United States Department of the Interior

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

IN REPLY REFER TO:
UC-700
ENV-7.0

JUL 13 2011

MEMORANDUM

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

From: Larry Walkoviak
Regional Director

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

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

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

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

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

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

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

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

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

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

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

Attachment

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

RECLAMATION

Managing Water in the West

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

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

July 8, 2011

Introduction

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

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

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

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

Changes to the Proposed Actions

The Modified Low Fluctuating Flow

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

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

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

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

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

Non-Native Fish Control

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

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

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

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

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

Proposed Non-Native Fish Research Activities

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

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

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

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

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

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

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

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

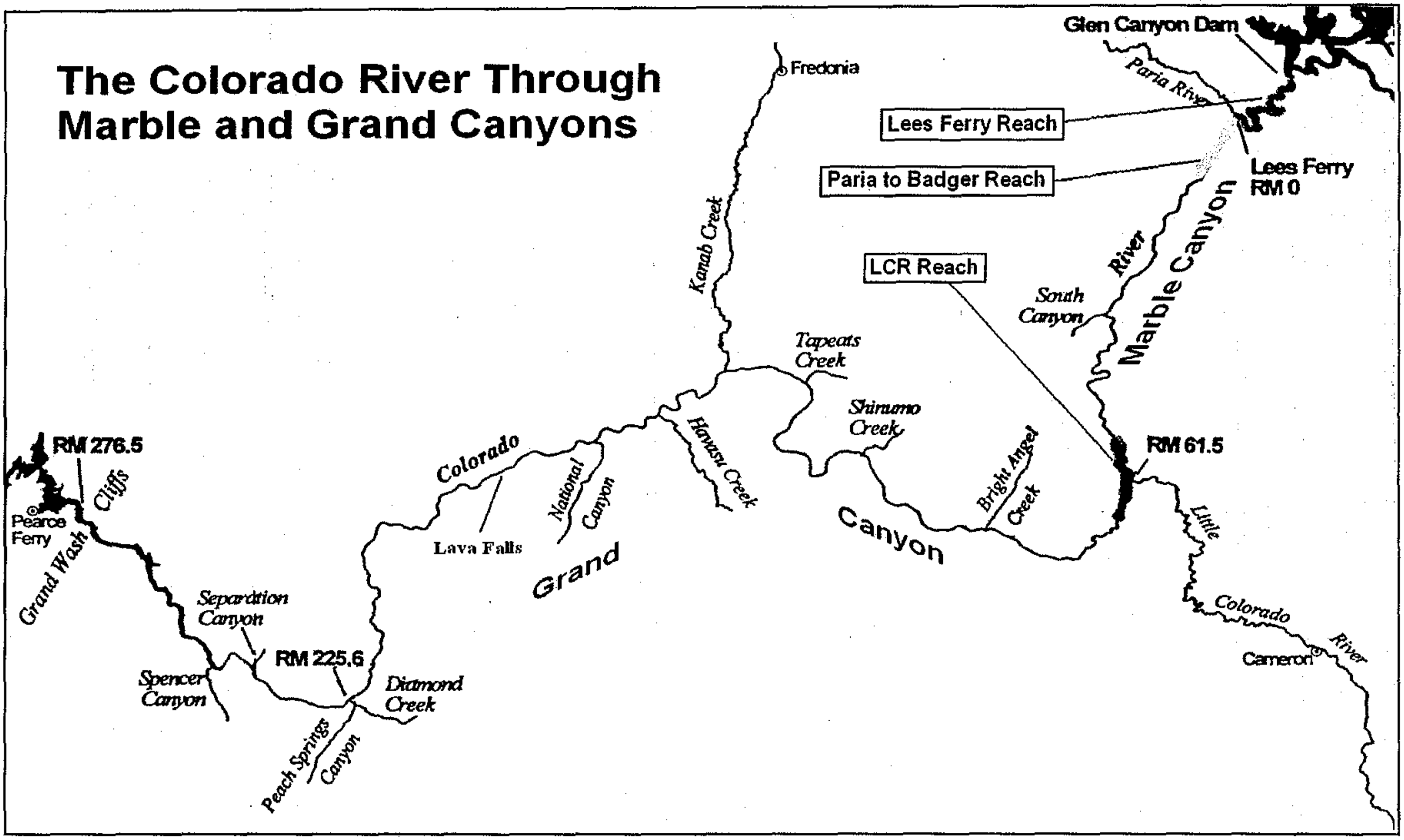

Figure 1. Map of the Colorado River from Glen Canyon Dam to Pearce Ferry in upper Lake Mead. The Lees Ferry, Paria to Badger reach (PBR), and Little Colorado River (LCR) reach are identified.

Rationale for Proposed Action

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Relationship of Proposed Action to Incidental Take

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

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

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

Changes to Effects Analysis

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

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

Species	Effects Determination	Basis for Determination
Humpback Chub	May affect, likely to adversely affect species and critical habitat	• Take could occur from downstream displacement of young into unsuitable habitat, especially during fall HFEs. Effects of displacement, if it occurs, are largely unknown. • Direct short-term reductions in near-shore habitat could occur in the vicinity of the LCR with changes in flow stage, but long-term benefit is expected from sand redeposition that rebuilds and maintains near-shore and backwater nursery habitats. • Direct short-term reductions in food supply could

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

		sucker through reduced numbers of non-native fish predators and competitors with the species.
Kanab Ambersnail	May affect, likely to adversely affect; no critical habitat designated	• Up to 119.4 m² (17 percent in 1996) of potential habitat may be inundated by 45,000 cfs. • Proportionally less habitat area scoured and fewer numbers of snails would be displaced by lower magnitude HFEs. • Sequential HFEs could reinundate and scour primary habitat prior to full recovery from previous HFE. • Non-native fish control actions would not affect this species. • MLFF at high releases of over 17,000 cfs can inundate and scour up to 10 percent of available habitat, but the habitat is of low quality and contains few snails. • Critical habitat has not been designated for the species.
Southwestern willow flycatcher	May affect, not likely to adversely affect; critical habitat not in area of proposed action	• Birds will not be present during spring HFEs, and nesting and feeding sites are not expected to be adversely affected. • Birds will be off nests by Sept-Oct, but birds will be foraging and there could be some indirect effect to their food supply. • Non-native fish control actions would not affect this species. • MLFF would have only limited effects of southwestern willow flycatcher. Nesting habitat occurs at stage elevations above 45,000 cfs, and normal operations below 25,000 cfs are unlikely to affect habitat for the species. Southwestern willow flycatcher critical habitat does not occur in the action area.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The MLFF would affect razorback sucker in much the same ways as it affects humpback chub. The MLFF modifies physical habitat by cooling the water temperatures of downstream releases, particularly in the summer months. Physical habitats, backwaters formed by fine sediment in particular, are eroded by MLFF. The cooling effect of MLFF likely provides a benefit in disadvantaging non-native fish species and fish parasites such as Asian fish tapeworm. However, because razorback sucker appear to be extirpated from the action area, although they do still occur as a small reproducing population downstream in Lake Mead (Albrecht et al. 2007), none of these effects would likely actually occur to the species. Razorback sucker critical habitat does occur in the action area and includes the Colorado River and its 100-year floodplain from the confluence with the Paria River (RM 1) downstream to Hoover Dam, a distance of nearly 500 miles, including Lake Mead to the full pool elevation. Razorback sucker critical habitat PCEs are exactly the same as those for humpback chub and would be affected in essentially the same ways as described above. In general, MLFF impacts critical habitat primarily through a cooling effect on water temperature, with some likely additional affects from shoreline erosion, and physical habitat manipulation through daily fluctuation. The

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

Effects of MLFF through 2020 on Kanab Ambersnail

Kanab ambersnail habitat can be adversely affected by scouring at Colorado River flows exceeding 17,000 cfs. MLFF has been implemented since 1991, and flows have consistently scoured Kanab ambersnail habitat, removing habitat and snails below about the 25,000 cfs flow level. The MLFF includes flows up to 25,000 cfs (and beyond in emergency situations; up to 33,200 cfs may be released at power plant capacity, plus 15,000 cfs from the river outlet works, and 208,000 cfs from the spillways). Flows in excess of 25,000 cfs rarely occur, only in wettest years, although if the HFE Protocol is implemented, could occur as often as twice a year if conditions are met (up to 45,000 cfs). Nevertheless some loss of habitat and snails would occur as MLFF flows in excess of about 17,000 cfs scour the vegetation at Vaseys Paradise and carry the snails downstream. But the amount of habitat that is subjected to this effect, which is usually incremental and continuous (as opposed to the high magnitude, short duration, and relatively instantaneous effect of a HFE), is a small proportion of habitat available to Kanab ambersnail at Vaseys Paradise. Meretsky and Wegner (2000) found that at flows from 20,000 to 25,000 cfs, only one patch of snail habitat is much affected (Patch 12), and a second patch to a lesser extent at flows above 23,000 cfs (Patch 11). The largest these patches have been recently was in July 1998 when the area of both patches was 28.68 m^2 (308.7 ft^2) (Meretsky and Wegner 2000). Total habitat available in July 1998 (minus two patches that were not included in the total measurement) was 276.82 m^2 (2,979.7 ft^2). Thus patches 11 and 12, even in a good year, constitute less than 10 percent of total habitat available. Also, very few Kanab ambersnail have been found in patches 11 and 12 historically, and these patches are of low habitat quality for Kanab ambersnail (Sorensen 2009). Currently the amount of habitat loss at the 25,000 cfs flow level due to scour would be low, and is estimated to be about 300-350 ft^2 (27.9-32.5 m^2) or less (Meretsky and Wegner 2000). Thus the scouring effect of MLFF is predicted to have little effect on the overall population of Kanab ambersnail at Vaseys Paradise because scouring would occur infrequently, would affect only a small proportion of overall habitat available, habitat lost would be of low quality, and is expected to contain few snails.

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

Effects of MLFF through 2020 on Southwestern Willow Flycatcher

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

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

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

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

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

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

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

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

Scenario 1: 10,000 Rainbow Trout in Lees Ferry

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

Scenario 2: 25,000 Rainbow Trout in Lees Ferry

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

Scenario 3: 50,000 Rainbow Trout in Lees Ferry

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

Scenario 4: 75,000 Rainbow Trout in Lees Ferry

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

Scenario 5: 100,000 Rainbow Trout in Lees Ferry

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

Trout Removal and HBC Trigger

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

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

Unknowns and Uncertainties

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

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

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

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

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

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

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

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

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

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

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

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

Summary of Anticipated Effects of Actions

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

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

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

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

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

Conclusions

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

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

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

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

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

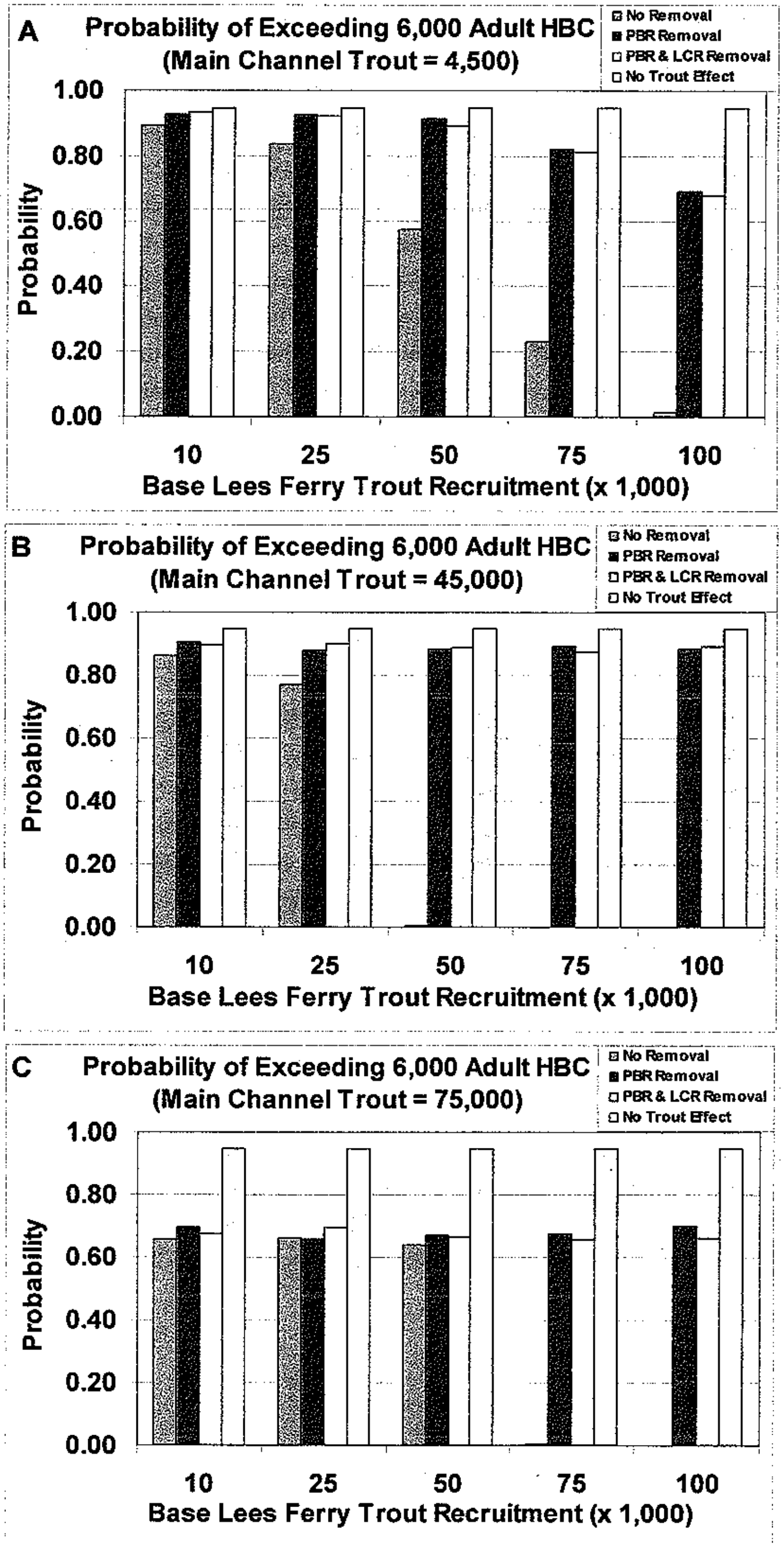

Figure 2. Probability of exceeding 6,000 adult humpback chub with main channel trout equilibriums of (A) 4,500, (B) 45,000, and (C) 75,000. Comparisons are made for no removal of trout, PBR removal only, PBR and LCR removal, and no trout effect (i.e., no trout present in the system).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

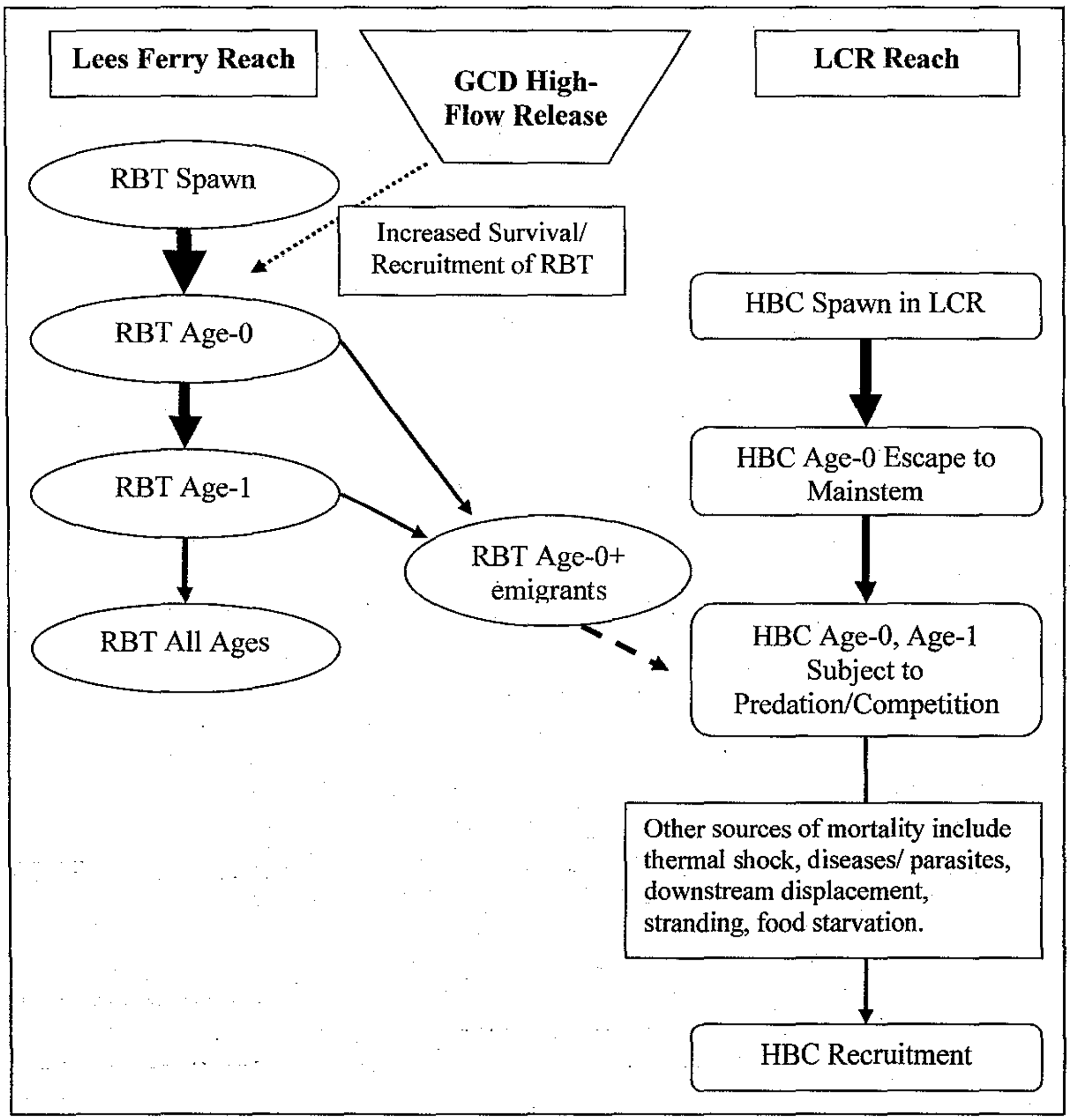

Figure A-1. Relationship of a high-flow release to rainbow trout and humpback chub.

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

The greatest concentration of young humpback chub occurs in the LCR reach, about 70-80 mi downstream from Glen Canyon Dam. This reach is the principal nursery area for young humpback chub that originate from spawning primarily in the LCR, but may also come from a small amount of mainstem spawning as far upstream as warm springs near RM 30 (Valdez and Masslich 1999; SWCA 2008), where there is evidence of overwinter survival in some years (Andersen et al. 2010).

Evidence of Trout Response to a High-Flow Release

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

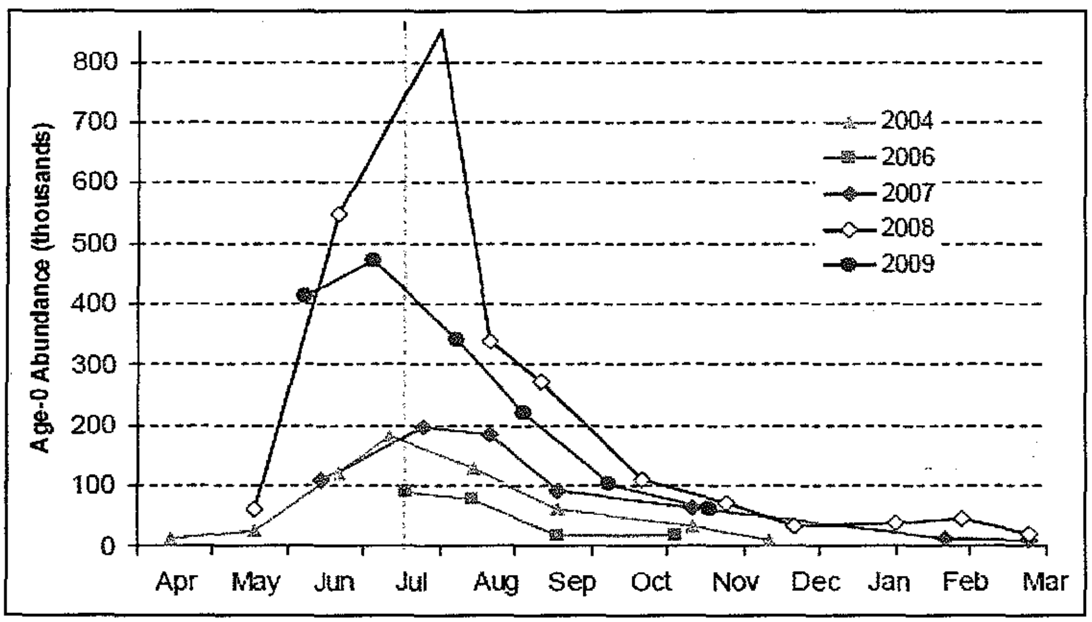

Figure A-2. Trends in the abundance of age-0 rainbow trout in the Lees Ferry reach through the year for several different brood years (years in which the eggs that produced the fish were fertilized). The vertical dashed line represents July 15, the date used as a standard time for the annual recruitment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

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

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

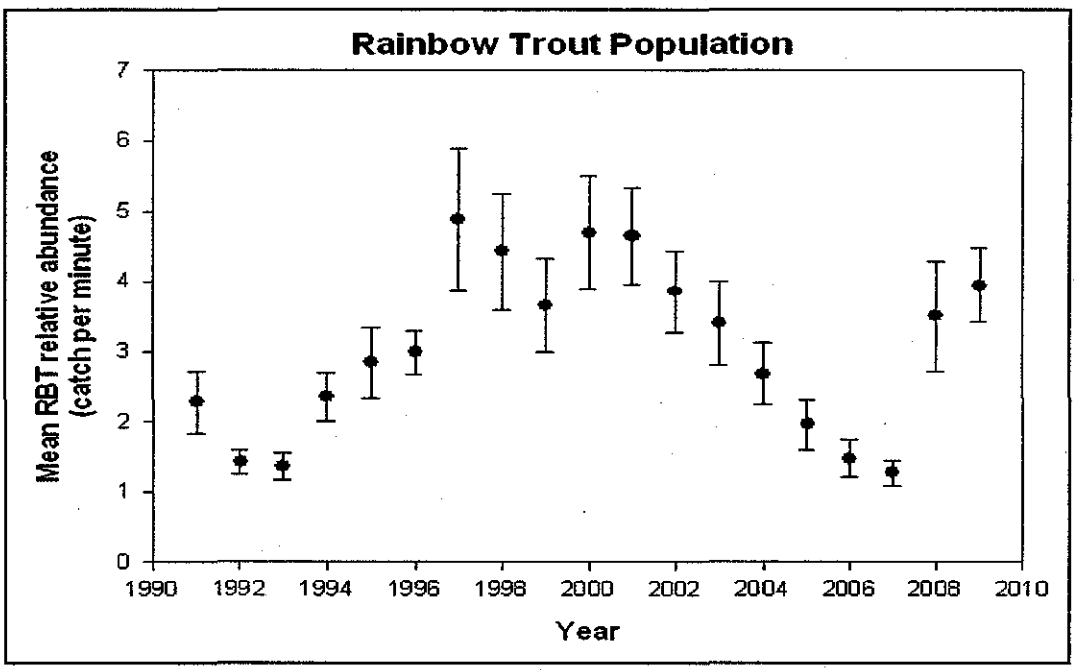

Figure A-3. Average annual electrofishing catch rates of rainbow trout in the Lees Ferry reach (Glen Canyon Dam to Lees Ferry) for 1991–2010 (from Makinster et al. 2010a).

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

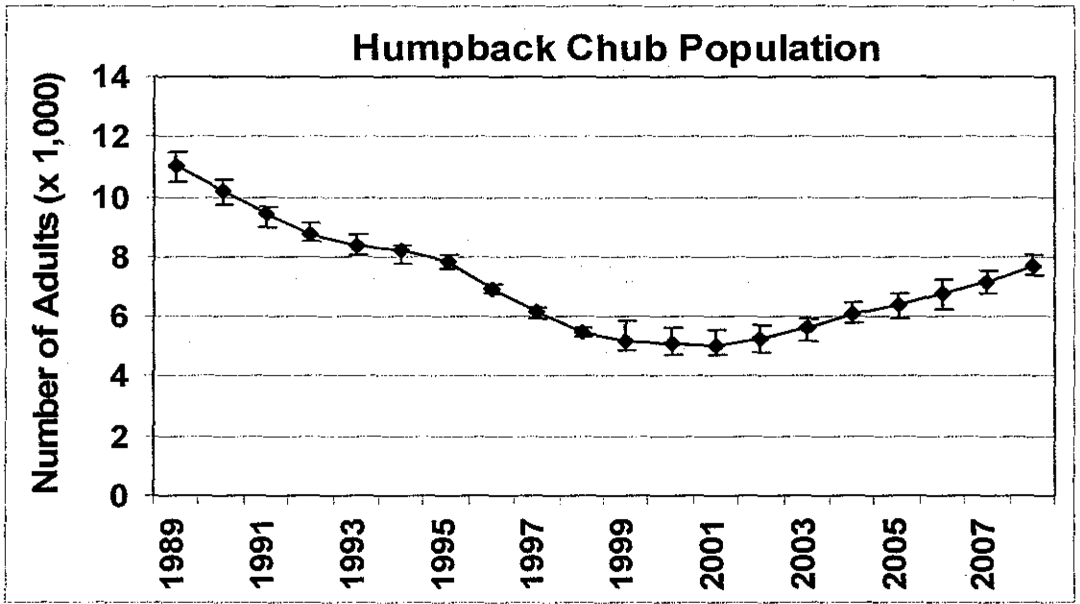

Figure A-4. Estimated adult humpback chub abundance (age 4+) from ASMR, incorporating uncertainty in assignment of age. Point estimates are mean values among 1,000 Monte Carlo trials, and error bars represent maximum and minimum 95-percent profile confidence intervals among 1,000 Monte Carlo trials.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

Effects of Past Removal Activities

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

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

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

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