# 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.

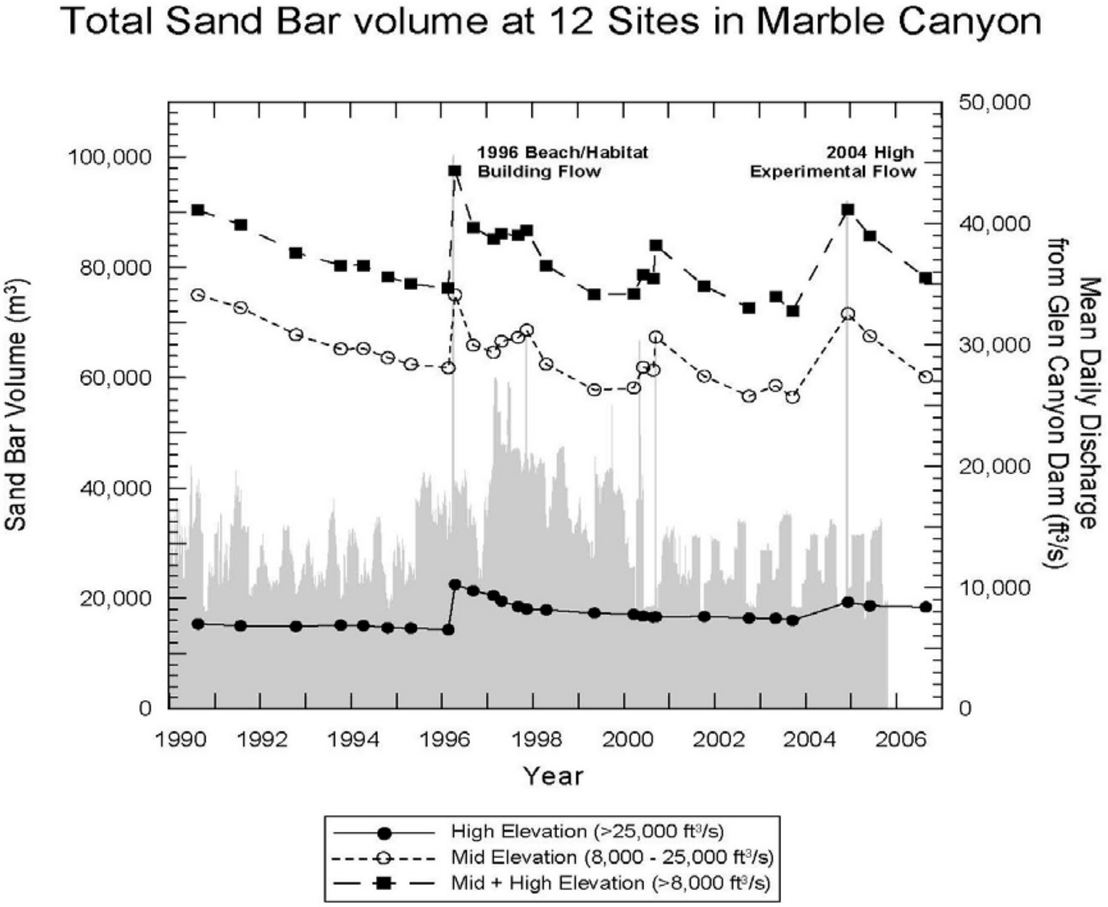

**Figure 6. Total sandbar volume at 12 sites in Marble Canyon.** ***Source:*** **J. Hazel, preliminary data courtesy of Northern Arizona University.**

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.

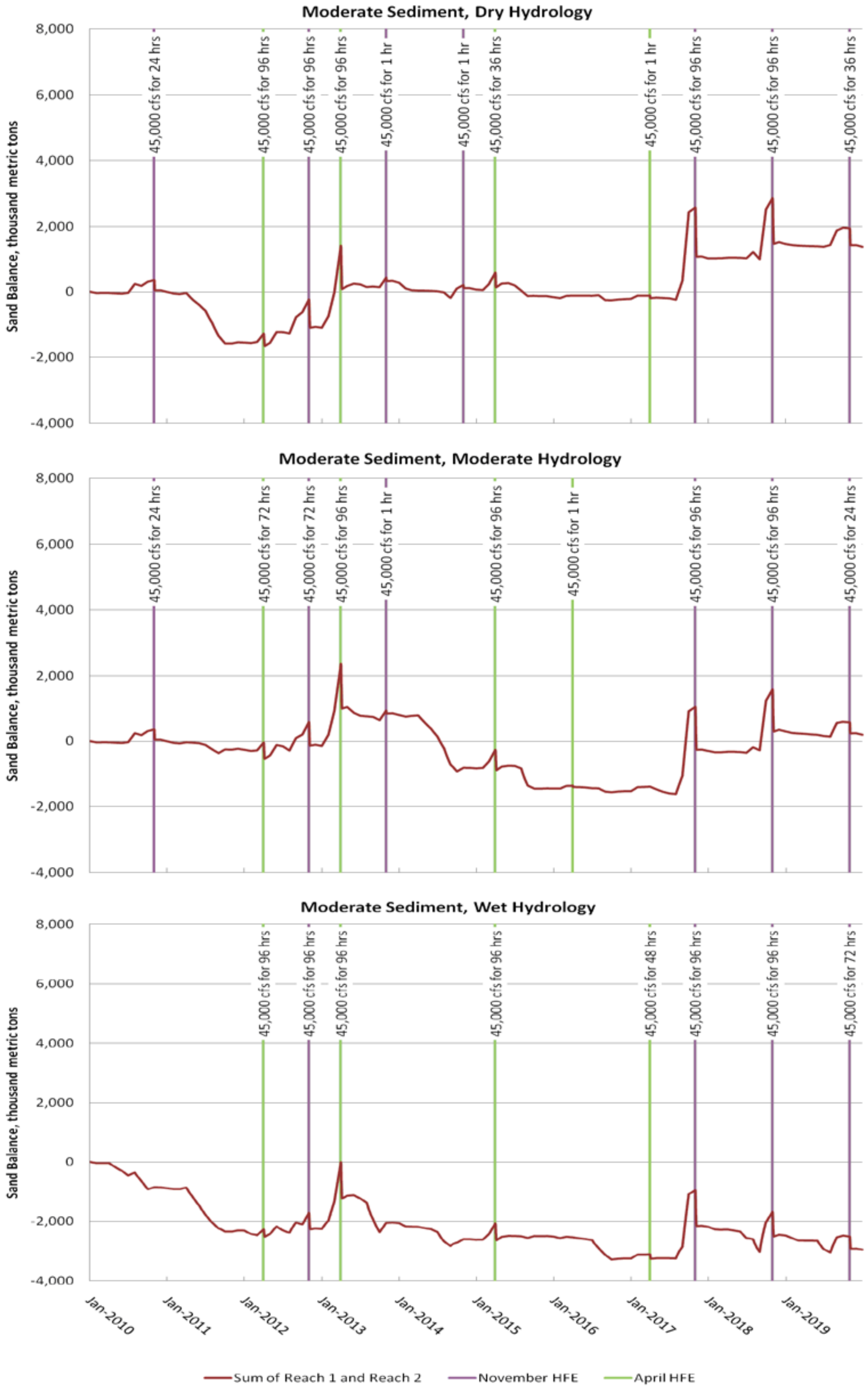

**Figure 7. Occurrence of described HFEs from model runs for moderate sediment with dry, moderate, and wet hydrology in reaches 1 and 2 (Russell and Huang 2010).**

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 $2.5 \times 10^8$ seeds per year. Warren and Turner (1975) used seed traps and found that about 100 seeds per square inch ($17/cm^2$) reached the soil surface in a dense tamarisk stand over one growing season; and that more than four seeds per square inch per day ($0.64$ seeds/$cm^2$/day) might settle on the soil surface during the peak of seed production. High stress induced by fire, drought, herbicides, or cutting can increase flowering and seed production in tamarisk.

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

Tamarisk leaf beetles (*Diorhabda* spp.) have been introduced to the Colorado River Basin and were discovered at Lees Ferry in 2009. By late 2010, they had colonized much of the riparian corridor of the Colorado River in Grand Canyon (Minard 2011). The effect of these beetles on the tamarisk population in Grand Canyon is not certain, but it is likely that they will defoliate and eventually kill many of the exotic trees. Loss of tamarisk could result in additional erosion of the riparian zone 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.

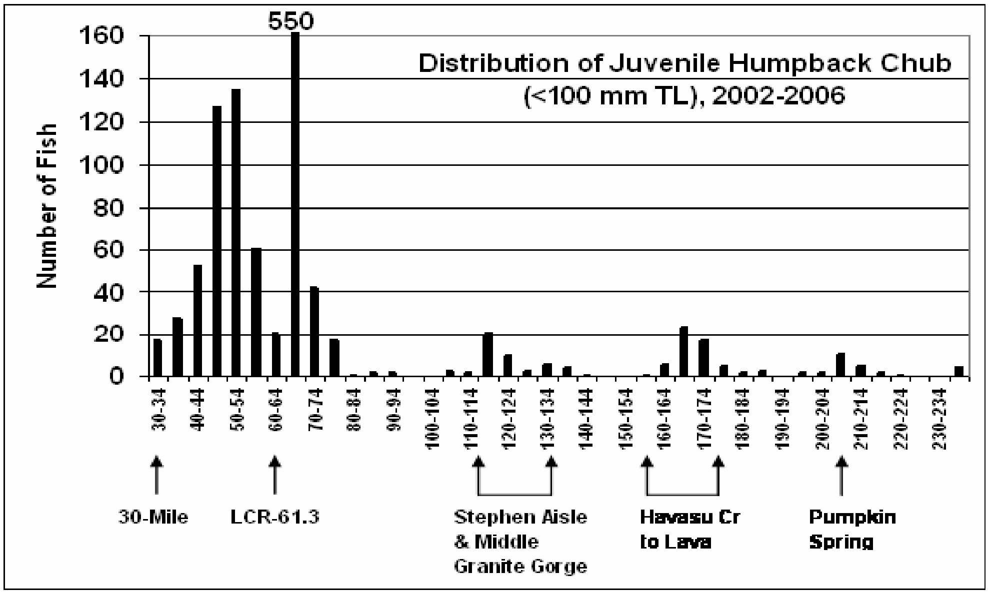

**Figure 8. Distribution of juvenile humpback chub < 100 mm TL during 2002-2006 by 5-mile increments from RM 30 to RM 230. Principal humpback chub aggregations are indicated (data from SWCA 2008).**

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.

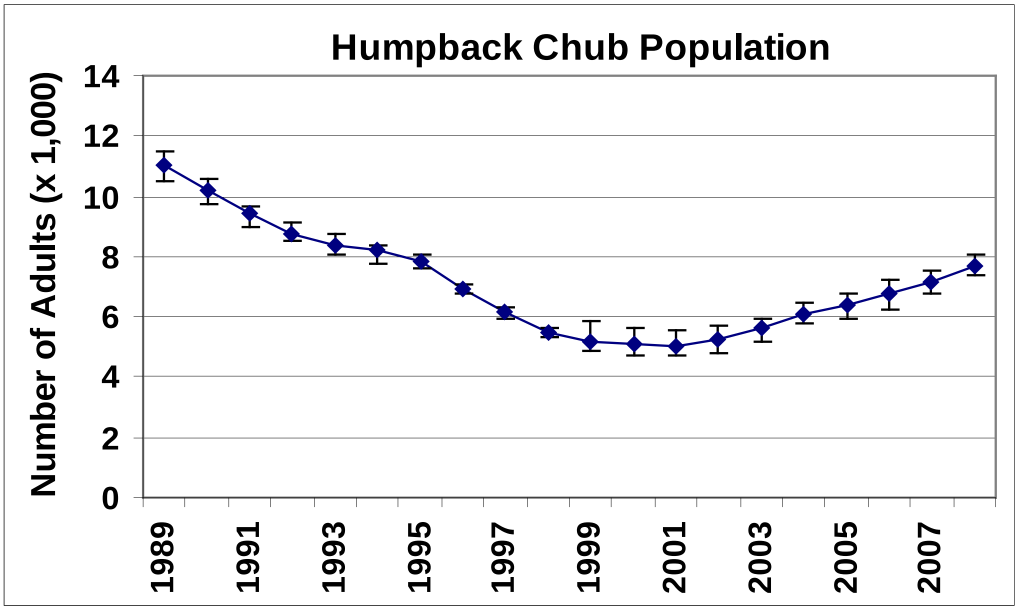

**Figure 9. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials. All runs assume the coefficient of variation of the Von Bertalanffy L∞ was CV (L∞) = 0.1 and adult mortality was M∞ = 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.

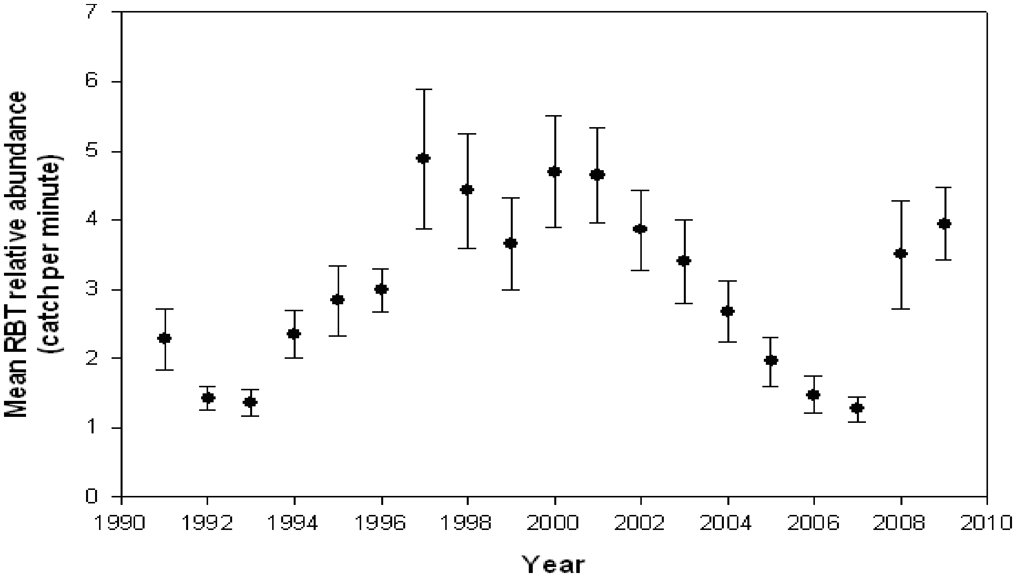

**Figure 10. Average annual electrofishing catch rate of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991-2010 (Makinster et al. 2010a).**

### 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.

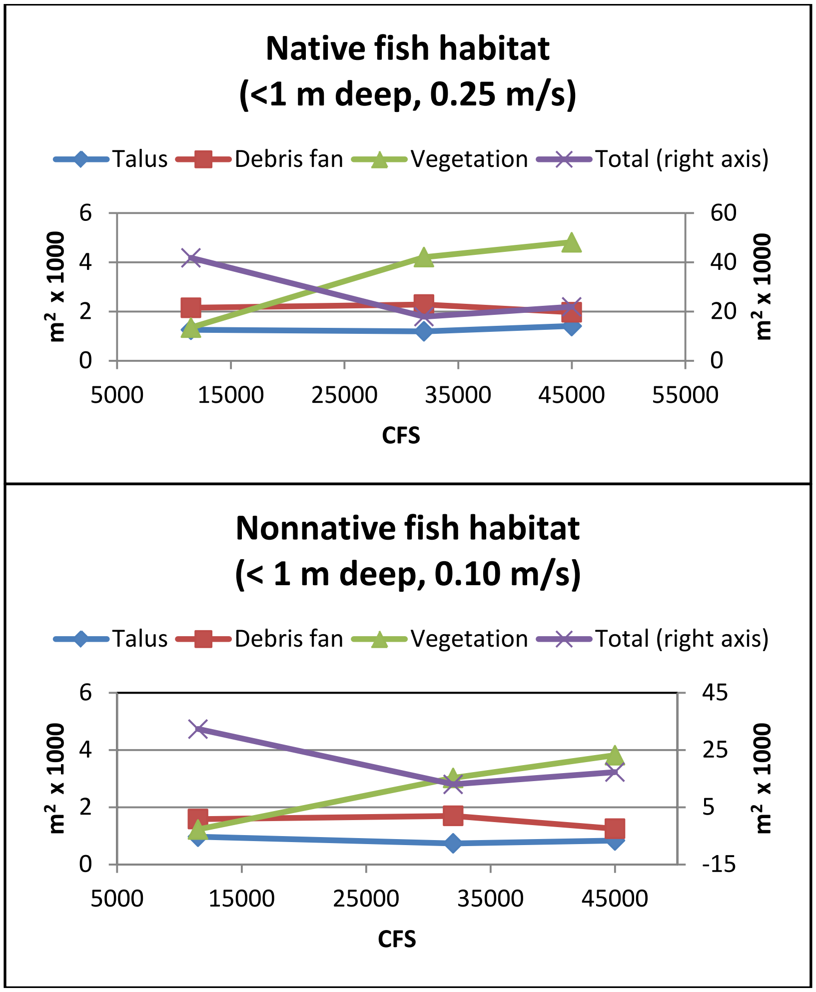

**Figure 11. Total suitable habitat (purple line, right axis) and breakdown by shoreline types (left axis) used by native fish (top; approximated by humpback chub parameters) and non-native fish (bottom). Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transect.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

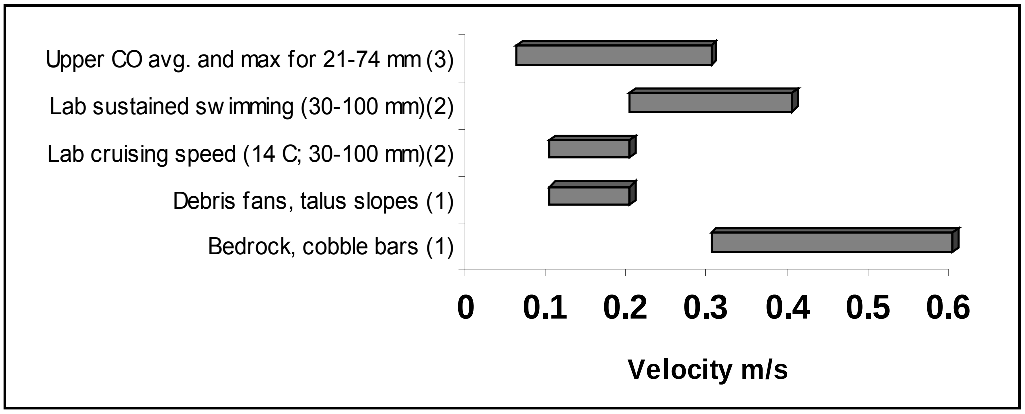

**Figure 12. Velocity preference criteria for humpback chub in the Colorado River, Grand Canyon. Sources include: (1) Converse et al. 1998; (2) Bulkley and Pimentel 1983; and (3) Valdez et al. 1990.**

### 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.

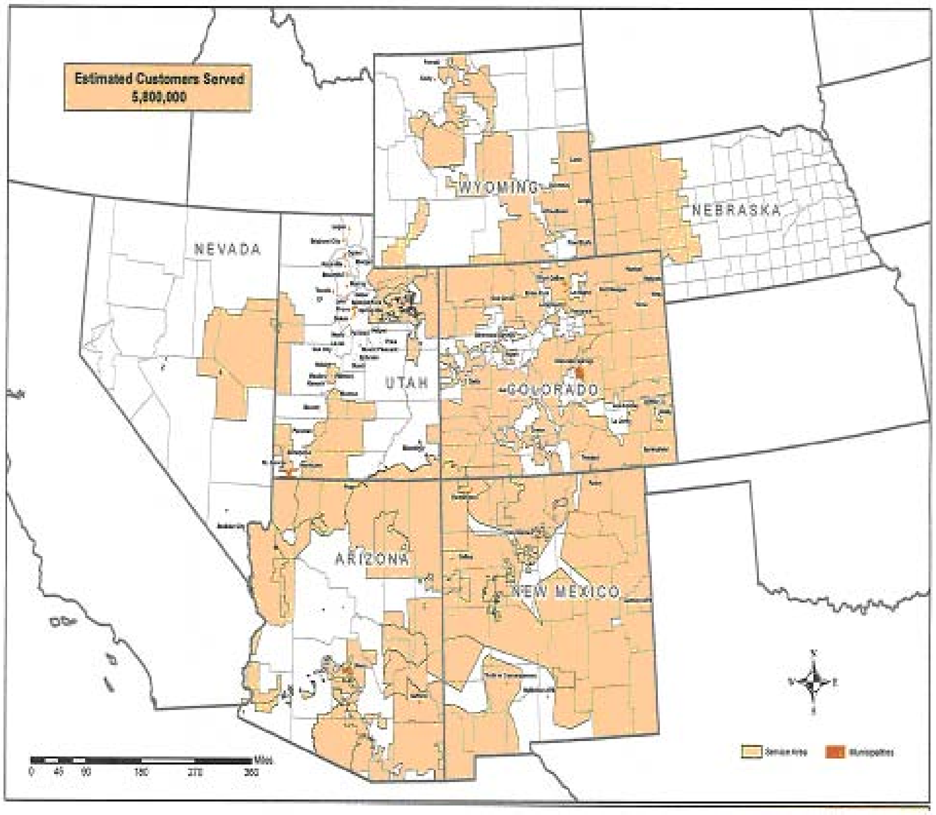

**Figure 13. Colorado River Storage Project management center service territory. Map courtesy of Western Area Power Administration.**

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.

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[3] For the March 2008 HFE, the projected total cost of the high-flow test for water year 2008 was estimated at $4.1 million, or a 9.4 percent increase in the purchase power requirement for 2008. For the analyses included in this document, the impact of an HFE or HFEs is considerably lower. This is because the proposed action includes HFEs of different magnitudes and durations. The #13 HFE (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.

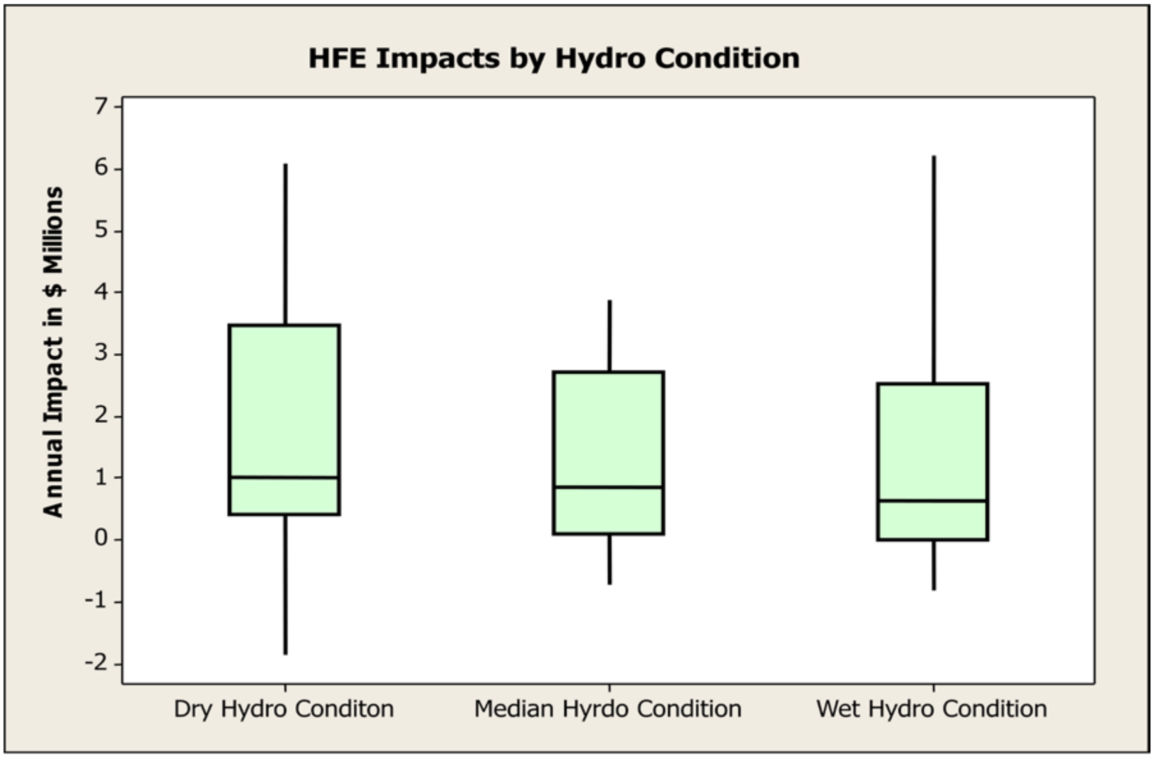

**Figure 14. Annual impacts in millions of dollars of HFEs during three different hydrological conditions.**

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.

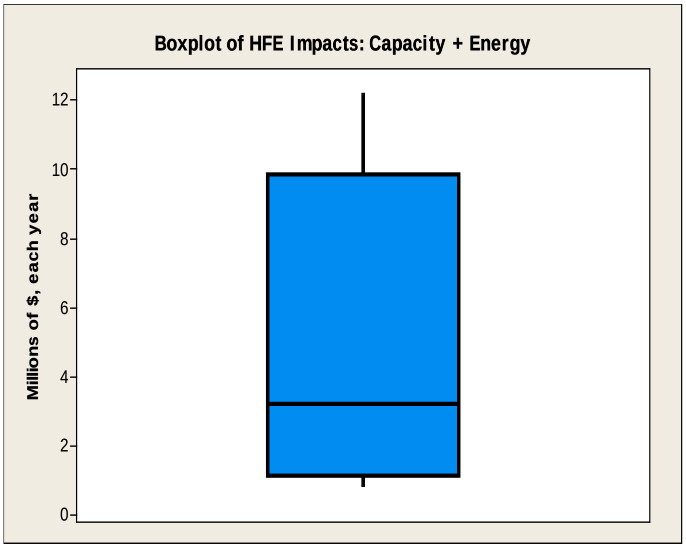

**Figure 15. An illustration of the variability of impacts of the proposed action on both energy <u>and</u> capacity. The blue box illustrates the interquartile range, the whiskers illustrate the range of impacts, from minimum to maximum.**

### 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).

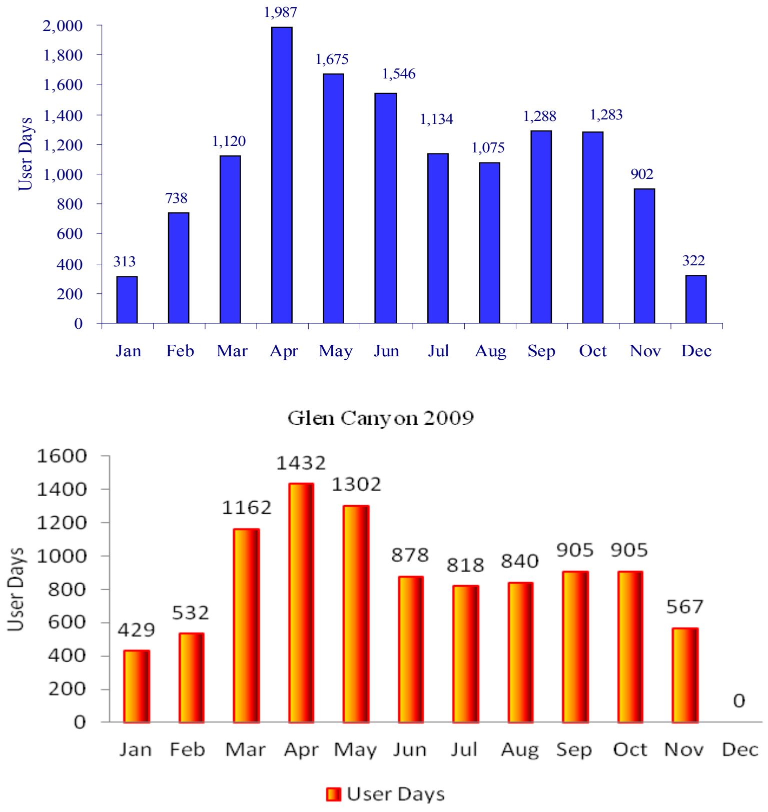

**Figure 16. Fishing user days by month in the Lees Ferry reach for 2006 (top) and 2009 (bottom). User days for December 2009, listed as 0, were not measured because the vehicle counter was broken.**

## 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.

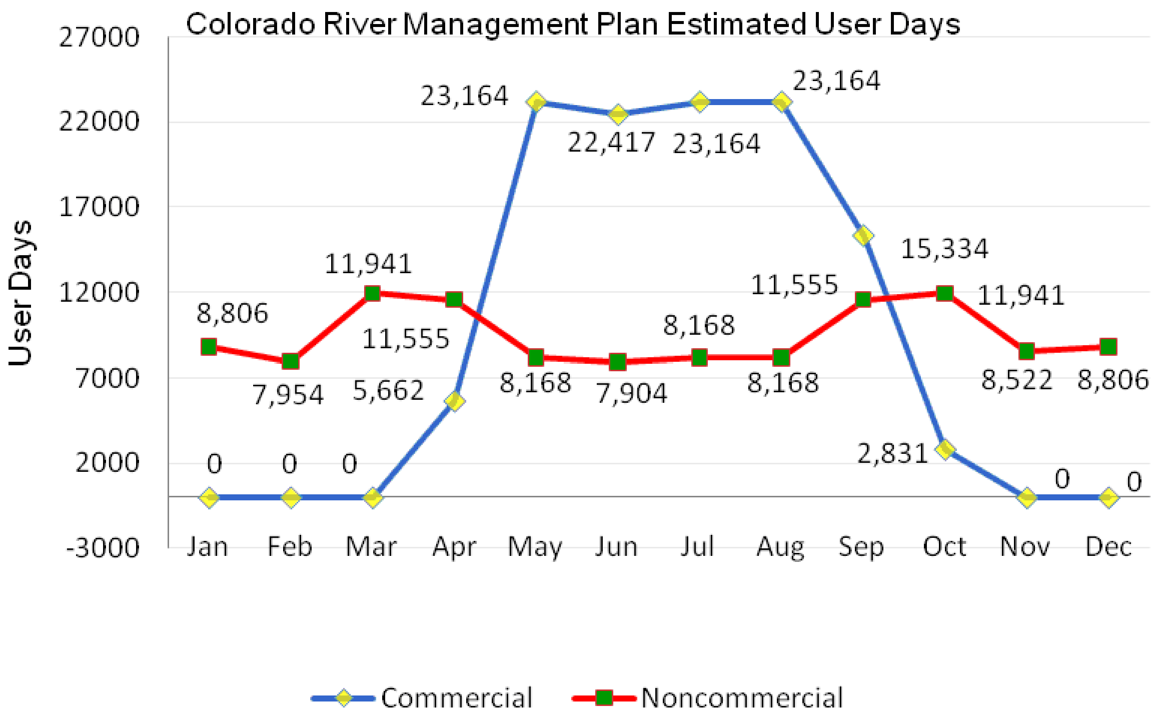

**Figure 17. Boating in the Grand Canyon, anticipated annual use by month (CRMP; NPS 2006).**

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.

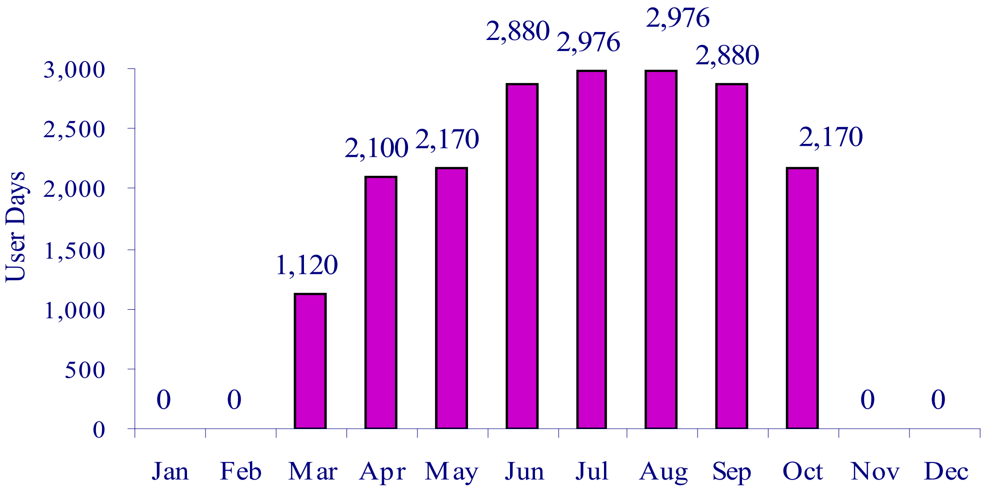

**Figure 18. Commercial boating recreation use below Diamond Creek (HRR maximum possible).**

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.

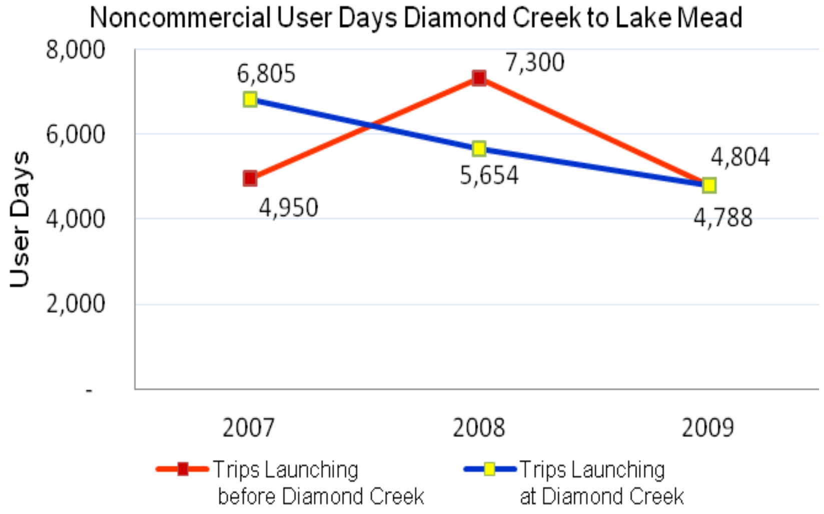

**Figure 19. Noncommercial user days – Diamond Creek to Lake Mead (NPS 2009b).**

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. |

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[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. |

<table>
<tr><th>Resource</th><th>Spring HFE Followed by Fall HFE</th><th>Fall HFE Followed by Spring HFE</th><th>More Than Two Consecutive HFEs</th></tr>
<tr><td>Kanab Ambersnail</td><td colspan="2">Impact same as single HFEs.</td><td>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.</td></tr>
<tr><td>Aquatic Foodbase</td><td>Impact same as single HFEs.</td><td>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.</td><td>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).</td></tr>
<tr><td>Humpback Chub</td><td colspan="2">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.</td><td>Moderate short-term impact from changes in foodbase and habitat; moderate displacement of young; uncertain long-term population effect.</td></tr>
<tr><td>Razorback Sucker</td><td colspan="2">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.</td><td>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.</td></tr>
<tr><td>Non-Listed Native Fish</td><td colspan="2">Impact same as single HFEs.</td><td>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.</td></tr>
</table>

| 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.