting	Flow alterations, non-native species
Arizona/California	Colorado River	Parker Dam to Imperial Dam	Delisting	Flow alterations, non-native species
Arizona	Gila River	New Mexico state line to Coolidge Dam	Delisting	Flow alterations, non-native species
Arizona	Salt River	Bridge to Roosevelt Dam	Delisting	Flow alterations, non-native species

Arizona	Verde River	Perkinsville to Horseshoe Dam	Delisting	Flow alterations, non-native species
Colorado	Colorado River	Rifle to Westwater	Downlisting	Flow alterations
Colorado	Gunnison River	Uncompahgre River to Redlands Diversion	Delisting	Flow alterations, non-native species
Colorado	Yampa River	Lily Park to Green River	Downlisting	Non-native species
New Mexico/Utah	San Juan River	Hogback Diversion to Neskahai Canyon	Downlisting	Non-native species
Utah	Colorado River	Westwater to Dirty Devil	Delisting	Non-native species
	Duchesne River	Lower 2.5 miles (4.0 km)	Delisting	Flow alterations, non-native species
	Green River	Yampa River to Sand Wash	Downlisting	Flow alterations, non-native species
	Green River	Sand Wash to Colorado River	Delisting	Flow alterations, non-native species
	White River	Lower 18 miles (29.0 km)	Delisting	Flow alterations, non-native species

Previous consultations

Section 7 consultations on razorback sucker include consultations on large-scale water management activities. For the upper basin, the UCRRP addresses the effects of such consultations on the species and provides conservation measures to somewhat offset the effects of proposed actions. In the lower Colorado River, the Lower Colorado River MSCP addresses effects of water management and provides conservation to offset effects of water operations. Several Statewide consultations have occurred including the Land and Resource Management Program with the Forest Service and the IntraService consultation on Sport Fish Restoration Funding which evaluated the sport fish stocking program funded by the FWS (UFSWS 2011b). Smaller site-specific consultations addressing channelization, recreational development, and implementing recovery actions have also occurred. All prior consultations have reached non-jeopardy and non-adverse modification conclusions. Biological opinions on actions potentially affecting razorback sucker in Arizona may be found at our website www.fws.gov/southwest/es/arizona in the Section 7 Biological Opinion page of the Document Library.

Kanab ambersnail

The Kanab ambersnail was listed as endangered in 1992 (57 FR 13657) with a recovery plan completed in 1995 (USFWS 1995a). No critical habitat is designated for this species. Unpublished results of an ongoing taxonomy study indicate that the Kanab ambersnail may actually be part of a much more widespread and abundant taxon (Culver et al. 2007).

Stevens et al. (1997) 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. The species occurs in Utah and at two populations 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, Meretsky and Wegner 1999, Meretsky et al. 2000, Webb and Fridell 2000).

The Kanab ambersnail lives approximately 12–15 months and is hermaphroditic and capable of self-fertilization (Pilsbry 1948). Mature Kanab ambersnail mate and reproduce in May–August (Stevens et al. 1997, Nelson and Sorensen 2001). Fully mature snail shells are translucent amber with an elongated first whorl, and measure about 23 mm (0.9 inches) in shell size (J. Sorensen, AGFD, written communication, 2011). 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 (USFWS 2011c, Stevens et al. 1997). Populations fluctuate widely throughout the year due to variation in reproduction, survival, and recruitment (Stevens et al. 1997). Current climate change science predicts decreases in precipitation and water resources in areas occupied by Kanab ambersnail. Because Kanab ambersnail populations are restricted to small wet vegetated habitat areas, we consider climate change and associated reduction in water resources a threat to Kanab ambersnail (USFWS 2011c).

The 5-year review on the Kanab ambersnail describes a draft report by Culver et al. (2007), which characterized mitochondrial diversity and AFLP marker diversity from 12 different southwestern *Oxyloma* populations (USFWS 2011c). The characterized populations included two Kanab ambersnail populations (Vasey's Paradise and Three Lakes) and 10 non-endangered ambersnail populations. Analysis detected some gene flow among the studied *Oxyloma* populations. The authors speculate that the measured gene flow demonstrates that all of the populations studied are members of the same interbreeding species (Culver et al. 2007). Thus, in contradiction to previous studies, they concluded that Kanab ambersnails are genetically the same as all other *Oxyloma haydeni (*Niobrara ambersnail*)* and subsequently Kanab ambersnails do not warrant subspecies status. A taxonomic change of Kanab ambersnail to Niobrara ambersnail could result in its downlisting or delisting. However, as of this writing, this report remains unpublished.

ENVIRONMENTAL BASELINE

The environmental baseline includes past and present impacts of all Federal, State, or private actions in the action area, the anticipated impacts of all proposed Federal actions in the action area that have undergone formal or early section 7 consultation, and the impact of State and private actions which are contemporaneous with the consultation process. The environmental baseline defines the current status of the species and its habitat in the action area to provide a platform to assess the effects of the action now under consultation.

Glen Canyon Dam has operated under MLFF since the Record of Decision was signed in 1996. Generally, the MLFF is a set of flow constraints that results in hourly, daily, and monthly variations in flow from Glen Canyon Dam. The MLFF is implemented by Reclamation through the GCDAMP as defined in the 1995 EIS and 1996 ROD (Reclamation 1995, 1996). The variations in flow resulting from MLFF affect many aspects of the ecosystem from Glen Canyon Dam to Lake Mead. Effects are on the abiotic aspects of the ecosystem (e.g., water temperature, turbidity, sediment transport, riverine habitat formation) and on the biotic aspects (e.g. food base dynamics, fish species abundance and composition, fish growth, fish predation rates, prevalence of disease or parasites). Many of these effects are poorly understood, and adding to the complexity is the fact that few if any effects can be analyzed separately because they interact. The proposed action will continue the MLFF and add NNFC and HFE Releases.

HFE Releases will occur during limited times and 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 5-year experimental flow plan began in 2008 and will continue through calendar year 2012 under the proposed action.

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

- 1996 Beach Habitat Building Flow (BHBF) 45,000 cfs for 7 days, March 26-April 2, 1996.
- 1997 Habitat Maintenance Flow (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 7, 1996 and included pre- and post-release steady flows of 8,000 cfs for 4 days each and a 7-day steady release of 45,000 cfs. Dam releases were increased and decreased gradually relative to the peak release in order to minimize damage to resources. The coordinated effort of scientists to evaluate the effects of the 1996 BHBF on physical, biological, cultural, and socio-economic resources were 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 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 the Record of Decision on 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 2004 HFE when a sediment enrichment condition existed (Reclamation 2002). This experiment was held November 21–23, 2004, and included a 60-hour release of 41,000 cfs. The 2004 HFE was conducted shortly after a large amount of sediment was delivered by the Paria River and it helped test the hypothesis that maximum sediment conservation would occur with a high flow shortly after the sediment was deposited in the mainstem. Suspended sediment concentrations 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).

Following these findings with respect to effectiveness of the 2004 HFE trigger and implementation, a third planned 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 wildlife and campsites for users of the Grand Canyon. The 2008 HFE was preceded by a sediment budget that was greater than the 2004 HFE and the net storage effect of the 2008 high-flow was positive. Although sandbar erosion occurred after the March 2008 HFE due to higher monthly water volumes, it was noted that the erosion rate slowed during the steady 8,000 cfs releases in September–October. Results of the 2008 HFE were summarized by Melis et al. (2010) and detailed in a number of USGS Open File Reports (Grams et al. 2010, Hilwig and Makinster et al. 2010, Korman et al. 2010, Rosi-Marshall et al. 2010, Topping et al. 2010, and others).

Three HMFs were held, including one in 1997 and two in 2000. Another HMF was scheduled in 2002 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 held in association with a low steady summer flows of 8,000 cfs from June 1 through September 4, 2000. The steady summer flows were designed to warm shoreline habitats for native and endangered fishes, especially humpback chub, and the HMFs were designed to maintain habitats, export invasive non-native fish, and evaluate ponding of tributary inflows. However, as noted in Ralston (2011), the variability of flow during this time may have hampered the effectiveness of studies to assess resource responses. Individual steady flows ranged from 4 days to 12 weeks. 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.

The Department of the Interior is currently undertaking an Environmental Impact Statement (EIS) process for the Long-Term Experimental and Management Plan (LTEMP), which will analyze and address flow and non-flow related options for future implementation as part of the Adaptive Management Program. Consultation on the LTEMP is anticipated to supersede the coverage provided by this biological opinion (76 FR 39435, 76 FR 64104).

A. STATUS OF THE SPECIES AND CRITICAL HABITAT WITHIN THE ACTION AREA

Humpback chub

The status of the humpback chub in the action area has improved since 2000 with increasing numbers of adult fish in the LCR Reach and evidence of y-o-y overwintering at 30-mile (Andersen et al. 2010, Yard et al. 2011). The Grand Canyon population consists primarily of adults residing in and near the LCR (the LCR Inflow aggregation), with eight other much smaller aggregations of the species scattered throughout approximately 180 river miles of the mainstem Colorado River as described above. Successful translocation of juvenile humpback chub into Havasu and Shinumo creeks is likely to increase the status of those aggregations and improve the species' status overall in the action area.

As stated in our 2008 and 2009 Supplemental Opinion, the population dynamics information for humpback chub is much improved since the 1995 opinion, with much more available information on humpback chub recruitment and abundance as a result of ongoing monitoring of the GCDAMP and the development of the ASMR (Coggins and Walters 2009). Coggins and Walters (2009) assessed the status and trend of the humpback chub in the LCR (the LCR Inflow aggregation) utilizing the ASMR model. As of 2008, the adult (age 4+) population of humpback chub was estimated to be about 7,650 fish, with a range between 6,000 and 10,000 fish. The ASMR indicates that a decline in the abundance of adult humpback chub occurred throughout the late 1980s and early 1990s, reached a low in the early 2000s, and has since trended upwards. This recent upward trend represents about a 50 percent increase in adult abundance since 2001 (Coggins 2008a, Coggins and Walters 2009) with the population size continuing to increase. The 2006 estimate was 5,300-6,700, an increase of about 50 percent since 2001 (Coggins 2008a, Coggins and Walters 2009). The change in status was due to an increase in recruitment that began before many actions predicted to improve the humpback chub status (such as mechanical removal of non-native fishes or warming of mainstem water temperatures in the Colorado River). Mainstem warming and mechanical removal effects both started in 2003 and could have begun affecting the abundance of age-2 recruits in 2004 and later, (brood-years 2002 and later). Notably, the largest increase in adult abundance occurred in 2007, when the 2003 brood-year matured to age-4 (Coggins and Walters 2009). This was the first year of non-native fish control, which coincided with warmer water releases from Glen Canyon Dam. This reinforces the findings of the 2008 Opinion in which we predicted those brood years would likely benefit from these changes to the mainstem critical habitat in Reach 7. According to C. Walters (2011, pers. comm., Anderson 2009, Coggins et al. 2011) and other sources current data are insufficient to support piscivory of non-native fish on humpback chub as the causal mechanism in the period of decline in humpback chub (approximately 1990-2000) because of the complexity of numerous factors and because the upward trend in adult humpback chub numbers appears to have started before warmer water and removal efforts to control non-native fishes began.

A 4-year mechanical removal effort to reduce rainbow trout abundance in target reaches of the Grand Canyon began in January 2003 (Coggins 2008, Coggins et al. 2011). To aid the mechanical removal effort, an experimental "non-native fish suppression flow" (NFSF) regime from Glen Canyon Dam was implemented between January and March in 2003–2005. These flows were intended to reduce rainbow trout abundance in the Lees Ferry reach by increasing mortality rates on incubating life stages. As discussed below, the "non-native fish suppression flows" resulted in a total redd loss of approximately 23% in 2003 and 33% in 2004. However, because of increases in survival of rainbow trout at later life stages, this increased mortality did not lead to reductions in overall recruitment of rainbow trout due to density compensation of high survival of age 1 trout (Korman et al. 2005, Korman et al. 2011). The flow element of non-native removal was not repeated after 2005 although mechanical removal continued through 2006 and once in 2009.

In 2008, a large rainbow trout cohort spawned in Lees Ferry, apparently as a result of the 2008 HFE (Korman et al. 2010, 2011). Large downriver migration of this cohort, combined with local recruitment along downriver sections, likely led to a roughly 800 percent increase in rainbow trout densities in the vicinity of the Little Colorado River since 2006 (Makinster et al. 2010, Wright and Kennedy 2011. Preliminary estimates of the 2011 Natal Origins field work has estimated trout numbers at over 1 million age 0 fish in the Lees Ferry Reach, or 17 times higher than the previous estimate after the 2008 HFE (J. Korman, Ecometric, pers. comm. 2011). Although the fate of those age 0 fish cannot be reliably predicted, it is possible that a portion of this cohort will emigrate downstream and potentially interact with native fish. This increase in trout numbers may be due to high and steady dam releases in 2011 due to a wet water year and resulting equalization flows (from Lake Powell to Lake Mead) under the Interim Guidelines. Mainstem warming and mechanical removal effects both started in 2003 and could have begun affecting the abundance of age-2 humpback chub recruits in 2004 and later, (brood-years 2002 and later). But the increase in humpback chub recruitment appears to have begun in the mid-1990s before the population was exposed to warmer Colorado River water temperatures and reduced non-native fish abundance near the mouth of the LCR. However, Coggins and Walters (2009) state that the low summer steady flow conducted during the summer of 2000 (primarily a low flow of 8,000 cfs from June to September; see Ralston and Waring 2008), which warmed the mainstem river, may have resulted in increased recruitment of the 1999, 2000, and possibly 1998 brood-years. The increase in recruitment in the 1990s could also have been due to the implementation of the MLFF. Although the contribution of the mainstem aggregations, other than the LCR Inflow aggregation, to the overall Grand Canyon population is not known, and most of the population likely occurs in the LCR Inflow aggregation, the Grand Canyon population of humpback chub (i.e. the lower Colorado River basin recovery unit) is the largest of the humpback chub population range wide, and the only one with an increasing trend.

Other monitoring information developed through the GCDAMP also indicates humpback chub status has been improving over the past decade. FWS monitoring efforts in the LCR indicate that beginning in 2007 the abundance of adult humpback chub ≥ 200 mm (7.9 inches) in the LCR during the spring spawning season significantly increased compared to estimates obtained between 2001 and 2006 (Van Haverbeke et al. 2011), and have continued to trend upwards. Furthermore, all post-2006 spring abundance estimates of humpback chub ≥150 mm (5.0 inches) in the LCR do not differ statistically from the spring 1992 estimates obtained by Douglas and Marsh (1996). Finally, all post-2006 spring abundance estimates of humpback chub between 150 and 199 mm (5.0 and 7.8 inches) in the LCR (Van Haverbeke et al. 2011) appear to have equaled or exceeded the estimate of mean annual adult mortality provided in Coggins and Walters (2009). These findings are significant because the objective and measurable recovery criteria in the recovery goals (USFWS 2002a) require that the trend in adult abundance does not decline significantly, and that the mean estimated recruitment of age-3 (150-199 mm [5.0 and 7.8 inches]) naturally produced fish equals or exceeds mean annual adult mortality. It would appear that at least the portion of the LCR aggregation that enters the LCR to spawn each spring have returned to levels of abundance documented in the early 1990s.

Most of Reclamation's conservation measures for humpback chub from the 2008 Opinion have either been implemented or are in the process of being implemented. The AMWG accepted the completed Humpback Chub Comprehensive Plan in August 2009, and Reclamation is currently implementing many aspects of the plan (Glen Canyon Dam Adaptive Management Program 2009). For example, translocations above Chute Falls were conducted every year between 2008 and 2011. Working with NPS, translocations have also occurred into Havasu and Shinumo Creeks. A genetics management plan for humpback chub was also completed in 2010.

One LCR reach non-native removal trip was conducted in 2009. No trips were conducted in 2010 or 2011 because of Tribal concerns. In November 2010, at Reclamation's request, this office prepared a separate Biological Opinion on the continued Operations of Glen Canyon without Mechanical Removal for a 13-month period. In our November 9, 2010 biological opinion, we concluded that this action would result in incidental take of y-o-y, juvenile, and some adult humpback chub due to increased fish predation and competition, but that this would not jeopardize the species or adversely modify its critical habitat (USFWS 2010 Cancellation Opinion).

The Near Shore Ecology study began in 2008 and field work concluded in 2011. The NSE project was designed to estimate monthly survival estimates of juvenile humpback chub between 40-80 mm (1.57 and 3.15 inches) to assess population responses to experimental steady flows. The NSE project continues to develop approaches to estimate annual survival rates with these data in the NSE study reach downstream of the LCR. Reclamation has also instituted and completed a Monthly Flow Transition Study conservation measure as referenced in the 2008 Biological Opinion. Development of a refuge for humpback chub at DNFHTC began in 2008 and is ongoing, with 885 juvenile humpback chub being transferred to the station for this specific purpose. These humpback chub have all been captured from the wild in the lower 5.9 miles (9.5 km) of the LCR (300 fish in 2008, 200 fish in 2009, 185 fish in 2010, and 200 fish in 2011). Reclamation completed a draft watershed plan for the LCR (Valdez and Thomas 2009) and continues to assist the Little Colorado River Watershed Coordinating Council in watershed planning efforts. To mitigate the adverse affects of the MLFF and the HFE Protocol, Reclamation has also committed to continue most of the conservation measures identified in previous biological opinions (USFWS 2008a, 2009) and as described in this opinion through 2020 as warranted, except for further non-native removal in the LCR reach which will only be conducted if certain triggers are met (Reclamation, Supplemental BA 2011).

As described earlier, translocation of humpback chub from the LCR to upstream of Chute Falls took place in between 2008 and 2011, as a conservation measure of the 2008 Opinion. Thus far, a total of 1,848 humpback chub have been translocated above Chute Falls. This upstream reach has been monitored since the first translocation in 2003, with annual mark-recapture methods being initiated in 2006. Humpback chub have consistently been found above the falls since then, a few adult chub have moved upstream on their own (thus the falls do not actually constitute an absolute barrier to humpback chub), and 156 humpback chub (120-344 mm [4.7-13.5 inches]) were captured above Chute Falls in monitoring in 2009 (Stone 2009). Between 2006 and 2009, population estimates of adult humpback chub (≥ 200 mm [7.9 inches]) above Chute Falls ranged from about 50 to 100 fish (Figure 5). However, in 2010 the abundance dropped to an estimate of only 2 fish. This decline is thought to be related to a protracted spring runoff event the LCR experienced during 2010 (Van Haverbeke et al. 2011).

The abundance of humpback chub in the lower reach immediately below Chute Falls in the Atomizer Falls complex increased dramatically in 2007, with hundreds of fish present, likely as a result of translocation efforts, although the humpback chub present were a mix of some translocated fish, some that had moved up from downstream areas of the LCR (upriver migrants), and fish of unknown origin that did not appear to have previously been tagged (Stone 2009, D. Stone, FWS, pers. comm. 2009). As with the severe decline of adult humpback chub above Chute Falls in 2010, the small reach of river immediately below Chute Falls also witnessed a dramatic decrease in 2010 (Figure 5).

Growth rates of translocated humpback chub are very high. Fish that are translocated at age 0-1 year have grown to maturity, over 200 mm TL (7.9 inches), within one year of being translocated. Typically a 200 mm TL (7.9 inches) fish in the Grand Canyon population is estimated to be 4 years old. Translocated fish may have spawned based on the presence of ripe fish and fry above Chute Falls, although only three fry have so far been captured, so spawning may be minimal (Van Haverbeke and Stone 2009). At least four humpback chub have been documented moving up Chute Falls on their own (Stone 2009, Van Haverbeke and Stone 2009), and in May of 2009 an adult female did so during base flow conditions, illustrating that even at base flow the falls are not a barrier to humpback chub movement (Stone 2009, D. Stone, FWS, pers. comm. 2009). Because PIT tagging was not initiated until the fourth translocation in 2008, there are not enough data to say with certainty what the contribution of translocated fish has been to the overall population. Given the high growth rate, the variable numbers between Atomizer and Chute falls, and the continued presence of humpback chub above Chute Falls, it seems reasonable that survivorship of translocated fish has been high. However, most humpback chub have moved below Chute Falls, calling any range extension from the translocation effort somewhat into question (Van Haverbeke and Stone 2009).

In June 2009, Grand Canyon National Park and Grand Canyon Wildlands Council translocated 300 age-1 humpback chub into Shinumo Creek. Additional stocking occurred in 2010; and the third translocation of humpback chub into Shinumo Creek occurred on June 21, 2011, when three hundred young humpback chub averaging 89 mm (3.5 inches) were stocked (Healy et al. 2011). Supplemental translocations were also conducted in 2010 and 2011 (Healy et al. 2011). The 2011 field season documented 54 of the translocated humpback chub including 5 from the 2009 stocking season and 36 from the 2010 season (Healy et al. 2011).

In another 2008 Opinion conservation measure over 900 non-native rainbow trout were removed from Shinumo Creek in May and June 2009, in preparation for the humpback chub release. Fisheries biologists also removed 394 rainbow trout from Shinumo Creek during the 2011 field season (Healy et al. 2011). Native bluehead sucker and speckled dace were also documented, measured, and returned to the creek. Following the 2009 humpback chub release, two monitoring trips, pre-and post-monsoon, were scheduled. The pre-monsoon monitoring trip was completed in July 2009. To help monitor potential downstream movement of translocated fish, two remote PIT tag antennas were installed in the lower end of the system above a waterfall near the mouth of Shinumo Creek. Monitoring indicated high retention of fish in the creek; 108 were captured in July, only six of which were below the falls, the rest in the two mile reach above the falls; the majority of these fish were in the same general location where they were released. Of the six humpback chub captured in the short reach below the falls, three (two young of year, and one 1-year old) were unmarked (Grand Canyon Wildlands Council 2009). The Shinumo aggregation is likely supporting a small mainstem spawning aggregation at Shinumo Creek, as captures of young fish indicates that successful spawning has occurred (Ackerman 2008, Grand Canyon Wildlands Council 2009).

In June 2011, 244 humpback chub approximately 95 mm TL (3.7 inches) were translocated to Havasu Creek in fulfillment of the translocation Conservation Measure of the 2008 Opinion. Native bluehead sucker (n=50), speckled dace (n=517), flannelmouth sucker (n=18), and unmarked humpback chub (7) were also documented in the creek, along with 22 rainbow trout (Smith et. al 2011). Reclamation has committed to continue support for translocation efforts as part of this biological opinion, which will help support expanding the range of humpback chub throughout its critical habitat in the action area.

Mainstem humpback chub spawning aggregations other than the LCR inflow were monitored in 2010 and 2011; however, preliminary data suggest that humpback chub abundance is either stable or increasing at most aggregations (W. Persons, USGS, written communication, 2011a).

Andersen et al. (2010) documented successful overwinter of y-o-y humpback chub at 30-mile. The 30-mile aggregation is the closest aggregation to the dam and thus water in this area would be warmed the least as it moves downstream. However, temperatures at the dam in 2005 were above the thermal minimum needed for successful humpback chub spawning, so it is conceivable that the 30-mile aggregation spawned. Monitoring of mainstem aggregations previously occurred every two years, but will now be conducted annually through the GCDAMP as a conservation measure of this biological opinion (described above).

Habitat Conditions

Water temperatures in the mainstem Colorado River below Glen Canyon Dam are an important factor of fishery habitat downstream. Glen Canyon Dam release temperature is a result of a combination of several factors: reservoir elevation (because warm water in the epilimnion, the warmest uppermost layer of a lake, is closer and more available to be released through the penstock intakes when lake elevation is low); temperature and volume of inflow (larger runoff volumes deepen the epilimnion, creating a larger, deeper body of warm water that is relatively closer to the penstocks at a given reservoir elevation, and therefore available to be released, than do smaller runoff volumes); and climate (solar insolation directly warms water). Releases from Glen Canyon Dam affect downstream temperature primarily as a function of release temperature and release volume. Wright et al. (2008a) found that mainstem temperatures at the LCR 124 km (77 miles) downstream of Glen Canyon Dam were influenced by both temperature and volume, but release temperature had the greater effect; generally, release temperature is more important closer to the dam, and volume more so further downstream. Release temperature peaked in 2005 when Lake Powell reached its lowest point since filling in the 1980s of 3,555.1 feet (1083.6 m) elevation on April 8. Since the 2008 Opinion, Lake Powell elevation has ranged from 3,588.26 feet (1093.70 m) on March 11, 2008 to 3,642.29 feet (1110.17 m) on July 12, 2009. Climate change is predicted to result in drier conditions in the Colorado River basin, thus lower Lake Powell reservoir elevations (and warmer release temperatures) may become the norm (Seager et al. 2007, U.S. Climate Change Science Program 2008a, 2008b).

Water temperatures in the mainstem Colorado River have generally been elevated over the last decade (Figure 4). These temperatures are not optimal for humpback chub spawning and growth, but may provide some temporary benefit and contribute to the improving status of the species. Release temperatures from Glen Canyon Dam have remained elevated relative to operations during the 1980s and 1990s due to continued drought-induced lower Lake Powell reservoir levels, and somewhat due to relatively high inflow in 2008, 2009, and 2011. Water temperature in the mainstem at Lees Ferry reached about 14 °C in 2008 (USGS 2009a), similar to temperatures in 2003 when drought effects from low Lake Powell levels began to raise Glen Canyon Dam release temperatures. The 2008 temperatures were warm enough to provide some benefit to humpback chub, though not as much as the high temperatures of 16° seen at Lees Ferry in 2005. Water temperatures peaked at 11° in 2010 and 13.5° in 2011 (Figure 4; USGS unpublished data).

Nearshore habitats are important nursery habitats for humpback chub (Valdez and Ryel 1995, Robinson et al. 1998, Stone and Gorman 2006). Temperature differences between mainchannel and nearshore habitats can be pronounced in backwaters and other low-velocity areas. The amount of warming that occurs in backwaters is affected by daily fluctuations, which cause mixing with cold mainchannel waters (AGFD 1996, Behn et al. 2010). Behn et al. (2010) found that the water in Grand Canyon backwaters completely exchanges with the mainstem an average of 6.5 times per day when discharge fluctuates but just 2.3 times per day when discharge is stable. Hoffnagle (1996) found that the mean, minimum, maximum, and daily range of water temperature in backwaters were higher under steady versus daily fluctuating flows, with mean daily temperatures (14.5 °C) under steady flows about 2.5 °C greater than those under fluctuating flows. Differences in the mainchannel temperatures during steady and fluctuating flows were also statistically significant, but mean temperatures differed by only 0.5 °C. Anderson and Wright (2007) also found that fluctuations have minimal effect on mainstem water temperatures but that fluctuations can have substantial effects to nearshore water temperatures. Similar results were documented by Trammell et al. (2002), who found backwater temperatures during the 2000 low steady summer flow experiment to be 2-4 °C above those during 1991-1994 under fluctuating flows. Korman et al. (2006) also found warmer backwater temperatures under steady flow conditions, concluding that backwaters were cooler during fluctuations because of the daily influx of cold main channel water. These effects were documented during the months of August and September, but not October, when cooler air temperatures caused backwaters to be about 1 °C cooler than the mainchannel. However, they also noted that the extent of the effect was variable and depended on the timing of daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater relative to solar insolation. Nevertheless, when mainstem temperatures are cold (i.e., <12 ° C) backwaters may provide a thermal refuge for juvenile and adult humpback chub, and the thermal conditions in backwaters are generally more favorable for native fish when discharge is stable relative to fluctuating. Use of thermal refuges (i.e., small, discrete locations that represent a more favorable thermal environment than the main river) by fish have been documented in a variety of systems (e.g., Ebersole et al. 2001, Torgerson et al. 1999).

The GCDAMP has been experimenting with high flow tests as a means to restore sand bars in Grand Canyon since 1996, most notably in 1996, 2004, and 2008. These tests have had varying results, and although a best case scenario of dam operations that permanently sustains existing sand bars appears feasible, this approach is still a research question (Wright et al. 2008b). HFEs do create sand bars and associated backwaters.

Although backwaters appear to be important habitat types of young humpback chub (AGFD 1996, Hoffnagle 1996), their overall importance relative to habitat suitability, availability, and humpback chub survival and recruitment are still in question, and additional research on this relationship has long been needed. A conservation measure of the 2008 Opinion aimed at meeting this need, the NSE, began in 2008. This study was designed to clarify the relationship between flows and mainstem habitat characteristics and habitat availability for young-of-year and juvenile humpback chub and other native and non-native fish species. The NSE has documented humpback use and available habitat in the small study area below the LCR between Heart Island and Lava Chuar rapid. Preliminary results suggest that backwater habitats in this reach were small and ephemeral with fluctuating flows because of the high shoreline gradients. When backwaters were present, these habitats were often submerged during higher water releases (>15,000). Additional preliminary NSE results suggest that during the NSE study period (July - October), humpback chub were most often found in talus slopes although positive selection for backwater habitats occurred when backwater habitats were available. However backwater habitats are clearly not required for humpback chub to persist in the NSE study reach because, while backwater habitats have been observed to be ephemeral in this study reach, juvenile humpback chub have been consistently collected and, as described below, exhibited juvenile survivorship between 12 NSE sampling trips (GCMRC unpublished data).

The NSE project has developed preliminary year-specific survival rates for humpback chub 40-99 mm (1.6- 3.9 inches) TL of 47% SE 3.5% (95% confidence interval [CI] 40-54%) in 2009 and 32% SE 6.1% (95% CI 21-45%) in 2010. For humpback chub 100-199 mm (3.9-7.8 inches) TL, year-specific annual survival rates were 52% SE 3.9% (95% CI 44% to 59%) in 2009 and 52% SE 7.5% (95% CI 37-66%) in 2010. The periods of these specific annual survival rates were selected based on the assumption that the majority of taggable y-o-y chub would begin entering the mainstem and encountering NSE gear (July 1). So the annual survival rate "2009" is the period from July 1, 2009 to June 30, 2010, and the "2010" survival rate is the period from July 1, 2010 to June 30, 2011. No information is available for humpback chub less than 40 mm (1.6 inches) because this size fish are too small to be marked and later identified (GCMRC unpublished data).

An important feature of the environmental baseline is climate change. Some studies predict continued drought in the southwestern United States, including the lower Colorado River basin due to climate change. Seager et al. (2007) analyzed 19 different computer models of differing variables to estimate the future climatology of the southwestern United States and northern Mexico in response to predictions of changing climatic patterns. All but one of the 19 models predicted a drying trend within the Southwest. A total of 49 projections were created using the 19 models and all but three predicted a shift to increasing aridity in the Southwest as early as 2021–2040 (Seager et al. 2007). Published projections of potential reductions in natural flow in the Colorado River Basin by the mid-21st century range from approximately 45 percent by Hoerling and Eischeid (2006) to approximately six percent by Christensen and Lettenmaier (2006). The U.S. Climate Change Science Program completed a report entitled “Abrupt Climate Change, A report by the U.S. Climate Change Science Program and the Subcommittee on Global Climate Change Research” (U.S. Climate Change Science Program 2008a) that concluded, if model results are correct, that the southwestern United States may be beginning an abrupt period of increased drought (U.S. Climate Change Science Program 2008b).

If predicted effects of climate change result in persistent drought conditions in the Colorado River basin similar to or worse than those seen in recent years, water resources will become increasingly taxed as supplies dwindle. Increased demand on surface and groundwater supplies throughout the Colorado River basin is also likely. The upper Colorado River basin states are not using their full allocations of Colorado River water and will likely look to implement projects to utilize additional water. For example, the Lake Powell Pipeline project is currently proposed to provide water from Lake Powell to communities in southwest Utah. The pipeline if it goes forward is anticipated to deliver approximately 100,000 acre-feet of water, likely resulting in lower Lake Powell reservoir elevations, and warmer Glen Canyon Dam release temperatures, on average, especially in the face of climate change (USFWS 2008).

Changes to climatic patterns may warm water temperatures, alter stream flow events, and increase demand for water storage and conveyance systems (Rahel and Olden 2008). Resulting warmer water temperatures across temperate regions are predicted to expand the distribution of existing warmer water aquatic non-native species by providing 31 percent more suitable habitat for aquatic non-native species, based upon studies that compared the thermal tolerances of 57 fish species with predictions made from climate change temperature models (Mohseni et al.

2003). Eaton and Scheller (1996) reported that while several cold-water fish species in North America are expected to have reductions in their distribution due to the effects of climate change, several warm water fish species are expected to increase their distribution. In the southwestern United States, this may occur where water remains perennial but warms to a level suitable to non-native species that were previously physiologically precluded from these areas. Species that are known or suspected to prey on or compete with humpback chub populations such as black bullhead, fathead minnow, common carp, channel catfish, and largemouth bass are expected to increase their distribution by 5.9 percent, 6.0 percent, 25.2 percent, 25.4 percent, and 30.4 percent, respectively (Eaton and Scheller 1996). Rahel and Olden (2008) also predict that changing climatic conditions will benefit warm water non-native species such as red shiner, common carp, mosquitofish (*Gambusia affinis*), and largemouth bass. All of the above-mentioned species already occur in the Colorado River in Marble and Grand canyons, but climate change and warmer water temperatures could lead to their proliferation and range expansion within the river. The effect of water temperature (and flow volume and fluctuation, which affect water temperature) on the abundance and composition of non-native fish species, and the tradeoff this represents to natives that benefit from warmer water, is an important consideration that was apparently identified at the time of the 1995 Opinion and earlier; however, the severity of this threat appears to have been underestimated by biologists of the time, given newer information available on the effects of non-native species population increases and concomitant decreases in humpback chub populations in the Yampa and Green rivers, and how closely this now appears linked to temperature and hydrology (USFWS 1978, 1995a, Finney 2006, Fuller 2009, Johnson et al. 2008, R. Valdez, pers. comm., 2009).

Rahel et al. (2008) also noted that climate change could facilitate expansion of non-native parasites. This may be an important threat to humpback chub. Optimal Asian tapeworm (*Bothriocephalus acheilognathi*) development occurs at 25-30 °C (Granath and Esch 1983), and optimal anchorworm temperatures are 23-30 °C (Bulow et al. 1979). Cold water temperatures in the mainstem Colorado River in Marble and Grand Canyons have prevented these parasites from completing their life cycles and limited their distribution. Warmer climate trends could result in warmer overall water temperatures, increasing the prevalence of these parasites, which can weaken humpback chub and increase mortality rates.

Predation and Competition from Non-native Fish

As discussed in the 2008 Opinion and 2009 Supplement Opinion, predation and competition from non-native fish species constitute a serious threat to humpback chub (Minckley 1991, Mueller 1995), and the non-native fish control conservation measure of the 2008 Opinion was developed to reduce that threat. Over a three year period, the mechanical removal program of 2003-2006 reduced estimated numbers of trout by 90% from about 6,446 (in January 2003) to 617 (in February 2006). This removal took place at a time when the population of rainbow trout was undergoing a systemic decline of about 20% per year, presumably because of poor water quality from low levels in Lake Powell. The mechanical removal program in the LCR reach was successful primarily at reducing the abundance of rainbow trout. However, maintenance of low rainbow trout abundance was facilitated by reduced immigration rates during 2005-2006 and the systemic decline in trout abundance (Coggins 2009).

The abundance of non-native rainbow trout in the important LCR Reach has increased since the 2008 High Flow experiment (Makinster et al. 2009a, 2009b) and brown trout numbers in Reach

3 (RM 69.1-109) have increased every year beginning in 2006 (Makinster 2010). Mainstem fish monitoring detected increases in rainbow trout in the LCR inflow reach of the Colorado River in 2008, prompting a removal trip in May of 2009. During the 2009 removal trip, AGFD removed 1,873 rainbow trout. The 2010 catch per unit effort in reach 2 (RM 56-69) was similar to 2009, but catch per unit effort in 2011 was nearly twice that of 2009 (B. Stewart, AGFD, written comm. 2011). These estimates may indicate that rainbow trout are likely increasing throughout Marble Canyon. Unlike the situation in 2003, however, the four native fish species occurring in Grand and Marble Canyons, flannelmouth sucker, bluehead sucker, speckled dace, and humpback chub, are still very abundant in the LCR inflow reach (Makinster et al. 2009b, Van Haverbeke et al. 2011).

The threat posed to humpback chub in Grand Canyon by non-native crayfish is unclear, although climate change could result in their spread in Marble and Grand Canyons due to warmer mainstem water temperatures (Valdez and Speas 2007, Rahel et al. 2008). Non-native crayfish have been found in Glen Canyon in the past, although they have not become established. At least two species of crayfish, the red swamp crayfish (*Procambaris clarki*) and the northern or virile crayfish (*Orconectes virilis*), have been introduced into the action area, which could affect native fish populations. The red swamp crayfish is well established downstream in Lake Mead, and northern crayfish is well established in Lake Powell (Johnson 1986). In 2007, northern crayfish were observed in Lees Ferry, although only three northern crayfish were observed, and none were captured in further intensive efforts to capture crayfish (A. Makinster, AGFD, pers. comm., 2009). Red swamp crayfish were also found as far upstream from Lake Mead as Spencer Canyon (RM 246) in 2003 (L. Stevens, Grand Canyon Wildlands Council, pers. comm., 2009). Presumably crayfish would have become established by now in Marble and Grand Canyons if conditions were suitable, given their close proximity in Lakes Powell and Mead, although precisely what conditions have prevented this are not known.

Crayfish appear to negatively impact native fishes and aquatic habitats through habitat alteration by burrowing into stream banks and removing aquatic vegetation, resulting in decreases in vegetative cover and increases in turbidity (Lodge et al. 1994, Fernandez and Rosen 1996). Crayfish also prey on fish eggs and larvae (Inman et al. 1998), and alter the abundance and structure of aquatic vegetation by grazing, which reduces food and cover for fish (Fernandez and Rosen 1996). Creed (1994) found that filamentous alga (*Cladophora glomerata*) was at least 10-fold greater in aquatic habitats absent crayfish. Filamentous alga is an important component of aquatic vegetation in Marble and Grand Canyons that is part of the food base for humpback chub (Valdez and Ryel 1995). Carpenter (2005) found that crayfish reduced growth rates of flannelmouth sucker, but Gila chub (*Gila intermedia*, a closely related species to humpback chub) were more affected by intraspecies competition than from competition with crayfish. Marks et al. (2009) found that, following eradication of non-native fishes and flow restoration in Fossil Creek, Arizona, crayfish abundance increased significantly, but this had no apparent effect on native roundtail chub (*Gila robusta*, another species closely related to humpback chub), which also increased in numbers significantly following removal of non-native fish. The threat posed to humpback chub in Grand Canyon by non-native crayfish is unclear, although climate change could result in their invasion in Marble and Grand Canyons due to warmer mainstem water temperatures (Valdez and Speas 2007, Rahel et al. 2008).

Humpback Chub Critical Habitat

Critical habitat for humpback chub in the action area consists of Critical Habitat Reach 6, the LCR, and Critical Habitat Reach 7, the Colorado River in Marble and Grand Canyons. Reach 6 consists of the lowermost 8 miles (13 km) of the LCR to its mouth with the Colorado River. Reach 7, consists of a 173-mile (278-km) reach of the Colorado River in Marble and Grand Canyons from Nautiloid Canyon (RM 34) to Granite Park (RM 208). The PCEs, as described in the Status of the Species section, are: Water of sufficient quality (W1) (i.e., temperature, dissolved oxygen, lack of contaminants, nutrients, turbidity, etc) that is delivered to a specific location in accordance with a hydrologic regime required for the particular life stage for each species (W2); Physical Habitat, areas for use in spawning (P1), nursery (P2), feeding (P3), and movement corridors (P4) between these areas; and Biological Environment, food supply (B1), predation (B2), and competition (B3) (Maddux et al. 1993a, 1993b, USFWS 1994).

Critical Habitat Reach 6 – Little Colorado River

The current condition of critical habitat in Reach 6, the LCR, is probably similar to historical conditions in many ways. As discussed in the Status of the Species section, all of the PCEs are provided for in this reach of humpback chub critical habitat, and this segment supports the majority of the Grand Canyon population, the largest of the humpback chub populations.

The PCE for water, water quality and quantity have likely been altered by land uses such as livestock grazing and development in the LCR basin, although little monitoring or research has been conducted on changes to this critical habitat segment from historical conditions. Water use in the basin has clearly diminished surface flows because much of the LCR is now intermittent while it was perennial historically (Valdez and Thomas 2009). But data for the USGS Cameron gauge (back to 1947) show that the LCR hydrograph has been highly variable with frequent floods as well as periods of low to no flow, with no discernable pattern. Flow in the reach of critical habitat is reduced annually to base flow from Blue Springs of about 225 cfs, although floods are common, and may even exceed historical floods in magnitude given that development results in greater peak runoff, and frequency and magnitude of flooding events (Hollis 1975, Neller 1988, Booth 1990, Clark and Wilcock 2000, Rose and Peters 2001, Wheeler et al. 2005). Livestock grazing, a land use throughout the LCR basin, similarly impacts aquatic and riparian habitats at a watershed level though soil compaction, altered soil chemistry, and reductions in upland vegetation cover, changes which lead to an increased severity of floods and sediment loading, lower water tables, and altered channel morphology (Rich and Reynolds 1963, Orodho et al. 1990, Schlesinger et al. 1990, Belsky et al. 1999).

Development can affect water quality in a number of ways. Urban runoff contains a variety of chemical pollutants including petroleum, metals, and nutrients from a variety of sources such as automobiles and building materials (Wheeler et al. 2005). Development also leads to increases in the number of dumps and landfills that leach contaminants into ground and surface water, reducing water quality and thereby degrading fish habitat, and there is evidence of this in the LCR, which contains surges of trash with each flooding event. Similarly, wastewater treatment plants that accompany development also can contaminate ground and surface water (Gallert and Winter 2005). Pharmaceuticals and personal care products also may contain hormones, which are present in wastewater, and can have significant adverse effects to fishes, particularly fish reproduction (Kime 1994, Rosen et al. 2007). The use of pesticides from agricultural and residential use may enter water sources which, can have lethal and sublethal effects to fish

(Ongley 1996). Despite the presence of much development in the LCR basin, we know of no significant water quality issues with W1 of critical habitat in Reach 6.

Whatever effect land and water use of the LCR basin has had on modification of the lower LCR and its hydrograph, it is not readily apparent from the physical habitats available to humpback chub. This could be because of the continued spring-fed base flow and the unique travertine geology of the system which forms a complex habitat matrix of pools, shallow runs, and races. Uncemented calcium carbonate particles form part of the stream bottom and contribute to the turbidity of the river (Kubly 1990), and flood flows are extremely turbid. This also could contribute to the lower levels of non-native predators in the LCR, which generally evolved and survive better in clear water. Perhaps also important, development of the LCR basin is widespread, but not dense, so effects of land uses are mediated by large expanses of open space and the sheer size of the basin. Regardless, all of the physical PCEs (P1-4) are provided for in the LCR, and the stream appears to fully support all life stages of the species, and all life stages appear to have been increasing in recent years (Coggins and Walters 2009, Stone 2008a, 2008b, Van Haverbeke et al. 2011).

Although the biological PCE for food supply (B1) is met in this reach (as described in the Status of the Species section), there appears to be greater food availability for adult humpback chub in the mainstem Colorado River based on body condition. Hoffnagle et al. (2000) reported that condition and abdominal fat were greater in the mainstem Colorado River than in the LCR during 1996, 1998, and 1999. Alternatively, this may have been due to the increased prevalence and abundance of parasites (especially *Lernaea cyprinacea* and Asian tapeworm) in the LCR fish as opposed to greater food availability in the Colorado River. The NSE study also documented higher growth rates of juvenile humpback chub in the mainstem relative to growth rates of juvenile fish in the LCR in 2009 and 2010 (GCMRC unpublished data), but it is uncertain whether these growth differences are a function of food availability, habitat, temperature, parasites, or a combination of these and other as of yet unidentified factors).

The biological PCEs of predation (B2) and competition (B3) from non-native species are also met. Non-native fish species that prey on and compete with humpback chub are present, but in very low numbers relative to native fishes including humpback chub. For example, although channel catfish captures increased between the spring and fall 2008 monitoring trips (from 1 fish in spring to 66 fish in the fall), even the increased number of channel catfish captured (n=66) was a small fraction of the total number of humpback chub captured (n=3,084) (Stone 2008a, 2008b). Although fish remains were found in non-native species in 2007 in the LCR, no direct evidence of humpback chub predation was documented, although predation on humpback chub by catfish and trout has been documented in the past (Marsh and Douglas 1997, Yard et al. 2008). However, for the LCR, the primary indication that the biological PCE, as well as the other PCEs, are met in the LCR is the increasing abundance of humpback chub and recruitment that has characterized the population in the LCR in recent years (Stone 2008a, Stone 2008b, Coggins and Walters 2009, Van Haverbeke et al. 2011).

The LCR reach of critical habitat plays an important role in the recovery of the species because this is the primary spawning and rearing area for the Grand Canyon population, which also constitutes (along with the mainstem Colorado River) the lower Colorado River Recovery Unit. As described in the Status of the Species section, demographic criteria must be met for this Recovery Unit, as well as for one or two core populations in the upper Colorado River basin, for downlisting and delisting, respectively, to occur (USFWS 2002a). As described earlier, in addition to the demographic criteria, the Recovery Goals also contain site-specific management actions and tasks and corresponding recovery factor criteria that must be met for downlisting and delisting to occur. In evaluating the effectiveness of the critical habitat unit in meeting recovery, the primary measure is the status of the population in relation to the demographic criteria, and the secondary measure is the state of the recovery factors and the implementation of their associated management actions and tasks, such as flow management and non-native fish control.

The 2008 abundance of humpback chub in the LCR was estimated to be 7,650 adults (between 6,000-10,000, age 4+; ≥ 200 mm (7.9 inches TL) which is nearing the 10,000-11,000 adults the ASMR estimates constituted the adult LCR population when marking began in 1989, and appears to have been in an upward increasing trend since 2001 (Coggins et al. 2006a, Coggins 2008a, Coggins and Walters 2009). The demographic criteria for the Grand Canyon population for downlisting is that the humpback chub population is maintained as a core population over a 5-year period, starting with the first point estimate acceptable to the FWS, such that the trend in adult (age 4+; ≥ 200 mm [7.9 inches]) point estimates does not decline significantly, the mean estimated recruitment of age-3 (150–199 mm [5.9-7.8 inches]) naturally produced fish equals or exceeds mean annual adult mortality, and the population point estimate exceeds 2,100 adults. The FWS Upper Basin (Region 6) has not yet determined that the demographic criteria for the Grand Canyon population have been met, but the best available science indicates that the demographic criteria are at least nearing being met. Given this, the PCEs in Critical Habitat Unit 6, the LCR, appear to be meeting the needs of recovery.

The recovery factor criteria and associated management actions and tasks that relate to this critical habitat unit are based on the five listing factors. Most of these are directed at improving and protecting humpback chub habitat including critical habitat and the PCEs of critical habitat. Those that relate to the LCR and Reach 6 are discussed below.

For Factor A, flows for the LCR that meet the needs necessary for all life stages of humpback chub to support a recovered Grand Canyon population appear to be met in recent years, given the status and trend of the LCR population (Stone 2008a, 2008b, Coggins and Walters 2009). However, a specific definition of the LCR flows that provides for these habitats, or a specific model that relates flow to habitat conditions, has not been developed and has been identified as a need by Valdez and Thomas (2009). They provide a comprehensive look at the LCR flow regime and the needs of the humpback chub in the LCR in a management plan for the LCR basin. This plan was developed in response to an element of the reasonable and prudent alternative of the 1995 Opinion (USFWS 1995b) which required that Reclamation be instrumental in developing a management plan for the LCR. LCR watershed planning was also a conservation measure of the 2008 Opinion and a project in the Humpback Chub Comprehensive Plan and will continue under this opinion (Glen Canyon Dam Adaptive Management Program 2009).

Valdez and Thomas (2009) discuss the effects of human land uses of the LCR watershed and how they affect ground and surface water and ultimately flow and humpback chub habitat in the lower LCR. Key water uses of the basin are associated with the communities of Flagstaff and Winslow and several regional power plants and associated withdrawals from the C-aquifer, the same aquifer that feeds Blue Spring. However, they also note that although these water uses clearly must have reduced inputs of surface flow causing the river to become intermittent, the change in the LCR hydrograph is not easy to detect. For example, for the period of record for the U.S. Geological Survey Cameron stream flow gauge (since 1947), there is no discernable pattern of no-flow days, although maximum daily flows have lowered since 1988, perhaps indicating an effect of drought and water use.

Factor B, overutilization, may not be relevant to the status of critical habitat, although there have been some concerns raised about handling stress from field surveys. An estimated 50-200 are killed each year during field activities and collection for scientific purposes, although the number has reached as high as 1,000 humpback chub during one year (P. Sponholtz, FWS, pers. comm., 2011). However, despite this mortality from handling stress, humpback chub in the LCR (the primary location of research efforts) have continued to increase in number over the last decade, and research and monitoring efforts have provided important insights into the recovery needs of the species.

For Factor C, the focus is on controlling the proliferation and spread of non-native species that prey on, compete with, and parasitize humpback chub, such as rainbow trout, channel catfish, black bullhead, and common carp, as well as the non-native internal fish parasite Asian tapeworm. Current levels of control of non-native fish species appear adequate in the LCR as non-native fish in Reach 6 of critical habitat continue to be at low levels, although high numbers of trout occur in the mainstem confluence area adjacent to the tributary. Clearly such low levels should be maintained, but a specific target level as in the Recovery Goals has not been identified. Non-native fishes stocked into the area utilizing Federal funds have been evaluated, and are not anticipated to significantly affect humpback chub or its critical habitat; however, illegal stocking in the area could result in adverse effects to humpback chub (USFWS 2011b).

Asian tapeworm has been documented at infestation rates of 31.6–84.2 percent in the LCR, and has been hypothesized as a factor in poor condition factor of humpback chub in the LCR (Meretsky et al. 2000, Hoffnagle et al. 2006). Nevertheless, the status and trend of the LCR population indicates that the negative effect of Asian tapeworm is not significant. Research efforts have also noted that infestation rates are highly variable, and may be dependent on river flow, size class of fish, or other factors. More research is needed to determine the population-level effect of Asian tapeworm and the need and scope of a possible control program for the parasite. In the 2010 spring sampling trip, *Lernaea* was observed on 67 of 3,264 humpback chub (2.0%); individual fish were carrying between 1 to 4 parasites each. *Lernaea* was also seen on one bluehead sucker, one flannelmouth sucker, and 5 speckled dace. During the fall sampling effort of 2010, *Lernaea* was observed on 181 humpback chub (6.2% of total humpback chub captures). The infected humpback chub on both trips appeared to be distributed between the confluence and the top of Salt reach. One flannelmouth sucker and one speckled dace were also observed carrying *Lernaea* each during the fall survey effort (Van Haverbeke et al. 2011). The New Zealand mud snail, *Potamopyrgus antipodarum*, was also detected in the Grand Canyon in 1995 and may be expanding. The Humpback Chub Comprehensive Plan includes a project for the monitoring and control of humpback chub parasites and diseases (Glen Canyon Dam Adaptive Management Program 2009).

For Factor D, existing regulatory mechanisms, the Recovery Goals identify the need to determine and implement mechanisms for legal protection of adequate habitat in the Little Colorado River through instream-flow rights, contracts, agreements, or other means. The most thorough accounting of the mechanisms and stakeholders needed to accomplish this for the LCR are provided by Valdez and Thomas (2009). As mentioned above, it appears as if flow needs for all life stages are met for humpback chub in Reach 6, a required task of the Recovery Goals, although Valdez and Thomas (2009) recommend that a model be developed that defines the instream flow needs of humpback chub to ensure continued support for all life stages of the species and relate flow to habitat needs of all life stages (Valdez and Thomas 2009). The current status and upward trends in population abundance and recruitment (Stone 2008a, 2008b, Coggins and Walters 2009, Van Haverbeke et al. 2011) indicate that the current flow conditions in the LCR are adequate.

For Factor E, other natural or manmade factors, the primary element relative to the LCR is to identify and implement measures to minimize the risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the Cameron Bridge spanning the Little Colorado River. This is also a project of the Humpback Chub Comprehensive Plan (Glen Canyon Dam Adaptive Management Program 2009). A plan is needed to address this threat and efforts to develop one have not been initiated, though the need has been identified since at least 2002, and would likely require minimal expense. Reclamation has, as a conservation measure of the 2008 Opinion, agreed to assist in implementing the Humpback Chub Comprehensive Plan and Reclamation has agreed to continue to implement this as part of the proposed action.

Critical Habitat Reach 7 – Colorado River in Marble and Grand Canyons

Critical habitat in Reach 7, in Marble and Grand canyons, has been altered dramatically from historical conditions, primarily due to emplacement of Glen Canyon Dam. In the 2008 and 2009 Supplemental Opinions we stated that the importance of habitat in the mainstem to recovery is not known. However, we know that these “big river fish” use a variety of riverine habitats, with adults especially found in canyon areas with fast current, deep pools, and boulder habitat, and at least some of the PCEs are functional as demonstrated by the NSE study and the persistence of mainstem aggregations. Reach 7 provides an important role in support of the Grand Canyon population (the largest of the humpback chub populations) although the relationship with the LCR and the overall importance of habitats in the mainstem to recovery is not yet known. This is because most of the humpback chub population occurs in the largest aggregation, the LCR inflow aggregation, which utilizes the LCR to a large degree. To put this in perspective, the population estimate produced for the population, currently estimated at 7,650 adult fish, is essentially the LCR inflow aggregation (Coggins and Walters 2009) because there is little movement between the LCR inflow aggregation and the other mainstem aggregations (Paukert et al. 2006). All the other aggregations are much smaller than this, and the largest of these, the Middle Granite Gorge aggregation (RM 126.1-129.0) was estimated by Valdez and Ryel (1995) to be 98 adult fish. Preliminary data from mainstem aggregation monitoring (Figure 3) show the distribution of catch rates of humpback chub in Reach 7. Catch of fish is not adjusted for effort, such as hours of netting, seine hauls, etc. Therefore, the number of humpback chub caught during different time periods does not represent density or relative abundance because effort and gear types are different during different time periods. Distribution of catches across river miles may also be somewhat biased by gear types used; however, a relatively wide distribution of humpback chub catches between river mile 25 and 250 has been documented. Longitudinal distribution has not decreased in the last decade and the data suggest a broader distribution of chub since 2000 compared to the 1990s as well as local increases in abundance (W. Persons, USGS, written communication, 2011b).

Most spawning takes place in the LCR, and some adults may never leave the LCR. Marsh and Douglas (1997) thought that there was a contingent of resident adult fish that never leave the LCR, and another contingent that migrated into the LCR to spawn. Valdez and Ryel (1995) hypothesized that large adult humpback chub may only utilize the LCR to spawn, and Gorman and Stone (1999) found that smaller adults remain in the LCR, but once they reach a certain size, they leave after spawning to spend non-spawning periods in the mainstem. Thus it is possible that the demographic criteria for the Grand Canyon population could be met by providing for all of the PCEs of critical habitat in Reach 6, the LCR, and a set of PCEs in the mainstem focused on needs of non-spawning adult fish. However, this seems unlikely, and at the least, providing for all the PCEs in Reach 7 would add resiliency to the overall population by maintaining some recruitment from the mainstem aggregations.

The flow of the Colorado River in Marble and Grand canyons has been modified by Glen Canyon Dam since dam completion in 1964, and the dam is a primary factor in the function of PCEs in this reach. Flows since Reclamation's 1995 Environmental Impact Statement (EIS) and 1996 ROD have been limited to 5,000 to 25,000 cfs except during experimental flows such as in 1996, 2004, and 2008, when experimental high flows from 41,500 to 45,000 cfs were tested. Prior to the current MLFF period of flow releases, daily fluctuations were greater, from 1,000 to 31,500 with unrestricted ramping rates (Reclamation 1995). To put this in context, historically flood flows of over 120,000 cfs were relatively common, occurring about every six years, and low flows of 500-1,000 cfs were also common. Daily variation in flow was relatively small, with a median of about 542 cfs (Topping et al. 2003). Releases from Glen Canyon Dam are now varied on an annual and daily time scale to meet the demand for electricity. The post-dam median daily change in discharge (8,580 cfs) is now approximately 15 times greater than pre-dam (542 cfs) and actually exceeds the pre-dam median discharge (7,980 cfs) (Topping et al. 2003). Post-dam changes in discharge create dramatic changes in daily river stage, 6.6 ft or greater in some areas; pre-dam, diurnal stage change was seldom more than 1.0 ft (GCMRC unpublished data).

Since closure of the dam the river has usually been perennially cold because Glen Canyon Dam typically releases hypolimnetic water (the deepest, coldest layer of the reservoir) with a relatively constant temperature which ranges from 6-8 °C at high reservoir levels. Releases from 2003 to present have been warmer due to lower Lake Powell reservoir levels, and reached as high as 16 °C in the Lees Ferry reach in 2005, 13-14 °C in 2008, and about 13 °C in 2009 (Vernieu et al. 2005, USGS 2009a, c). A low summer steady flow experiment in 2000 also warmed river temperatures significantly, and may have been responsible for increased recruitment of the 1999-2001 brood years (Trammel et al. 2002, Coggins and Walters 2009). However, the warmer flows may also have provided an advantage to warm water predators of and competitors with humpback chub, which include fathead minnows, plains killifish (*Fundulus zebrinus*). Those two species and even rainbow trout appear to benefit from warmer water or reduced fluctuations, or both (Ralston 2011). Other warm water fish present in the Colorado River such as smallmouth bass, channel catfish, black bullhead, and common carp are also likely to benefit from warmer water. Climatologists predict that the southwest will experience extended drought, so lower Lake Powell Reservoir elevations and warmer release temperatures may become the norm (Seager et al. 2007, U.S. Climate Change Science Program 2008a, b).

Water temperature also affects the food base available for fish, also a PCE of critical habitat for humpback chub. When water temperatures are higher, rates of algae and invertebrate production in the mainstem river likely increase (Yard 2003, Sutcliffe et al. 1981, Hauer and Benke 1987, Benke and others 1988, Pockl 1992, Huryn and Wallace 2000), and both algae and invertebrates represent important food resources for native and non-native fish (Donner 2011, Zahn-Seegert 2011, Cross et al. 2011, Valdez and Ryel 1995, McKinney et al. 2001). Warmer water temperatures also increase the survival and growth of other mainstem non-native fishes that compete with and prey on humpback chub, so warmer water temperatures present a tradeoff in a sense of providing more food and better growing conditions for humpback chub, but also more non-native fish predators and competitors (Peterson and Paukert 2005), some of which, (such as rainbow trout which are functioning below their optimum temperature preference), have high dietary overlap with humpback chub (Valdez and Ryel, 1995, Donner, 2011).

The complex relationship between temperature, physical habitat, and biological habitat PCEs for humpback chub may provide some explanation for why humpback chub have persisted in Grand Canyon, and even thrived over the past decade, despite co-occurring with non-native fish species such as rainbow trout and channel catfish. Although water temperatures may not reach the optimal of 16-24 °C for humpback chub spawning, rearing, and growth, temperatures of 12-16 °C, at which humpback chub can complete their life cycle but are not optimal, have occurred and in fact have been much more common in recent years. Temperatures in the 12-16 °C range have occurred every year since 2003 at the mouth of the LCR, although temperatures there have only exceeded 16 °C in one year, 2005 (P. Grams, USGS, oral communication, 2011).

The LCR aggregation of adult humpback chub has been steadily increasing in number since 2001 based on the ASMR through 2008 (Coggins and Walters 2009) and on closed population estimates in the Little Colorado River by the FWS through 2010 (Van Haverbeke et al. 2011). During this same period, other humpback chub aggregations in the mainstem Colorado River also appear to be increasing (R. Van Haverbeke, FWS, pers. comm., 2011, W. Persons, USGS, written communication, 2011b) although abundance estimates are not available. One possible explanation for this may be that although temperatures in the 12-16 °C range are not optimal for humpback chub survival and growth, the conditions provided for suitable PCEs of critical habitat in the mainstem necessary for humpback chub to survive and recruit. Another explanation is that the LCR population is stable and increasing and provides a significant source of fish to mainstem aggregations during passive and active egress out of the LCR. In this case, the LCR acts as "source" of fish to a "sink" population (a population that dies without reproduction or expansion) in the mainstem. Temperatures in this range may be high enough during certain critical periods to negate cold water shock of humpback chub moving from the LCR to the mainstem (Ward et al. 2002). These conditions allow for better growth of humpback chub in the mainstem (Hamman 1982, Marsh 1985, Valdez and Ryel 1995), promote better swimming ability, and may improve their ability to avoid predation (Ward and Bonar 2003, D. Ward, USGS, oral communication, 2011). Mainstem temperatures in this range may also provide for better food availability which may give humpback chub a competitive advantage over non-native fishes. Yet because these temperatures are also suboptimal for non-native fish predators and competitors, competition and predation from some non-native fishes (not including brown trout which do not appear to be affected at these temperature ranges), are somewhat kept in check, at least to the extent that humpback chub can survive and have some limited recruitment in the mainstem.

As described above, mainstem water temperatures have been warmer in recent years due to climate conditions/drought and lower Lake Powell elevation (USGS 2009b). The temperature of dam release temperatures peaked in 2005 when they exceeded 16° C and Lake Powell elevation dropped to 3535 feet (1077 m) elevation, its lowest since filling in 1980. A low summer steady flow experiment in 2000 also warmed river temperatures significantly, and may have been responsible for increased recruitment of the 1999-2001 brood years (Trammel et al. 2002, Coggins and Walters 2009). Releases in that 2000 experiment and releases since 2003 during low Lake Powell reservoir levels have resulted in temperatures exceeding 12 °C at the mouth of the Little Colorado River (Figure 6), and this may in part explain why humpback chub status has been steadily increasing during this period (Coggins and Walters 2009).

Cold water is also a factor in juvenile humpback chub vulnerability to predation by non-native fishes. Mass movement of larval and juvenile humpback chub out of the LCR occurs during the summer, especially during monsoon rain storms in late summer (Valdez and Ryel 1995). These movements may also occur during high spring flows (Robinson et al. 1998). Young humpback chub that are washed into the mainstem are subjected to a significant change in water temperature which can be as much as 10 °C or more. This results in thermal shock of young fish, and a reduction in swimming ability, which also increases their vulnerability to predation (Lupher and Clarkson 1994, Valdez and Ryel 1995, Marsh and Douglas 1997, Robinson et al. 1998, Clarkson and Childs 2000, Ward et al. 2002). Due to the effects of thermal shock, juvenile humpback chub exiting the warm LCR and entering the cold mainstem may be too lethargic to effectively avoid predation or swim to suitable nearshore habitats (Valdez and Ryel 1995, Robinson et al. 1998). Cold water by itself also results in mortality of eggs and larval fish (Hamman 1982, Marsh 1985). It is not known if the warmer mainstem temperatures observed since 2003 limited the effects of thermal shock versus conditions that occurred in the 1990s.

Glen Canyon Dam operations also modify the hydrograph (the timing of water delivery in the river). The MLFF produces a hydrograph with the highest flow volumes in the winter and summer months to meet increased demand for electricity. Humpback chub evolved with a historically variable hydrograph in Grand and Marble canyons, but with consistently high flows in the spring following snow melt and low flows in the summer (Topping et al. 2003). The high spring flows of the natural hydrograph provided a number of benefits. Bankfull and overbank flows provide energy input to the system in the form of terrestrial organic matter and insects that are utilized as food. High spring flows clean spawning substrates of fine sediments and provide physical cues for spawning. High flows also form large recirculating eddies used by adult fish. High spring flows have been implicated in limiting the abundance and reproduction of some non-native fish species under certain conditions and have been correlated with increased recruitment of humpback chub (Chart and Lentsch 1997). Valdez and Ryel hypothesized that, in the post-dam era, the maximum release at powerplant capacity (31,500 cfs) is likely too low to provide many of the spring-flood benefits to native fishes (Valdez and Ryel 1995), although Schmidt et al. (2007) found that these flows can provide a moderate increase in sandbar area and total backwater habitat area. High flow tests that utilize the outlet works (such as the March 2008 high flow test of 41,500 cfs) provide more significant positive flood-flow benefits to humpback chub by building sandbars, rearranging sand deposits in recirculating eddies, and effectively reshaping reattachment bars and eddy return current channels (see discussion of high flow tests here and in the 2008 Opinion).

The daily hydrograph under MLFF is also adjusted to meet the changing demand for electricity throughout the day within the constraints of MLFF. This typically results in a unimodal hydrograph for warmer months of the year, with peak releases during the day, and low releases at night when demand for electricity is lowest. During the colder months, the daily hydrograph is typically more bimodal, because electricity demand wanes in the afternoon and resumes in the evening to meet heating needs of residences in the evening. Daily fluctuations can be highly variable, however, depending on electrical demand. Daily fluctuations have relatively little effect on warming mainstem temperatures, at least compared to release water temperatures or release volume (Wright et al. 2008a). As discussed earlier, daily fluctuations have a significant effect on the water temperatures of nearshore habitats such as backwaters that may be important nursery habitats for juvenile humpback chub (Hoffnagle 1996, Robinson et al. 1998, Trammel et al. 2002, Korman et al. 2005).

Despite the changes in Reach 7 of critical habitat caused by the dam, humpback chub successfully spawn in the LCR, and likely move into other aggregations, such as 30-mile where they may have spawned and successfully overwintered as documented by Andersen et al. (2010). The 30-mile aggregation is the furthest upstream and thus would be warmed the least by warmer Glen Canyon Dam release temperatures because the river gets warmer as it moves downstream from the dam. However, restricted flows and warmer water releases from Glen Canyon Dam along with reduced numbers of rainbow trout contributed to conditions that accommodated mainstem overwintering of y-o-y humpback chub.

Evidence of recruitment to other mainstem aggregations is suggested by presence of juvenile fish, although recruitment of juveniles into adults has not been documented. The status of most aggregations has remained stable or increased over the last decade, indicating recruitment of fish to adult size (W. Persons, USGS, written communication, 2011b) although numbers are likely very low. Young-of-year and juvenile humpback chub (< 121 mm [4.8 inches] TL) outside the LCR aggregation were most often captured at RM 110-140 (Stephen Aisle and Middle Granite Gorge aggregations) and RM 160-200 (Johnstone and Lauretta 2004, 2007, Trammell et al. 2002, AGFD 1996, Ackerman 2008). Seine catches of all young-of-year humpback chub outside the nine aggregations were at their highest in 21 years during 2004 (Johnstone and Lauretta 2007). Four humpback chub were also collected at Separation Canyon (RM 239.5) in 2005 (Ackerman et al. 2006). Trammell et al. (2002) noted that the Middle Granite Gorge aggregation appeared to be stable or perhaps even increasing in size beginning in 1993, but that it may be sustained via immigration from the LCR aggregation, as well as local reproduction. Few humpback chub have been caught at the Havasu Inflow and Pumpkin Spring aggregations since 2000 (Ackerman 2008).

Valdez and Ryel (1995) provided mark-recapture estimates for PIT-tagged humpback chub adults (≥200 mm [7.9 in] TL) in five of the remaining eight aggregations, including 30-Mile (estimate, n-hat = 52), Shinumo Inflow (n-hat = 57), Middle Granite Gorge (n-hat = 98), Havasu Inflow (n-hat = 13), and Pumpkin Spring (n-hat = 5). Population estimates have not been made for other mainstream aggregations since 1993 (Trammell et al. 2002). Data collected through 2006 indicate that humpback chub may have spawned and recruited at 30-mile (Anderson 2009, Trammell et al. 2002). Information from monitoring mainstem aggregations over the past 10 years indicates that catch rates have increased (W. Persons, USGS, written communication, 2011a). Monitoring efforts in 2010 and 2011 have also indicated that these aggregations persist and the Shinumo aggregation appears to have been augmented by translocations of humpback chub to Shinumo Creek which subsequently entered the mainstem, which has the possibility of increasing the size of the aggregation (Healy et al. 2011).

The effect of Glen Canyon Dam release temperature on humpback chub and conservation has long been recognized (USFWS 1978), and Reclamation has made several attempts to investigate modifying the dam to release warmer water. In January 1999, Reclamation released a draft environmental assessment on a temperature control device (TCD) for Glen Canyon Dam (Reclamation 1999). The preferred alternative included a selective withdrawal structure, a single inlet, fixed elevation design with an estimated cost of $15,000,000. Sufficient concern was evidenced in the review of the EA (Mueller 1999) for the potential unintended negative effects, such as non-native fish proliferation in response to prolonged water warming, as a result of the operation of a TCD, as well as the lack of a detailed science plan to measure those effects, that the environmental assessment was withdrawn.

A risk assessment of the Glen Canyon Dam TCD proposal from the GCDAMP Science Advisors (Garrett et al. 2003) recommended the installation of a TCD for Glen Canyon Dam as soon as possible and the construction of a pilot TCD in the interim. However, Reclamation completed a risk assessment to help evaluate responses of aquatic resources in Grand Canyon to the construction and implementation of a TCD (Valdez and Speas 2007). The risk assessment utilized standard protocols and a mathematical model as a tool to quantify risks and benefits to fish, fish parasites, zooplankton, and macroinvertebrates from water temperature changes resulting from modification of two of the eight generation units on the dam. All taxa present or with known potential to access the area were inventoried for each of six regions, including lower Lake Powell, Glen Canyon Dam to Paria River, Paria River to LCR, LCR to Bridge Canyon, and Bridge Canyon to Pearce Ferry. Results suggested benefits to all native fishes, but correspondingly higher benefits to many non-native fish species that may compete with or prey upon native species. Fish species carrying the highest potential for benefiting from warmer water were rainbow trout, brown trout, common carp, fathead minnow, red shiner, channel catfish, and smallmouth bass (temperatures for all of these species in Grand Canyon are currently below their optimum temperature preferences). Preliminary results also showed more suitable conditions for warm water fish parasites, including anchor worm and Asian fish tapeworm. Results also predicted an increase in periphyton biomass and diversity with warmer water, which could lead to increased food and/or substrate for epiphytes, aquatic invertebrates, fish, and waterfowl. Warm water impacts to macroinvertebrates include minor shifts in relative abundance of existing taxa with the possibility of increased taxa richness, which could be beneficial if limited to insect taxa. However, increased potential for invasion by crayfish and other nuisance species which adversely affect native species is significant.

Reclamation concluded that a TCD designed to allow only warmer water to be released downstream is technically feasible, but that the risks in terms of increases in non-native species and their predatory and competitive effects to humpback chub are potentially significant. In light of these concerns and with the recommendation of an independent scientist panel convened in April 2007 (USGS 2008) to discuss long-term experimental planning, Reclamation also briefly investigated whether construction of a TCD with both warm- and cold-water release capability is possible and under what circumstances cold water would be available for release. Due to the high cost of design investigation, no specific design work or feasibility analysis was completed, thus feasibility of a TCD with both warm- and cold-water release capability remains a question and an information need. Specifically, if the operational feasibility of a warm- and cold-water TCD is considered, detailed aquatic modeling is needed that will examine and show predictive outcomes for young and adult age classes of rainbow and brown trout, smallmouth bass, green and other sunfish species, bullheads and catfish, striped bass, carp (including Asian carp if accidentally introduced), crayfish, other invertebrates, and parasites and diseases on humpback chub and other native fish populations.

Another aspect of the changes in water quality in Grand Canyon that may affect humpback chub is turbidity. Pre-dam, turbidity was very high much of the year except during base flows. The dam largely eliminated most of the sediment supply in the river, which greatly reduced turbidity in the mainstem. Most sediment in the mainstem now is derived from tributary inputs, and the mainstem is turbid now only at times of tributary flooding. With increases in non-native fishes over the last century in Grand Canyon, especially sight-feeding predators like rainbow trout, this loss of turbidity may cause humpback chub to be more susceptible to predation by non-native fishes (Ward and Bonar 2003, GCDAMP 2009). During the summer of 2000, high abundance of adult brown and rainbow trout in the mainstem and the high water clarity throughout the river corridor may have contributed to higher predation rates on native fish near the LCR (Ralston 2011). Reclamation completed a feasibility assessment for large-scale sediment augmentation in 2007. The project would collect sediment from Lake Powell and use a slurry pipeline to deposit it downstream of the dam. This would create a more turbid river and address the erosion of beaches and fine sediment-formed fish habitats by adding sediment directly to the river. The assessment concluded that such a project is feasible, though costs were estimated at $140 million for construction and $3.6 million annually for operation (Randle et al. 2007).

The physical PCEs (physical habitat for spawning [P1], nursery habitat [P2], feeding areas [P3], and movement corridors [P4]) of humpback chub critical habitat are also affected by dam releases and may benefit or be negatively affected by HFEs. In general, the deep low-velocity habitats that adult humpback chub prefer are provided by the large deep pools and eddy complexes available in Marble and Grand canyons, and are sufficiently available to provide adequate habitat for adult humpback chub in the mainstem (Valdez and Ryel 1995). In fact, the condition factor of adult fish of the mainstem has been documented to be better than adult fish in the LCR (Hoffnagle et al. 2006), suggesting that food availability (PCEs P3 and B1) may be better for adults in the mainstem. However, as stated earlier, the humpback chub condition in the LCR may have been limited by parasites (Hoffnagle et al. 2006). Studies completed by GCMRC and the University of Wyoming found a high degree of dietary overlap between humpback chub and rainbow trout (Donner et al. 2011). Both species rely on black flies and midges which are in short supply, so the degree of resource overlap is very high. In fact, consumption of invertebrate prey by the fish assemblage at all sites that were studied overlaps with independent estimates of invertebrate production. In other words, the fish assemblage appears to be consuming close to, or all of, the available midge and black fly production that occurs annually. This indicates the fish assemblage may be food-limited. The spatial overlap between humpback chub and rainbow trout is the highest at the LCR confluence.

Juvenile humpback chub also prefer lower velocity habitats in the mainstem, but in shallow nearshore areas (Valdez and Ryel 1995). Fluctuating flows cause these nearshore habitats to be in constant change. Korman et al. (2006) found that nearshore areas affected by fluctuating flows warmed substantially for brief periods each day, which posits an ecological trade-off for fish utilizing these areas (also discussed in Reclamation 2007). On the one hand, fish may choose to exploit the warmer temperatures of the fluctuating zone on a daily basis and simply sustain any bioenergetic disadvantages of acclimating to rapidly changing discharge; or they may choose to remain in the permanently wetted zone, which is colder than the immediate near-shore margin. In a separate study, Korman et al. (2005) observed that slightly more than half of observed young-of-year rainbow trout in the Lees Ferry reach maintained their position as flows fluctuated rather than follow the stream margin up slope. Thus, for trout, it appears that the bioenergetic cost of changing stream position with fluctuations in discharge perhaps outweighs the benefits of exploiting the slightly warmer stream margins. Additionally, Korman and Campana (2009) found that juvenile rainbow trout in Lees Ferry did increase use of shallow nearshore habitats during periods of stable flow, and that growth of juvenile trout increased as a result.

Backwaters are thought to be important rearing habitat for native fish due to low water velocity, warm water, and high levels of biological productivity. They are formed as water velocity in eddy return channels declines to near zero with falling river discharge, leaving an area of partially to completely non-flowing water surrounded on three sides by sand deposits and open to the mainchannel environment on the fourth side. Reattachment sandbars are the primary geomorphic features which function to isolate nearshore habitats from the cold, high velocity mainchannel environment (Reclamation 2007). Approximately 84-94 percent of the fine sediment input is now trapped behind the dam, and the post-dam median discharge of 12,600 cfs causes remaining fine sediment, and associated habitat types, to be lost continually (Topping et al. 2004, Topping et al. 2003, Wright et al. 2005). Beaches and associated habitats such as backwaters can be recreated with high flow tests as in March of 2008, but the long-term efficacy of this approach is unknown (Wright et al. 2008b). As discussed previously and in the Effects of the Proposed Action section below, the effects of high flows on the physical PCEs of critical habitat are quite variable.

The physical PCE for spawning (P1) does not appear to be met in most of the mainstem. All of the mainstem aggregations are small, although small fish have been captured (Johnston and Lauretta 2007), and overwintering of y-o-y have been documented at the 30-mile aggregation (Andersen et al. 2010) and the LCR Reach (GCMRC unpublished data). Nursery habitat (P2) for juvenile humpback chub may be limited by fluctuating flows that alternately flood and dewater mainstem near shore habitats important to early life stages of humpback chub (AGFD 1996), and by the loss of sediment-formed habitats. Feeding areas are available to all life stages, especially for adult fish as indicated by condition factor of adult fish in the mainstem compared to those in the LCR (Hoffnagle et al. 2006), although feeding areas may be limiting for juvenile humpback chub due to the effect of fluctuations on nearshore habitats (AGFD 1996). Movement corridors (P4) appear to be adequate based on movements of humpback chub throughout the system (Valdez and Ryel 1995, Paukert et al. 2006).

The biological environment PCEs in Reach 7 of humpback chub critical habitat have also responded to the post-dam changes to the ecosystem. Productivity is much higher in terms of algal and invertebrate biomass, thus food availability for fishes (PCE B1), especially adult fishes, is likely greater than pre-dam (Blinn and Cole 1991), although the previously discussed effects of cold water temperatures and fluctuations on the nearshore environment may inhibit the optimal suitability of nursery habitats (P2) and feeding areas (P3) for juvenile warm water fishes like humpback chub in most years. Grand et al. (2006) found that the most important biological effect of fluctuating flows on backwaters is reduced availability of invertebrate prey caused by dewatered substrates (see also Blinn et al. 1995), exchange of water (and invertebrates) between the mainchannel and backwaters, and (to a lesser extent) reduced temperature. As the magnitude of within-day fluctuations increases, so does the proportion of backwater water volume influx, which results in a net reduction in as much as 30 percent of daily invertebrate production (Blinn et al. 1995, Grand et al. 2006). However, recent investigations into the use of nearshore habitats in the mainstem just downstream of the LCR by 0-3 year old humpback chub (40-199 mm [1.6-7.8 inches] TL) indicate that the PCEs of critical habitat in the area immediately downstream of the LCR confluence appears to be functioning properly and may support recovery. Juvenile humpback chub used a variety of mainstem nearshore habitats, and survivorship and growth of fish in these habitats was documented (GCMRC unpublished data). Humpback chub in other aggregations in Marble and Grand canyons also appear to have persisted and possibly increased in size in recent years (W. Persons, USGS, written communication, 2011a); other native fish including flannelmouth sucker that have similar habitat needs have also increased in abundance in western Grand Canyon (Makinster et al. 2010). Thus, there are several lines of evidence indicating that the biological environment PCEs of critical habitat in Reach 7, although limited, may have improved in recent years which is important for recovery.

Non-native fish species that prey on and compete with humpback chub affect the PCEs (B2 and B3) of the biological environment aspect of critical habitat. Catfishes (channel catfish and black bullhead), trouts (rainbow and brown trout), and common carp are well established in the action area and will continue to function as predators or competitors of humpback chub. Minckley (1991) hypothesized that non-native fish predation and competition may be the single most important threat to native fishes in Grand Canyon (Valdez and Ryel 1995, Marsh and Douglas 1996, Coggins 2008b, Yard et al. 2008). Valdez and Ryel (1995) estimated that 250,000 humpback chub are consumed by channel catfish and, rainbow and brown trout annually. Small-bodied species such as fathead minnow, red shiner, plains killifish, and mosquitofish are also found in nearshore areas of Marble and Grand canyons and may be important predators and/or competitors of juvenile humpback chub in nearshore habitats. Marsh and Douglas (1997) suggested that entire year classes of humpback chub may be lost to predation by non-native fish species, and Yard et al. (2008) estimated that, although predation rate of rainbow trout on humpback chub is likely low, at high densities, trout predation can result in significant losses of juvenile humpback chub. Yard et al. (2011) also concluded that even though predation levels were high (humpback chub comprised approximately 30% of the identifiable fish in trout stomachs), it is not evidence that there was a population-level effect on humpback chub.

Efforts by the GCDAMP to mechanically remove non-native fishes in the LCR inflow reach were successful in removing trout (Coggins 2008b). In total, between January 2003 and August 2006, it is estimated that approximately 36,500 fish from 15 species were removed from this stretch of river. However, due to a system-wide decrease in trout populations independent of the removal effort and warmer river temperatures, it is unclear whether removal of trout contributed to the increases seen in native fish populations. Yet stomach sample analyses, show that rainbow and brown trout predation on native fishes clearly occurs. During the first two years of removal, 2003 and 2004, it was estimated that over 30,000 fish (native and non-native species combined) were consumed by rainbow trout (21,641 fish) and brown trout (11,797 fish) (Yard et al. 2011). On average, 85% of the fish ingested were native fish species, in spite of the fact that native fish constituted less than 30% of the small fish available in the study area (Yard et al. 2011). According to Yard et al. (2011), even though rainbow trout had a large cumulative piscivory effect, the annual per capita consumption rate was low overall. On average, each rainbow trout consumed 4 fish/year (both native and non-native) in the upstream reach and 10 fish/year in the downstream reach. In contrast, per capita rates of fish consumption by brown trout were much higher: 90 fish/year in the upstream reach and 112 fish/year in the downstream reach, meaning that 200 brown trout could consume as much fish as 4,000 rainbow trout (Yard 2011). The majority of the humpback chub consumed by trout were young of the year and subadults (age < 3), and it is likely that the loss of so many young fish affects recruitment to the humpback chub population (Coggins and Walters 2009).

The level of non-native fish decreased over the next three years resulting in non-native fish comprising only 10% of the species composition in August 2006 (Coggins et al. 2011). Yet the efficacy of a similar effort today is questionable given current densities of trout and high immigration rates that may occur from the Lees Ferry Reach. Since immigration rates drive the level of effort necessary to effectively remove rainbow and brown trout from the LCR reach, it is unknown at this time what level of removal effort would be necessary to substantially reduce non-native trout at the LCR confluence. Reclamation will conduct two PBR test trips during FY 2012. This will provide useful information about emigration rates of rainbow trout out of the Lees Ferry Reach. These tests trips and the Natal Origins Study will provide the GCDAMP with additional information on trout movement and other needed field studies during the 10-year life of the project, which will provide important information for use in evaluating and potentially revising the trigger for implementation of LCR reach removal efforts, as well as other possible non-native fish control actions.

When the mechanical removal began in 2003 approximately 90% of the species composition was rainbow trout in the LCR Reach. Species composition and abundance of non-native fishes is dynamic and affected by natural conditions and other factors throughout the canyon, with colder water species dominating closer to the dam, and warm water species downstream. Common non-native fish species in Grand Canyon, such as channel catfish, black bullhead, common carp, rainbow trout, brown trout, and fathead minnow likely spawn in the mainstem river and in nearby tributaries or tributary mouths, although more information is needed on spawning locations to better target control efforts (GCMRC unpublished data). Immigration of non-native fishes from basins that feed into Grand and Marble canyons is also a source of non-native fish (Stone et al. 2007), and stocking of sport fish in these basins is an action that may contribute to source populations of non-native fish that invade the mainstem river, although the 2011 Sport Fish Opinion has concluded that this is not a significant factor. Lake Powell and Lake Mead are also sources of non-native species as evidenced by the presence of walleye (*Sander vitreus*) and green sunfish in Glen Canyon (AGFD 2008) that either were illegally stocked or came through Glen Canyon Dam, and striped bass, which likely move up from Lake Mead and are common in lower Grand Canyon.

However other mortality factors, such as disease, are not known. Just as the ultimate causes of the improved status of humpback chub is not known, a causal link between removal of non-native fish and humpback chub population parameters has not been established (Coggins 2008b). However, removal efforts are one suspected cause or contributor to recent increases in humpback chub recruitment (Andersen 2009).

Climate change is predicted to result in greater aridity in the southwest (Seager et al. 2007, U.S. Climate Change Science Program 2008a, b). Greater aridity is likely to reduce inflows to Lake Powell (Seager et al. 2007), and implementation of the Interim Guidelines, will result in lower Lake Powell reservoir elevations, and increase Glen Canyon Dam release temperatures. Warming downstream temperatures will benefit native fishes, and likely already has (Andersen

2009, Coggins and Walters 2009). But warmer Colorado River temperatures are just as likely to benefit some warm water non-native species that may function as competitors or predators to humpback chub and other native fish (Valdez and Speas 2007, Rahel and Olden 2008, Rahel et al. 2008). Recent changes in the fishery of the Yampa River illustrate how these changes could occur. Drought significantly reduced stream flows in the Yampa River in 2002, which elevated river temperatures, resulting in a rapid spread of smallmouth bass (Fuller 2009). Prior to 2002, smallmouth bass were very rare in the system, and humpback chub were common, with a small but stable population of several hundred adults. This rapid expansion of smallmouth bass essentially eliminated the humpback chub population in the Yampa in a matter of a few years (Finney 2006, T. Jones, FWS, pers. comm. 2009). The shift in the fish community in the Yampa River due to water temperature and hydrologic changes is now the greatest threat to the native fishery, and non-native fish control efforts are so far not effective (Fuller 2009). The Yampa example illustrates what could happen if efforts by the GCDAMP to warm mainstem water temperatures (e.g. through the use of a TCD or seasonal steady flows) result in the unintended consequence of an invasion or expansion of non-native fish species. Indeed, given climate change predictions, an increased capacity to deliver cold water for sustained periods seems more pressing. The relationship between warmer water temperatures and non-native fishes was recognized at the time of the 1995 Opinion, but was apparently not considered as severe a threat as it is today, especially given the newest information on climate change and its potential effect on the expansion of non-native fishes.

In the 2008 and 2009 Supplemental Opinions, we stated that the biological environment PCE for food base (B1) appears met for adult humpback chub, but may be limiting for juveniles. This was because available information indicated that adult humpback chub in the mainstem portion of the LCR reach had a higher condition factor compared to those in the LCR (Hoffnagle et al. 2006). We now question whether B1 is being met for adult humpback chub in all parts of Reach 7, given the small size of other mainstem aggregations. Based on some preliminary research on food base, it appears that in years when discharge is high over the winter, and light levels are low, primary production is very low (Yard 2003). Algae is readily consumed by aquatic invertebrates (i.e., midges and black flies; Stevens et al. 1997, Wellard Kelly 2010, T. Kennedy, USGS, written communication, 2011) that are important food items eaten by native and non-native fish in the system (Valdez and Ryel 1995, Donner 2011, Zahn-Seegert 2011), and native fish including humpback chub also directly consume algae (Valdez and Ryel 1995, Zahn-Seegert 2011, Donner 2011). As fish need to have sufficient food resource reserves (lipids) in order to produce eggs, humpback chub could get the lipids they need from direct consumption of algae or from consumption of invertebrates on the algae that are themselves rich in lipids. One possible reason for the near absence of documented spawning in the downstream reaches and small aggregation size may be the lack of food resources (lipids) over the winter months to prepare adult humpback chub to be able to mature eggs in spring. Some of the tributaries such as Havasu and Kanab creeks are warm enough to allow for spawning, and the discovery of untagged humpback chub in Havasu Creek in June 2011 (Smith et al. 2011, Sponholtz et al. 2011) suggests that the habitat and food resources are supportive of humpback chub using Havasu Creek for at least part of the year, where spawning may have occurred this year (P. Sponholtz, FWS, pers. comm., 2011). We believe that additional information is needed to evaluate overwintering conditions, and specifically whether the rates of primary production and food resources over the winter months are sufficient to prepare humpback chub to spawn/reproduce the following spring, especially in the western portion of Reach 7.

PCEs B2 (competition) and B3 (predation) continue to threaten the conservation of humpback chub, particularly in Reach 7. However, there appears to be an important relationship between the effects of dam operations on the water and physical PCEs of critical habitat and the biological PCEs of non-native fish competition and predation that needs more careful consideration before additional efforts to manipulate water temperature are attempted. Reclamation has committed to evaluating flow and non-flow non-native suppression experiments focused on the Lees Ferry reach to lower emigration of trout, which may be particularly informative in years like fiscal year 2012 when trout numbers are very high. Also, Reclamation will continue to support research on juvenile humpback chub use of Grand Canyon, which will help to better understand the degree to which predation and competition may be limiting recruitment.

Most of the Grand Canyon population relies on the LCR for spawning and a proportion of the population may never leave the LCR. Nevertheless the recent improvement in status of the Grand Canyon population, which also constitutes the lower Colorado River Recovery Unit, has coincided with improvements in the PCEs in this mainstem reach of critical habitat, with no obvious changes in the PCEs of the LCR (Reach 6). As described earlier, the PCEs for water improved largely due to warmer water temperatures between 2004 and 2011 from low Lake Powell reservoir levels and/or warm water releases. The physical PCEs improved temporarily through high flow tests that have improved nearshore habitats, and the biological environment PCEs of predation and competition improved by removal of non-native fishes between 2003 and 2009. Considering the improvement in the status of humpback chub over this period, obtaining and maintaining high quality PCEs for humpback chub in this reach of critical habitat is likely essential to recovery of the species. As noted in the 2008 Opinion and 2009 Supplemental Opinion, conservation measures are an important aspect of Reclamation's proposed action. In collaboration with the GCDAMP and associated research efforts, literature and peer reviewed reports are regular products of the program providing updated information about native fishes throughout Grand Canyon.

As described in the Status of the Species section, demographic criteria must be met for this Recovery Unit as well as for one or two core populations in the upper Colorado River basin for downlisting and delisting, respectively, to occur (USFWS 2009). As described earlier, in addition to the demographic criteria, the Recovery Goals also contain site-specific management actions and tasks and corresponding recovery criteria that must be met for downlisting and delisting to occur.

As described earlier, the abundance of humpback chub in the LCR is estimated to be 7,650 adults (between 6,000-10,000, age 4+; ≥ 200 mm [7.9 inches] TL); this is nearing the 10,000-11,000 adults the ASMR estimates constituted the adult LCR population when marking began in 1989, and appears to have been in an upward increasing trend since 2001 (Coggins et al. 2006a, Coggins and Walters 2009). FWS monitoring efforts in the LCR in 2008 and 2009 also indicate increasing recruitment and abundance. Van Haverbeke and Stone (2009) note that the 2007 and 2008 closed estimates of humpback chub abundance in the LCR do not differ statistically from the 1992 spring abundance estimates obtained by Douglas and Marsh (1996). This is significant because the Recovery Goals require an increasing trend relative to prior abundance estimates (USFWS 2009), and Douglas and Marsh (1996) provided one of the earliest robust estimates of humpback chub abundance in the LCR. Thus it now appears that humpback chub have returned to levels of abundance first documented in the early 1990s.

The improvement in humpback chub status is primarily in the LCR aggregation, but apparently also in some of the other mainstem aggregations downstream from Glen Canyon Dam (W. Persons, USGS, written communication 2011b). Since 2003, water temperature of dam releases has been above average below Glen Canyon Dam (>12 ^{o}C at the LCR), and for the variety of reasons discussed above, this may in part explain the improvement in the species over this period.

Nevertheless, questions remain about the role of the mainstem in recovery, and how best to improve the PCEs in this reach to best promote recovery. These questions are outlined in the Recovery Goals recovery factor criteria and management actions and tasks, and are currently the focus of a number of monitoring and research efforts of the GCDAMP. The recovery factor criteria and associated management actions and tasks that relate to this critical habitat unit are based on the five listing threat factors. These management actions and tasks are directed at research to determine the role of the mainstem Colorado River in providing for recovery of humpback chub. Those that relate to the Colorado River in Marble and Grand Canyons and Reach 7 of critical habitat are summarized here:

Factor A: Adequate habitat and range for recovered populations provided; investigate the role of the mainstem Colorado River in maintaining the Grand Canyon humpback chub population and provide appropriate habitats in the mainstem as necessary for recovery, including operating Glen Canyon Dam water releases under adaptive management to benefit humpback chub in the mainstem Colorado River through Grand Canyon as necessary and feasible, and investigate the anticipated effects of and options for providing suitable water conditions in the mainstem Colorado River through Grand Canyon (steady flows and flows that suppress non-native fish) that would allow for range expansion of the Grand Canyon humpback chub population and provide appropriate water temperatures if determined feasible and necessary for recovery.

Factor B: Adequate protection from overutilization; protect humpback chub populations from overutilization for commercial, recreational, scientific, or educational purposes through implementation of identified actions to ensure adequate protection for humpback chub populations from overutilization.

Factor C: Adequate protection from diseases and predation; identify and implement levels of control of non-native fish (from Lees Ferry, Bright Angel, and other areas), as necessary for recovery, and develop and implement procedures for stocking sport fish to minimize escapement of non-native fish species into the Colorado River and its tributaries through Grand Canyon.

Factor D: Adequate existing regulatory mechanisms; determine and implement mechanisms for legal protection of adequate habitat in the Colorado River in Marble and Grand Canyons through instream-flow rights, contracts, agreements, or other means.

Factor E: Other natural or manmade factors; minimize the risk of hazardous-materials spills in critical habitat by reviewing and implementing modifications to State and Federal hazardous-materials spills emergency-response plans to ensure adequate protection for humpback chub populations from hazardous-materials spills, including prevention and quick response to hazardous-materials spills.

The Recovery Goal recovery factor criteria for Factor A in the mainstem require that life stages and habitats of humpback chub be identified and the relationship between individuals in the mainstem and the LCR are determined. The Colorado River through Grand Canyon must provide for adequate spawning, nursery, juvenile and adult habitat. Although a TCD will not be pursued at this time, other flow options could be developed through the GCDAMP to take advantage of years when above normal water temperatures are released from Glen Canyon Dam to provide suitable water temperatures in the mainstem Colorado River through Grand Canyon that would allow for range expansion of humpback chub (see earlier discussion on the history and current state of TCD investigations).

The PCEs W1 and W2 in Reach 7 appear to be achieving recovery, with the caveat that the needs necessary for all life stages of humpback chub in the mainstem to support a recovered Grand Canyon population are still under investigation. The GCDAMP continues to provide information and address the recovery goal of determining the importance of the mainstem in recovery and defining a Glen Canyon Dam release flow that meets all the habitat needs of a recovered Grand Canyon population. Ongoing research, such as the Natal Origins study should serve to provide much valuable information on the needs of the species in this reach of critical habitat in terms of Glen Canyon Dam flows and water temperature of releases, and how the PCEs function in meeting the recovery needs of the species.

Factor B is not significant to humpback chub in the mainstem although there have been some concerns raised about handling stress from field surveys. As explained in other parts of the document, monitoring efforts that cause handling of humpback chub do cause some mortality. However, this mortality does not appear to have impacted the Grand Canyon population, and has resulted in important findings on the recovery needs of humpback chub.

For Factor C, the focus of the Recovery Goals in the mainstem Colorado River is on controlling the proliferation and spread of non-native fish species that prey on and compete with humpback chub. The Recovery Goals identify the need to develop, implement, evaluate, and revise (as necessary through adaptive management) procedures for stocking sport fish to minimize escapement of non-native fish species into the Colorado River and its tributaries through Grand Canyon. Stocking, both legal and illegal, throughout the LCR basin, has been suspected of resulting in non-native fish moving into the lower LCR (Stone et al. 2007), and likely into the mainstem Colorado River as well. As discussed below, the Sport Fish Opinion has evaluated impacts to humpback chub and its critical habitat in Arizona and concluded that given the distance from sport fish stocking sites in the upper LCR watershed, those stocking sites have only a minor effect to humpback chub populations and do not have a “meaningful role in affecting humpback chub recovery” (USFWS 2011b).

The Recovery Goals also identify the need to develop and implement levels of control for rainbow trout, brown trout, and warm water non-native fish species (USFWS 2002a). Non-native fish control has been a focus of the GCDAMP for some time. The degree to which these removal efforts have improved the PCEs B2 and B3 is still a research question, although Yard et al. (2008) estimated that the 2003-2006 removal of rainbow and brown trout contributed significantly to reduce predation losses of juvenile humpback chub. Andersen (2009) and Coggins and Walters (2009) noted the potential role these removal efforts may have had in improving the status of the humpback chub in Marble and Grand Canyons, but the available information is insufficient to evaluate the effects of removal alone. The GCDAMP and GCMRC have been testing various methods to monitor and remove warm water non-native fish species, so far with little success. Information on which non-native species should be removed during which times of the year continues to be a research question.

For Factor D, adequate existing regulatory mechanisms, the Recovery Goals identify the need to determine and implement the mechanisms for legal protection of habitat in the mainstem Colorado River, through instream-flow rights, contracts, agreements, or other means. The Law of the River (which determines water delivery), coupled with the protection afforded by Grand Canyon National Park, may or may not be sufficient to meet this need in reach 7 of critical habitat, but such an analysis has not been completed.

For Factor E, the Recovery Goals identify the need to review and recommend modifications to State and Federal hazardous-materials spills emergency-response plans to ensure adequate protection for humpback chub populations from hazardous-materials spills, including prevention and quick response to hazardous-materials spills. This applies mostly to the Highway 89 bridge at Cameron. Other bridges could be an issue, such as Navajo Bridge in Marble Canyon, although it carries much less traffic. A comprehensive evaluation of State and Federal hazardous-materials spills emergency-response plans to ensure adequate protection for humpback chub populations from hazardous-materials spills has not been completed for the Colorado River.

In summary, the Recovery Goals provide specific criteria for Reach 7 of critical habitat and its PCEs, and the most important of these are to identify Glen Canyon Dam releases that maintain adequate humpback chub habitat to support recovery and to implement levels of non-native fish control as necessary to support recovery. Reclamation's proposed action includes an active adaptive management program that is progressively testing different flow regimes. Reclamation has also included in its proposed action several projects to monitor and evaluate the effect of these experimental flows on the PCEs of critical habitat in this reach, including the Natal Origins Study, and various monitoring and research projects of the GCDAMP annual work plans (as discussed earlier in the Proposed Action). Reclamation has also included non-native fish control as a conservation measure. The benchmark for success of these efforts is the Recovery Goals demographic criteria for humpback chub in the lower Colorado River basin Recovery Unit. Although FWS has not yet determined that the demographic criteria have been met, recent monitoring has documented an increase in humpback chub numbers and the native fish community.

Razorback sucker

Available information suggests that historically, the razorback sucker was not common in the canyon-bound reaches of Marble and Grand Canyons (Minckley et al. 1991, Valdez 1996). The Recovery Goals for razorback suckers in the Lower Basin includes two self-sustaining populations (e.g., mainstem and/or tributaries) maintained over a 5-year period, but does not specify the Grand Canyon or any other specific location (USFWS, Razorback Sucker Recovery Goals, 2002b). Ten records for razorback sucker were documented by 1995; one at Bright Angel Creek in 1944, one in the mainstem below the dam in 1963, a total of four in the Paria River in 1978 and 1979, one near Bass Canyon in 1986, three in Bright Angel Creek in 1987, and three in 1989 and 1990 at the mouth of the Little Colorado River. Hybrids between razorback sucker and flannelmouth sucker have also been reported several times near the Paria River and Little Colorado River (Valdez 1996).

Razorback suckers are currently known from Lake Mead outside of the action area and there are records of razorback suckers collected from Gregg Basin dating from 1978-1979 (McCall 1979). Razorback suckers are recruiting in three areas of Lake Mead outside the action area, most recently in 2008 (Shattuck et al. 2011). The population at the upper end of Lake Mead was re-documented in 2000-2001 through larval collections between Grand Wash Cliffs and Iceberg Canyon; although no adults were captured in net sets in 1999-2000 and 2002-2003 (Albrecht et al. 2008). AGFD captured an adult razorback sucker in Gregg Basin in 2008 (cited in Kegerries and Albrecht 2011). In 2010 and 2011, wild razorback suckers were captured in Gregg Basin and spawning locations were identified. These wild fish were aged at between 6 and 11 years old. It is unknown if these wild razorbacks are the result of recruitment at the Colorado River Inflow, or represent movements of wild razorback suckers from the known recruitment areas (two sites in the Overton Arm [the Virgin-Muddy River inflow and Echo Bay] and Las Vegas Wash) to the inflow area. In addition, nine razorback-flannelmouth sucker hybrids were captured and aged. These fish were between 6 and 10 years old, with four born in 2003 (Kegerries and Albrecht 2011). The radio-tagged stocked razorbacks from this study did not move upstream into Iceberg Canyon during the survey period, however, they did move between the more riverine and more lentic areas over the course of the monitoring, and were found with wild razorback suckers (Kegerries and Albrecht 2011).

At full-pool elevation (1229 ft [375 m] NGVD), Lake Mead impounds water up to Separation Canyon (RM 239.5); however, the effects of "ponding" of water (reduced velocity and increased sediment deposition) can extend upstream for several miles to Bridge Canyon (RM 235) as noted by Valdez (1994). Lake levels have declined since the late 1990s, reaching a low of 1081 feet (329 m) in November, 2010. This decrease in lake elevations increases the length of "riverine" habitat from Separation Canyon downstream and alters the structure of the habitat as the river downcuts through accumulated sediment and forms a channel with limited backwaters or shallow margins (Van Haverbeke et al. 2007). By 2011, the lake/river interface was in the upper portion of Gregg Basin (Kegerries and Albrecht 2011). How razorback suckers use the riverine portion versus the lentic portion of the Colorado River inflow area and how that changes with lake elevation is yet unclear.

Razorback Sucker Critical Habitat

Critical habitat for the razorback sucker extends from the mouth of the Paria River downstream to Hoover Dam, including Lake Mead to its full-pool elevation. Maddux et al. (1993) discussed how the PCEs for razorback sucker function in this reach; we summarize that discussion below.

In the riverine portion of the reach (Paria River to Separation Canyon), the PCEs for water, physical habitat, and biological environment have been altered by creation of Glen Canyon Dam as described earlier for the humpback chub. The suitability of the physical habitat conditions for razorback sucker in this reach were likely significantly less even before closure of the dam as razorback suckers are generally not found in whitewater habitats that are home to humpback chub (Bestgen 1990).

Operations of Glen Canyon Dam changed the natural flow cycle of the Colorado River and altered water quality parameters as described for humpback chub. The distance downstream that fluctuating flows can be detected has changed as operations of the dam have changed. In 1992, Valdez (1994) measured a daily stage change of 60 cm (23.6 inches) at Spencer Creek (RM 246) and noted that stage changes were ameliorated by Lake Mead below Quartermaster Canyon (RM 259). In 1992, Lake Mead was between 1150 and 1175 feet (350 to 358 m) and the lake-river interface was downstream from Separation Canyon. With the implementation of interim operating criteria in 1991, it is uncertain if the stage changes reported in1992 were indicative of those resulting from previous operations. Under the MLFF, releases from Glen Canyon Dam are less extreme and effects to the river below Bridge Canyon (RM 235) from the fluctuating flows are considered insignificant.

There is information that indicates that at least some portions of the Colorado River through the canyon can provide the physical PCEs needed by razorback sucker. The most recent report is from a raft survey in 2009 (Speas and Trammel 2009) where the reach from Lava Falls to South Cove of Lake Mead (in Gregg Basin) was visually evaluated for habitat features that could support razorback sucker populations. Features evaluated included backwaters, islands/side channels, habitat types (runs, riffles, eddies, spawning cobble, shallow waters), and cover (turbidity or vegetation). Using these features, reaches of the river were determined have complex, less complex, or poor habitat quality for razorback suckers. Complex habitat extended from Lava Falls to Granite Park (RM 179-208), and Granite Spring to near 224 mile (RM 220-223). Less complex habitat was found from Granite Park to Trail Canyon (RM 209-219) and 224 mile to Last Chance Rapid (RM 224-253). Poor habitat extended from Last Chance Rapid to Pearce Ferry (RM 253-279). The poor habitat began 14 miles (22.5 km) below the full pool elevation of Lake Mead and was characterized as a straight, incised channel with little backwater areas and predominately swift run habitat. This condition extended further to the upper end of Gregg Basin where the river-lake interface was located in 2011 (Kegerries and Albrecht 2011).

The lower Grand Canyon fish fauna is affected by the non-native fish community moving upriver from Lake Mead (Valdez 1994, Ackerman et al. 2006, Van Haverbeke et al. 2007, Makinster et al. 2010) and large populations of non-native predators and competitors are present. Flannelmouth suckers, bluehead suckers, and speckled dace are the native species found. Razorback suckers, flannelmouth suckers and hybrids of the two species were found in Gregg Basin in 2011 (Kegerries and Albrecht 2011). Like other areas in Lake Mead with successful razorback sucker spawning and recruitment, the inflow area is highly turbid, and that may provide cover for young razorbacks.

Kanab ambersnail

The Kanab ambersnail status is discussed in the status of the species. During the early 2000s, Kanab ambersnails found in the zone that would be inundated during the high flow test and their habitat was temporarily removed, irrigated, and returned after the high flow because this saved potentially tens or hundreds of snails and approximately 15 percent (17 m2 [180 ft2]) of the Kanab ambersnail habitat that would have been flooded and scoured by the HFE. However, in a draft report, Culver et al. (2007) characterized mitochondrial diversity and AFLP marker diversity from 12 different southwestern *Oxyloma* populations. The characterized populations included two Kanab ambersnail (Vasey's Paradise and Three Lakes) and 10 non-endangered ambersnail populations. Analysis detected some gene flow among the studied *Oxyloma* populations. The authors speculate that the measured gene flow demonstrates that all of the populations studied are members of the same interbreeding species (Culver et al. 2007). Thus, in contradiction to previous studies, they concluded that Kanab ambersnails are genetically the same as all other *Oxyloma haydeni* and that Kanab ambersnails may not deserve subspecies status. The FWS discussed this in a recent 5-year review of Kanab ambersnail, and noted that if a taxonomic change occurs, the snail could subsequently be downlisted or delisted.

B. FACTORS AFFECTING SPECIES' ENVIRONMENT WITHIN THE ACTION AREA

Humpback chub

Successful humpback chub adult recruitment depends on spawning success, normal levels of predation on young of year and juveniles, habitat (water temperature), pathogens, adult maturation, food availability, and competition. Flow conditions can vary significantly from year to year. The average unregulated inflow to Lake Powell from 2005 through 2011 was 11.2 maf which is slightly below the official average of 12.0 maf (based on the period from 1971 through 2000). The annual variability from 2005-2011 has varied from a low water year unregulated inflow slightly below average in 2005, 8.4 maf (70% of average) in water year 2006, to a high of over 17.0 maf (141% of average) into Lake Powell in 2011 (R. Clayton, Reclamation, written communication, 2011). The 2011 water year release volume from Glen Canyon Dam was 12.52 maf and this was the largest water year release volume made from Glen Canyon Dam since water year 1998 (R. Clayton, Reclamation, written communication, 2011).

The Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Mead and Lake Powell will govern releases from Glen Canyon Dam through September 2026. Flows were developed in the 1996 Record of Decision on the Operations of Glen Canyon Dam, and currently follow the MLFF 5-Year Plan. A full description of the operation strategies is discussed in the 2007 Shortage Opinion (USFWS 2007). Reclamation conducted a high flow test initiated on March 5, 2008, and completed on March 9, 2008. During the high flow experiment, Reclamation released water through Glen Canyon Dam's powerplant and bypass tubes to a maximum amount of 41,500 cfs for 60 hours. As a result of the high flow test, the elevation of Lake Powell dropped by approximately 2.3 feet (0.7 m). The annual volume of water released from Lake Powell for water year 2008 was not modified as a result of the high flow experiment. Although 2008 was originally projected to be an 8.23 maf release year, the April 24-month study projected the September 30, 2008, Lake Powell elevation to be above 3,636 feet (1,108 m) (the equalization level for water year 2008), based on the April 1st final inflow forecast.

The Arizona statewide sport fishing program as funded by the Federal Wildlife and Sport Fish Restoration Program was evaluated in a 2011 Opinion on Sport Fish Restoration. The Opinion evaluated stocking of non-native sport fish species, and analyzed the distance and availability of surface water, flood events, and fish movement to determine the degree of connectivity and subsequent exposure to humpback chub and critical habitat with a focus on three areas: Havasu Creek, Canyon Diablo, and the White Mountain area. Although the risk is low, there is opportunity for stocked non-native fishes to move downstream into the action area during flood events, although this is likely to be an infrequent occurrence.

For the Havasu Creek stocking sites, the FWS concluded that any individuals of the stocked species, particularly channel catfish, could access the humpback chub habitats alive after being transported by flood waters. However, the spill potential from the stocking sites, the distances involved, and the physical conditions encountered, when considered together, leads to a very low risk of exposure of humpback chub to these fish. This low potential for exposure also leads to our determination that PCEs B2 and B3 would not be affected to the extent that the conservation value of the Colorado River Marble and Grand Canyon critical habitat reach would be diminished.

For the Canyon Diablo stocking sites, we concluded that any individuals of the stocked species, particularly channel catfish, could access the humpback chub habitats alive after being transported by flood waters. The spill potential from the stocking sites, the distances involved, and the physical conditions encountered, when considered together, leads to a very low risk of exposure of humpback chub to these fish.

For the White Mountain stocking sites we concluded that individuals of the stocked species, particularly channel catfish, could access the humpback chub habitats alive after being transported by flood waters. There is connectivity between the Little Mormon Lake stocking site and the LCR through White Mountain Lake for channel catfish if reproduction occurs in Little Mormon Lake; the grate on the outflow would prevent stocked adult channel catfish from escaping but not juvenile catfish which would only be present if reproduction occurs at this site (reproduction has never been documented at this site). Channel catfish maintain a reproducing population in White Mountain Lake, and any channel catfish exiting the lake to Silver Creek would most likely come from that population and not the stocking sites. However, the tributaries and mainstem LCR independently support wild populations of channel catfish that are not reliant on escapees from White Mountain Lake to maintain their populations.

Channel catfish can be a significant predator on young humpback chub, and the connectivity from the White Mountain stocking sites is directly into the area above Chute Falls where translocations of small humpback chub have occurred. The numbers of channel catfish in that reach of the LCR is not known; however, augmentation of those numbers is likely to be deleterious to the chub. However, we concluded that stocking channel catfish into Little Mormon and Whipple lakes has no measurable effect on existing channel catfish populations in this drainage or in the LCR because of the very low likelihood that they could survive transport to the lower LCR area.

Non-native fishes, including channel catfish, are an identified concern for PCEs B2 and B3 for humpback chub critical habitat. Based on our analyses, we concluded that the channel catfish associated with stocking events have, at most, an extremely minor effect to recovery values in the LCR since their ability to reach the critical habitat is very limited. Also, neither stocked channel catfish nor their progeny are supporting the currently established populations of that species in Lyman Lake, lower Chevelon Creek, and Clear Creek Reservoir or washes draining into the LCR from the north. It is far more likely that individuals from those self-sustaining populations would access the LCR below Grand Falls as described by Stone et al. (2007). The Sport Fish Stocking Opinion concluded that that the stocking events covered did not have any meaningful role in affecting humpback chub recovery in the Little Colorado River critical habitat unit or Havasu Creek, and are not likely to contribute additional non-native predators to the existing populations in the mainstem Colorado River. Non-native rainbow and brown trout in the LCR itself do not appear to be problematic because seasonal warm temperatures and high salinity levels limit the suitability of LCR habitats to support these species. Thus, changes to PCEs B2 and B3 are not anticipated, so the conservation value of the critical habitat is not impaired by federally funded sport fish stocking.

The act of stocking fish obtained from AGFD hatcheries or other sources has the potential to introduce unwanted aquatic organisms to the receiving water, although the use of hatchery and operational protocols for the movement of stocked species is designed to reduce the opportunity for the transmission of other non-native fish species, parasites, or diseases via stocking actions. Illegal or inadvertent movement of unwanted aquatic organisms between waters in Arizona may also occur. Disease and parasites are additional threats to humpback chub populations. Parasites may be introduced incidentally with the spread of non-native species. Transmission may occur via introduced fish species, and bait species used for angling such as crayfish and waterdogs (tiger salamanders). Asian tapeworm from grass carp introductions was first documented in the Virgin River basin in 1979 (Heckmann et al. 1986), probably carried there by red shiner. It later appeared in the Little Colorado River in Grand Canyon in 1990 (Clarkson et al. 1997).

As a result of the 2011 Opinion on the Sport Fish Restoration Funding of AGFD's Statewide and Urban Stocking program, the AGFD has committed to incorporating some aspects of the Integrated Fisheries Management Plan for the Little Colorado River (Young et al. 2001). The LCR drainage above Grand Falls has been identified as a source of non-native fish species (particularly channel catfish) into occupied humpback chub habitat in the lower LCR (Stone et al. 2007). In the 2011 Opinion on Sport Fish Restoration Funding, we concluded that there is very limited potential for connectivity between the stocking sites in the Little Colorado River. No incidental take was anticipated in r the Sport Fish Restoration Funding Opinion (USFWS 2011b). However, a conservation measure was included in the proposed action to assess native and non-native fisheries management in the Little Colorado River basin which will assist in evaluating any future risks to humpback chub in the LCR.

As part of the humpback chub annual monitoring, some are killed each year during field activities (P. Sponholtz, FWS, pers. comm., 2011). Agencies must report such incidents to the results of info to the FWS as part of their 10(a)(1)(A) collecting permit. The numbers of injuries and delayed mortalities are not known and much more difficult to track. However, we know that when bonytail chub and razorback suckers are collected in trammel nets in temperatures that exceed 20 ºC, mortality associated with handling stress increases significantly (Hunt 2009). Despite inevitable take of humpback chub from monitoring and research activities, as described earlier, the status of the species has improved over about the last decade, and research and monitoring efforts have provided invaluable information to humpback chub recovery.

Razorback sucker

The razorback sucker has not been reported upstream from about Pearce Ferry since 1990 and only 10 adults were reported between 1944 and 1995 (Valdez 1996, Gloss et al. 2005). Carothers et al. (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 fully 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. For the first time in many years in 2011, BioWest documented wild razorback suckers in the Lake Mead Colorado River Inflow area, including larval razorback suckers providing evidence that razorback sucker spawned below the action area (Kegerries and Albrecht 2011). 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, warmer habitat offered by the Lake Mead inflow area currently located downstream from Pearce Ferry. Changes in Lake Mead water levels will alter the location of the river/lake interface as the inflow and alter the location of suitable habitat.

Kanab Ambersnail

There has likely been some loss of snails and habitat from the highest MLFF flows, although this has been undetectable in surveys conducted since the 2008 Opinion. Kanab ambersnail habitat only begins to be affected by flows at about 17,000 cfs (Sorensen 2009), and flows only exceeded this level in 2011. 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 significantly affected (Patch 12), and a second patch is impacted to a lesser extent at flows above 23,000 cfs (Patch 11). Very few Kanab ambersnail have been found in patches 11 and 12 historically, and habitat in these patches is of low quality (Sorensen 2009). Surveys in 2008 and 2009 indicated that overall, habitat at Vasey's Paradise is in good condition, and the species is in numbers that are comparable to recent years, although their numbers are lower than levels during the late 1990s and early 2000s. The abundance of Kanab ambersnail has not returned to levels seen before the 2002-2003 drought that severely reduced the amount of available habitat and likely cropped the population in that year (J. Sorensen, AGFD, pers. comm., 2009).

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). In previous Biological Opinions on the operations of Glen Canyon Dam operations, we concluded that up to 350 ft^2 (32.5 m^2) of the habitat and resident ambersnails would be lost by the highest flows from Glen Canyon Dam during MLFF (25,000 cfs), and that up to 117 m^2 (1259 ft^2) would be lost during the largest HFE (45,000 cfs). We anticipate the same level of habitat and snail loss during the 10-year life of the project.

The translocated population at Elves Chasm is not affected by dam operations and appears to have recovered from drought conditions, and surveys in 2009 found more snails than in previous years. The habitat also now has more wet habitat than in prior years (J. Sorensen, AGFD, pers. comm. 2009). Critical habitat for Kanab ambersnail has not been designated, thus none will be affected. The habitat at Vasey’s Paradise remains somewhat stable from year to year but is easily scoured by high floods and likely is affected by microclimatic conditions such as higher humidity and lower air temperatures. The surrounding environments and high vegetative cover may be important habitat features related to Kanab ambersnail survival (Sorenson and Nelson 2002).

EFFECTS OF THE ACTION

Effects of the action refer 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 and interdependent with that action that will be added to the environmental baseline. Interrelated actions are those that are part of a larger action and depend on the larger action for their justification. Interdependent actions are those that have no independent utility apart from the action under consideration. Indirect effects are those that are caused by the proposed action and are later in time, but are still reasonably certain to occur.

Humpback chub

As discussed in the 2008 Opinion and 2009 Supplemental Opinion, the operation of Glen Canyon Dam has adverse affects to humpback chub (USFWS 1995b, 2008, and 2009 Supplement). The 2008 Opinion and 2009 Supplemental Opinions provide thorough analyses of these effects and the parts of those opinions that were not challenged are incorporated here by reference. The MLFF will continue as described in the 1995 EIS and 1996 ROD. The MLFF as defined in the 1995 EIS (Reclamation 1995) was implemented following the 1995 EIS and 1996 ROD as part of an action that included formation of the GCDAMP, and with the intention of modifying the action over time based on the principles of adaptive management. This approach utilizes science, monitoring, and stakeholder and public involvement to improve management decisions on implementing changes in management (Williams et al. 2007), in this case Glen Canyon Dam releases. Many of the effects documented during the first years of MLFF are expected to be seen during this 10-year project as discussed in detail in the 2008 and 2009 Supplemental Opinion; those discussions are incorporated by reference.

Reclamation's action of fluctuating daily volume to meet power demand will continue to have direct and indirect effects to humpback chub. We acknowledge many improvements to the understanding and status of humpback chub during the past implementation of the MLFF. However, as a result of the existence and operations of Glen Canyon Dam, this endangered species will continue to experience altered water temperatures, flow regimes, and sediment loads. Pending experimental results from the HFE Protocol, it is not known if the managed sediment transport under the HFE Protocol will benefit or reduce the formation of nursery habitats downstream throughout Marble Canyon. Juvenile humpback chub prefer nearshore habitats in association with vegetation and talus slopes, where the effects of fluctuating daily volumes are concentrated (Valdez and Ryel 1995, Robinson et al. 1998, Stone and Gorman 2006, Korman and Campana 2009). Because of this preference y-o-y and juveniles are likely to be most affected by the fluctuating flows associated with continuation of the MLFF. However, the MLFF may also have a key beneficial effect, because it disadvantages non-native warm water fish that prey on and compete with humpback chub. Also, humpback chub recruitment appears to have improved during a period when the only known change to the system was from the MLFF (Coggins and Walters 2009). Thus, as discussed in other parts of this document, MLFF and other changes to the system, in particular changes that have led to warmer water temperatures may have improved conditions to support the humpback chub's ability to recover. Further the humpback chub is a long-lived and fecund species, living 30 years or more and producing about 2,500 eggs per female per year (Hamman 1982). This type of evolutionary adaptation is typical for a species that provides little parental care (humpback chub use broadcast spawning and do not protect young or use a nest) and are subjected to hostile environmental conditions that seldom provide adequate habitat for the survival of young, which are numerous due to normal losses from predation and the environment. This evolutionary strategy enables survival despite sporadic and poor recruitment in most years (Minckley and Deacon 1991, Jakobsen 2009). To summarize, the information available today indicates that although MLFF may have adverse effects, it also may provide sufficient habitat for humpback chub to survive and recover, and we do not find that MLFF will have result in adverse modification to critical habitat for this reason.

The operation of Glen Canyon Dam is directly linked to survival rates and production of rainbow trout downstream of the dam (Korman and Melis 2011). Preliminary information indicates that high steady flows in 2011 have resulted in a significant increase in rainbow trout reproduction at Lees Ferry (J. Korman, Ecometric, written communication, 2011). High steady flows are also likely to occur in 2012 to fulfill equalization requirements. However, it is not known if and/or when high numbers of rainbow trout will move out of the Lees Ferry Reach into the LCR Reach. The Natal Origins and other mainstem monitoring work will provide some additional assessment, but overall we anticipate a significant adverse effect to the biological elements of humpback chub critical habitat: food supply (B1), predation (B2), and competition (B3) in Reach 7. However, we do not anticipate adverse modification to critical habitat from this effect because under this Opinion Reclamation will institute non-native fish control based on a series of data-driven triggers and re-evaluate project implementation every three years which will provide sufficient opportunities to re-direct management through the GCDAMP.

The majority of the humpback chub are distributed throughout the LCR. Rainbow trout, although prominent in the mainstem, are rare in the LCR. Most humpback chub spawning takes place in the LCR, and some adults may never leave the LCR. Douglas and Marsh (1996) hypothesized that there was a contingent of resident adult fish that never leave the LCR, and another contingent that migrated into the LCR to spawn. Since many humpback chub inhabit the upper reaches of the LCR, they are not affected by the operations of Glen Canyon Dam, at least while they are in the LCR. Most of the humpback chub in the LCR are not impacted by the daily operations of Glen Canyon Dam except when these fish enter the mainstem. However, the species has had few opportunities to expand into the mainstem aggregation because of cold water, the loss of seasonal flows, daily fluctuating flows, and the presence of predators and competitors. However, as discussed throughout the document, new information from the NSE study indicates that young humpback chub may be able to survive in mainstem habitats.

With the continuation of MLFF, outside of equalization flows, the highest monthly flow releases will likely continue to occur in the winter and summer when power demands are highest. This is in contrast to historical pre-dam hydrograph patterns when the spring months delivered the highest flows, followed by low summer flows which allowed the water to warm sufficiently and accommodate mainstem reproduction and recruitment of humpback chub. Low summer flows to benefit young of year humpback chub that are displaced into the mainstem via monsoon flows from tributaries such as the LCR will not occur in a manner that resembles the pre-dam conditions to which humpback chub are adapted. However, preliminary estimates that show apparent good survival rates of young of year humpback chub in the mainstem near the LCR have been documented between 2009 and 2011 when water temperatures were relatively warm, and this may continue during years of above average water temperature (S. VanderKooi, USGS, oral communication, 2011).

During years when water levels in Lake Powell are high, water temperature of Glen Canyon Dam releases are typically cold, averaging between 8 and 10 ºC. This effect is seen clearly in Figure 6, which illustrates that water temperatures at the LCR failed to reach 12 ºC every year from 1990 to 2003 with the exception of the low summer steady flow experiment conducted in 2000. If Lake Powell elevations rise to full pool levels again during the proposed action, humpback chub in the mainstem would experience water temperatures not conducive to successful mainstem spawning, egg incubation and optimal survival of young. As such, river conditions would limit humpback chub spawning and rearing in a significant portion of the action area. However, juvenile and adult life stages will persist throughout the action area, primarily in association with small aggregations near tributary mouths or small, warm springs.

During years when Lake Powell elevations are lower, water temperatures are more likely to be above average (Figure 6, years 2003 to present). The ability of humpback chub to effectively avoid some predators may increase with temperature, especially when temperatures are closer to 20 ºC as preliminary data for rainbow trout indicates (D. Ward, USGS, written communication, 2011). Modeling predictions and the regional projections relative to climate change predictions for the southwestern United States all tend to indicate that the river may continue to be warm, at least relative to conditions downstream from Glen Canyon Dam since the dam was completed and filled in 1980.

Reclamation also predicted that Lake Powell elevations would be lower on average, and water temperatures of Glen Canyon Dam releases higher on average, under operations of Glen Canyon Dam defined by the Interim Guidelines which will be in effect through 2026 (G. Knowles, Reclamation, written communication 2011).

A more natural hydrograph including low steady flows in the summer months has long been supported by some researchers. In some years, when equalization flows occur between lakes Powell and Mead, such as in water year 2011, flows will tend to be steady. The steady flows may occur later in the year such as in November 2011, when releases were steady near 15,500 cfs due to ongoing maintenance work at Glen Canyon Dam. Projections for steady flows are likely to continue at approximately 22,600 cfs through the end of the 2011 calendar year (R. Clayton, Reclamation, written communication, 2011).

The use of steady flows to accommodate downstream and nearshore warming also requires elevated air temperatures, so low steady flows in the late fall (that is, past about mid-October) are not expected to increase water temperature. This is supported by the fact that mainstem monitoring in the LCR Reach in 2009 and 2010 did not document any benefit to humpback chub in this portion of in Reach 7 (GCMRC unpublished data). Steady flows were discussed at the 2007 Long Term Experimental Plan (LTEP) Workshop (GCMRC 2008). Researchers at the workshop concluded that if the primary goal is to promote humpback chub spawning and increase larval survival in the mainstem, then efforts to increase mainstem temperatures through the use of steady flows should be initiated in June. If the goal is limited to promoting survival and growth of fish produced in the LCR that are transported into the mainstem of the Colorado River by late summer monsoon rain events, then efforts to increase mainstem temperatures should be initiated in August (GCMRC 2008). The use of steady flows to accommodate downstream and nearshore warming also requires elevated air temperatures, so low steady flows in late fall (that is, past about mid-October) are not expected to increase water temperature. In addition, little to no benefit has been documented for humpback chub in the LCR Reach from the

September-October steady flow experiment (GCMRC unpublished data). In fact, during the 2011 Knowledge Assessment Workshop, some researchers hypothesized that steady flows would benefit rainbow trout and other non-natives more than humpback chub. However, Ralston (2011) concluded that "When reservoir elevations allow discharge temperatures to exceed 13ºC, it may be informative to implement steady discharges to see how YOY [fish at the LCR respond to warmer temperatures and steady discharges. The results can be compared with data collected [from] 2003–6 during fluctuating discharges and possibly different predator loads, provided sufficient long-term monitoring is in place." As stated previously, the high steady flows associated with equalization may be providing a large benefit to rainbow trout by providing additional habitat in the Lees Ferry Reach. Without suppression flows or non-native removal, this may have significant effects on the humpback chub and its critical habitat. Ongoing monitoring and information gathered from the Natal Origins study will provide additional information.

Humpback chub and other native fish (flannelmouth and bluehead sucker) known to use tributaries for spawning appear to be persisting in stronger numbers in recent years (Van Haverbeke et al. 2011). Additional mainstem translocations of humpback chub and exploratory efforts for razorback sucker may result in positive effects for both species. Reclamation's commitment to continue working with the NPS and other partners to support translocation of humpback chub will further conserve the species. If humpback chub populations can be secured in tributaries other than the LCR, adult chub can be expected to move into the mainstem aggregations and other areas of the mainstem river and augment the distribution of humpback chub throughout the action area.

Several researchers have reported that transport of young humpback chub from the LCR to the mainstem occurs primarily with monsoonal rainstorm floods during July and August (Valdez and Ryel 1995, Douglas and Marsh 1996, Gorman and Stone 1999) and this will continue during the life of the project. As they enter the mainstem Colorado River, these fish will experience slower growth rates, predation, and effects from flow fluctuations, possible cold-water shock, diseases, and other factors (USFWS 2002a). Depending on the strength of the year-class, impacts from humpback chub escapement can vary (Valdez and Ryel 1995), with age-0 and age-1 humpback chub groups expected to be most impacted during the 10-year life of the project.

Under the proposed action, we anticipate that the majority of humpback chub will spend most if not all of their life in a very small portion of the action area. This is because the largest aggregation of humpback chub in the Grand Canyon (the LCR aggregation), occupies only a few miles of river in Grand Canyon. Many subadult and adult humpback chub (approximately 200 mm and larger) leave the LCR once they reach a certain size to spend non-spawning periods in the mainstem (Gorman and Stone 1999). These larger size classes are more likely to withstand cold water temperatures and avoid most predators. While this movement is part of their life history, some scientists believe that these fish move into mainstem habitats because of density dependent factors in the LCR. That is, food resources in the LCR are limited and competition is high so the larger individuals move into the mainstem in search of food. Thus, as stated in our 2008 Opinion, it is possible that the recovery goal for the Grand Canyon population could be met by providing for all of the PCEs of critical habitat in Reach 6, the LCR, and a set of PCEs in the mainstem focused on needs of non-spawning adult fish. We conclude that prospects for recovery would improve by providing for all the PCEs in Reach 7, which would add resiliency to the overall population by maintaining some recruitment from the mainstem aggregations.

Reclamation has committed to work through the GCDAMP to monitor the abundance of humpback chub and species composition at the eight mainstem aggregations of humpback chub in Marble and Grand Canyon annually. This monitoring will provide additional information to determine the level at which the PCEs in the mainstem Colorado River are functioning.

If the spring 2008 HFE conditions are repeated between 2010 and 2020, we can expect rainbow trout cohorts that hatch after April 15 to have high early survival rates particularly since redds would not be subject to scour and burial, and hatchlings would be less susceptible to displacement from the high flows associated with HFE. Instead, these cohorts will likely emerge into a benthic invertebrate community that was enhanced by the flood event, with some portion of the trout likely moving downstream into humpback chub habitat. In future spring HFEs, number of non-native fish is likely to be limited when additional mortality can be applied to older life stages after the majority of density-dependent mortality has occurred (Korman et al. 2011).

The increase in brown trout may continue with or without HFEs, and their high piscivory rates appear to be unaffected by temperature, turbidity levels, or flows. However, Reclamation's commitment to continued coordination with NPS for brown trout control may ameliorate the situation somewhat. A complete understanding of the effect of increases in trout numbers on humpback chub survival and recruitment will take many years to achieve. This is because it will take time for these newly hatched trout to grow and disperse. In addition, it takes at least 4 years for humpback chub to reach maturity and be counted as an adult, as determined by the ASMR (Coggins et al. 2006, Coggins and Walters 2009).

The overall effect of fall HFEs on rainbow trout abundance is unclear. As discussed above, the 2008 HFE resulted in an 800 percent increase in rainbow trout in the LCR reach as a likely result of improved habitat conditions in Glen Canyon and subsequent emigration downstream (Makinster et al. 2010, Korman et al. 2011, Wright and Kennedy 2011). Although there are fewer data from the 2004 fall HFE, some effects appeared to have occurred to rainbow trout as well. During a three-week period that spanned the November 2004 HFE, abundance of age-0 trout, estimated to be approximately 7 months old at that time, underwent a three-fold decline (Korman et al. 2010). The decline may have been due to either increased mortality or displacement/disbursal as a result of the higher flow of the HFE (Korman et al. 2010). However, long-term trout monitoring data indicated that trout started to decline system-wide in 2001-2002, declined through the period of the 2004 HFE, and only began to recover in about 2007 (Makinster 2009b). Also, key monitoring programs to detect ecosystem pathways that affect rainbow trout in Lees Ferry were not in place at the time of the 2004 HFE (Wright and Kennedy 2011). Higher water temperatures and lower dissolved oxygen in fall 2005 also may have increased mortality and reduced 2006 spawning activity (Korman et al. 2010).

Impacts to food resources are expected to occur during the life of this project. As stated in the 2008 and 2009 Supplemental Opinions, fluctuations and seasonal variation in flow volume to meet electricity demand also affects the food base available for fishes. As flow volume increases, Valdez and Ryel (1995) documented increasing densities of chironomids and simuliids in the drift (water current) on the descending limb of the diurnal hydrograph, and McKinney et al. (1999) documented a similar response for *G. lacustris*. Chironomids and simuliids are important food items for adult humpback chub (Valdez and Ryel 1995), thus flow fluctuations may make these prey items more available in the drift. Flow fluctuations may have a negative effect on food availability in nearshore habitats, reducing the food base of juvenile humpback chub. In a study conducted in the upper Colorado River basin (middle Green River, Utah), Grand et al. (2006) found that the most important biological effect of fluctuating flows in backwaters is reduced availability of invertebrate prey caused by dewatered substrates (see also Blinn et al. 1995), exchange of water (and invertebrates) between the mainchannel and backwaters, and (to a lesser extent) reduced temperature. As the magnitude of within-day fluctuations increases, so does the proportion of backwater water volume influx, which results in a net reduction in as much as 30 percent of daily invertebrate production (Grand et al. 2006).

Field studies have documented a reduction in primary productivity during high steady flows in the winter months such as occurred during equalization flows of FY 2011. These equalization flows, which are expected to continue into 2012, will likely preclude enough light from reaching the river bottom to support algae growth thereby reducing algae production to just the edges of the river (Yard 2003, T. Kennedy, USGS, oral communication, 2011). It is not known if these flows will have a long-term affect. Invertebrate biomass and production on cobble is significantly higher than other habitat types (i.e., talus, cliff, backwaters) likely because cobble also has the highest algae biomass of any habitat (Stevens et al. 1997, T. Kennedy, USGS, oral communication, 2011). During spring HFEs, a switch from diatoms to filamentous algae may dominate the aquatic community, as was documented after the 2008 spring HFE. Both midges and black flies in Lees Ferry benefitted from this disturbance (Kennedy et al. 2011). Although production of black flies and midges was unaffected by the 2008 HFE at downstream sites, production of these taxa did increase in Lees Ferry and drove the significant increase in juvenile rainbow trout survival rates (Korman et al. 2011). This increase in food resources in the Lees Ferry Reach likely benefits rainbow trout but no benefit is expected to downstream food resources. Thus, it stands to reason that future spring HFEs are unlikely to be detrimental to key food items at downstream locations where humpback chub occur. The effect of future winter timed HFEs is highly uncertain but could be detrimental to the aquatic community downstream. Additional research is needed to determine the extent to which October - November HFEs and other high winter flows affect humpback chub.

Reclamation has committed to periodic “re-evaluations” of the proposed action with the FWS beginning in 2014. The purpose of this first evaluation is to undertake a review of the first two years of implementation of the proposed actions through a workshop with scientists to assess what has been learned; a written report will be prepared. Subsequent re-evaluations will occur every 3 years.

Non-Native Fish Control

As part of the proposed action, Reclamation will be conducting some non-native fish control efforts. Allowing trout populations to increase without an effective strategy for reduction poses a risk to the humpback chub population. Several techniques have been considered by Reclamation. In addition to mechanical removal of non-native fish in the PBR and the LCR Reaches, it may be possible that the increase in rainbow trout reproduction could be mitigated by suppression flows, although the subsequent density dependent offsets are unknown and may actually increase the survival of rainbow trout at latter life stages (i.e. age 1) because of lower trout densities overall, as documented by Korman et al. (2011). Increased flow fluctuations during summer may be effective at reducing trout numbers, because these fluctuations negatively affect fry growth and habitat use.

It is hypothesized that the trout population in the mainstem Colorado River near the LCR is not self-sustaining but is maintained by rainbow trout immigration into the reach (Makinster et al. 2010) likely by trout from the Lees Ferry, although rainbow trout may also reproduce in Marble Canyon (Coggins and Yard 2010, Coggins et al. 2011). Korman et al. (2011) noted that y-o-y trout numbers decline over the summer in the Lees Ferry Reach, especially when abundance is high, such as following the 2008 HFE, and speculated that this is likely due to either density-dependent mortality or emigration. Thus, when trout numbers are high in Lees Ferry, emigration may increase as a result of increased density. Recent monitoring in November 2011 indicate that numbers of y-o-y rainbow trout in Lees Ferry are very high, likely due to good spawning and nursery conditions caused by the wet hydrologic year and corresponding high steady equalization releases in 2011 under the Interim Guidelines, and numbers of rainbow trout in the Lees Ferry Reach are currently estimated to be over 1 million (J. Korman, Ecometric, pers. comm., 2011). This set of circumstances could lead to increases in numbers of rainbow trout in the LCR reach in 2012, adding to already high numbers of rainbow trout, and increasing potential losses of y-o-y and juvenile humpback chub to predation and competition.

Although humpback chub are generally a small component of the rainbow trout diet (Yard et al. 2011), in years such as 2011 when rainbow trout densities throughout Marble Canyon are high, their predatory impact on humpback chub could be very large. During the 2003-2004 study periods, rainbow trout consumed 65% of the total fish even though they are less piscivorous than brown trout. But because of their abundance (rainbow trout constituted 98% of salmonids in the catch initially), rainbow trout had a greater cumulative piscivory effect (Yard et al. 2011). In the 2010 Opinion, the efficiency rate of non-native mechanical removal was estimated. With a low electrofishing efficiency rate, it was estimated that predation on humpback chub would be reduced by 10-14%. If mechanical removal rates experienced an average efficiency rate, predation on humpback chub would be reduced by 41-70%, and if high efficiency field efforts were to occur, predation rates could be reduced by 49-85%. Based on GCMRC data, the canceling of two non-native removal efforts in 2009 resulted in the estimated loss of 1,000 to 24,000 mostly y-o-y and age 1- humpback chub. The average loss of humpback chub across variable predation and immigration rates was estimated at 10,817 juvenile and y-o-y fish. Based on the numbers of fish eaten during the 2003 and 2004 field season (Yard et al. 2011), we estimate that similar numbers of fish will be lost in each year when trout numbers are above 1,200 in the LCR Reach when (approximately 30,000 fish [native and non-native species combined] were consumed by rainbow trout [21,641 fish] and brown trout [11,797 fish] including 9,326 humpback chub). Additional modeling data by Yard et al. (2011) estimated predation rates in 2009 at 16,215 fish, which is still within the anticipated range of take of 1,000 to 24,000 fish. Given the high piscivory rate of brown trout, the losses of humpback chub could be much higher. However, as stated in the Description of the Proposed Action, Reclamation has committed to working with NPS to expand the brown trout removal efforts both in Bright Angel Creek and the mainstem Colorado River.

Semi-annual or quarterly monitoring trips will be conducted throughout the year to estimate both juvenile humpback chub and rainbow and brown trout abundance in the mainstem at the LCR confluence. These efforts will use mark-recapture abundance estimation techniques for trout and humpback chub focused at estimating rainbow trout abundance below the LCR confluence. This sampling effort would be scheduled around and throughout the water year. The resulting analysis and reporting will occur in January to allow for sufficient time to plan and schedule mechanical removal in the following year. The trout abundance trigger for mechanical removal is based on prior efforts (Coggins et al. 2011). The trigger would be reached if population estimates exceed average monthly abundance estimates of 760 rainbow trout, 50 brown trout, and the number of adult humpback chub drops below 7,000 adults. These estimates will also serve as trigger for ceasing removal.

We believe that reducing the production of rainbow trout in the Lees Ferry reach could help to negate the long-term need for mechanical removal in the LCR reach because it will reduce the number of fish available to emigrate into the LCR reach from upstream areas. These efforts are predicated on the assumption that non-native fish have a negative population level impact on native fish. The LCR reach non-native removal program (as in 2003-2006, 2009) demonstrated our ability to remove non-native fish and this program could be successfully re-implemented if necessary to reduce the numbers of non-natives in the LCR reach. Removal of non-native fish represents a major concern to Tribes in the LCR reach, plus uncertainty persists as to whether action is required at this time because a link between predation by trout and humpback chub population levels at the LCR has not been established. As discussed throughout this document and in Coggins et al. (2011), earlier removal efforts were successful at removing non-native fish and concurrent with this time period humpback chub populations were showing increased recruitment and increasing abundance. However, they further point out that this non-native fish removal occurred during a period of system-wide declines in rainbow trout associated with warming water in the Colorado River, which may also have increased humpback chub recruitment rates and abundance. The removal experiment was therefore confounded by increasing riverine water temperatures due to drought. Coggins et al. (2011) concluded that "…these early signs of [humpback chub] increasing survival and recruitment are encouraging, [but] they are not adequate to infer the success of the non-native removal policy primarily because of the nearly perfect correlation between the unplanned increases in release water temperature and the magnitude of the non-native fish reduction." Additionally, other assessments (Coggins and Walters 2009) suggest that increases in humpback chub may have begun prior to the 2003 mechanical removal effort. Thus uncertainty persists in whether non-native fish, through direct or indirect interactions with humpback chub, are increasing the risk of extinction or delaying recovery time for this species.

Similarly, Reclamation-proposed reductions in juvenile and adult brown trout numbers at their source in Bright Angel Creek could reduce the numbers of fish emigrating to the LCR reach, but this still has not been effectively demonstrated. Currently, brown trout in the mainstem Colorado River are primarily limited to the reach near the mouth of Bright Angel Creek (Makinster et al. 2010). Based on catch rates, preliminary abundance estimates of brown trout near Bright Angel (RM 87.4-89.9) were 621 ± 154 (95% confidence) (B. Stewart, AGFD, pers. comm., 2011). Reclamation has committed to working with NPS on an expansion of the brown trout removal effort through the GCDAMP. However, brown trout control may require an ecosystem or watershed level approach to be effective overall.

In addition to effects from predation, the high number of trout may also impact the humpback chub in the LCR reach through competition. All fish species compete for food resources and living space where ever they occur. Rainbow trout and adult humpback chub are both mid-water swimming fish, often found occupying the same habitat in the LCR reach, and are presumably competing for food and space. Reducing the production of trout in the Lees Ferry reach will not substantially reduce the abundance of trout in the LCR reach in the near-term because of the presence of trout that have already migrated into the LCR reach (Wright and Kennedy 2011). Further, it may take up to 5 years to significantly reduce the abundance of trout in the LCR reach depending on movement rates of rainbow trout from the Lees Ferry Reach (Coggins et al. 2011). On the other hand, significant reductions in the abundance in trout numbers were clearly made with only 1 year of mechanical removal efforts at the LCR Reach (Coggins et al. 2011).

If, as currently proposed by Reclamation, future removal efforts are directed at upstream areas such as PBR to intercept rainbow trout as they migrate downstream, it may take several years before the effects of intercepting rainbow trout in the PBR reach reduces rainbow trout populations in the LCR reach. This is because prior removal efforts targeted the non-native fish in the LCR reach directly (Coggins et al. 2011), while the PBR removal effort would only affect trout abundance in the LCR reach indirectly by intercepting the fish upstream while waiting for the LCR reach population of non-native fish to die of natural causes. Additionally, the PBR removal effort target a much larger number of rainbow trout. To accelerate the reduction in the biomass of rainbow trout in the LCR reach, further, mechanical removal may be necessary in the short-term to reduce the existing rainbow trout population biomass in the LCR as the PBR removal program reduces the new emigrants into this population from upstream.

Reclamation has committed to removing non-native fishes at the LCR reach only if 1) rainbow trout abundance estimates in the portion of the reach from RM 63.0-64.5 exceeds 760 fish, and 2) if the brown trout abundance estimate for this reach exceeds 50 fish (evaluated each calendar year in January); and 3) the abundance of adult humpback chub declines below 7,000 adult fish based on the ASMR. This model estimate will be conducted every 3 years, and each year the latest ASMR results will be evaluated with the other elements of the trigger (i.e. numbers of trout) each calendar year in January.

OR

The above conditions 1 and 2 for trout abundance are met, and all of the following three conditions are also met:

1. In any 3 of 5 years during the proposed action using data extending retrospectively to 2008, the abundance estimate of humpback chub in the LCR between 150-199 mm TL (5.9- 7.8 inches) within the 95 percent confidence interval drops below 910 fish (evaluated each calendar year in January); and

2. Temperatures in the mainstem Colorado River at the LCR confluence do not exceed 12 ºC in two consecutive years (evaluated each calendar year in January); and

3. Annual survival of young humpback chub (40-99 mm [1.6-3.9] TL) in the mainstem in the LCR Reach drops 25 percent from the preceding year (evaluated each calendar year in January).

Based on the fact that high trout numbers existed in the LCR Reach before the 2003-2006 non-native mechanical removal effort, and high numbers returned to 2003 levels after only a 2-year hiatus of mechanical removal, we conclude that a mechanical removal program in the LCR reach would, on its own, be inefficient at maintaining low densities of trout in the LCR reach for extended periods of time. If the PBR removal effort is ineffective, trout production in Lees Ferry would likely out-pace the removal efforts in the LCR reach and could result in an extended and expensive, but perhaps ineffective, mechanical removal program.

We know that the majority of the humpback chub consumed by trout are y-o-y and subadults (age < 3), and this is expected to continue during the life of this project. The loss of so many young fish will affect recruitment to the humpback chub population. However, Yard et al. (2011) stated that "Our findings show that humpback chub are vulnerable to trout predation at an individual level, but it is uncertain whether or not trout piscivory has had a population-level effect on this endangered species." This idea is further validated by the fact that the number of adult fish has increased in recent years both with and without removal of trout. This increase occurred in the presence of warmer water; future years of cold water and high trout numbers may have less favorable results. Reclamation's proposed action will both provide more information about the effect of predation and competition from non-native fish on humpback chub, and implement strategies to protect humpback chub if predation and competition are found to affect humpback chub status.

We believe that the increase in rainbow trout reproduction could be mitigated by suppression flows particularly in summer which could reduce rainbow trout survival in the Lees Ferry Reach. From 2003-2005 "Nonnative Fish Suppression Flows" were tested. These flows consisted of fluctuating dam releases daily from 5,000 to 25,000 cfs, from January 1 to approximately April 1, to evaluate their ability in controlling the trout population in the Lees Ferry reach. Although the "non-native fish suppression flows" did result in a total redd loss estimate of 23% in 2003 and 33% in 2004, this increased mortality did not lead to reductions in overall recruitment due to increases in survival of rainbow trout at later life stages (Korman et al. 2005, Korman et al. 2011). It has been suggested that such flows, if tested in the future, be referred to as "fishery management flows" since reducing the overall population of rainbow trout in Lees Ferry would theoretically benefit the Glen Canyon population of rainbow trout by reducing intra-species competition among trout in that reach, and benefit native fishes downstream through reduced emigration of trout from Glen Canyon to areas downstream, therefore reducing predation and competition from rainbow trout on native fishes. Reclamation has committed to study the use of suppression flows during the first two years of the proposed action. These studies would include some of the concepts addressed in the Saguaro Ranch workshop (discussed below) (Valdez et al. 2010), particularly the strategies to increase the daily down ramp rate, or high flows followed by low flows to strand or displace age 0 trout.

Rainbow trout are sensitive to Glen Canyon dam operations because habitat conditions are directly tied to flow conditions and are significant in determining the number of juveniles recruiting to the mainstem. Yet trout response to the low steady summer flows (LSSF) in 2000 was uncertain both in magnitude of response but also the extent of the outmigration after the LSSF was concluded (Ralston 2011). Increased flow fluctuations during summer may also be effective at reducing trout numbers, because these fluctuations negatively affect fry growth and habitat use. If the production of rainbow trout in the Lees Ferry reach could be reduced, the long-term need for mechanical removal in the LCR reach may diminish. However, there are currently so many trout in the LCR Reach that additional measures may be needed in the short-term, especially if water temperatures decrease, which could cause humpback chub to become more vulnerable to predation by rainbow trout (S. VanderKooi, GCMRC, pers. comm., 2011).

Reclamation has committed to a comprehensive program review in 2014, and this short-term measure will be re-evaluated at that time.

The prey base (mostly chironomids, simuliids, and plant material) for fish in the Colorado River below Glen Canyon Dam will persist under MLFF, but because invertebrate diversity and production is low, competition for these limited food resources is likely at locations where native and non-native fishes overlap. As stated previously, studies completed by GCMRC and the University of Wyoming have found a high degree of dietary overlap between humpback chub and rainbow trout (Donner et al. 2011). In fact, consumption of invertebrate prey by the fish assemblage at all sites that were studied overlaps with independent estimates of invertebrate production. In other words, the fish assemblage appears to be consuming close to, or all of, the available midge and black fly production that occurs annually. This indicates that the fish assemblage may be food-limited. The spatial overlap between humpback chub and rainbow trout is the highest at the LCR confluence. Fish production in the mainstem Colorado River is supported by a small array of food resources of potentially limited availability, which may lead to strong competition for food among fishes, including competition with non-native species that may constrain production of the remaining native fishes in this river (Donner 2011). Competition between these species includes y-o-y and age 1 humpback chub when they enter the mainstem through adulthood, which may result in a much larger concern than just predation alone and may be compounded given the high numbers of trout predicted to be near the LCR confluence area now and in the future after spring HFEs.

In April 2010, a group of independent scientists, during a meeting at Saguaro Lake, developed a Discussion Paper to assimilate some of the many discussions among scientists and managers faced with the challenge of balancing non-native fish populations in Grand Canyon with conservation of native and endangered fish species. As stated above, we believe that paper summarizes the appropriate objectives of the mechanical removal effort and provides a framework for understanding the degree to which rainbow trout emigrating from the Lees Ferry reach result in increased trout abundance in the LCR reach; and will help evaluate the efficacy of removing rainbow trout in the PBR Reach. The April 2010 paper identifies several alternatives for meeting the objectives described below. These were also considered in the structured decision making report that helped develop Reclamation's proposed action (Runge et al. 2011):

1. Reduce annual production rates of rainbow trout in the Lees Ferry reach,
2. Sustain a healthy Lees Ferry trout population with a balanced age-structure,
3. Reduce emigration rates of rainbow trout from Lees Ferry to downstream reaches occupied by humpback chub, and
4. Reduce numbers of brown trout in Bright Angel Creek and thus emigration rates to the LCR reach.

The effectiveness of rainbow trout removal in the PBR is not known, and is proposed to occur only as a test phase during fiscal year 2012. Testing trout removal in the PBR is expected to inform decisions on the further use of this portion of the proposed action. Some scientists have stated that PBR trout removal is not likely to affect the number of trout in the LCR reach (C. Walters, pers. comm. 2011). Depending on the number of trips per year, we believe that the PBR effort may result in a decline of rainbow trout available to move down into the LCR Reach, based on the estimates of the number of trout that may be removed from the PBR Reach. We believe that PBR may be effective, especially if tested in conjunction with flows or environmental conditions that limit rainbow trout recruitment.

To summarize, Reclamation anticipates removing rainbow trout from the PBR reach with up to 10 trips per year. However, for 2012, only two trips are planned as an experimental test of this concept. There is also a commitment to remove non-native fishes from the LCR reach based on the estimates of adult humpback chub provided by the ASMR and the number of trout in the LCR confluence and other triggers as described above. Reclamation has also committed to examine further the potential to use flows and other non-flow actions to improve the effectiveness of non-native fish control, including testing various flows as recommended at the Saguaro Ranch science workshop.

In conclusion, humpback chub status has improved in the Grand Canyon, in the LCR aggregation in particular, but apparently also in some of the other mainstem aggregations downstream from Glen Canyon Dam. These improvements coincided with management under MLFF. Recovery of a species is based on reduction or removal of threats and improvement of the status of a species during the period in which it is listed. Competition and predation by non-native fishes, including rainbow trout and brown trout, will continue to reduce the survival and recruitment of young humpback chub in the mainstem, which could threaten the potential recovery of the species. As discussed, the ultimate effect of predation and competition on humpback chub is still in question. Reclamation has designed a proposed action to both help answer this question and provide contingency for large-scale removal of non-native fishes if significant population-level effects are detected.

Near term modeling predictions through 2012, longer term predictions of the implementation of the Shortage Guidelines through 2026, and the regional projections relative to climate change predictions for the southwestern United States all tend to indicate that the river may continue to be warm, at least relative to conditions downstream from Glen Canyon Dam since the dam was completed and filled in 1980. Although these warmer water temperatures may still be too cold to provide optimal conditions for humpback chub, they will likely periodically provide sufficient conditions that support survival and recruitment of the Grand Canyon population because, as described earlier, the warmer water may provide sufficient temperatures for humpback chub spawning, survival of young, and growth.

Effects to Humpback Chub Critical Habitat

In our analysis of the effects of the action on critical habitat, we consider whether or not the proposed action will result in the destruction or adverse modification of critical habitat. In doing so, we must determine if the proposed action will result in effects that appreciably diminish the value of critical habitat for the recovery of a listed species (see p. 4-34, USFWS and National Marine Fisheries Service 1998). To determine this, we analyze whether the proposed action will adversely modify any of those physical or biological features that were the basis for determining the habitat to be critical 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, and the physical and biological features of those units, to determine the overall ability of all designated critical habitat to support recovery. Further, the functional role of each of the affected critical habitat units in recovery must also be defined.

The water and physical habitat PCEs of critical habitat of the LCR reach (Reach 6) will be little affected by MLFF because dam operations affect the mainstem Colorado River primarily, and would only affect the lower-most portion of the LCR via mainstem effects on the configuration of the mouth of the LCR, which is less than a quarter of a mile of the eight mile reach, (about three percent of critical habitat in Reach 6). Protiva (Protiva, in Ralston and Waring 2008) found that optimal habitat conditions for juvenile humpback chub at the LCR inflow, in terms of temperature and flow, are achieved at about 13,000 cfs in the mainstem. Because daily fluctuations are constantly changing conditions at the mouth in a manner that differs from pre-dam conditions, this theoretically results in less-than-optimal habitat conditions for juvenile humpback chub much of the time (Protiva, in Ralston and Waring 2008). At high flows, ponding can also occur (Protiva, in Ralston and Waring 2008), which may provide a benefit by slowing current velocity in the LCR and reducing passive or active emigration from the LCR, thereby increasing the residence time of juvenile humpback chub in the LCR where they have higher survival rates. Ponding only occurs at flows of more than 40,000 cfs however (Protiva, in Ralston and Waring 2008). But the effect of dam operations on the mouth of the LCR is likely a minimal effect overall to humpback chub, and only occurs in a very small portion of Reach 6.

In Reach 7, HFEs are likely to affect the following non-biological primary constituent elements: water (W1) water quality (W2), and physical habitat (nursery (P2) and feeding habitat (P3)). One of the desired outcomes of HFE protocol implementation is frequent rebuilding of sandbars and beaches through re-suspension and deposition of channel sediment deposits at higher elevations. HFEs may provide some rearranging of sand deposits in recirculating eddies, but that is expected to be quickly lost with a return to daily fluctuations. Reclamation's BA on HFEs noted that the 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. However, the return to fluctuating flows may make these habitats temporal, as documented in the months following the 2008 HFE, when erosion of sandbars and deposition in eddy return-current channels caused reductions of backwater area and volume. A temporary decline in benthic invertebrate numbers and fine particulate organic matter were documented after the 1996 high flow, but levels rebounded quickly and were available as food for y-o-y humpback chub the same year (Brouder et al. 1999). Overall, HFEs are likely to have a benefit to backwaters. As discussed previously, the MLFF directly affects water temperature, part of PCE W1 of Reach 7, by cooling mainstem water temperatures. However, overwintering and recruitment are expected to continue at 30-mile and other mainstem aggregations, particularly during years when water temperatures are above average and flows trend toward less daily fluctuations, although daily fluctuations may not be as significant limiting factor when water temperatures are warm. An increase in warmer water will likely result in increased growth rates of humpback chub but may be a tradeoff for improved conditions for brown trout, fathead minnows, and other warm water species that prey on or compete with humpback chub. As described earlier, water temperatures for about the last decade have consistently exceeded 12 °C, which may represent the threshold temperature for humpback chub given the improvement in the species status over this period.

The PCEs associated with the biological environment including food supply (B1), and predation from non-native fish species (B2), are expected to be adversely affected with HFEs. Food supply is a function of nutrient supply, productivity, and availability of food to each life stage of the species. Based on the currently available information, negative effects to the benthic community are not expected for HFEs below 31,500 cfs. However, the aquatic food base is expected to be scoured by spring HFEs between 41,000 and 45,000 cfs. The effect will decrease with downstream distance away from the dam, and recovery will be shorter in the downstream reaches, as was reported after the 2008 HFE (Rosi-Marshall et al. 2010). More information is needed on the effect of fall HFEs; however, in Reclamation's BA on HFEs, it is predicted that a fall HFE followed by a spring HFE could cause long-term damage to the food base. Since only 4 or 5 months would separate the two events, this is insufficient time to allow for complete recovery of most benthic invertebrate assemblages, although chironomids may recover within 3 months (Brouder et al. 1999.) In years when the food base recovery from a fall HFE is delayed until the following spring because of reduced photosynthetic activity over the winter months, a subsequent spring HFE could scour the remaining food resources and further delay recovery of the food base. Whenever two HFEs are conducted in a 12-month period, we anticipate adverse effects to the humpback chub food supply.

Predation and competition are normal components of the ecosystem, but are out of balance due to introduced fish species within critical habitat unit Reach 7, and are likely to remain sub-optimal with or without HFEs. The incidence of piscivory on humpback chub could be reduced during HFEs by periods of high turbidity. HFEs will redistribute sediment and will create periods of high turbidity during March-April and October-November, when sediment levels warrant a HFE. Since rainbow trout are visual feeders, their ability to prey on humpback chub should be limited during periods of HFEs. However, the opposite was documented in 2003 and 2004. Yard et al. (2011) documented higher piscivory rates of rainbow and brown trout during periods when the waters were consistently turbid downstream of the LCR. The cause of the increase in predation is not known and may be due to an increase in prey availability (i.e. small humpback chub moving passively out of the LCR with sediment), fish behavior, or other factors (Yard et al. 2011). Brown trout piscivory levels in the Colorado River have not been shown to be affected by turbidly and may cause substantial losses of to humpback chub.

Reclamation has also included in its proposed action several projects to monitor and evaluate the functioning of the critical habitat in Reach 7. Further, Reclamation will continue to work through the GCDAMP to 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 to better inform future decision making regarding dam operations and other related management actions.

Effects of the Action on the Role of Critical Habitat Reach 6 in Recovery

The LCR reach of critical habitat plays an important role in the recovery of the species because this is the primary spawning and rearing area for the Grand Canyon population, which constitutes the lower Colorado River Recovery Unit. As described in the Status of the Species section, demographic criteria must be met for this Recovery Unit as well as for one or two core populations in the upper Colorado River basin for downlisting and delisting, respectively, to occur (USFWS 2002a). The demographic criteria constitute the best scientific information with which to analyze the performance of critical habitat reaches in meeting the recovery needs of the species. As described earlier, in addition to the demographic criteria, the Recovery Goals also contain site-specific management actions and tasks and corresponding recovery factor criteria that must be met for downlisting and delisting to occur. So in evaluating the effectiveness of the critical habitat unit in meeting recovery, the primary measure is the status of the population in relation to the demographic criteria, and the secondary measures are the state of the recovery factors and implementation of their associated management actions and tasks.

As stated in the 2008 an 2009 Supplemental Opinions, the current abundance of humpback chub in the LCR is estimated to be 7,650 adults (between 6,000-10,000, age 4+; ≥ 200 mm [7.8 inches] TL) which is nearing the 10,000-11,000 adults the ASMR estimates constituted the adult LCR population when marking began in 1989, and appears to have been in an upward increasing trend since 2001 (Coggins et al. 2006a, Coggins and Walters 2009). The net effect of implementation of MLFF in recent years does not appear to be restricting the ability of critical habitat in Reach 6 to meet the demographic criteria of recovery.

The recovery criteria and associated management actions and tasks that relate to this critical habitat unit are based on the five listing factors. Most of these are directed at improving and protecting humpback chub habitat including critical habitat and the PCEs. For Factor A, an adequate flow for the LCR that meets the needs necessary for all life stages of humpback chub to support a recovered Grand Canyon population appears to be met in recent years, given the status and trend of the LCR population (Stone 2008a, 2008b, Coggins and Walters 2009). However, a specific definition of the LCR flow that provides for these habitats, or a specific model that relates flow to habitat conditions, has not been developed (Valdez and Thomas 2009). MLFF will have minor effects to the flow in the LCR, limited to the effects on habitat suitability related to flow conditions in the immediate vicinity of the mouth of the LCR. This is a very small percentage of habitat in the LCR that is impacted by MLFF or HFEs, thus these effects are likely negligible in terms of a population-level response.

Valdez and Thomas (2009) have a completed a draft management plan for the LCR basin that focuses on the needs of humpback chub, which was developed in response to an element of the reasonable and prudent alternative of the FWS 1994 jeopardy biological opinion (USFWS 1994). That reasonable and prudent alternative required that Reclamation be instrumental in developing a management plan for the LCR (USFWS 1995). The LCR watershed planning is also a conservation measure of the 2008 Opinion and thus part of Reclamation's proposed action, and is also a project in the Humpback Chub Comprehensive Plan (Glen Canyon Dam Adaptive Management Program 2009). Reclamation's assistance in this regard will help protect critical habitat in the LCR to the extent consistent with Reclamation's legal authority.

Factor B, overutilization, may not be relevant to the status of critical habitat, although there have been some concerns raised about handling stress in Reach 6 and 7. The highest estimated mortality rate of humpback chub associated with scientific collection during field activities is about 1,000, but most years the numbers are much lower (200 or less) (P. Sponholtz, FWS pers. comm., 2011). Despite the effects of handling stress on the species from repeated monitoring, the Grand Canyon population of humpback chub has improved in the last decade, and the results of research and monitoring activities have provided invaluable insight into the conservation needs of this endangered fish.

For Factor C, the focus of the Recovery Goals is on controlling the proliferation and spread of non-native fish species that prey on, compete with, and parasitize humpback chub. For the non-native fish species, current levels of control appear adequate. Non-native fish in Reach 6 of critical habitat continue to be at low levels (see Tables 6 and 7). Clearly such low levels should be maintained, but a specific target level as alluded to in the Recovery Goals has not been identified. Better regulation of sport fish stocking through development and implementation of stocking goals with the relevant basin states has not occurred, is still needed, and is a project of the Humpback Chub Comprehensive Plan (Glen Canyon Dam Adaptive Management Program 2009). As a conservation measure of the 2008 biological opinion, Reclamation will continue to support the implementation of the Humpback Chub Comprehensive Plan, which will assist with this aspect of recovery.

However, recently FWS completed consultation on the Arizona Statewide Sport Fish Stocking Program, and concluded that stocking would have minimal effect on the Grand Canyon population of humpback chub. Thus, at least with regard to legal stocking in Arizona, this aspect of the recovery goals has at least partially been addressed.

Asian tapeworm has been documented at infestation rates of 31.6–84.2 percent in the LCR, and has been hypothesized as a factor in the poor condition factor of humpback chub in the LCR (Hoffnagle et al. 2006, Meretsky et al. 2000). Nevertheless, the status and trend of the LCR population indicates that the negative effect of Asian tapeworm is not significant. Because MLFF results in net cooling effect to the mainstem and nearshore habitats of the mainstem, MLFF contributes to the suppression of both non-native fish species and Asian tapeworm.

For Factor D, existing regulatory mechanisms, the Recovery Goals identify the need to determine and implement mechanisms for legal protection of adequate habitat in the Little Colorado River through instream-flow rights, contracts, agreements, or other means. The most thorough accounting of the mechanisms and stakeholders needed to accomplish this for the LCR are provided in Valdez and Thomas (2009). As mentioned above, a primary need is to develop a model to define the instream flow needs of humpback chub to provide for all life stages of the species and relate flow to habitat needs of all life stages (Valdez and Thomas 2009). The current status and upward trends in population abundance and recruitment (Stone 2008a, 2008b, Coggins and Walters 2009) indicate that the current hydrograph of the LCR is adequate to achieve recovery. Reclamation will also continue to support watershed management efforts as a conservation measure of the proposed action, such as creation of the Valdez and Thomas' (2009) management plan, which will also help achieve this aspect of recovery for Reach 6.

For Factor E of the Recovery Goals, other natural or manmade factors, the primary element relative to the LCR is to identify and implement measures to minimize the risk of hazardous-materials spills from transport of materials along U.S. Highway 89 at and near the Cameron Bridge spanning the Little Colorado River. This is also a project of the Humpback Chub Comprehensive Plan (Glen Canyon Dam Adaptive Management Program 2009). A plan is needed to address this threat and efforts to develop one have not been initiated, though the need has been identified since at least 2002, and would likely require minimal expense. The Humpback Chub Comprehensive Plan includes a project to create this plan (Glen Canyon Dam Adaptive Management Program 2009). Reclamation will continue to support development and implementation of the Humpback Chub Comprehensive Plan as a conservation measure of the 2008 Opinion, which will serve to address this recovery need in Reach 6.

In summary, non-native fish in Reach 6 of critical habitat are expected to continue to be at low levels. As a conservation measure of the 2008 biological opinion, Reclamation will continue to support the implementation of the Humpback Chub Comprehensive Plan. Because MLFF results in net cooling effect to the mainstem and nearshore habitats of the mainstem, MLFF contributes to the suppression of both non-native fish species and Asian tapeworm. Non-native fish control efforts in the mainstem Colorado River may also provide some benefit to the PCEs in Reach 6 because warm water non-native fish will also be removed, preventing these fish from moving into the LCR and preying upon or competing with humpback chub. HFEs may result in short-term reductions in near shore habitat in the vicinity of the LCR confluence. However, sand re-deposition that rebuilds and maintains near shore and backwater habitats in the LCR confluence will benefit the functionality of the PCEs in this portion of critical habitat.

Effects of the Action on the Role of Critical Habitat Reach 7 in Recovery -

The MLFF will continue to affect the PCEs of humpback chub critical habitat in Reach 7 by manipulating flow releases on an hourly, daily, and monthly basis, affecting the timing and volume of delivery of water, water quality (W1, W2), the formation and quality of nearshore habitats (P2, P3), the composition of the food base, and the abundance and distribution of native and non-native fishes (B1, B2, and B3). The Recovery Goals relevant to Reach 7 are the demographic criteria and the mainstem recovery factor criteria. The mainstem recovery factor criteria focus on determining the role of mainstem habitats in humpback chub recovery and the relationship of mainstem flow to habitat, providing the appropriate Glen Canyon Dam releases, and reducing other threats in the mainstem, in particular, the threat of predation and competition from non-native fish species, as necessary to meet the demographic criteria for the Grand Canyon population. Although not explicitly mentioned in the Recovery Goals, all of the critical habitat PCEs in reach 7, water quality and quantity (W1 and W2), physical habitat for spawning, nursery areas, feeding and movement (P1-4), and the food supply, predation and competition components of the biological environment (B1-3), must be addressed in determining the needs of the species in the mainstem.

As described in the Status of the Species section, demographic criteria must be met for this Recovery Unit as well as for one or two core populations in the upper Colorado River basin for downlisting and delisting, respectively, to occur (USFWS 2002a). The current abundance of humpback chub in the LCR is estimated to be 7,650 adults (between 6,000-10,000, age 4+; ≥ 200 mm [7.8 inches] TL) which is nearing the 10,000-11,000 adults the ASMR estimates constituted the adult LCR population when marking began in 1989, and appears to have been in an upward increasing trend since 2001 (Coggins et al. 2006a, Coggins and Walters 2009). Van Haverbeke and Stone (2009) also note that closed estimates of abundance of humpback chub in the LCR in 2008 are now equivalent to closed estimates utilizing very similar methods conducted in the early 1990s (Douglas and Marsh 1996). The demographic criteria for the Grand Canyon population for downlisting includes the humpback chub population maintained as a core over a 5-year period, starting with the first point estimate acceptable to the FWS, such that the trend in adult (age 4+; ≥ 200 mm [7.8 inches] TL) point estimates does not decline significantly, the mean estimated recruitment of age-3 (150–199 mm [5.9- 7.8 inches] TL) naturally produced fish equals or exceeds mean annual adult mortality, and the population point estimate exceeds 2,100 adults.

As discussed earlier, the FWS has not yet determined that the demographic criteria for the Grand Canyon population has been met, but the best available science indicates that the PCEs in Critical Habitat Unit 7 are contributing to recovery because the demographic criteria are near to being met and the status of the species continues to improve in portions of the mainstem Colorado River. The Recovery Goals identify the need to determine the role of habitats in the mainstem in meeting the demographic criteria for humpback chub in Grand Canyon, and to determine and implement Glen Canyon Dam releases that will meet these needs in the mainstem. Reclamation is in the process of determining what flows are necessary in the mainstem to meet humpback chub habitat needs, which consist of all of the PCEs of critical habitat. The current focus of the GCDAMP is to complete the research needed to address the first criterion of Factor A in the Recovery Goals for Grand Canyon, to determine the relationship between humpback chub and its habitat in the mainstem and humpback chub and its habitat in the LCR, and determine what Glen Canyon Dam releases are required to meet and maintain the demographic criteria for the species. The steady flow experiment in September and October from 2008 - 2012, the 2008 high flow test, the NSE, and other research, monitoring, and management actions, tested how the MLFF affects the PCEs of critical habitat, in comparison to how steady flows affect the PCEs of critical habitat. A key component of this research, the NSE, will be continued by Reclamation as part of the Natal Origins Study, and evaluate the response of fish and other variables in nearshore habitats such as backwaters under different flows to help clarify the relationship between flows and mainstem habitat characteristics, and the availability of nursery habitat for y-o-y and juvenile humpback chub, and the degree to which humpback chub are effected by competition and predation in these nearshore habitats.

Ongoing research efforts of the proposed action will better define how the PCEs in Reach 7 function in recovery, and will help meet the recovery criteria of determine the relationship of habitats in the mainstem and the LCR, thus defining appropriate operations of Glen Canyon Dam to achieve humpback chub recovery, as required by the Recovery Goals. The Recovery Goals require that procedures for stocking sport fish be updated to minimize escapement of non-native fish species into the Colorado River and its tributaries through Grand Canyon to minimize negative interactions between non-native fishes and humpback chub. Information provided in the FWS Sport Fish Opinion has provided updated information on the threat of sport fish stocking and AGFD has committed to implement the Conservation and Mitigation Program (CAMP) which uses a suite of tools to provide on-the-ground conservation benefits to the native aquatic species and, where appropriate, to riparian or terrestrial species indirectly affected by anglers. Reclamation has also included as a conservation measure in the 2008 and 2009 Supplemental Opinions continued support for the implementation of the Humpback Chub Comprehensive Plan; the plan included a project to develop sport fish stocking procedures with the relevant basin states to minimize escapement of sport fish into humpback chub critical habitat (Glen Canyon Dam Adaptive Management Program 2009).

The Recovery Goals also identify the need to develop and implement levels of control of non-native fish species. As a conservation measure of the proposed action, Reclamation has also committed to continue implementation of non-native fish control efforts. As discussed above, the GCDAMP has demonstrated that successful removal of non-native trout is possible, and may benefit humpback chub (Coggins 2008b, Yard et al. 2008). The degree to which these removal efforts have improved the PCEs B2 and B3 is still a research question, although Yard et al. (2011) found that the 2003-2006 removal of rainbow and brown trout contributed significantly to reduce predation losses of juvenile humpback chub. Non-native removal has been identified by several authors as a possible cause of improved status of humpback chub (Andersen 2009, Coggins and Walters 2009, Van Haverbeke and Stone 2009). Reclamation's proposed action also includes evaluation of various non-native fish control techniques which will continue to refine methods of controlling non-native fish species. Reclamation's effort to control non-native fish species directly addresses this recovery need for the B2 and B3 PCEs of Reach 7.

Temperature is also likely key in the increasing numbers of humpback chub. Temperature analysis has revealed that there may be a minimum temperature at which survivorship of young humpback chub in the mainstem Colorado River near the LCR improves. Preliminary results from recently conducted research on the predation of trout on humpback chub has revealed that humpback chub appear better able to avoid predation by rainbow trout as temperatures increase (D. Ward, USGS, oral comm., 2011). Also, hatching success, growth, and survival of larval and y-o-y humpback chub all increase with temperature up to about 20 °C. Interestingly, humpback chub status has increased since about 2000 (Coggins and Walters 2009) and temperatures since that time have consistently been above 12 °C in the mainstem (P. Grams, USGS, oral comm., 2011). Therefore, LCR reach removal will also be triggered based on temperature of the mainstem at the LCR confluence. If in any two consecutive years temperature in the mainstem does not exceed 12 °C, this trigger will be reached. This trigger will be evaluated every January for the prior two years of temperature data. Further, Reclamation predicts that water temperatures in the future are likely to be higher as a result of the Interim Guidelines and global climate change. Thus, although not entirely as result of Reclamation's action, this PCE may also improve over the life of the project.

In summary, the Recovery Goals provide specific criteria for Reach 7 of critical habitat and its PCEs, and the most important of these are to identify Glen Canyon Dam releases that maintain adequate humpback chub habitat to support recovery and to implement levels of non-native fish control as necessary to support recovery. Reclamation's action includes an active adaptive management program that is progressively testing different flow regimes to benefit native fishes, and taking corrective actions based on the status of the humpback chub and its habitat. Reclamation has also included in its proposed action several projects to continue to monitor and evaluate the effect of flows and other actions on the PCEs of critical habitat in this reach. During the life of the proposed action, Reclamation will implement Non-native Fish Control when necessary, and is actively working to refine methods to remove and control the spread of non-native fishes. The benchmark for success of these efforts is the Recovery Goals demographic criteria for humpback chub in the lower Colorado River basin Recovery Unit. Although FWS has not yet determined that the demographic criteria have been met, as stated in the 2009 Supplemental Opinion, recent monitoring and modeling suggests that it has (Coggins and Walters 2009, Van Haverbeke and Stone 2009).

Razorback Sucker and its Critical Habitat

Because the species is very rare in the action area (limited to the very lower portion of Grand Canyon), the possibility of adverse affects to individuals is low through most of the action area. In the inflow area to Lake Mead, razorback suckers may use portions of the river upstream of Pearce Ferry; however the extent of such use is uncertain due to limited habitat available. Normal MLFF flows have little to no effect to the area likely occupied by razorback sucker as the fluctuations have attenuated to the point that significant stage change is unlikely to occur.

The known razorback sucker spawning area in Gregg Basin could be affected by HFEs, particularly in the spring (March-April) when razorbacks are documented to be spawning (Kegerries and Albrecht 2011). The increased amount of water moving from the river to the lake will raise water levels at the inflow and possibly increase turbidity with additional sedimentation once the water slows down in the upper lake. Razorback suckers spawn on gravel and cobble bars, and if eggs are present, any sediment deposition could result in damage or mortality to eggs. Depending on the change in water temperature from the HFE flows, development of eggs and the health of larval razorback suckers may be affected. Razorback sucker larvae may also be displaced from nursery areas and moved into unsuitable habitats as the water deepens with passage of the HFE. Our knowledge of the inflow razorback sucker population is limited, and factors controlling recruitment at this location are unknown. A project initiated by Reclamation in September 2010 is designed to evaluate habitat potential of razorback sucker in lower Grand Canyon and to identify possible and existing linkages with the reproducing population in Lake Mead.

Spawning of razorback suckers in Grand Canyon proper has never been documented and post-dam cool water temperatures likely limit spawning throughout most of the river. Although cold water is anticipated for the near future, warmer water is likely in the long-term. The warmer water should benefit razorback sucker but may also result in the expansion on non-native fishes and Asian tapeworm. The proposed action will continue to affect sediment transport and flow levels. The sediment transport may affect the availability of fine sediment and, therefore, the availability of backwaters in areas above Separation Canyon. Without aggressive management (i.e. movement of adult razorback suckers into secluded areas and removal of non-native species) high numbers of non-native fishes will continue to occupy the same backwaters that are very important for young razorback sucker throughout the action area.

The proposed actions will affect razorback sucker critical habitat in Grand and Marble Canyons in the same ways it affects humpback chub critical habitat, primarily by cooling water temperatures, providing for the presence of high numbers of cold-water predators, and dewatering effects on nearshore habitats from daily fluctuations in flow. Razorback suckers have always been rare in the action area, and the ability of the Glen and Grand Canyon reaches of the Colorado River to fully provide the PCEs is uncertain, although events (i.e. stocking of adults, collection of larvae) in the lower portion of the action area may be promising. Razorback suckers historically migrated as adults to spawn, often over long-distances, thus their historical presence in Grand Canyon may have been as a movement corridor.

The largest HFE (45,000 cfs for 96 hours) could increase the level in Lake Mead by 1 or 2 feet (0.3 to 0.6 m) (Reclamation, BA on HFE, 2011). It is not known if this will encourage or discourage spawning by razorback suckers. However, HFEs may improve food availability (B1) by creating a boost in the amount of organic matter into the Lake Mead area and inundating areas available for spawning. There may be an increase in the number of predators and non-native fish moving into the Lake Mead inflow area (B2) but given the large numbers of carp, channel catfish, and other non-natives already in the lake, it is not known whether this change will be measurable. Based on the rarity of razorback suckers in the action area, and the apparent lack of suitable habitat, the proposed action is not expected to further diminish the conservation contribution from this stretch of river and critical habitat.

Kanab ambersnail

Kanab ambersnail habitat will be adversely affected by scouring at Colorado River flows exceeding 17,000 cfs. In general, MLFF will scour Kanab ambersnail habitat, actually removing habitat and snails above the 25,000 cfs flow level. Reclamation's action under MLFF includes flows up to 25,000 cfs, but flows of this magnitude would occur rarely, only in wet years. Most of the HFE flows are expected to be at 45,000 cfs and may occur more than once a year and in consecutive years. As a result, some loss of habitat and snails will occur as these flows scour the vegetation and carry the snails downstream. If conducted frequently enough, HFEs may result in some permanent loss of habitat. Meretsky and Wegner (2000) noted that at flows from 20,000 to 25,000 cfs, only one patch of snail habitat was much affected (Patch 12), and a second patch to a lesser extent at flows above 23,000 cfs (Patch 11). According to estimates in 2000, 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).

Total habitat available in July 1998 (minus two patches that were not included in the total measurement) was 276.82 m^2 (2,979.7 ft^2). Thus, the patches expected to be affected by MLFF (patches 11 and 12), even in a good year, constitute less than 10 percent of total habitat available. Also, very few Kanab ambersnail have been found in patches 11 and 12 historically, and these patches are of low habitat quality for Kanab ambersnail (Sorensen 2009). The amount of habitat loss at the 25,000 cfs flow level due to scour would be low, and is estimated to be about 300-350 ft^2 (27.9-32.5 m^2) or less (Meretsky and Wegner 2000). Thus the scouring effect of MLFF is predicted to have limited effect on the overall population of Kanab ambersnail at Vasey's Paradise and scouring would occur in habitat low quality.

During the 2004 HFE, approximately 25 – 40 percent (29m^2 to 47m^2; [312 ft^2 to 506 ft^2]) of habitat that would have been lost due to scour effects from the high flow test was temporarily removed prior to the test flow and replaced afterwards; 55 live Kanab ambersnails were also found and moved above the 41,500 cfs flow line, and essentially all of the habitat had recovered six months later (Sorensen 2005). This conservation measure was also conducted during the 2008 HFE. As discussed previously, Reclamation will not carry out this conservation measure for the proposed action because FWS and Reclamation have determined that this is no longer necessary. Instead, Reclamation will, through the GCDAMP, monitor the population on a periodic basis. It is worth noting that the median pre-dam high discharge was 51,200 cfs (Topping et al. 2003), thus historically, Kanab ambersnails were subjected to flows in excess of those proposed under the HFE Protocol on an annual basis, and it is likely that none of the habitat that will be affected by the proposed action existed historically.

Kanab ambersnails are pulmonate or air-breathing mollusks, but are able to survive underwater for up to 32 hours in cold, highly oxygenated water (Pilsbry 1948). In previous biological opinions on the operations of Glen Canyon Dam, we concluded that up to 350 ft^2 (32.5 m^2) of the habitat and resident ambersnails would be lost by the highest flows from Glen Canyon Dam during MLFF (25,000 cfs), and that up to 117 m^2 (1259 ft^2) would be lost during the largest HFE (45,000 cfs). We anticipate the same level of habitat and snail loss during the 10-year life of the project.

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. Kanab ambersnail at Elves Chasm would also be unaffected by MLFF because the snails and their habitat are located up the chasm well above the Colorado River and the influence of dam operations on flow. No critical habitat has been designated for Kanab ambersnail, thus none would be affected.

Climate Considerations for Effects to Humpback Chub

Climatologists predict that the southwest will experience extended drought, so lower Lake Powell Reservoir elevations and warmer release temperatures may be more common over the life the proposed action when compared to historical conditions (Seager et al. 2007, U.S. Climate Change Science Program 2008a, b). Modeling conducted by Reclamation to evaluate the effects of the Interim Guidelines provided predictions of water temperatures below Glen Canyon Dam through 2026. Reclamation utilized 100 years of Colorado River flow data to portray the potential effects of operational changes in wet (90th percentile, i.e. only 10 percent of the 100 years were above the 90th percentile of runoff), average (the 50th percentile), and dry (the 10th percentile). At the confluence of the LCR, during 10th percentile years, the average water temperature near the LCR was predicted to be slightly warmer (less than 0.8ºF [17 ºC]) under the Interim Guidelines in most months. During 50th percentile years, average water temperature near the LCR would also be slightly warmer from April through August. Overall, the predictions were that water temperatures downstream from Glen Canyon Dam would be warmer under the implementation of the Interim Guidelines (Reclamation 2007).

Reclamation has also completed finer-resolution modeling based on hydrological modeling for its October 24-Month Study forecast for Colorado River reservoir operations (Figure 7). Model predicted release temperatures from Glen Canyon Dam were computed based on model inputs from analogous years as determined by a comparison of forecasted Lake Powell hydrology with historic hydrology between the years 1990 and 2010. The forecast is provided as a range based on minimum, maximum, and most probable inflow volumes to Lake Powell. The forecasted Glen Canyon Dam release temperatures for the period through September 29, 2013 are expected to be relatively cooler compared with the period since 2003, but warmer than the historical period of 1978-2000 (Figure 6). Perhaps more importantly, the most probable scenarios predict release temperatures would exceed 12 °C in 2012. Thus 2012 is likely to continue the period since 2003 of 12+ °C temperatures at the LCR confluence, which as described above, may be at least partly responsible for the improvement in status of humpback chub over this period. Although these warmer water temperatures may not be optimal for humpback chub, they appear to provide, and may continue to provide, conditions that support survival and recruitment of the Grand Canyon population.

CUMULATIVE EFFECTS

Cumulative effects include the effects of future State, tribal, local or private actions that are reasonably certain to occur in the action area considered in this biological opinion. Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the ESA.

Cumulative effects to the humpback chub and its critical habitat stem from Native American actions, and State, local, or private actions in tributary watersheds upstream of the action area. Native American use of the Colorado River in Grand Canyon includes cultural, religious, and recreational purposes, as well as land management of tribal lands (e.g. recreational use including rafting, hunting, and fishing). These uses affect humpback chub and its critical habitat in similar ways to uses permitted by NPS, although on a much smaller scale thus far, and thus are projected to have minimal effects to humpback chub and its critical habitat.

Stone et al. (2007) describes the potential for non-native fishes, including those hosting parasites, to invade the lower LCR from upriver sources 155 miles (250 km) away during certain flood events travelling through the intermittent river segments. Non-native fishes stocked into the area in Arizona utilizing Federal funds have been evaluated, as described above, and are not anticipated to significantly affect humpback chub or its critical habitat; however, illegal stocking in the area could result in adverse effects to humpback chub.

Non-Federal actions on the Paria River and Kanab Creek are limited to small developments, private water diversions, and recreation, and are expected to continue to have little effect on humpback chub and its critical habitat. Non-Federal actions in the LCR drainage are extensive, but as discussed in the Environmental Baseline section, these effects have thus far not had a detectable adverse effect on humpback chub and its critical habitat in the LCR, perhaps because these effects are diffuse over a wide area, and are distant from humpback chub and its critical habitat. The draft management plan for the LCR watershed (Valdez and Thomas 2009) provides recommendations to conserve humpback chub in light of these potential effects.

Razorback sucker critical habitat will be affected through the same activities as humpback chub critical habitat. Ongoing land uses around the non-Federal properties are not expected to change during the 10-year period covered by the proposed action, with agricultural uses, urban/suburban development, and recreational uses continuing.

Kanab ambersnail occurrence in the action area is entirely on Federal lands managed by Grand Canyon National Park, and thus would not be subject to these effects, although their habitat is created by springs, and it is conceivable that some distant non-Federal action could affect the ground water that supplies these springs. We are currently unaware of any possible future non-Federal actions that affect the aquifers that create Kanab ambersnail habitat.

Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the ESA. Since a significant portion of the action area is on Federal lands, any legal actions occurring in the future would likely be considered Federal actions, and would be subject to additional section 7 consultation. All activities will occur with the uncertainty surrounding the effects of climate change. The potential for alteration of flows in the basin as a result of climate change could have large impacts on the basin's aquatic ecosystem, including changes in the timing of peak flows from an earlier snowmelt; lower runoff peaks because of reduced snow packs; and higher water temperatures from increased air temperature. Not only would climate change affect the ecology of the species, it also could greatly affect the management of the programs through changes in politics and economics, such as a greater evaporation losses in the larger reservoirs that may reduce flexibility of operations; and drier conditions in the basin that may cause irrigators to call on their water rights more often or request more water rights.

CONCLUSION

This biological opinion does not rely on the regulatory definition of "destruction or adverse modification" of critical habitat at 50 CFR 402.02. Instead, we have relied upon the statutory provisions of the ESA to complete the following analysis with respect to critical habitat. We have also relied upon the U.S. Fish and Wildlife Service and National Marine Fisheries Service Consultation handbook (Consultation Handbook) (U.S. Fish and Wildlife Service and National Marine Fisheries Service 1998), which provides guidance on determining adverse modification of critical habitat, including the following (p. 4-34): "Adverse effects on individuals of a species or constituent elements or segments of critical habitat generally do not result in jeopardy or adverse modification determinations unless that loss, when added to the environmental baseline, is likely to result in significant adverse effects throughout the species' range, or appreciably diminish the capability of the critical habitat to satisfy essential requirements of the species."

After reviewing the current status of the humpback chub, razorback sucker, and Kanab ambersnail, the environmental baseline for the action area, the effects of the proposed actions, and the cumulative effects, it is the FWS's biological opinion that the actions, as proposed, are not likely to jeopardize the continued existence of the humpback chub, razorback sucker, or Kanab ambersnail and are not likely to destroy or adversely modify designated critical habitat for razorback sucker or humpback chub for the following reasons.

Humpback chub

As stated in the 2008 and 2009 Supplemental Opinions and re-affirmed in 2011, the Grand Canyon population appears to have improved to approximately 7,650 adult fish (age 4+) (an increase of 1,650 since the 2008 Opinion). This estimate is similar to the number of adult fish thought to be present in Grand Canyon in 1995, and is nearing or has met the demographic criteria for this population (USFWS 2002). The status of the species overall is reduced from what it was in 1995 because of declines in populations of the upper basin as of September 2009, most notably in Yampa, Desolation, and Gray canyons, due primarily to the proliferation of non-native fishes that prey on and compete with humpback chub. The most recent and best available estimates for the Grand Canyon humpback chub population trend (Coggins and Walters 2009) indicate that there has been increased recruitment into the population from some year classes starting in the mid- to late-1990s, during the period of MLFF operations, causing the decline in humpback chub to stabilize and begin to reverse in 2001. And the Grand Canyon population of humpback chub has increased in number during implementation of MLFF. This improvement in the population status and trend has been attributed in part to actions taken pursuant to MLFF, such as non-native fish mechanical removal, and the 2000 low steady summer flow experiment and other experimental flows and actions, as well as a serendipitous warming of Glen Canyon Dam releases due to lower reservoir elevations and inflow events (Andersen 2009). However, population modeling indicates the improvement in humpback chub status and trend was due to increased recruitment in the mid to late 1990s (Coggins and Walters 2009), 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. The exact causes of the increase in recruitment, and whether it is attributable to conditions in the mainstem or in the Little Colorado River are unclear. The increase in recruitment may have been due to the implementation of MLFF. Reclamation's proposed conservation measures and ongoing research will likely be beneficial to humpback chub and its critical habitat.

Population modeling indicates an upward trend in the number of adult humpback chub which continues to be the largest population range wide. This is in part due to the security of humpback chub in the LCR which are largely unaffected by dam operations or other factors.

The proposed action includes several projects to monitor and evaluate the effect of the proposed action including various monitoring and research projects of the GCDAMP annual work plans, which will provide timely information if the upward trend in humpback chub were to change .

Reclamation is committed to implementing a suite of conservation measures, through the GCDAMP, that will benefit humpback chub and its critical habitat. We are confident that Reclamation will implement these measures because of their continued demonstration of effectiveness in implementing past and ongoing conservation measures. These conservation measures further increase our confidence in our opinion that any and all adverse affects of the proposed action are reduced to the point that the action will not jeopardize the species or result in the destruction or adverse modification of critical habitat by precluding or compromising humpback chub recovery. The proposed action includes a number of actions to benefit the species. Conservation measures and ongoing research that will likely be beneficial to both the humpback chub and its critical habitat. The following is a summary of past efforts that demonstrate Reclamation's commitment to implementing these conservation measures to benefit humpback chub, and future conservation measures that will be implemented as part of the proposed action.

Fish Research and Monitoring

- As discussed in the 2008 and 2009 Supplemental Opinions, 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 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, ongoing monitoring of fish in the mainstem Colorado River, and monitoring of the abundance of humpback chub and species composition at the eight mainstem aggregations of humpback chub in Marble and Grand Canyon annually.

- Reclamation will, through the Natal Origins Study, continue research efforts on nearshore ecology of the LCR reach to better understand the importance of mainstem nearshore habitats in humpback chub recruitment and the effect of non-native fish predation on humpback chub recruitment, and to monitor the trend in annual survival of young humpback chub in the mainstem for use in determining the need for non-native fish control.

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 fish control planning, non-native fish 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 non-native 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 has provided $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 the proposed action. 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 non-native fish 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. As stated in our 2009 Supplemental Opinion, 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 has funded additional translocations of humpback chub into Shinumo and Havasu Creeks since that time. Reclamation assisted the USFWS with development and funding of a broodstock management plan and creation and maintenance of the refuge population at the DNFHTC. These translocations and the refuge population help to offset losses of young humpback chub due to predation and displacement of young by HFEs. This effort will continue as described in the Description of the Proposed Action in this document.

- Reclamation will also, as a conservation measure of the proposed action, fund an investigation of the genetic structure of the humpback chub refuge housed at DNFHTC that will include: 1) a genotype of the refuge population at DNFHTC using microsatellites; 2) an estimate of humpback chub effective population size; 3) a calculation of pairwise relatedness of all individuals in the DNFHTC Refuge population.

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Re-Evaluation Points

- Reclamation and FWS agree to meet at least once every 3 years to specifically review the need for reinitiation of consultation based on humpback chub status and other current and relevant information. Reclamation will undertake a review in 2014 of the first two years of implementation of the proposed action through a workshop with scientists to assess what has been learned, which will also serve as the first re-evaluation point. Reclamation will also produce a written report of each evaluation and either FWS or Reclamation may require reinitiation of formal consultation on the proposed action to reevaluate the effects of the action if warranted.

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 Reclamation will continue to support research on the effects of parasites such as the Asian tapeworm on humpback chub and potential methods of controlling these parasites.

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 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 have 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 2011). 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. 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 with 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 identified some of the primary water development risks to sustainable humpback chub critical habitat, as well as steps toward effective risk management, and key players in the implementation of the management plan (Valdez and Thomas 2009).

Humpback Chub Critical Habitat

- We believe humpback chub critical habitat in Reach 6, the LCR, will remain functional and continue to serve the intended conservation and recovery role for the humpback chub. MLFF should have minimal effect on PCEs of this unit, and some PCEs of critical habitat will be protected by the proposed action.

- The W1 and W2 PCEs of critical habitat in Reach 6 will benefit from Reclamation's efforts to address watershed planning for the LCR, and projects in the Humpback Chub Comprehensive Plan provide protective measures for PCEs in Reach 6, such as watershed planning to protect flows, and spill prevention planning for the U.S. Highway 89 Cameron Bridge spanning the Little Colorado River. PCEs B2 and B3 of Reach 6 will benefit from efforts to control non-native species, and perhaps from the cooling effect that MLFF has on the mainstem, which may suppress warm water non-native species.

- In summary, we find that the proposed action will not result in jeopardy to humpback chub or adverse modification of its critical habitat. The MLFF, periodic HFEs, and non-native fish control will have adverse effects to humpback chub, most notably due to changes in the river flows and their effect on near shore habitats for young humpback chub. However, the best available information indicates that the species' status began to improve for during implementation of MLFF and, new information indicates that while water temperatures have not been optimal for the species, they periodically occur at a level that allows for survival and recovery. HFEs may have adverse effects to humpback chub due to displacement and beneficial effects to rainbow trout, but also may improve habitats for humpback chub through the creation of more diverse near shore habitats, i.e. backwaters. Although there is evidence that young humpback chub are lost to predation, there remains uncertainty as to whether these losses will ultimately result in reduced abundance of humpback chub in the LCR area. And finally, Reclamation has developed a history of successfully implementing conservation measures, and will continue to implement these important actions such as translocation and refuge maintenance for the life of the proposed action.

Razorback sucker and Critical Habitat

Continuation of MLFF flows is unlikely to have any significant effect to razorback suckers in the Colorado River inflow area since effects of those releases are attenuated by the time the water reaches what is likely to be occupied habitat, and razorback sucker are very rare in the action area. The HFE flows may have some effect to spawning and recruitment if conducted during the spring; however, the potential for these adverse effects is limited by the number of potential HFE flows that could be conducted in the spring.

- Similar to the discussion of PCEs of Reach 7 for humpback chub, PCEs in the mainstem for razorback sucker will be directly and negatively affected by the proposed actions, but long-term conservation goals will not be precluded. Reclamation operates the dam using adaptive management through the GCDAMP and a series of conservation measures to sustain the existing primary constituent elements.

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 2009 to evaluate the suitability of habitat in lower Grand Canyon and Lake Mead inflow. Reclamation is undertaking this effort in collaboration with the FWS, GCDAMP, LCR MSCP, NPS, GCMRC, Nevada Department of Wildlife, and the Hualapai Tribe. This measure will help to better understand the status of the razorback sucker in the lower end of the Grand Canyon. Information from the HFE monitoring of habitats in the lower Canyon could lead to a better understanding of how to offset effects of the proposed action.

Kanab ambersnail

- As stated in the 2008 and 2009 Supplemental Opinions, although the MLFF will result in some loss of Kanab ambersnails and their habitat at Vasey's Paradise, we anticipate this loss will be small and not impair the long-term stability of the population because MLFF will only scour habitat at the highest flows during median and wet years, thus scouring would occur infrequently, and scouring would affect only a small proportion of overall habitat available; the habitat lost would be of low quality, and is expected to contain few snails. Kanab ambersnails have been subjected to such flows in the past under MLFF since 1991 and this occasional scouring effect of high MLFF releases appears to have had a negligible effect on the status and trend of the Vasey's Paradise population and is not expected to preclude the species' conservation. HFEs likely will result in the loss of some habitat, and Reclamation will monitor how this effects the population status.

The conclusions of this biological opinion are based on full implementation of the project as described in the Description of the Proposed Action section of this document, including any Conservation Measures that were incorporated into the project design.

INCIDENTAL TAKE STATEMENT

Section 9 of the ESA and Federal regulations pursuant to section 4(d) of the ESA prohibit the take of endangered and threatened species, respectively, without special exemption. "Take" is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. "Harm" is further defined (50 CFR 17.3) to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering. "Harass" is defined (50 CFR 17.3) as intentional or negligent actions that create the likelihood of injury to listed species to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding or sheltering. "Incidental take" is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited taking under the ESA provided that such taking is in compliance with the terms and conditions of this Incidental Take Statement.

The measures described below are non-discretionary, and must be undertaken by Reclamation so that they become binding conditions of any grant or permit issued, as appropriate, for the exemption in section 7(o)(2) to apply. Reclamation has a continuing duty to regulate the activity covered by this incidental take statement. If Reclamation (1) fails to assume and implement the terms and conditions or (2) fails to require any applicant to adhere to the terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, the protective coverage of section 7(o)(2) may lapse. In order to monitor the impact of incidental take, the Reclamation must report the progress of the action and its impact on the species to the FWS as specified in the incidental take statement. [50 CFR §402.14(i)(3)].

AMOUNT OR EXTENT OF TAKE

Humpback Chub

Similar to previous consultations related to the operations of Glen Canyon Dam, incidental take is expected from the effects of suboptimal water temperatures and displacement, as well as indirect mortality from increased competition and predation rates by non-native fish predators. Based on the analysis presented in the Effects of the Action section of this Opinion, y-o-y and juvenile humpback chub are likely to be killed or harmed with implementation of the proposed dam operations. In the 2008 and 2009 Supplemental Opinions, a surrogate level of incidental take was determined because of the limitations on estimating the number of y-o-y and age 1 humpback chub. With improved modeling, these estimates are more precise and in the 2010 Cancellation Opinion, Reclamation estimated that between 1,000 and 24,000 y-o-y or juvenile humpback chub will be lost to predation annually as a result of the proposed action, and estimated an average loss of approximately 10,000 fish per year. In years with non-native removal, the incidental take levels may be lower to some unknown extent. But in years such as 2012 when rainbow trout levels are very high, we anticipate higher losses of humpback chub to predation. We do not know how high these losses will be. We can, however, use the results of modeling efforts to estimate losses and through the ongoing adaptive management program implement conservation measures necessary to alleviate losses in the future.

Removal of non-native fish at the LCR reach would only occur if 1) rainbow trout abundance estimates in the portion of the reach from RM 63.0-64.5 exceeds 760 fish, and 2) if the brown trout abundance estimate for this reach exceeds 50 fish (evaluated each calendar year in January); and 3) the abundance of adult humpback chub declines below 7,000 adult fish based on the ASMR. This model estimate will be conducted every 3 years.

OR

The above conditions 1 and 2 for trout abundance are met, and all of the following three conditions are also met:

1. In any 3 of 5 years during the proposed action using data extending retrospectively to 2008, the abundance estimate of humpback chub in the LCR between 150-199 mm (5.9-7.8 inches) TL within the 95 percent confidence interval drops below 910 fish (evaluated each calendar year in January); and

2. Temperatures in the mainstem Colorado River at the LCR confluence do not exceed 12 degrees 12º C in two consecutive years (evaluated each calendar year in January); and

3. Annual survival of young humpback chub (40-99 mm [1.6-3.15 inches]TL) in the mainstem in the LCR Reach drops 25 percent from the preceding year (evaluated each calendar year in January).

PBR removal may occur at other times in coordination with the GCDAMP. With the occurrence of other lethal and nonlethal stressors from suboptimal water temperatures and unstable shoreline habitat associated with fluctuating flows, we do not anticipate that incidental take will exceed the 24,000 estimate/year in any year. We contemplate that take within these limits will still allow some recruitment to the adult population and therefore not preclude recovery. The incidental take is expected to be in the form of mortality, harm, and harassment. Take from mortality will be predominantly to y-o-y and juvenile humpback chub, size classes that have high mortality rates, and thus these losses may not affect the adult population. If these losses do affect the adult population, or even have measurable effects to young humpback chub, the trigger for LCR removal and other aspects of Reclamation's proposed action are designed to be implemented, through adaptive management, to continue to ensure that the humpback chub status does not decline and continues the improvement seen over the last decade.

Razorback Sucker

Based on the very low numbers of razorback suckers in the action area, we do not believe that incidental take of razorback sucker is reasonably certain to occur.

Kanab Ambersnail

The level of take that could occur from the proposed action would be in the form of harm or mortality resulting from scouring of habitat during the highest flows of the MLFF. The anticipated take is not expected to substantially diminish the size or vigor of the Vasey's Paradise population. The number of individual snails cannot be estimated because of seasonal and annual fluctuations in the population; therefore, as a surrogate measure of take, we will consider anticipated take to be exceeded if the proposed action results in more than 17% of Kanab ambersnail habitat being removed at Vasey's Paradise in any one year and this loss is attributable to the MLFF and/or the HFEs.

EFFECT OF THE TAKE

In this biological opinion, the FWS determines that this level of anticipated take is not likely to result in jeopardy to the species or destruction or adverse modification of critical habitat.

REASONABLE AND PRUDENT MEASURES AND TERMS AND CONDITIONS

In order to be exempt from the prohibitions of section 9 of the ESA, Reclamation must comply with the following terms and conditions, which implement the reasonable and prudent measures, described above and outline required reporting/monitoring requirements. These terms and conditions are non-discretionary.

Humpback chub

The following reasonable and prudent measures and terms and conditions are necessary and appropriate to minimize incidental take of humpback chub.

1. Reclamation has committed to develop, with GCDAMP and stakeholder involvement, additional non-native fish control options during the first two years of the proposed action to reduce recruitment of non-native rainbow trout at, and emigration of those fish from, Lees Ferry. Reclamation will coordinate the development of these actions with the on-going NPS Management Plan for native and non-native fish downriver of Glen Canyon Dam in both the GCNRA and GCNP. Both flow and non-flow experiments focused on the Lees Ferry reach may be conducted in order to experiment with actions that would reduce the recruitment of trout in Lees Ferry, lowering emigration of trout. Additional environmental compliance may be necessary for implementation of the following types of experiments that will be considered.

> A. Within two years, Reclamation should include an assessment of the feasibility to disadvantage reproduction of rainbow trout as described in Treatment #3 and Treatment #4 in Valdez et al. 2010, and repeated here.
>
> ***Treatment 3: Increase Daily Down-Ramp to Strand or Displace Age-0 Trout***
> This treatment would use dam releases during June through August to strand or displace age-0 trout and reduce rainbow trout survival. Increased down-ramp rates could reduce survival of age-0 trout by stranding them in exposed dewatered areas or by displacing them into less favorable habitats where they are subject to increased predation. Increased fluctuations would be most effective if they occurred daily from June through August

when young fish occupy habitats that are more affected by fluctuating flows; i.e., shallow, low-angle habitats. This treatment may only need to be done once a week. Several dam release options may be used to achieve this treatment including (1) a wider range in flows (higher maximum, lower minimum; e.g., summer normal 16,000 to 10,000 cfs, could be modified to 16,000 to 5,000 cfs and keep at 5,000 cfs for 3 hrs), (2) lower minimum flow than ROD flows (e.g., 3,000 cfs) for a short period of time (e.g., 1 hr) with a step up to a higher minimum that is within the ROD (e.g., 8,000 cfs); and (3) same range as ROD with faster ramp rates.

Treatment 4: High Flow Followed by Low Flow to Strand or Displace Age-0 Trout
Under this treatment, flows would be held high and steady (about 20,000 cfs) for a few days during June and July. Recently emerged trout tend to migrate to the lower edge of the varial zone, and steady flows are expected to produce an aggregation of fish in near-shore habitats. This would be followed by a quick down-ramp to a minimum flow (about 8,000 cfs) which would be held for 12-14 hours. This operation would be done every 2-3 weeks in June and July. Because this operation might not need to be done every day during the summer, there should be less impact to other resources compared to Treatment # 3. However, it could be used more frequently.

B. Explore flow and non-flow options for controlling trout movement downstream (such as coordination with angling community, NPS, AGFD, Tribes, and other groups, to better manage the Lees Ferry trout fishery through such actions as changing fishing regulations).

2. Reclamation shall protect y-o-y and juvenile humpback chub, monitor the incidental take resulting from the proposed action, and report to the FWS the findings of that monitoring.

A. Reclamation shall monitor the action area and ensure the long-term protection of the humpback chub as established by the GCDAMP.

B. Reclamation shall submit annual monitoring reports to the Arizona Ecological Services Office beginning in 2012 in collaboration with other GCDAMP participants including GCMRC, AGFD, NPS, and other cooperators to complete this monitoring and reporting. These reports shall briefly document for the previous calendar year the effectiveness of the terms and conditions and locations of listed species observed, and, if any are found dead, suspected cause of mortality. The report shall also summarize tasks accomplished under the proposed minimization measures and terms and conditions.

Kanab Ambersnail

The following reasonable and prudent measures and terms and conditions are necessary and appropriate to minimize incidental take of Kanab ambersnail.

1. Reclamation shall monitor project effects on Kanab ambersnail and its habitat to document levels of incidental take and report the findings to the FWS.

A. Reclamation shall work in collaboration with the GCDAMP participants including GCMRC, AGFD, and other cooperators to complete this monitoring.

Review requirement: The reasonable and prudent measures, with their implementing terms and conditions, are designed to minimize incidental take that might otherwise result from the proposed action. If, during the course of the action, the level of incidental take is exceeded, such incidental take would represent new information requiring review of the reasonable and prudent measures provided. Reclamation must immediately provide an explanation of the causes of the taking and review with the AESO the need for possible modification of the reasonable and prudent measures.

Disposition of Dead or Injured Listed Species

Upon locating a dead, injured, or sick listed species initial notification must be made to the FWS's Law Enforcement Office, 2450 W. Broadway Rd, Suite 113, Mesa, Arizona, 85202, telephone: 480/967-7900) within three working days of its finding. Written notification must be made within five calendar days and include the date, time, and location of the animal, a photograph if possible, and any other pertinent information. The notification shall be sent to the Law Enforcement Office with a copy to this office. Care must be taken in handling sick or injured animals to ensure effective treatment and care, and in handling dead specimens to preserve the biological material in the best possible state.

CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the ESA directs Federal agencies to utilize their authorities to further the purposes of the ESA by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information.

1. We recommend that Reclamation provide funding to verify temperature suitability needed for continued maintenance of the aquatic ecosystem food base and y-o-y humpback chub and other native fish. With the creation of the refuge population of HBC at DNFHTC, the FWS has the ability to spawn humpback chub to provide eggs, larvae and y-o-y for research. There remains some outstanding questions related to swimming ability at colder temperatures that have yet to be quantified for humpback chub as well as the question, can we quantify take associated with MLFF for the Incidental Take Statement. We recommend that Reclamation provide funding for life history research in the context of the water temperature profile available from the Glen Canyon Dam. This effort should recognize the on-going USGS work (such as D. Ward studies) and support it or other studies as appropriate.

2. We recommend that Reclamation develop an assessment report within the first two years of the proposed action that identifies and evaluates potential sites that could be used for rearing and release of humpback chub in the event of excessive predation, some other environmental factor, and/or a contaminant spill that eliminates or significantly reduces humpback chub populations.

3. Reclamation should consider providing funds to the FWS and AGFD to carry out preparation of the reports described in 1 and 2 above.

4. Reclamation should consider supporting the recommendations in the Kanab ambersnail 5-year review including convening a team of snail, taxonomy, and genetics experts to conduct a Structured Decision Making exercise focused on reviewing or revising the current taxonomic status of the *Oxyloma* genus.

5. Establish a second, offsite refuge for humpback chub including investigation of the most appropriate facility and infrastructure improvements (quarantine area) if necessary.

In order for the FWS to be kept informed of actions minimizing or avoiding adverse effects or benefiting listed species or their habitats, the FWS requests notification of the implementation of any conservation recommendations.

REINITIATION NOTICE

This concludes formal consultation on the action outlined in the Project Description of this Opinion. As provided in 50 CFR §402.16, reinitiation of formal consultation is required where discretionary Federal agency involvement or control over the action has been retained (or is authorized by law) and if: (1) the amount or extent of incidental take is exceeded; (2) new information reveals effects of Reclamation's action that may affect listed species or critical habitat in a manner or to an extent not considered in this opinion; (3) the agency action is subsequently modified in a manner that causes an effect to the listed species or critical habitat not considered in this opinion; or (4) a new species is listed or critical habitat designated that may be affected by the action. In instances where the amount or extent of incidental take is exceeded, any operations causing such take must cease pending reinitiation.

In keeping with our trust responsibilities to American Indian Tribes, we encourage you to continue to coordinate with the Bureau of Indian Affairs in the implementation of this consultation and, by copy of this biological opinion, are notifying the following Tribes of its completion: the Southern Paiute Consortium, Fredonia, Arizona, Havasupai Tribe, Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Navajo Nation, Pueblo of Zuni, and San Juan Southern Paiute Tribe. We also encourage you to continue to coordinate with the Arizona Game and Fish Department.

We appreciate the Bureau of Reclamation's efforts to identify and minimize effects to listed species from this project. For further information please contact Debra Bills (ext. 239) or Steve Spangle (ext. 244). Please refer to the consultation number 22410-2011-F-0100, in future correspondence concerning this project.

/s/ Steven L. Spangle

cc: Regional Director, Fish and Wildlife Service, Albuquerque, NM (ARD-ES) (J. Bair; M. Oetker)
Project Coordinator, Arizona Conservation Office, Flagstaff, AZ (P. Sponholtz)

Chief, Natural Resources Division, National Park Service, Grand Canyon, AZ

Glen Canyon Natural Recreation Area, Page, AZ
Chief, Habitat Branch, Arizona Game and Fish Department, Phoenix, AZ (B. Stewart)
Director, Environmental Programs, Bureau of Indian Affairs, Phoenix, AZ
Havasupai Tribe, Supai, AZ
Hopi Tribe, Kykotsmovi, AZ
Hualapai Tribe, Peach Springs, AZ
Kaibab Band of Paiute Indians, Pipe Springs, AZ
Navajo Nation, Window Rock, AZ
Pueblo of Zuni, Zuni, NM
San Juan Southern Paiute Tribe, Tuba City, AZ
Southern Paiute Consortium, Fredonia, AZ

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APPENDIX A AND LITERATURE CITED ON THE FOLLOWING PAGES

APPENDIX A

SOUTHWESTERN WILLOW FLYCATCHER

Status in the Action Area

The southwestern willow flycatcher was listed as endangered without critical habitat on February 27, 1995 (60 FR 10694; USFWS 1995b). Critical habitat was later designated on July 22, 1997 (62 FR 39129; U.S. Fish and Wildlife Service 1997). On October 19, 2005, the FWS re-designated critical habitat for the southwestern willow flycatcher (70 FR 60886; USFWS 2005b). Critical habitat was voluntarily remanded by the FWS in 2009 and revised proposal was published August 15, 2011(76 FR 50542) but does not include the Colorado River through Grand Canyon. The 2005 critical habitat designation remains in effect until the current proposal is finalized. Proposed critical habitat on the Lower Colorado River begins at RM 243. A final recovery plan for the southwestern willow flycatcher was completed in 2002 (USFWS 2002c).

Flycatchers have nested along the Colorado River in Grand Canyon over the last 30 years, with territories typically located in tamarisk-dominated riparian vegetation along the river corridor (James 2005). Suitable nesting habitat is extremely disjunct from approximately RM 28 to RM 274 (Holmes et al. 2005, James 2005). Surveys conducted between 1992 and 2007 documented a very small breeding population in upper Grand Canyon, mostly at RM 50-51 and the area around RM 28-29, although only 1 to 5 territories have been detected in any one year (Holmes et al. 2005, James 2005). Another area of importance in the mid-1990s was RM 71-71.5. However, that area does not appear to have been occupied for the last 10 years (Holmes et al. 2005, James 2005). A total of 16 breeding sites have been detected through 2007, with a high of 16 territories detected in 1998 (Sogge and Durst 2008), but that declined to an estimated 4 territories in 2007 (Durst et al. 2008). The lack of flycatchers recently in Grand Canyon is likely more a function of decreasing numbers in more important areas nearby, like Lake Mead, than from changes in habitats in Grand Canyon.

Non-native tamarisk beetles have recently been found along the Colorado River from Navajo Bridge all the way downstream where intermittent defoliation occurred along the river corridor to just below Lower Lava rapid (~Mile 181). It is likely the beetle will continue to spread through Grand Canyon, which may adversely affect the suitability of flycatcher nesting habitat where tamarisk is an important component of the vegetation (G. Beatty, USFWS, pers. comm., 2011).

Analysis of Effects

The southwestern willow flycatcher can be adversely affected by high flows through scouring and destruction of willow-tamarisk shrub nesting habitat or wetland foraging habitat, or conversely, through a reduction in flows that desiccate riparian and marsh vegetation. However, willow flycatcher nests in Grand Canyon are typically above the 45,000 cfs stage, and thus would not be affected by the highest Glen Canyon Dam releases (Holmes et al. 2005). Flycatchers nest primarily in tamarisk shrub in the lower Grand Canyon (Sogge et al.1997), which is quite common, and can tolerate very dry and saline soil conditions, and thus is capable of surviving lowered water levels (Glenn and Nagler 2005). Therefore, maximum flows of the MLFF of 25,000 cfs and minimum flows of 5,000 cfs are neither expected to scour or dewater habitats enough to kill or remove tamarisk, and no loss of southwestern willow flycatcher nesting habitat from flooding or desiccation is anticipated. HFEs may create flows of up to 45,000 cfs for up to 96 hours; similar flows have been tested in past HFEs and have not affected southwestern willow flycatcher habitat.

An important element of flycatcher nesting habitat is the presence of moist surface soil conditions (USFWS 2002c). Moist surface soil conditions are maintained by overbank flow or high groundwater elevations supported by river stage, and provide nesting habitat of riparian trees, and habitat for insects that contribute to the food base for flycatchers. The HFEs may result in the distribution of fine sediments extending farther laterally across the floodplain and deeper underneath the surface providing for the retention of subsurface water, which may provide for the development of the vegetation that provides flycatcher habitat and microhabitat conditions. The MLFF flows have been implemented since 1991, and given the typical range of daily fluctuations, groundwater elevations adjacent to the channel are not expected to modify nesting habitat. Thus the proposed action will likely have little effect on the abundance or distribution of southwestern willow flycatcher in the action area.

Conclusions

After reviewing the status of the southwestern willow flycatcher including the environmental baseline for the action area, and the effects of the proposed action, we concur that the proposed action may affect, but is not likely to adversely affect the southwestern willow flycatcher. No southwestern willow flycatcher critical habitat occurs in the action area, thus none will be affected. The downstream proposed critical habitat will not be affected.

We base our concurrence on the following:

- Flycatcher habitat in the action area consists of tamarisk, which is not likely to be affected by flows within the limits of the MLFF or HFEs.
- The flow limits of the MLFF are not expected to desiccate flycatcher habitat to the point that food base for willow flycatcher is affected.
- HFEs may result in the distribution of fine sediments extending farther laterally across the floodplain and deepening the soils surface providing for the retention of subsurface water, which may provide for the development of the vegetation that provides flycatcher habitat and microhabitat conditions.

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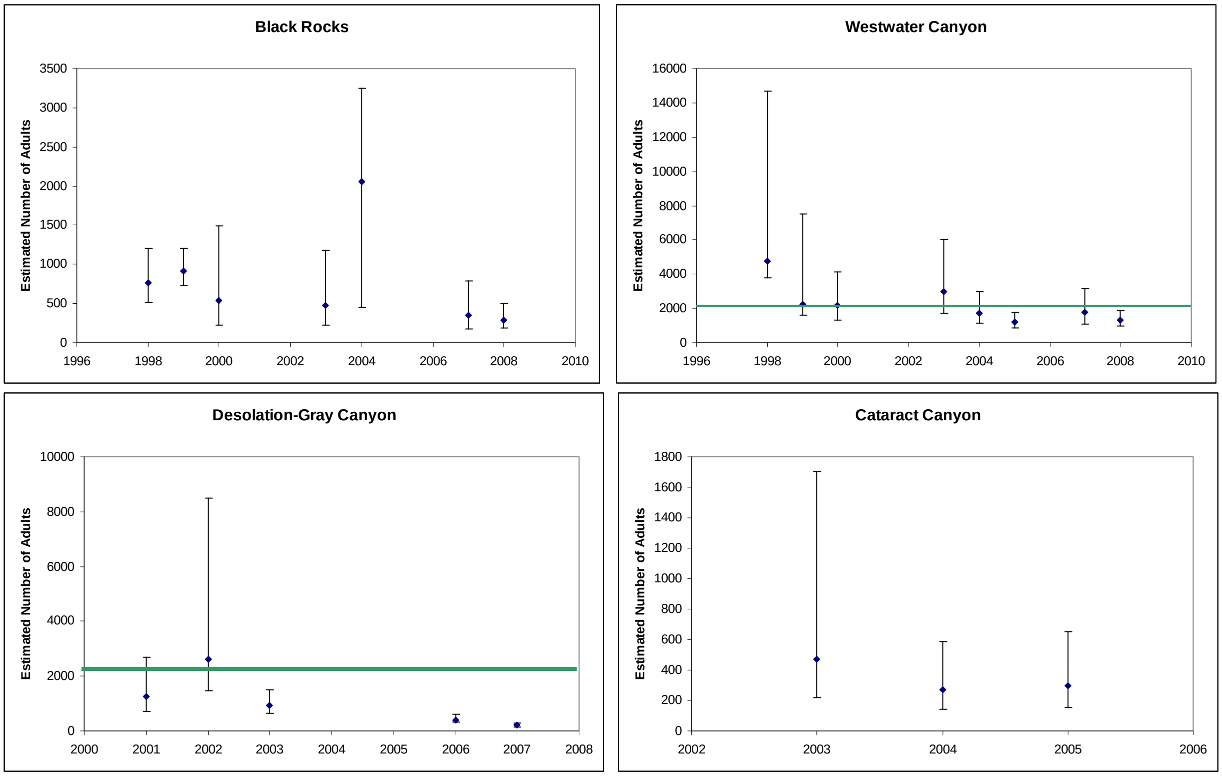
FIGURES –

BIOLOGICAL OPINION ON 10-YEAR MODIFIED LOW FLUCTUATING FLOW, HIGH FLOW PROTOCOL AND NON-NATIVE FISH CONTROL BELOW GLEN CANYON DAM

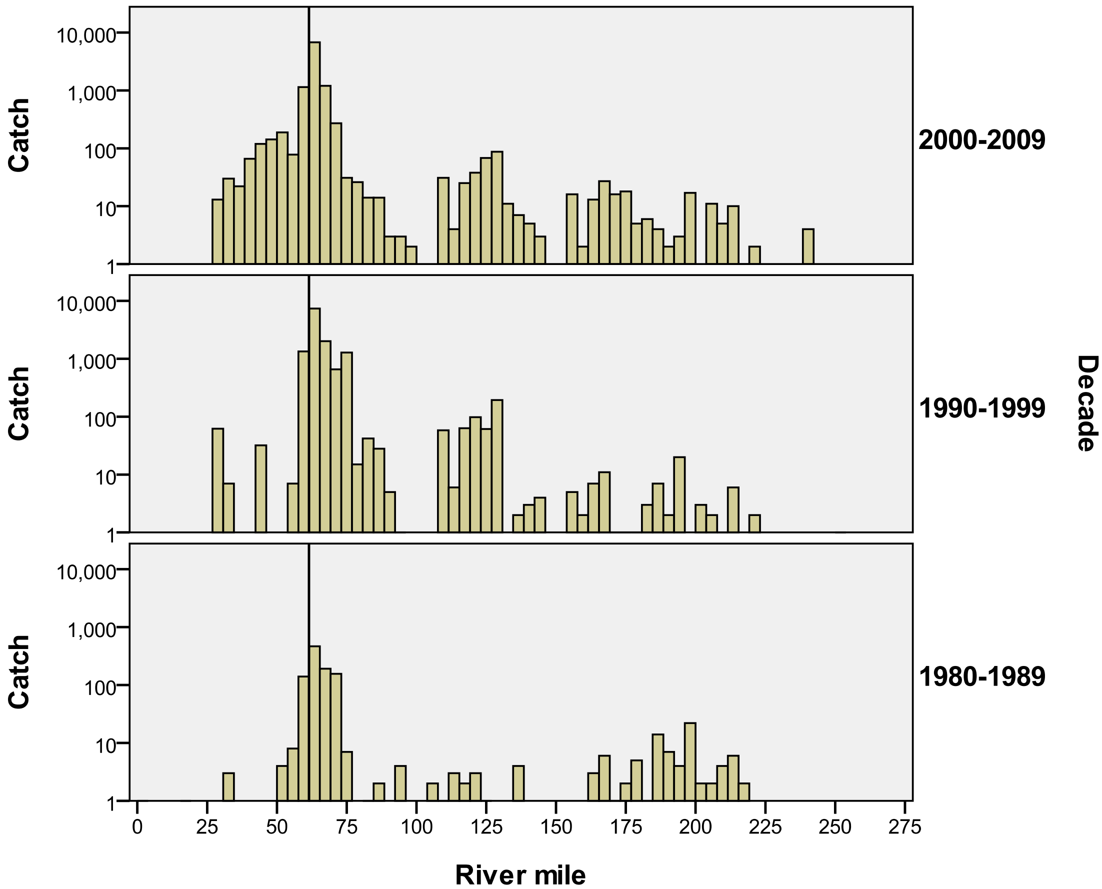
Figure 1. Distribution of humpback chub in the Colorado River System

Figure 2



Estimated numbers of humpback chub adults (≥ 200-mm TL) in 4 of 5 populations of the Upper Colorado River Basin. Error bars are 95% confidence intervals. The line at 2,100 represents the minimum viable population number; for core populations they need to exceed this level. Data from Black Rocks (McAda 2003a; 2007), Westwater Canyon (Elverud 2008), Desolation/Gray Canyons (P. Badame, Utah Division of Wildlife Resources, pers. comm.), and Cataract Canyon (Badame 2008) (From the USFWS 5-Year Review 2011)

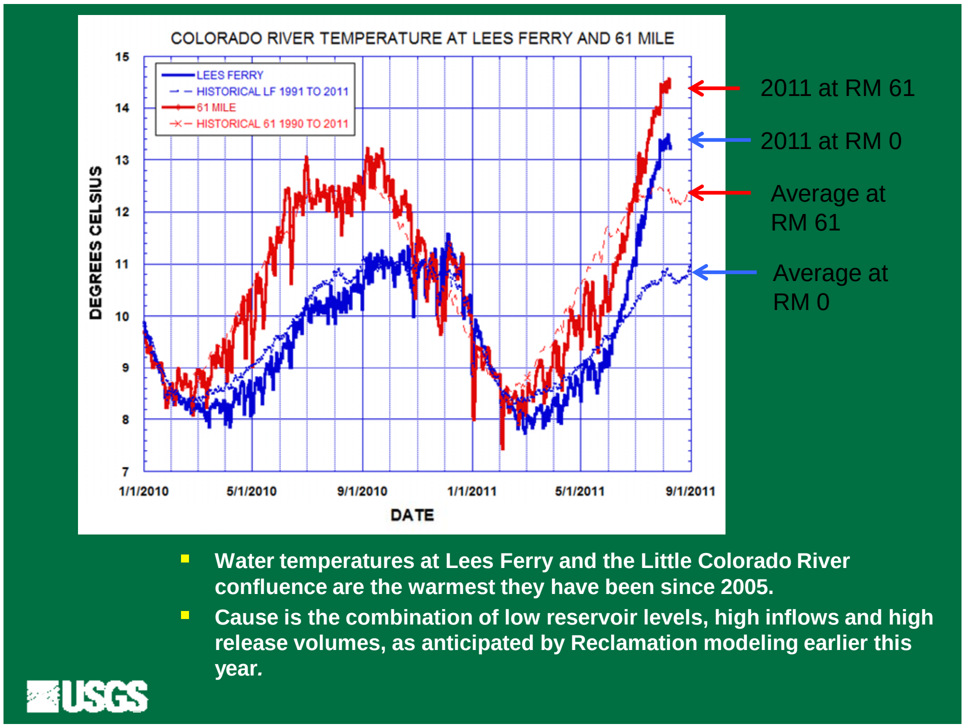
Figure 3



Number of humpback chub collected in Colorado River by river mile, 1980-2009. Vertical line is at River mile 61.5, the confluence of the Little Colorado River. Note y axis is log scale.

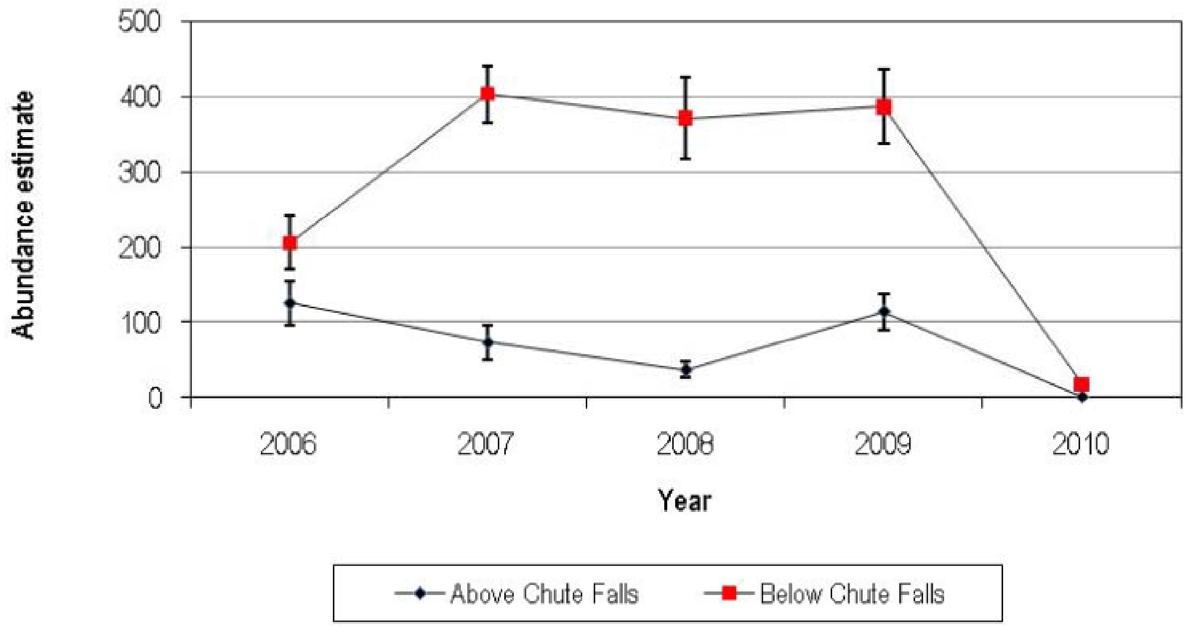
1977-1989 n = 1,081
1990-1999 n = 13,447
1999-2009 n = 10,958

Figure 4



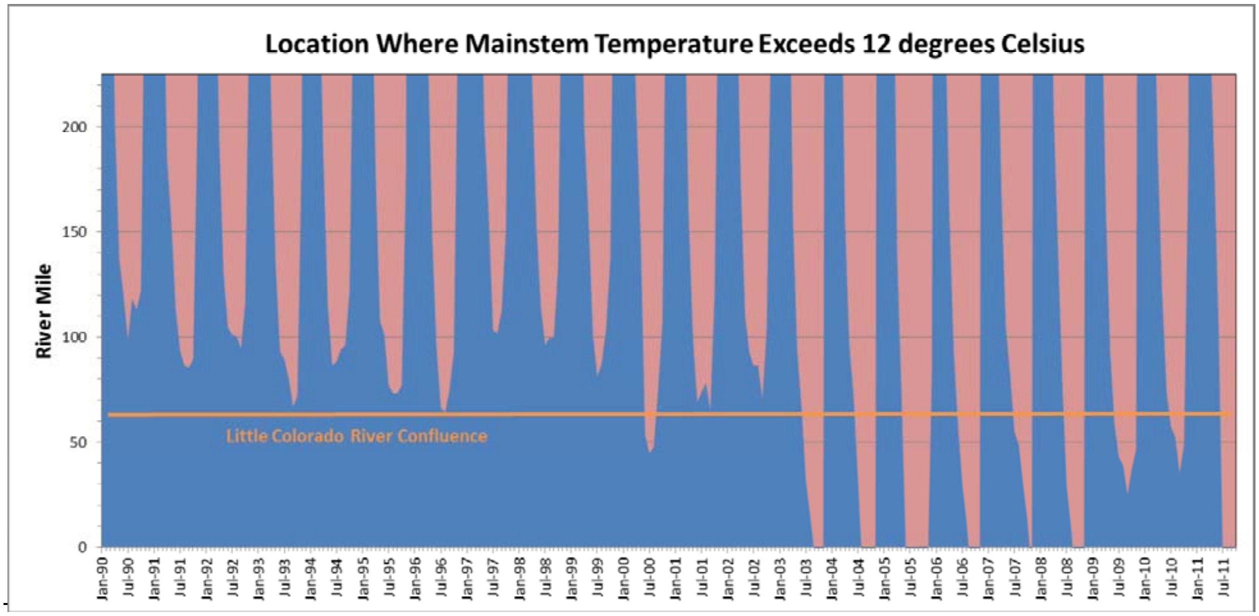
Colorado River water temperatures at Lees Ferry and the LCR confluence from January 2010 to September 1, 2011; upublished data from USGS.

Figure 5



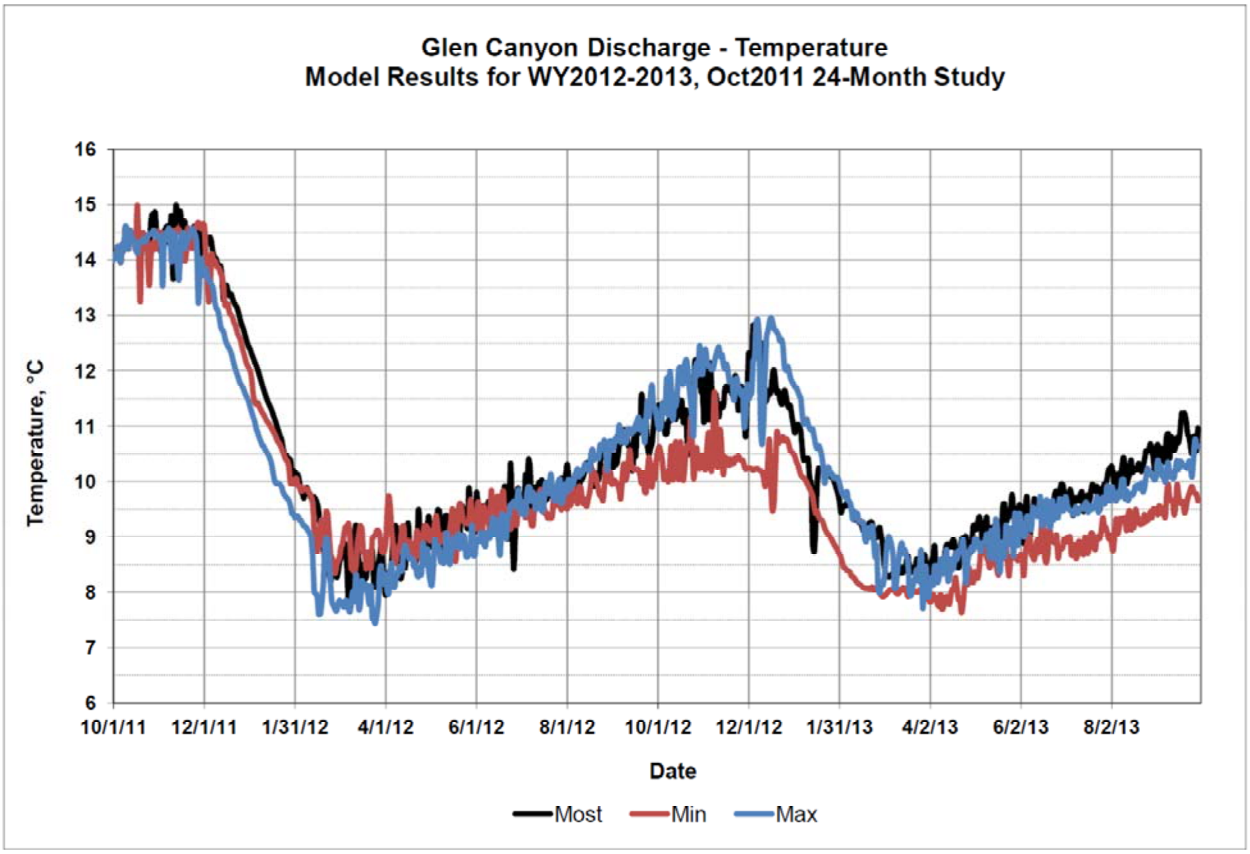
Abundances of adult humpback chub (≥ 200 mm) from lower reach below Chute Falls (13.6 to 14.1 km) and from upper reach above Chute (14.1 to 18 km) since summer 2006 (from Van Haverbeke et al. 2011).

Figure 6



Location in the mainstem Colorado River in River miles downstream from Lees Ferry by year from January 1990 through July 2011 of temperatures exceeding 12 °C (USGS GCMRC unpublished data using the temperature model of Wright et al. 2008).

Figure 7



Forecasted Glen Canyon Dam release temperature modeling results based on the October 2011 24-Month Study for projected operations for the Colorado River system reservoirs (Bureau of Reclamation unpublished data).