12-2007

Biological Assessment on the Operation of Glen Canyon Dam and Proposed Experimental Flows for the Colorado River Below Glen Canyon Dam During the Years 2008-2012

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

United States Department of the Interior

BUREAU OF RECLAMATION
Upper Colorado Regional Office
125 South State Street, Room 6107
Salt Lake City, Utah 84138-1147

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IN REPLY REFER TO:

UC-700
ENV-7.0

DEC 21 2007

MEMORANDUM

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

From: Larry Walkoviak
Regional Director

Subject: Transmittal of Bureau of Reclamation Biological Assessment Regarding the Operation of Glen Canyon Dam

Pursuant to Section 7(a)(2) of the Endangered Species Act, 16 U.S.C. § 1531 *et seq*. and the implementing regulations at 50 C.F.R. 402.16, Reclamation requested reinitiation of formal consultation with the U.S. Fish and Wildlife Service (Service) regarding operations of Glen Canyon Dam, Colorado River Storage Project, Coconino County, Arizona, by letter dated November 13, 2007.

The basis of this request is new information that may reveal effects of dam operations that may affect listed species including Kanab ambersnail (*Oxyloma haydeni kanabensis*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), and southwestern willow flycatcher (*Empidonax traillii extimus*), or designated critical habitat in a manner or to an extent not previously considered. In addition to this new information, Reclamation is proposing experimental modifications of dam operations through water year 2012, as are described in detail in the attached Biological Assessment.

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

- may affect, is likely to adversely affect the humpback chub and Kanab ambersnail due to potential take of individuals of both species resulting from the proposed high flow test of 41,500 cubic feet per second in March 2008;

- may affect, is not likely to adversely affect the razorback sucker, Southwestern willow flycatcher, and bald eagle because these species are not likely to be present in the action area during the proposed high flow test in March 2008 and because the steady flows proposed during the fall of 2008 through 2012 are not likely to have any measurable effect on the population numbers, distribution, or breeding, feeding, or shelter of these species.

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

- is not likely to result in destruction or adverse modification of designated critical habitat for the endangered humpback chub, listed birds, or invertebrates; and

- the critical habitat for the razorback sucker should now be considered unoccupied critical habitat because the species has not been documented in the action area recently.

In compliance with section 9 of the Endangered Species Act, Reclamation anticipates potential take of individual humpback chub and Kanab ambersnail from the proposed March 2008 high flow test. The form of take is expected to be displacing individual humpback chub and potential harm to Kanab ambersnail resulting from degradation of their habitat during the proposed high flow test. Reclamation is hoping to continue to consult with you regarding ways to minimize or mitigate this incidental take; however, it should be noted that Reclamation does not believe the level of take would result in jeopardy to the continued existence of any species identified in the Service's letter of December 5, 2007.

We appreciate your expedited consideration of this request for reinitiation of consultation in light of the proposal to undertake a high flow experimental release in early March 2008. We also understand that the U.S. Geological Service has nearly completed the science plan associated with the proposed high flow test. In the next few days, we will forward this science plan and wish it to be considered along with the information in this Biological Assessment.

If you have questions regarding the Biological Assessment, please contact Randall Peterson at 801-524-3758.

Attachment

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

RECLAMATION
Managing Water in the West

Biological Assessment on the Operation of Glen Canyon Dam and Proposed Experimental Flows for the Colorado River Below Glen Canyon Dam During the Years 2008-2012

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

December 2007

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1 Introduction and Background

This document serves as the biological assessment for the Bureau of Reclamation's (Reclamation) re-initiation of consultation on the operation of Glen Canyon Dam and proposed experimental flows for the Colorado River below Glen Canyon Dam during the years 2008-2012. It is prepared by Reclamation as part of its compliance with the Endangered Species Act of 1973 (ESA), 87 Stat. 884, as amended, 16 U.S.C. §1531 *et seq*. This document is designed to facilitate compliance with Sections 7 and 9 of the ESA with respect to potential effects to listed species within the United States (US).

1.1 Proposed Federal Action

Reclamation, an agency within the Department of the Interior (Department), operates Glen Canyon Dam of the Colorado River Storage Project as a multipurpose storage facility in northern Arizona. Construction of the dam was authorized by the 1956 Colorado River Storage Project Act and operation of the dam is governed by a complex set of compacts, federal statutes and regulations, court decrees, and an international treaty commonly referred to as the Law of the River and as further described in Section 1.2.1. In the 1980s, Reclamation studied the relationship between the condition of downstream river resources and operations of Glen Canyon Dam, culminating in an environmental impact statement (EIS) finalized in 1995 (Reclamation 1995). Based on analyses in the EIS, the Secretary of the Interior determined in a 1996 record of decision (ROD) that the dam should be operated using the Modified Low Fluctuating Flow (MLFF) Alternative. Region 2 of the U.S. Fish and Wildlife Service (FWS) issued a biological opinion on implementation of the MLFF in 1995 (FWS 1995). The fundamental direction contained in the 1995 Biological Opinion was that future modifications to Glen Canyon Dam operations be analyzed in the context of adaptive management. The 1996 ROD established the Glen Canyon Dam Adaptive Management Program (AMP). Reclamation has undertaken a number of experimental actions consistent with these elements of the ROD and the Biological Opinion; these experimental actions have involved section 7 consultation with the FWS regarding benefits and impacts to listed species, and are fully identified and described in Section 2.1.

In a letter to the FWS dated November 13, 2007, Reclamation requested re-initiation of formal ESA Section 7 consultation on the operation of Glen Canyon Dam. This request is based on the acquisition of new scientific information about the status and trends of federally listed species and effects of dam operations on the species and critical habitat. In a letter dated December 5, 2007, the FWS provided Reclamation with a species list that included humpback chub, razorback sucker, Kanab ambersnail, and Southwestern willow flycatcher.

The request is also based on the fact that Reclamation proposes to conduct experimental releases from Glen Canyon Dam, including one experimental high flow test during 2008 and five years of experimentation implementing steady dam releases during the months of September and October for the period 2008 - 2012. This action is intended to assist in the conservation of endangered species as well as providing benefits to sediment conservation, increase scientific understanding, and to collect data for use in determining future dam operations. Scientific information leading to re-initiation of ESA consultation and the identification of the Proposed Action and preparation of this BA have been developed based on nearly 30 years of experimentation, research, and monitoring of resources of the Colorado River below Glen Canyon Dam, with emphasis on information gained through experimentation and monitoring under the auspices of the AMP, pursuant to the framework required by the 1995 biological opinion. This information includes results of studies gained through implementation of the 2002 Experimental Plan that was the subject of previous Section 7 consultation, and undertaken as part of the AMP, as provided in the 1996 ROD. This research and monitoring information was collected as part of the AMP through a cooperative effort with the US Geological Survey's Grand Canyon Monitoring and Research Center (GCMRC). Participants within the AMP that have contributed the new research and monitoring information include the Adaptive Management Work Group, the Technical Work Group, Science Advisors, and scientists. It is important to note that the Proposed Action is expected to produce an overall additional positive benefit to endangered species (over and above the recent improving status of the endangered humpback chub), as well as critical habitat downstream of Glen Canyon Dam. Reclamation's conclusion is that this overall additional positive benefit will exceed anticipated short-term minor impacts to some resources, including anticipated temporary downstream displacement of humpback chub during experimental high-flow releases designed to enhance areas of backwater habitat.

1.2 Relevant Statutory Authority

In compliance with ESA §7(a)(2) and its implementing regulations, Reclamation is responsible for defining the extent of its discretionary authority with respect to this action. Reclamation's authority stems from the following laws.

1.3 The Law of the River

The 1922 Colorado River Compact divided the mainstream Colorado River and tributaries above Lee Ferry (approximately one mile below the confluence of the Paria and Colorado rivers) into the Upper Basin, and the river and tributaries below that into the Lower Basin. The Secretary of the Interior is vested with the responsibility to manage the mainstream waters of the Lower Basin pursuant to applicable federal law. The responsibility is carried out consistent with a body of documents commonly referred to as the Law of the River. While there is no universally accepted definition of this term, the Law of the River comprises numerous operating criteria, regulations, and administrative decisions included in federal and state statutes, interstate compacts, court decisions and decrees, an international treaty, and contracts with the Secretary.

Notable among these documents are:

1) The Colorado River Compact of 1922 (Compact), which apportioned beneficial consumptive use of water, in perpetuity, between the Upper Basin and Lower Basin;

2) The 1944 Treaty (and subsequent minutes of the International Boundary and Water Commission) related to the quantity and quality of Colorado River water delivered to Mexico;

3) The Upper Colorado River Basin Compact of 1948, which apportioned the Upper Basin water supply among the Upper Basin states;

4) The Colorado River Storage Project Act of 1956 (CRSPA), which authorized a comprehensive water development plan for the Upper Basin, including the construction of Glen Canyon Dam and other facilities;

5) The 1963 United States Supreme Court Decision in *Arizona v. California* which confirmed that the apportionment of the Lower Basin tributaries was reserved for the exclusive use of the states in which the tributaries are located; confirmed the Lower Basin mainstream apportionments of 4.4 million acre-feet (maf) for use in California, 2.8 maf for use in Arizona and 0.3 maf for use in Nevada; provided water for Indian reservations and other federal reservations in California, Arizona and Nevada; and confirmed the significant role of the Secretary in contracting for, and managing the mainstream Colorado River within the Lower Basin;

6) The 1964 US Supreme Court Decree in *Arizona v. California* which implemented the Court's 1963 decision; the Decree was supplemented over time after its adoption and the Supreme Court entered a Consolidated Decree in 2006 which incorporates all applicable provisions of the earlier-issued Decrees;

7) The Colorado River Basin Project Act of 1968 (CRBPA) which authorized construction of a number of water development projects including the Central Arizona Project and required the Secretary to develop Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs (LROC), and issue an annual operating plan (AOP) that, among other information, identifies the anticipated annual operation for mainstream Colorado River reservoirs. The AOP is a single, integrated reference document required by section 602(b) of the CRBPA regarding past and anticipated operations;

8) The Colorado River Basin Salinity Control Act of 1974, which authorized a number of salinity control projects and provided a framework to improve and meet salinity standards for the Colorado River in the United States and Mexico; and

9) The Grand Canyon Protection Act of 1992, which addressed the protection of resources in Grand Canyon National Park and in Glen Canyon National Recreation Area, consistent with applicable federal law.

1.4 Detailed Description of the Proposed Action

1.4.1 Proposed Operation of Glen Canyon Dam

The Proposed Action is to continue Modified Low Fluctuating Flow releases as described in the 1995 EIS. Nothing in this Proposed Action would modify the annual volume of water released from Glen Canyon Dam; this determination is made pursuant to the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Guidelines or Shortage ROD). These Guidelines were adopted pursuant to a ROD, signed by the Secretary of the Interior on December 13, 2007.

As Reclamation implements the Shortage ROD, MLFF flows will be released as provided in the 1996 ROD, which places significant constraints on allowable fluctuations of powerplant releases. Section 2.2 describes these constraints in greater detail (Table 5). Exception criteria as outlined in the 1997 Glen Canyon Dam Operating Criteria would also continue.

As part of this experimental action, Reclamation proposes to incorporate experimental flows that have been designed to benefit endangered humpback chub and conservation of sediment resources in Grand Canyon. The experimental Proposed Action is: (1) an experimental high flow test of approximately 41,500 cubic feet per second (cfs) for a maximum duration of 60 hours in March 2008, and (2) fall (September and October) steady flows over the next five years (2008 - 2012). The high flow test hydrograph will duplicate the November 2004 high flow test hydrograph and consists of the following elements:

- on the evening of March 2, 2008 (or other approximate date in early March 2008) the MLFF release pattern will increase at a rate of 1,500 cfs/hour until powerplant capacity is reached;
- once powerplant capacity has been reached each of the four bypass tubes will be opened beginning on the morning of March 3, 2007, where once every three hours bypass releases will be increased by 1,875 cfs until all bypass tubes are operating at full capacity for a total bypass release of 15,000 cfs;
- an essentially constant flow of 41,500[1] cfs will be maintained for 60 hours, with flow changes less than 1,000 cfs/day;
- discharge will then be decreased at a down-ramping rate of 1,500 cfs/hour until the normal powerplant releases scheduled for March have been reached[2];

The steady releases during September and October of 2008 through 2012 will include the following constraints:

- the typical monthly dam release volumes will be maintained in all water years except water year (WY) 2008, where reallocation of water would occur for the high flow test in March;
- the dam releases for September and October will be steady[3], with a release rate determined to yield the appropriate monthly release volume;

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[1] Maximum capacity value calculated from the November 24-Month Study projected March 2008 Lake Powell reservoir elevation of 3586 feet and interpolated from the maximum full gate turbine capacity for seven units. One of the powerplant units will be off-line for repairs and unavailable for use in the experiment.

[2] If this element of the Proposed Action is undertaken, implementation of the high flow experiment will not affect the annual volume of water released from Glen Canyon Dam during WY 2008.

[3] Regulation release capacity of +/- 1,200 cfs will be available if needed for hydropower system regulation within each hour during the steady flow periods. Also, spinning reserves will be available if needed for emergency response purposes.

- If possible, the monthly dam release volumes should be managed and determined to produce similar volumes in the months of September and October (Table 1).

Monthly dam release volumes during the period of the Proposed Action could vary depending on the annual water release volume, as determined by the Shortage ROD. After 2012, releases would be made according to the 1996 ROD unless the AMP proposes and Reclamation implements experimental alternative release patterns.

Water year 2008 monthly water release volumes would be adjusted to provide water for a March high flow test (Table 1), but this would not cause the annual release from Glen Canyon Dam in WY 2008 to change. Maximum releases during March 2008 under the Proposed Action would be approximately 41,500 cfs during the peak high experimental flows. Tables 2 and 3 provide monthly release volumes and mean, minimum, and maximum daily releases for 10^{th}, 50^{th}, and 90^{th} percentiles determined for the Shortage EIS and ROD (Reclamation 2007). The 7.48 maf release pattern corresponds to the 10^{th} percentile category (dry hydrology), the 50^{th} percentile corresponds to the 8.23 maf pattern, and the 12.3 maf monthly release pattern (wet hydrology) corresponds to the 90th percentile volume for the period of the Proposed Action (2008-2012). All monthly volumes are modeled volumes and subject to change based on actual hydrology and operations.

Releases greater than 9.5 maf generally occur during periods of equalization of reservoir storage contents between Lake Powell and Lake Mead. Implementation of equalization and balancing will follow the Shortage ROD. When operating in the equalization tier, the upper elevation balancing tier, or the lower elevation balancing tier, scheduled water year releases from Lake Powell will be adjusted each month based on forecasted inflow and projected September 30 active storage at Lake Powell and Lake Mead, as discussed in the Shortage ROD.

The high flow test is intended to create and improve eddy complexes, including backwater habitats and beaches. With respect to potential benefits for native fish, the hypothesis to be tested is that widespread beach building and sediment retention will result from controlled releases from the dam under sediment-enriched conditions in Grand Canyon. It is also hypothesized that high releases from the dam will increase sandbar crest height, while increasing return channel depth through scouring. If these geomorphic changes occur as a result of the high flow test, greater and more persistent backwaters could be created, which may benefit conservation of the humpback chub and other native fish species.

Second, by steadying flows during September and October, backwater and other near shore habitat used by young native and endangered fish will become more hydraulically stable, with potentially warmer water temperatures than would exist under regular MLFF operations. These changes could create conditions for improved young-of-year humpback chub survival and growth rates, more persistent suitable habitat (depth and velocity over preferred substrates), and increased productivity of algal and invertebrate prey items for use by humpback chub.

Reclamation considers the high flow test and the steady fall releases experimental actions to better understand benefits to humpback chub and native fish. Hence, the evaluation of the high flow test should focus on benefits to shaping humpback chub habitat, especially nursery backwaters, and the possible downstream transport of young humpback chub. Evaluation of the steady fall flow is important to better understand the contrast between fluctuating flows and steady flows with respect to the extent of longitudinal warming, warming of shoreline habitats and nursery backwaters, stability of shoreline habitats, and the effect on humpback chub survival, growth, and bioenergetic expenditure. Full evaluation of this aspect of the Proposed Action is important to better understand how such test flows affect humpback chub and long-term species conservation. There is a high likelihood that dam releases during this proposed five-year experiment will be cool or cold. If so, this experiment also could provide the opportunity to contrast recent years of cool to warm release temperatures (2003 - 2005) with cool to cold release temperatures during the test period.

Table 1. Projected Glen Canyon Dam releases for Water Year 2008

	Without Proposal (No Action)				Proposed Action			
Month	Monthly Volume (maf)	Mean (cfs)	Min (cfs)	Max (cfs)	Monthly Volume (maf)	Mean (cfs)	Min (cfs)	Max (cfs)
Oct	600	9,758	6,800	12,800	601	9,774	6,800	12,800
Nov	600	10,083	7,100	13,100	604	10,134	7,200	13,200
Dec	800	13,011	9,000	17,000	800	13,011	9,000	17,000
Jan	800	13,011	9,000	17,000	800	13,011	9,000	17,000
Feb	600	10,804	7,800	13,800	600	10,804	7,400	13,400
Mar	600	9,758	6,800	12,800	830	13,499	7,200	13,200
Apr	600	10,083	7,100	13,100	550	9,243	6,200	12,200
May	600	9,758	6,800	12,800	555	9,042	6,000	12,000
Jun	650	10,924	7,900	13,900	650	10,924	7,900	13,900
Jul	850	13,824	9,800	17,800	820	13,336	9,300	17,300
Aug	900	14,637	10,600	18,600	820	13,336	9,300	17,300
Sep	630	10,588	7,600	13,600	600	10,083	10,083	10,083

Table 2. Projected releases from Glen Canyon Dam without the Proposed Action under dry (7.48 maf), median (8.23 maf), and wet (12.3 maf) conditions, 2009-2012

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

Table 3. Projected releases from Glen Canyon Dam with the Proposed Action under dry (7.48 maf), median (8.23 maf), and wet (12.3 maf) conditions, 2009-2012

	7.48 maf			8.23 maf			12.3 maf		
Month	Mean (cfs)	Min (cfs)	Max (cfs)	Mean (cfs)	Min (cfs)	Max (cfs)	Mean (cfs)	Min (cfs)	Max (cfs)
Oct	7,502	7,002	8,002	9,758	9,258	10,258	9,378	8,878	9,878
Nov	7,563	5,900	10,900	10,083	7,100	13,100	9,075	7,100	13,100
Dec	9,378	6,800	12,800	13,011	9,000	17,000	12,503	9,000	17,000
Jan	12,503	9,000	17,000	13,011	9,000	17,000	17,510	14,200	22,200
Feb	8,470	7,800	13,800	10,804	7,800	13,800	13,903	13,700	21,700
Mar	9,378	6,800	14,800	9,758	6,800	12,800	14,776	11,400	19,400
Apr	7,563	5,900	10,900	10,083	7,100	13,100	14,551	12,200	20,200
May	9,378	6,800	12,800	9,758	6,800	12,800	14,880	11,500	19,500
Jun	9,075	7,100	13,100	10,924	7,900	13,900	17,009	14,900	22,900
Jul	12,503	9,000	17,000	13,824	9,800	17,800	19,776	16,600	24,600
Aug	12,503	9,000	17,000	14,637	10,600	18,600	23,883	20,900	25,000
Sep	9,075	8,575	9,575	10,588	10,088	11,088	21,056	20,556	21,556

1.4.2 Basis and Approach to Proposed Action

The purpose of the special experimental high flow test is to take advantage of large amounts of sediment available in the Grand Canyon that currently exist in order to further analyze, through a high flow test, the effectiveness of such an approach to protect and improve downstream resources in the Grand Canyon.

Following the proposed experimental high flow test, the Department will analyze the data collected during the test, as well as information collected during the previous 1996 and 2004 high flow experiments, and other information, in order to develop predictive models and other analytical tools to better inform future decision making regarding dam operations and other related management actions. The Department does not propose through this Proposed Action to undertake any further experimental high flow testing until the information from this element of the Proposed Action is fully analyzed, presented to the Adaptive Management Work Group and the general public and can be integrated into an appropriate analytical framework based on predictive models and other analytical tools.

In proposing this element, the Department intends to undertake a unique experiment based on the extremely favorable sediment conditions afforded by recent high-volume 2006-2007 sediment inputs into the Grand Canyon below Glen Canyon Dam. In proposing this high flow experiment, the Department is not modifying, in any manner, the current long-term management approach to implementation of "beach-habitat building flows" as described in section 3 of the Operating Criteria for Glen Canyon Dam, published at 62 Fed. Reg. 9447 (Mar. 3, 1997). As provided in section 3 of the Operating Criteria, in adopting the management approach for "beach-habitat building flows" the Secretary found that releases pursuant to such an approach "are consistent with the 1956 Colorado River Storage Project Act, the 1968 Colorado River Basin Project Act, and the 1992 Grand Canyon Protection Act." Id. While no modification is proposed or anticipated at this time, any future potential modification of the 1996 ROD or 1997 Glen Canyon

Dam Operating Criteria would only occur after public review, comment and consultation, as well as any required environmental compliance efforts.

The Department recognizes that differences exist with respect to interpretations of certain provisions contained in the "law of the river" related to the implementation of “beach-habitat building flows (BHBFs)” and the proper application and interpretation of those provisions of law. In proposing a single experimental high flow test of approximately 41,500 cfs for a maximum duration of 60 hours in March 2008, the Department does not intend at this time to revisit or modify, in any manner, the determinations or considerations that led to the adoption of the management approach for BHBFs contained in Section 3 of the 1997 Glen Canyon Dam Operating Criteria or the 1996 ROD. Nor does the Department intend that the implementation of this experimental high flow test constitute a formal determination regarding the multiple and complex issues that would need to be considered in the event that a decision were made to revisit the BHBF management strategy contained in Section 3 of the Glen Canyon Operating Criteria. Accordingly, the Department recognizes that positions and rights concerning the issues related to BHBF management strategies and releases of water from Lake Powell are reserved, and shall not prejudice the position or interests of any stakeholder. The Secretary, through this Proposed Action, makes no determination with respect to the correctness of any interpretation or position of the individual Colorado River Basin states or any other stakeholder. Implementation of this element of the Proposed Action shall not represent a formal interpretation of existing law by the Secretary, nor predetermine in any manner, the means of operation of Glen Canyon Dam that the Secretary may adopt in the future following implementation of the Proposed Action, nor the design and implementation of future experimental actions.

1.4.3 Geographic Scope and Extent of Action Area

The area directly affected by this Proposed Action is Glen Canyon Dam in Coconino County, Arizona downstream to Separation Canyon, Mohave County, Arizona below the 41,500 cfs stage level of the Colorado River, as shown in Figure 1. Below Separation Canyon, ESA compliance is not addressed within the AMP but within the Lower Colorado River Multi-species Conservation Program (MSCP). The MSCP addresses areas up to and including the full-pool elevation of Lake Mead, and downstream areas along the Colorado River within the U.S.

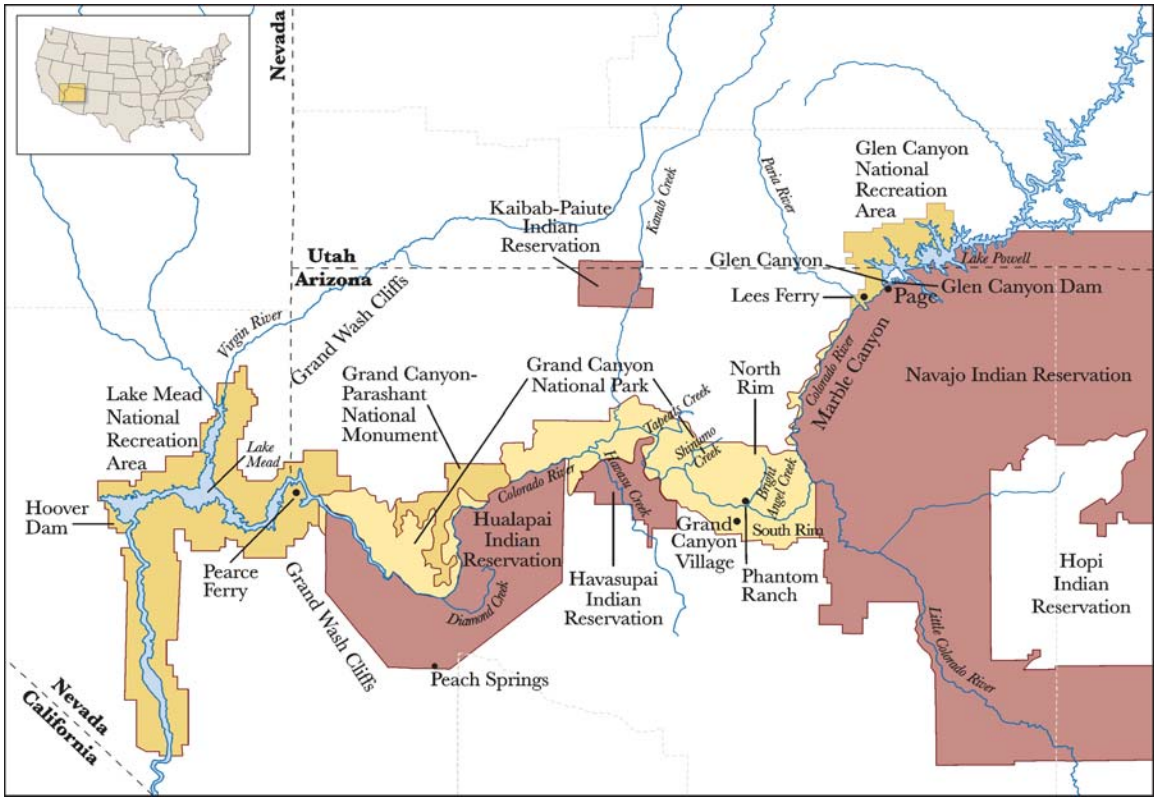


Figure 1. Action area from below Glen Canyon Dam to Separation Canyon.

1.5 Species Identified for Analysis

Four species identified as threatened or endangered are addressed in this biological assessment: Kanab ambersnail (*Oxyloma haydeni kanabensis*), humpback chub (*Gila cypha*), razorback sucker (*Xyrauchen texanus*), and southwestern willow flycatcher (*Empidonax traillii extimus*). Critical habitat also is considered for humpback chub, razorback sucker, and southwestern willow flycatcher. The list of species is based on a December 5, 2007, letter from the FWS. This biological assessment summarizes Reclamation's consultation history, actions taken in response to the 1995 biological opinion, and distribution and abundance, life requisites, new information resulting from onsite inspections, views of recognized experts, review of the current literature, and potential impacts of the test flows on these species and their habitats. Summary effect determinations are provided in Table 4.

Table 4. Summary of effects determinations for the four listed species

Species	Determination	Basis for Determination
Humpback chub	May affect, is likely to adversely affect	Take could occur from downstream transport during high flow test; long-term benefit to critical habitat from high flow test and potential benefit to juvenile fish from steady fall flows

Razorback sucker	May affect, not likely to adversely affect	Critical habitat in action area is unoccupied
Kanab ambersnail	May affect, is likely to adversely affect	A percentage of snails and habitat will be translocated during high flow test; while moving snails, some take may occur resulting in an adverse effect; no effect on snails or habitat would result from steady fall flows
Southwestern willow flycatcher	May affect, not likely to adversely affect	Birds will not be present during high flow test, resulting in no effect; birds will be off nests by Sept-Oct, but they will be foraging and there could be some indirect effect to their food

1.6 Summary of New Information

The following bullets identify the key elements of new information referenced in Section 3.2 with respect to these species.

1.6.1 Fluvial Geomorphology and High Flow Tests

- The EIS assumption about main channel accumulation of sediment during years of below average sediment and constant sediment rating curves has been shown to be an incorrect assumption based on more recent monitoring and experimentation (Topping et al. 2000a, b).
- Sediment rates vary significantly with grain size (Topping et al. 2000a, b).
- Tributary inputs are typically transported downstream within months under ROD operations (Rubin et al. 2002).
- Current sediment in the upper reaches of the Grand Canyon are the highest since 1998, and are three times the amount available at the time of the 2004 high flow test.
- Above average sediment inputs were unexpectedly retained during 2006-2007 (USGS 2006b).

1.6.2 Backwaters

- Persistence of backwaters created during 1996 appeared to be strongly influenced by post-high flow dam operations (Brouder et al. 1999).
- Biological effects of fluctuating flows include reduced availability of invertebrate prey, water exchange with main channel, and reduced temperature (Grand et al. 2005).
- There is a strong need for additional research on relationship between backwaters and fish habitat suitability and humpback chub survival and recruitment.

1.6.3 Water Temperature and Flow Regime

- Reduced Lake Powell elevations can produce significant increases in dam release temperatures.
- Downstream warming of water is directly affected by seasonal climatology and water release volumes (Vernieu et al. 2005).
- Nearshore river areas warm substantially for brief periods each day (Korman 2006).
- Modeling predicts dam releases likely will be cold (<11 °C) during the five years of the Proposed Action.

1.6.4 Humpback Chub

- Recruitment failure through the mid-1990's resulted in a decline of the Little Colorado River (LCR) population of humpback chub to 2,400 to 4,400 adult fish (Coggins et al. 2006).
- Increase in recruitment of humpback chub under MLFF began 4 to 9 years prior to implementation of non-native fish control, warmer dam release temperatures, the 2000 steady flow experiment, and the 2004 high flow test (Coggins 2007).
- Significantly greater numbers of young humpback chub have been found in the mainstem during 2002 to 2006, including upstream of the LCR (Ackerman 2007).
- Current adult population estimates for humpback chub have increased to an estimated 5,300 to 6,800 adult fish in 2006 (Coggins 2007).
- Humpback chub translocated above Chute Falls have experienced high survival and growth rates, and are a source of recruitment to the lower LCR and the mainstem (Stone 2007).
- Douglas and Douglas (2007) recommended further study of the 30-mile aggregation of humpback chub to evaluate their potential distinctiveness.
- Mainstem parasite infestation rates in humpback chub are much lower than fish in the LCR, and may be temperature-limited (Arizona Game and Fish Department [AGFD] 1996).
- Hoffnagle (2000) reported greater condition and abdominal fat of humpback chub in the mainstem than the LCR, possibly due to increased prevalence of parasites in the LCR fish.

1.6.5 Non-Listed Native and Non-native Fish

- The Grand Canyon fish community has shifted in the last five years from one dominated by non-native salmonids to one dominated by native species (Ackerman 2007).
- Trout abundance in the Lees Ferry reach has declined but trout condition has increased, reflecting a strongly density dependent fish population (McKinney and Speas 2001).
- A wide range of non-native fish have been captured in the LCR (Stone 2007), indicating that the LCR is a viable conduit for introduction of non-native fish into the mainstem.

1.6.6 Non-native Fish Control

- Electrofishing has reduced the rainbow trout population in the vicinity of the LCR confluence by about 90 percent during 2003-2006 (GCMRC unpublished data).

- Backpack electroshocking in Bright Angel and Shinumo Creeks [has reduced rainbow trout populations] by about 50 percent (Leibfried 2006).

2 Environmental Baseline

2.1 Regulatory Context

The focus of this biological assessment is on the threatened and endangered species that live in the Colorado River and floodplain between Glen Canyon Dam and Separation Canyon, near the inflow area of Lake Mead, Coconino and Mohave counties, northern Arizona (Figure 1). The river flows through the lowermost portion of Glen Canyon National Recreation Area and Grand Canyon National Park.

Observed flows recorded at Lees Ferry, Arizona surface water discharge station for the period 1922 through 2006 are shown in Figure 2. Flow in the Colorado River has varied significantly during the 20th century due to a combination of El Niño-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) processes and due to consumptive use upstream (Webb et al. 2005). For example the highest annual flow volume occurred in 1984 (22.2 maf), and the highest three-year average flow was 20.3 maf for the period 1983-1985. Prior to the current drought, the lowest previous three-year average flows were 7.3 maf from 1954-1956 and 8.0 maf from 1933-1935 (Webb 2004). This variability in annual flow, as well as the water temperature of discharges from Lake Powell as a result of the construction of Glen Canyon Dam, were previously considered by the FWS in their 1995 biological opinion, and thus are part of the baseline.

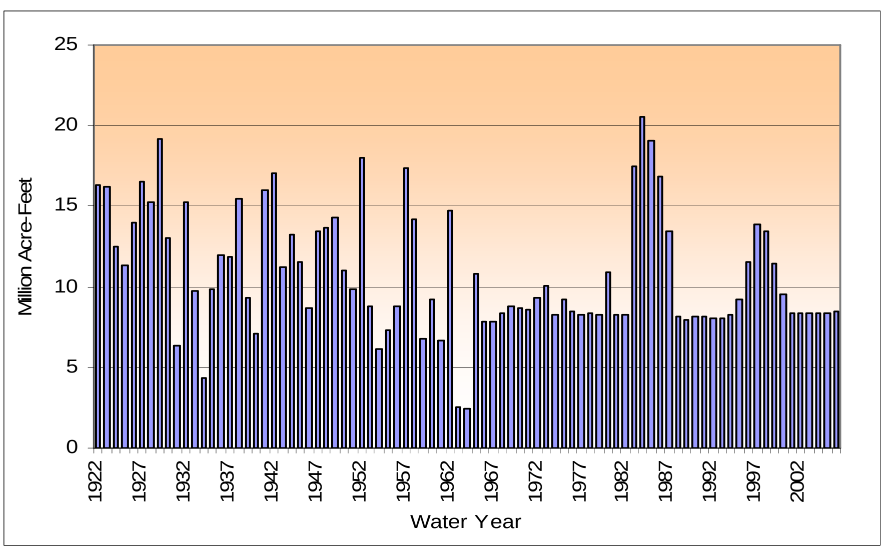


Figure 2. Observed annual stream flow volume (million acre feet) for the Colorado River at Lee's Ferry, AZ, 1922 to 2006.

The eight-year period from 2000 through 2007 was the driest eight-year period in the 100-year historical record of the Colorado River. This drought in the Colorado River Basin has reduced Colorado River system storage, while demands for Colorado River water supplies have continued to increase. From October 1, 1999 through September 30, 2007, storage in Colorado River reservoirs decreased from 55.8 maf (approximately 94 percent of capacity) to 32.1 maf approximately 54 percent of capacity), and was as low as 29.7 maf (approximately 52 percent of capacity) in 2004. Annual releases from Glen Canyon Dam since 2000 have not exceeded 8.23 maf.

Following adoption of the 1996 ROD, Glen Canyon Dam has been operated in accordance with release constraints in Table 5, aside from specific experimental releases in 1996, 1997, 2000 and 2004. These requirements, coupled with those from the Department's Shortage ROD (2007) and its associated biological opinion (FWS 2007), serve as the regulatory baseline for this biological assessment.

Table 5. Glen Canyon Dam release constraints under the 1996 ROD and 1997 Glen Canyon Operating Critera

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 emergency and during extreme hydrological conditions. Emergency exception criteria also exist during normal operations.

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.

Since 1970, the annual volume of water released from Glen Canyon Dam has been made according to the provisions of the LROC that include a minimum objective release of 8.23 maf. The Shortage ROD (Reclamation 2007b), which implements relevant provisions of the LROC for an interim period through 2026, allows Reclamation to modify these operations by allowing for potential annual releases both greater than and less than the minimum objective release under certain conditions. However, even in years with an annual release less than 8.23 maf, daily and hourly releases would continue to be made according to the parameters of the 1996 Glen Canyon Dam ROD (Reclamation 1996b), which would not be affected in any manner by the Proposed Action. See discussion at Shortage 2007 biological opinion (FWS 2007) and Section 2.2.6 (infra). By comparison, the No Action alternative as described in the Shortage FEIS (Reclamation 2007a) depicts how Reclamation would likely have operated Glen Canyon Dam under shortage conditions without adoption of the Guidelines.

Cold water discharges that have adversely affected native warm water fish and their habitat are part of the baseline. Variations in water year annual releases are in the baseline due to consultations resulting in the 1995 and 2007 biological opinions. Monthly releases that were the subject of prior consultations, as well as the daily fluctuation patterns in Table 5, are also in the baseline.

2.2 Related Consultation History and Experimental Actions Pursuant to the AMP

Reclamation has consulted with the FWS under section 7 of the ESA for various projects that could have had effects on ESA listed species and designated critical habitat within the action area, leading to the definition of the current baseline. Since 1995, Reclamation has consulted with FWS on a total of 5 important experimental actions, and undertaken a sixth experimental action that did not required separate ESA consultation. This history is listed and described below. The FWS issued a "jeopardy" biological opinion in the 1995 biological opinion, but non-jeopardy opinions on all other actions.

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

Reclamation received a final biological opinion from the FWS on the proposed preferred alternative for the Operation of Glen Canyon Dam EIS in January 1995. The FWS concluded that without the included reasonable and prudent alternative, implementation of the MLFF alternative was likely to jeopardize the continued existence of the humpback chub and razorback sucker and was likely to destroy or adversely modify their critical habitat, but was not likely to jeopardize the bald eagle, Kanab ambersnail and peregrine falcon. The 1995 biological opinion on the Operation of Glen Canyon Dam identified one reasonable and prudent alternative (RPA) containing four elements that were necessary to avoid jeopardizing the continued existence of the humpback chub and razorback sucker. These elements are described in more detail in Section 3.1. Reclamation has implemented these elements through the principles of adaptive management since 1996 within the Glen Canyon Adaptive Management Program. The FWS has agreed with Reclamation that sufficient progress has been made on some elements of the 1995 biological opinion, which are discussed in detail below in Section 3. Among other considerations, Reclamation has formulated this Proposed Action to address areas that have been identified as not fully achieving sufficient progress.

2.2.2 Spring 1996 High Flow Test from Glen Canyon Dam

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

2.2.3 November 1997 Fall Test Flow from Glen Canyon Dam

The 1997 action was proposed as a test of a powerplant capacity release of 31,000 cfs for 48 hours. While powerplant capacity releases were described in the 1995 EIS as habitat maintenance flows, such a test in the fall was not addressed in the 1995 FEIS, which necessitated additional consultation. The FWS in its biological opinion concluded that the test flow was not likely to jeopardize the continued existence of the humpback chub or Kanab ambersnail and was not likely to destroy or adversely modify designated critical habitat for the humpback chub. The FWS concluded the action would have no effect on the bald eagle or the American peregrine falcon.

2.2.4 2000 Steady Flow Test from Glen Canyon Dam

During the period March 25, 2000 through September 30, 2000, Reclamation conducted a 6-month test of steady flows, high in the spring and low during the summer and fall. Included were two high flow releases at powerplant capacity (31,000 cfs) during early-May and early September. Releases from late-March to late-May were generally steady at about 17,000 cfs, except for a week of high releases of about 19,000 cfs during late-May. Releases during the remainder of the period were steady at 8,000 cfs. This test was performed in accordance with the 1995 biological opinion element, so no additional consultation with FWS was conducted.

2.2.5 2002-2004 Experimental Releases from Glen Canyon Dam and Removal of Non-Native Fish

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

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

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

FWS translocated young humpback chub above Chute Falls in the Little Colorado River (ca. 16 km from the confluence). Under contract with GCMRC, FWS translocated nearly 300 young humpback chub above a natural barrier in the Little Colorado River located 16 km above the confluence in August 2003. This translocation was followed by another 300 fish in July 2004, and finally by another 567 fish in July 2005 (Sponholtz et al. 2005; Stone 2006). Preliminary results indicate that translocated fish survival and growth rates are high; limited reproduction and downstream movement below Chute Falls has also been documented (Sponholtz et al. 2005; Stone 2007).

The sediment input-triggered high experimental flow was analyzed for an indefinite period of time because of the uncertainty of knowing when the sediment trigger would be reached. The other two actions were analyzed for water years 2003 and 2004. Consultation was initiated in 2004 to make several changes to the timing and duration of the proposed experiments described in the 2002 consultation. The 2004 high flow experiment was intended to occur immediately following significant tributary sediment inputs, while the 2002 high flow experiment was proposed to occur in winter or spring. In a biological opinion dated November 2004, the FWS concurred with Reclamation that the action was not likely to adversely affect razorback sucker or its critical habitat, California condor or southwestern willow flycatcher. The FWS concluded that the modified action was not likely to jeopardize the continued existence of the humpback chub, Kanab ambersnail, or bald eagle. The FWS also concluded that designated humpback chub critical habitat would not be destroyed or adversely modified. The biological opinion included the 2002 conservation measures related to humpback chub including the continuation of translocating humpback chub in the Little Colorado River, and further study and monitoring of the results and study of effects on chub from various flow conditions.

Reclamation reinitiated Section 7 consultation in March 2003 (Peterson 2003) to propose a change in the size of humpback chub translocated as part of the management activities detailed in the Environmental Assessment of 2002 (USDI 2002). The FWS (2003a) responded with a finding of no jeopardy to the proposed changes. A Finding of No Significant Impact was made in July 2003 by Reclamation and others (2003) on a proposed modification to remove non-native fish from the Colorado River in an expanded area downstream of the confluence with the LCR. The FWS (2003b) concurred with a finding of no jeopardy on the expanded non-native fish action in August 2003. Activities to remove non-native fish from the expanded area (river mile 56.2 to 72.7) were thus incorporated into future non-native removal efforts (Coggins and others 2002).

Kanab ambersnail conservation measures included removal and safeguard of Kanab ambersnail habitat that would be inundated by the experimental release. Reclamation implemented conservation measures for Kanab ambersnail and humpback chub in conjunction with the proposed activities (Peterson 2002).

2.2.6 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead, Final EIS

The December 2007 biological opinion on the Shortage ROD included the geographic scope of this biological assessment, Glen Canyon Dam to Lake Mead. The Shortage ROD specified reduction of consumptive uses below Lake Powell during times of low reservoir conditions and modification of the annual release volumes from Lake Powell. The Shortage ROD, as adopted on December 13, 2007 establish annual release volumes from Glen Canyon Dam, but do not, in any manner, alter the constraints imposed by the 1996 ROD or as adopted in the 1997 Glen Canyon Dam Operating Criteria (discussed in Section 1.4.2). Since many of the potential resource impacts identified in that final EIS were being investigated in the AMP, the biological opinion made use of this institutional arrangement as a key mechanism for addressing these impacts. With respect to the listed species in Grand Canyon the FWS determined that implementation of the Guidelines is not likely to jeopardize the continued existence of the humpback chub, the southwestern willow flycatcher, or the Kanab ambersnail, and is not likely to destroy or adversely modify designated critical habitat for the humpback chub or the southwestern willow flycatcher.

The following conservation measures were included in the biological opinion: non-native fish control, humpback chub refuge, genetic biocontrol symposium, sediment research, parasite monitoring, and other monitoring and research. These measures are summarized here.

Non-native Fish Control

In coordination with other Interior AMP participants and through the AMP, Reclamation will continue efforts to control both cold- and warm-water non-native fish species in the mainstem of Marble and Grand canyons, including determining and implementing levels of non-native fish control as necessary. Control of these species using mechanical removal and other methods will help to reduce this threat.

Humpback Chub Refuge

Reclamation will assist FWS in development and funding of a broodstock management plan and creation and maintenance of a humpback chub refuge population at a Federal hatchery or other appropriate facility by providing expedited advancement of $200,000 in funding to the FWS during CY 2008; this amount shall be funded from, and within, the amount identified in the MSCP biological opinion (FWS 2005a; page 26). Creation of a humpback chub refuge will reduce or eliminate the potential for a catastrophic loss of the Grand Canyon population of humpback chub by providing a permanent source of genetically representative stock for repatriating the species.

Genetic Biocontrol Symposium

Reclamation will transfer up to $20,000 in fiscal year 2008 to FWS to help fund an international symposium on the use and development of genetic biocontrol of non-native invasive aquatic species which is tentatively scheduled for October 2009. Although only in its infancy, genetic biocontrol of non-native species is attracting worldwide attention as a potential method of controlling aquatic invasive species. Helping fund an effort to bring researchers together will further awareness of this potential method of control and help mobilize efforts for its research and development.

Sediment Research
In coordination with other Interior AMP participants and through the AMP, Reclamation will monitor the effect of sediment transport on humpback chub habitat and will work with the GCMRC to develop and implement a scientific monitoring plan acceptable to FWS. Although the effects of dam operation-related changes in sediment transport on humpback chub habitat are not well understood, humpback chub are known to utilize backwaters and other habitat features that require fine sediment for their formation and maintenance. Additional research will help clarify this relationship.

Parasite Monitoring
In coordination with other Interior AMP participants and through the AMP, Reclamation will continue to support research on the effects of Asian tapeworm (Bothriocephalus acheilognathi) on humpback chub and potential methods to control this parasite. Continuing research will help better understand the degree of this threat and the potential for management actions to minimize it.

Monitoring and Research
Through the AMP, Reclamation will continue to monitor Kanab ambersnail and its habitat in Grand Canyon and the effect of dam releases on the species, and Reclamation will also continue to assist FWS in funding morphometric and genetic research to better determine the taxonomic status of the subspecies.

Monitoring and Research
Through the AMP, Reclamation will continue to monitor southwestern willow flycatcher and its habitat and the effect of dam releases on the species throughout Grand Canyon and report findings to FWS, and will work with the NPS and other AMP participants to identify actions to conserve the flycatcher.

2.3 Description of Glen Canyon Dam Adaptive Management Program

The 1996 ROD directed the formation and implementation of an adaptive management program to assist in monitoring and future recommendations regarding the impacts of Glen Canyon Dam operations. The AMP was formally established in 1997 to implement the Grand Canyon Protection Act (GCPA), the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement, and the 1996 ROD. The AMP provides a process for assessing the effects of current operations of Glen Canyon Dam on downstream resources and using the results to develop recommendations for modifying dam operations and other resource management actions. This is accomplished through the Adaptive Management Work Group (AMWG), a federal advisory committee to the Secretary of the Interior. The AMWG consists of stakeholders that are federal and state resource management agencies, representatives of the seven Basin States, Indian Tribes, hydroelectric power marketers, environmental and conservation organizations and recreational and other interest groups. The duties of the AMWG are in an advisory capacity only. Coupled with this advisory role are long-term monitoring and research activities that provide a continual record of resource conditions and new information to evaluate the effectiveness of the operational modifications to Glen Canyon Dam and other management actions.

The AMP consists of the following major components:

- The AMWG which is a federal advisory committee which makes recommendations on how to adjust the operation of Glen Canyon Dam and other management actions to fulfill the obligations of the GCPA.

- The Secretary of the Interior's Designee which serves as the chair of the AMWG and provides a direct link between the AMWG and the Secretary of the Interior.

- The Technical Work Group (TWG) which translates AMWG policy into information needs, provides questions that serve as the basis for long-term monitoring and research activities, and conveys research results to AMWG members.

- The USGS Grand Canyon Monitoring and Research Center (GCMRC) which provides scientific information on the effects of the operation of Glen Canyon Dam and related factors on natural, cultural, and recreational resources along the Colorado River between Glen Canyon Dam and Lake Mead.

- The independent review panels (IRPs) which provide independent assessments of the AMP to assure scientific validity. Academic experts in pertinent areas make up a group of Science Advisors (SAs).

2.4 Description of Species Identified for Analysis

2.4.1 Humpback Chub

Legal Status

The humpback chub (*Gila cypha*) is currently listed as "endangered" under the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.). It was first included in the List of Endangered Species issued by the Office of Endangered Species on March 11, 1967 (32 FR 4001) and was considered endangered under provisions of the Endangered Species Conservation Act of 1969 (16 U.S.C. 668aa). The humpback chub was included in the United States List of Endangered Native Fish and Wildlife issued on June 4, 1973 (38 FR No. 106) and received protection as endangered under Section 4(c)(3) of the original ESA of 1973. The latest revised humpback chub recovery plan was approved on September 19, 1990 (FWS 1990a) and Recovery Goals were approved on August 1, 2002 (FWS 2002a). The Recovery Goals were declared "of no force and effect" by a federal judge on January 23, 2006, and were withdrawn by the FWS. Revised Recovery Goals are expected to be issued in 2008. The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374) and final designation became effective on April 20, 1994. Critical habitat includes 280 km of the Colorado River through Marble and Grand canyons from Nautiloid Canyon (RM 34) to Granite Park (RM 208) and the lower 13 km of the LCR. Primary threats to the species include streamflow regulation and habitat modification (including cold-water dam releases and habitat loss), competition with and predation by non-native fish species, parasitism, hybridization with other native Gila, and pesticides and pollutants (Colorado River Fishes Recovery Team 1990; FWS 2002a).

Historical and Current Range

The humpback chub is a moderately large cyprinid fish endemic to the Colorado River system (Miller 1946) that was first described from Grand Canyon specimens in 1946 (Miller 1946). The species was rare in early collections and historical distribution is not known with certainty (Valdez and Clemmer 1982; Tyus 1998). It probably existed in extant populations, each centered in relatively inaccessible canyons at middle elevations of the Colorado River system. It is surmised from various reports and collections that the species presently occupies about 68 percent of its historic habitat of about 756 km of river (FWS 2002a). Range reduction is thought to have been caused primarily by habitat inundation from reservoirs, cold-water dam releases, and non-native fish predation.

Six humpback chub populations are currently known—all from canyon-bound reaches (FWS 2002). Five are in the upper Colorado River Basin and the sixth is located in Marble and Grand canyons of the lower basin. Upper basin populations range in size from a few hundred individuals to about 5,000 adults. These populations are located in reaches that vary from 4 to 74 km within Black Rocks, Westwater Canyon, and Cataract Canyon of the Colorado River; Desolation and Gray canyons of the Green River; and Yampa Canyon of the Yampa River. The lower basin population is found in the Little Colorado River and the Colorado River in Marble and Grand canyons.

Population within the Action Area

The humpback chub presently occurs as nine aggregations within the action area in Marble and Grand canyons (Valdez and Ryel 1995). These aggregations are found within about 295 km of the Colorado River in Marble and Grand canyons and are known as 30-Mile (RM 29.8-31.3), LCR Inflow (RM 57.0-65.4), Lava to Hance (RM 65.7-76.3), Bright Angel Inflow (RM 83.8-92.2), Shinumo Inflow (RM 108.1-108.6), Stephens Aisle (RM 114.9-120.1), Middle Granite Gorge (126.1-129.0), Havasu Inflow (RM 155.8-156.7), and Pumpkin Spring (RM 212.5-213.2). Subsequent monitoring of fish in Marble and Grand canyons has confirmed the persistence of these aggregations (Trammell et al. 2000), although few or no humpback chub have been caught at the Havasu Inflow and Pumpkin Spring aggregations since 2000 (Ackerman 2007). Humpback chub have been caught infrequently downstream of Pumpkin Spring. One adult was captured downstream of Maxson Canyon (RM 244) in 1994 (Valdez 1994), and four humpback chub were caught at Separation Canyon (RM 239.5) in 2006 (AGFD 2006).

The largest aggregation is a self-sustaining population located in the lower 13 km of the Little Colorado River and the adjoining 15 km of the Colorado River (RM 57.0-65.4). This population has been expanded upstream of Chute Falls through mechanical translocation of fish (Stone and Sponholtz 2003, 2004) as described in Section 2.1.4.

The population of humpback chub associated with the LCR inflow aggregation is believed to be stable with about 6,000 adults in 2006 (age 4+, ≥200 mm total length (TL); Figure 3; Coggins 2007). Catch rates using hoop nets for subadults and adults show a similar pattern to adult population numbers with earlier decreases followed by more recent increases (Figure 4). Apparent recruitment failure through the mid 1990s resulted in a population decline to a low in 2001 of between 2,400 and 4,400 age 4+ fish (Gloss and Coggins 2005; Coggins et al. 2006). While the recent increase in population size and stability has previously been attributed to increased recruitment resulting from warmer water temperatures, mechanical removal of non-native piscivorous fish and/or experimental flows (high flow tests, steady flows in 2000), recent modeling suggests that increased recruitment predates each of these factors by at least four years (Coggins et al. 2007). No explanations for this recruitment increase have been proposed to date, particularly whether the increase was due to factors associated with the Little Colorado River, the mainchannel Colorado River, or both parts of the system.

The first population estimate for humpback chub in Grand Canyon was based on a mark-recapture estimator with Carlin-tagged fish (Kaeding and Zimmerman 1982) and yielded a "ball park" estimate of 7,000-8,000 individuals in 1982 larger than 200 mm TL in the Little Colorado River. The estimates shown in Figure 3 are based on the mark and recapture histories of humpback chub with PIT tags, a marking program that began in May of 1989. Valdez and Ryel (1995) used PIT-tagged fish and estimated 3,482 adult (>200 mm TL) humpback chub in a 14-km reach of the mainstream Colorado River near the Little Colorado River inflow for 1990-1993. Douglas and Marsh (1996) estimated the LCR population in 1992 for PIT-tagged humpback chub greater than 150 mm total length at about 4,346 individuals. Since a portion of the humpback chub population moves back and forth between the Little Colorado River and mainstream, some of the same individuals were likely included in both estimates and the total population was less than the sum of these estimates. Valdez and Ryel (1995) also provided mark-recapture estimates for PIT-tagged humpback chub adults (≥200 mm TL) in five of the remaining eight aggregations, including 30-Mile (estimate, n-hat = 52), Shinumo Inflow (n-hat = 57), Middle Granite Gorge (n-hat = 98), Havasu Inflow (n-hat = 13), and Pumpkin Spring (n-hat = 5).

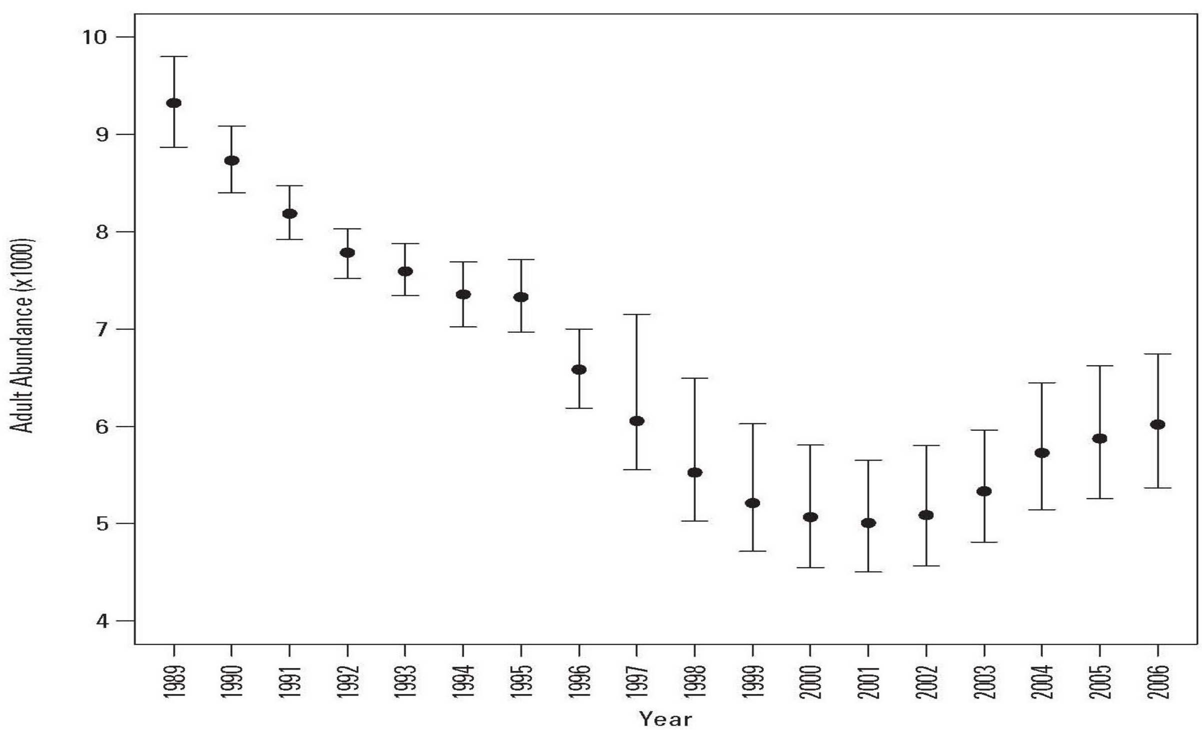


Figure 3. Adult (age 4+) humpback chub population estimates (1989-2005) for the Little Colorado River. Error bars are 95 percent Baysian credibility intervals and reflect uncertainties in assignment of age (USGS 2007).

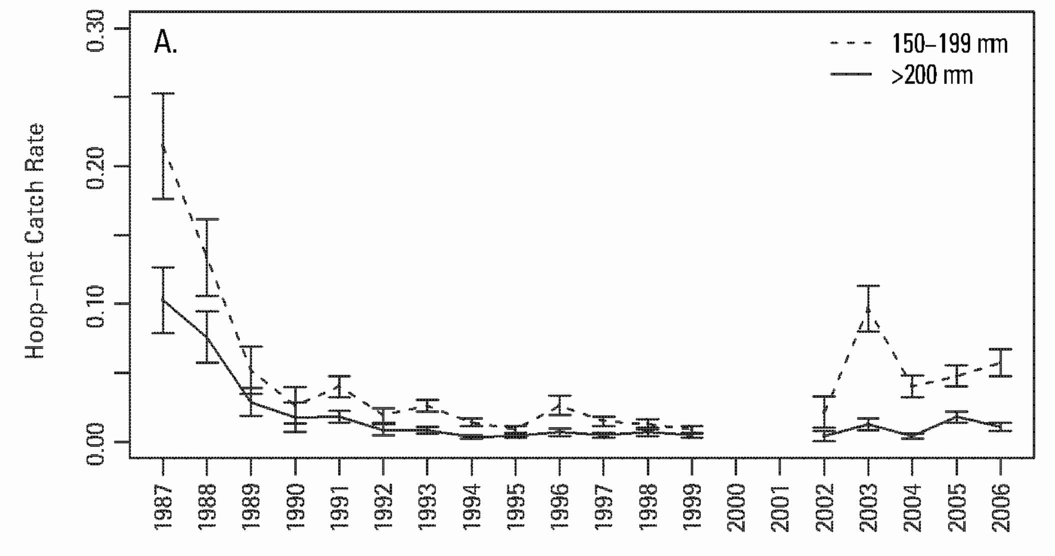


Figure 4. Relative abundance indices of sub-adult (150–199 mm total length (TL)) and adult (>200 mm TL) humpback chub based on hoop-net catch rate (fish/hour) in the lower 1,200-m section of the Little Colorado River.

Young and juvenile humpback chub are found primarily in the Little Colorado River and the Colorado River near the Little Colorado River inflow. Reproduction by humpback chub occurs annually in spring in the Little Colorado River, and the young fish either remain in the Little Colorado River or disperse into the Colorado River. Dispersal of these young fish has been documented as nighttime larval drift during May through July (Robinson et al. 1998), as density-dependence movement during strong year classes (Gorman 1994), and as movement with summer floods caused by monsoonal rain storms during July through September (Valdez and Ryel 1995). Survival of these young fish in the mainstem is thought to be low because of cold mainstem temperatures, but fish that survive and return to the Little Colorado River contribute to recruitment in this population. Fish distribution patterns in the Colorado River downstream of the Little Colorado River and size composition of humpback chub aggregations suggest that young dispersing from the Little Colorado River also recruit into downstream aggregations (Valdez and Ryel 1995). However, the young fish in these aggregations may not all be from the Little Colorado River and some may originate from local reproduction.

Young-of-year and juvenile humpback chub were commonly found from RM 110-130 (Middle Granite Gorge) and RM 160-200 (Ackerman 2007; AGFD 1996; Johnstone and Lauretta 2004, 2007; Trammell et al. 2002). The Middle Granite Gorge aggregation (which includes adults) has been stable or increasing in size since 1993 (Trammell et al. 2002) and may be sustained via immigration from the LCR aggregation, as well as local reproduction. Valdez et al. (2000) identified this aggregation as the most likely candidate for a second spawning population in the mainchannel given favorable conditions (mainly temperature). Population estimates have not been made for other mainstream aggregations since 1993 (Trammell et al. 2002).

Reproduction

The humpback chub is an obligate warm-water species that requires relatively warm temperatures of about 16-22 °C for spawning, egg incubation, and survival of young. Spawning is usually initiated at about 16 °C (Hamman 1982). Highest hatching success is at 19–20 °C with incubation time of 3 days, and highest larval survival is slightly warmer at 21–22 °C (Marsh 1985). Hatching success under laboratory conditions was 12 percent, 62 percent, 84 percent, and 79 percent in 12–13 °C, 16–17 °C, 19–20 °C, and 21–22 °C, respectively, whereas survival of larvae was 15 percent, 91 percent, 95 percent, and 99 percent, at the same respective temperatures (Hamman 1982). Time from fertilization to hatching ranged from 465 hours at 10.0 °C to 72 hours at 26.0 °C, and time from hatching to swim-up varied from 372 hours at 15.0 °C to 72 hours at 21.0–22.0 °C. The proportion of abnormal fry varied with temperature and was highest at 15.0 °C (33 percent) and was 17 percent at 25.0 °C. Marsh and Pisano (1985) also found total mortality of embryos at 5, 10, and 30 °C. Bulkley et al. (1981) estimated a final thermal preference of 24ºC for humpback chub during their first year of life (80–120 mm).

Humpback chub are broadcast spawners with a relatively low fecundity rate compared to cyprinids of similar size (Carlander 1969). Eight humpback chub (355–406 mm TL), injected with carp pituitary and stripped in a hatchery, produced an average of 2,523 eggs/female, or about 5,262 eggs/kg of body weight (Hamman 1982). Egg diameter ranged from 2.6 to 2.8 mm (mean, 2.7 mm). Eleven humpback chub from the LCR yielded 4,831 eggs/female following variable injections of carp pituitary and field stripping (Clarkson 1993).

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

Unlike larvae of other Colorado River fishes (e.g., Colorado pikeminnow and razorback sucker), larval humpback chub show little evidence of long-distance drift (Robinson et al. 1998). At hatching, larvae have nonfunctional mouths and small yolk sacs (Muth 1990). The larvae swim up about 3 days after hatching but tend to remain close to spawning sites. Robinson et al. (1998) found small numbers of larvae drifting in the LCR from May through July, primarily at night. Hence, it is believed that the majority of newly-hatched humpback chub remain close to their natal sites.

The presence of young humpback chub in various locations of the Colorado River in Marble and Grand canyons indicates that recruitment is occurring from the Little Colorado River, but there is also a strong evidence of mainstem reproduction. Young humpback chub have been collected in or near Bright Angel Creek, Shinumo Creek, Kanab Creek, and Havasu Creek (Arizona Game and Fish Department 1996, Brouder et al. 1997; Maddux et al. 1987; Kubly 1990). Aside from mainstem reaches immediately below the LCR, young-of-year and juvenile humpback chub have been found in the mainchannel Colorado River most commonly from RM 110-130 (Middle Granite Gorge) and RM 160-200 (AGFD 1996; Trammell et al. 2000; Johnstone and Lauretta 2004, 2007; Ackerman 2006). During 2002-2006, a total of 1,191 humpback chub <100 mm TL were caught in the Colorado River through Marble and Grand canyons (Ackmerman 2007; Figure 5); 442 (mean = 38 mm TL) were upstream of the Little Colorado River and 749 (mean = 67 mm TL) were downstream. Of the 749 fish downstream of the Little Colorado River, 135 were downstream of RM 108 (Shinumo Creek inflow). The fish downstream of Shinumo Creek occurred as three distinct groups, at Stephen Aisle and Middle Granite Gorge (n=40, RM115-135), Havasu Creek to Lava (n=58, RM 155-190), and Pumpkin Spring (n=23, RM 195-220). Four juveniles (64-67 mm TL) were also caught at Separation Canyon (RM 239.5). The combination of larval to postlarval sizes and the low probability of these fish surviving the extreme rapids of the inner gorge in Grand Canyon strongly suggest that their origin is natural reproduction outside of the Little Colorado River.

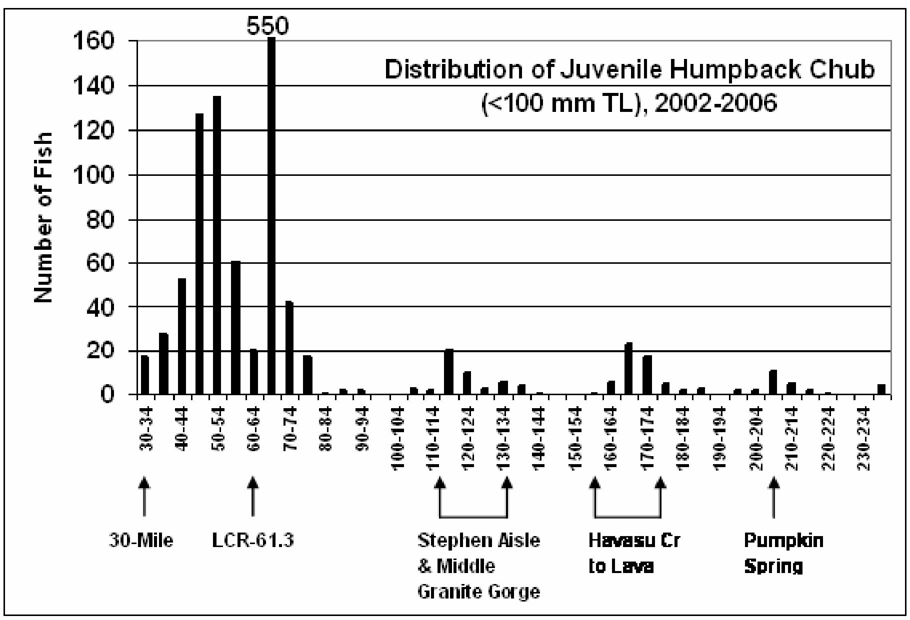


Figure 5. Distribution of juvenile humpback chub <100 mm TL during 2002-2006 by 5-mile increments from RM 30 to RM 230 (data from Ackerman 2007).

Young humpback chub have also been caught upstream of the Little Colorado River. An unknown number of juveniles were caught at RM 44 between 1970 and 1976 (Carothers and Minckley 1981; Suttkus et al. 1976). In 1993, the Arizona Game and Fish Department (1994) captured 20 young-of-year (20-50 mm TL) in a backwater at RM 44.3. The only documented evidence of reproduction was the capture of post-larvae in July, 1994, in a thermal riverside spring located at RM 30.9, about 72 km downstream of Glen Canyon Dam (Valdez and Masslich 1999). The 30-Mile aggregation of humpback chub is associated with this complex of eight warm springs, but the large size structure of the aggregation indicates little recruitment (Valdez and Ryel 1995). During 2002-2006, a total of 442 humpback chub <100 mm TL were captured upstream of the Little Colorado River inflow (RM 61.3) as far upstream as RM 30.7 (Ackmerman 2007). Of the 442 fish, 225 (13-66 mm TL) were caught between RM 30 and RM 50. The 30-Mile aggregation is located 31 miles upstream of the Little Colorado River inflow and it is unlikely that the young humpback chub swam upstream for that distance, especially in the cold mainstem temperatures. Bulkley et al. (1982) found that juvenile humpback chub 73-134 mm TL forced to swim at a velocity of 0.51 m/sec fatigued after an average of 85 minutes at 20 °C, but fatigued after only 2 minutes at 14 °C; a decrease of 6 °C reduced fatigue time by 98 percent. Furthermore, the distribution of these fish (Figure 5), as well as averages size above (mean = 38 mm TL) and below the LCR (mean = 67 mm TL), indicate that the natal source is upstream of RM 50 and not from the Little Colorado River.

From the time that Lake Powell first filled in about 1980 until about 2000, cold hypolimnetic releases of 8-10 °C were characteristic of Glen Canyon Dam operations. These cold temperatures largely prevented mainstem reproduction by humpback chub, except perhaps in localized warm springs (Valdez and Masslich 1999). Throughout this post-dam period, low survival of larval and post-larval fish led to low recruitment to the adult population. This trend was attributed to effects of cold water temperatures (thermal shock, poor swimming performance and predator avoidance) and non-native fish predators and competitors (Lupher and Clarkson 1994, Valdez and Ryel 1995, Marsh and Douglas 1997, Clarkson and Childs 2000, Robinson and Childs 2001; Ward et al. 2002). Low reservoir elevations in recent years have resulted in withdrawal of warmer epilimnetic water from Lake Powell and warmer water temperatures through Marble and Grand canyons, such that in 2005, dam release temperatures reached 18 °C. Dramatic increases in numbers of young flannelmouth suckers and bluehead suckers indicate that these species are spawning in the mainstem with increased growth and survival as a result of warmer temperatures or are experiencing enhanced survival of young fish moving from tributaries to the mainstem. These warm releases may be similarly affecting humpback chub.

Habitat and Movement

At the macrohabitat scale, humpback chub occupy swift, deep, canyon reaches of river (Archer et al. 1985; Valdez and Clemmer 1982; Valdez and Ryel 1995), but microhabitat use varies considerably among age groups (Valdez et al. 1990). Within Grand Canyon, adults demonstrate high microsite fidelity and occupy main channel eddies, while subadults use nearshore habitats (Valdez and Ryel 1995). Young-of-year humpback chub use shoreline talus, vegetation, and backwaters typically formed by eddy return current channels (AGFD 1996). These habitats are usually warmer than the main channel especially if they persist for a long time and are not inundated or desiccated by fluctuating flows (Stevens and Hoffnagle 1999). During the summer months, backwaters offer low velocity, relatively warm, protected, food-rich environments when compared to nearby mainstream habitats (Maddux et al. 1987; Kennedy 1979; Grabowski and Hiebert 1989; Arizona Game and Fish Department 1996; Hoffnagle 1996). Subadults also use shallow, sheltered shoreline habitats but with greater depth and velocity (Valdez and Ryel 1995; Childs et al. 1998). In Grand Canyon, nearly all fish smaller than 100 mm TL were captured near shore, whereas most fish larger than 100 mm TL were captured in offshore habitats (Valdez and Ryel 1995). Highest densities of subadults were found along shorelines with vegetation, talus, and debris fans (Converse et al. 1998). Korman et al. (2004) predicted that downstream displacement rates of small-bodied fish in the Colorado River immediately below the Little Colorado River will increase with increased discharge, but that this pattern would vary considerably with reach geomorphology and assumptions on swimming behavior of the fish.

Valdez and Ryel (1995, 1997) reported that adult humpback chub in the Colorado River in Grand Canyon used primarily large recirculating eddies, occupying areas of low velocity adjacent to high-velocity currents that deliver food items. They also reported that adults congregated at tributary mouths and flooded side canyons during high flows. Adults were captured (88 percent) and radio-contacted (74 percent) primarily in large recirculating eddies disproportionate to their availability (21 percent). Smaller percentages of adults were captured or radio contacted in runs (7 percent and 16 percent, respectively) that comprised 56 percent of surface area, pools (1 percent and 3 percent, respectively) that comprised 16 percent of surface area, and backwaters (4 percent and 7 percent, respectively) that comprised 0.1 percent of surface area. Hoffnagle et al. (1999) reported that juveniles in Grand Canyon used talus shorelines at all discharges and apparently were not displaced by controlled flood of 45,000 cfs in late March and early April, 1996. Valdez et al. (1999) also reported no displacement of radiotagged adults, with local shifts in habitat use to remain in low-velocity polygons within large recirculating eddies.

As young humpback chub grow, they exhibit an ontogenic shift toward deeper and swifter offshore habitats that usually begins at age 1 (about 100 mm TL) and ends with maturity at age 4 (≥200 mm TL; Valdez and Ryel 1995, 1997). In the Colorado River in Grand Canyon, minimum, average, and maximum velocities selected by young-of-year (21–74 mm TL) were 0.0, 0.06, and 0.30 m/s, respectively, all at depths less than 1 m. Minimum, average, and maximum velocities selected by humpback chub (75–259 mm TL) were 0.0, 0.18, and 0.79 m/s, respectively, all at depths less than 1.5 m. Hence, young humpback chub remained along shallow shoreline habitats throughout their first summer, but shifted to more offshore habitats by fall and winter.

Ontogenic shifts in habitat use were also seen in the Little Colorado River. Larval and early juvenile humpback chub used shallow, low-velocity habitats, different than those used by young of other native species, indicating resource partitioning (Childs et al. 1998). Gorman (1994) found that juveniles or early stages less than 50 mm TL occupied near-benthic to mid-pelagic positions in shallow, nearshore areas that were less than 10 cm deep and had low-velocity flow, small substrate particle sizes, moderate cover, and vertical structure. Juveniles 50–100 mm TL used similar habitats of moderate depth (less than 20 cm) that had small to large substrate, moderate to high cover, and vertical structure. Juveniles 100–150 mm TL used shoreline and offshore areas of moderate to deep water (less than 30 cm during the day; less than 20 cm at night) that had slow currents, small and large substrate particle size, moderate to high levels of cover, and vertical structure.

Humpback chub spawn in spring but little is known about specific habitat used for spawning. Gorman and Stone (1999) reported ripe male humpback chub in the Little Colorado River in areas of complex habitat structure (i.e., matrix of large boulders and travertine masses combined with chutes, runs, and eddies, 0.5–2.0 m deep) and associated with deposits of clean gravel. In the Upper Colorado River Basin during spring runoff, spawning adult humpback chub appear to utilize cobble bars and shoals adjacent to relatively low-velocity shorelines that are typically described as runs and eddies (Valdez et al. 1982; Karp and Tyus 1990; Valdez et al. 1990; Valdez and Ryel 1995, 1997). Tyus and Karp (1989) reported that humpback chub in the Yampa

River occupy and spawn in or near shoreline eddy habitats. They hypothesized that spring peak flows were important for reproductive success and that loss or reduction of spring peak flows could potentially reduce availability of spawning habitat.

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

Growth

Humpback chub attain a maximum size of about 480 mm TL and 1.2 kg in weight (Valdez and Ryel 1997) and can live to be 20-30 years old (Hendrickson 1993). Humpback chub grow relatively quickly at warm temperatures until maturity at about 3 years of age, then grow rate slows substantially. Humpback chub larvae are approximately 7 mm long at hatching (Muth 1990). In a laboratory, post-larvae grew at a rate of 10.63 mm/30 days at 20 °C, but only 2.30 mm/30 days at 10 °C (Lupher and Clarkson 1994). Similar growth rates were reported from back-calculations of scale growth rings in wild juveniles at similar water temperatures from the Little Colorado River (10.30 mm/30 days at 18–25 °C) and the mainstem Colorado River in Grand Canyon (3.50–4.00 mm/30 days at 10–12 °C; Valdez and Ryel 1995). Clarkson and Childs (2000) found that lengths, weights, and specific growth rates of humpback chub were significantly lower at 10 °C and 14 °C (similar to hypolimnetic dam releases) than at 20 °C (i.e., more characteristic of Little Colorado River temperatures during summer months).

Growth rates of humpback chub differ between the Little Colorado River and the mainstem Colorado River. Based on scale back-calculations, humpback chub from the Little Colorado River were 100 mm TL at 1 year of age and 250–300 mm TL at 3–4 years of age (Kaeding and Zimmerman 1983); whereas, fish 1, 2, and 3 years old from the mainstem Colorado River in Grand Canyon were 95, 155, and 206 mm TL, respectively (Valdez and Ryel 1995). Using 30-day growth rates of humpback chub from the Little Colorado River (Minckley 1992), lengths at ages 3 and 4 were estimated at 170 and 200 mm TL, respectively. Mark-recapture data from the Little Colorado River (Minckley 1992) and the Colorado River in Grand Canyon (Valdez and Ryel 1995) show that young humpback chub grow faster in the Little Colorado River (about 10 mm/30 days) than in the mainstem (2–4 mm/30 days), but fish older than about 3 years of age grow faster in the mainstem (0.79–2.79 mm/30 days) than in the Little Colorado River (<1–1.4 mm/30 days). Apparently food resources, habitat, and water temperatures are more suitable for young fish in the Little Colorado River, but habitat, food, and space may be limiting for adults. Abundant habitat, suitable food, and a relatively stable, regulated flow may favor adult growth in the mainstem, despite cold water temperatures.

Hendrickson (1993) aged humpback chub from the Little Colorado River and the mainstem Colorado River in Grand Canyon and showed a maximum of 23 annular rings. Based on polynomial regression of average number of annuli from otoliths (lapillus and asteriscus) and opercles, age-3 fish were 157 mm TL and age-4 fish were 196 mm TL. Valdez and Ryel (1995) recorded size at first observed maturity (based on expression of gametes, presence of spawning tubercles) of humpback chub in Grand Canyon at 202 mm TL for males and 200 mm TL for females; computed length of age-4 fish with a logarithmic growth curve was 201 mm TL.

Meretsky et al. (2000) reported a decline in condition factor of adult humpback chub not in immediate spawning condition from the Little Colorado River confluence from 1978 to 1996, hypothesizing that the decline could be caused by one or more factors; e.g., a recent invasion of the Asian tapeworm (*Bothriocephalus acheilognathi*), researcher variation in weighing fish, or natural population variation. Hoffnagle (2000) reported that condition and abdominal fat were greater in the mainstem Colorado River than in the Little Colorado River during 1996, 1998, and 1999 possibly because of an increased prevalence and abundance of parasites (especially *Lernaea cyprinacea* and *Bothriocephalus acheilognathi*) in the Little Colorado River fish and/or greater food availability in the Colorado River.

Diet

Humpback chub are typically omnivores with a diet consisting of insects, crustaceans, plants, algae, seeds, and occasionally small fish and reptiles (Kaeding and Zimmerman 1982, Kubly 1990, Valdez and Ryel 1995). They appear to be opportunistic feeders, capable of switching diet according to available food sources, and ingesting food items from the water's surface, mid-water, and river bottom. Specimens caught below Glen Canyon Dam in the early 1970's had been feeding on zooplankton flushed from Lake Powell (Minckley 1973). Juvenile humpback chub forage near the substrate, feeding on benthic insect larvae, crustaceans, and organic detritus (Carothers and Minckley 1981). Guts of 158 adults from the mainstem Colorado River, flushed with a nonlethal stomach pump, had 14 invertebrate taxa and nine terrestrial taxa (Valdez and Ryel 1995), including simuliids (blackflies, in 77.8 percent of fish), chironomids (midges, 57.6 percent), *Gammarus* (freshwater shrimp, 50.6 percent), *Cladophora* (green alga, 23.4 percent), Hymenoptera (wasps, 20.9 percent), and cladocerans (water fleas, 19.6 percent). Seeds and human food remains were found in eight (5.1 percent) and seven (4.4 percent) fish respectively. Longitudinal differences in diet were evident reflecting relative abundance of available food sources; i.e., simuliids were available and consumed throughout the canyon, but terrestrial invertebrates replaced *Gammarus* in lower reaches where the latter were absent. Seasonal differences were also evident with *Gammarus* as the primary food item in spring (40.1 percent by volume), and simuliids in summer (46.4 percent) and fall (44.7 percent). Diets of adult humpback chub during an experimental high dam release in 1996 showed a preference for terrestrial insects and aquatic invertebrates dislodged by the flood and entrained in large recirculating eddies (Valdez and Hoffnagle 1999).

Diets of humpback chub from the Little Colorado River and mainstem differ markedly, reflecting available food sources. Although larvae of simuliids and chironomids were present in both groups, *Gammarus* comprised only 1 percent volume of the diet of Little Colorado River fish (Kaeding and Zimmerman 1983), but approximately 64 percent of the diet of mainstem fish (Valdez and Ryel 1995); *Gammarus* are abundant in the mainstem but rare in the Little Colorado River. Adult humpback chub from the Little Colorado River have also been reported to be cannibalistic on their young during periods of high reproductive success (Gorman 1994). Arizona Game and Fish Department (1996a) reported that juvenile humpback chub in Grand Canyon consumed 19 different prey items, eight more than any other species examined. Chironomid larvae, terrestrial insects, simuliid larvae, and copepods were all found in at least 5 percent of the stomachs examined.

A number of investigators have reported large volumes of the green alga *Cladophora* mixed with a variety of invertebrates and detritus in diets of humpback chub from Grand Canyon (Minckley et al. 1980; Carothers and Minckley 1981; Kubly 1990; Valdez and Ryel 1995), suggesting that the fish feed on invertebrates entrained in the algae or the epiphytic diatoms may be an important source of lipids as was found for rainbow trout (Leibfried 1988). Humpback chub diet changes over the course of the year in response to food availability, dam releases and turbidity-related decreases in benthic standing biomass over distance downstream from Glen Canyon Dam (Blinn et al. 1995). However, composition and amount of humpback chub stomach contents were not altered significantly as a result of the 1996 high flow test (Valdez and Hoffnagle 1999).

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.* In contrast, Grand et al. (2006) predicted that increased daily fluctuations can impede benthic productivity in backwater environments due to dewatered substrate, export of invertebrates through frequent water exhange, and lower temperatures. Thus availability of principle humpback chub forage items may actually be enhanced by daily fluctuations in flow in the mainchannel environment (most frequently occupied by subadult- and adult chub), but not backwaters, which are utilized heavily by young-of-year humpback chub during the months of June through October.

Parasites

The majority of parasites of humpback chub are alien to the Colorado River system, introduced through non-native fishes. Most notable are the external parasitic copepod, *Lernaea cyprinacea*, and the intestinal Asian tapeworm, *Bothriocephalus acheilognathi*. During 1990–1993, *L. cyprinacea* was found on 8 of 6,294 fish from the Colorado River in Grand Canyon for an infection rate of only 0.13 percent and an average of 1.25 copepods (range, 1–2) per infected fish (Valdez and Ryel 1997). None of the infected fish showed signs of stress or illness, although open lesions had formed at some anchor points. This parasite infected 5.3 percent of humpback chub from the Little Colorado River (Hoffnagle et al. 2000). *Lernaea cyprinacea* was first reported from Grand Canyon in 1979 (Carothers et al. 1981) but has not become problematic because the mainstem fails to reach optimum maturation temperatures of 23–30 °C (Bulow et al. 1979). *Lernaea* matures at temperatures as low as 18 °C (Grabda 1963).

The internal Asian tapeworm was first reported from Grand Canyon in 1990 (Brouder and Hoffnagle 1997; Clarkson et al. 1997). During 1990–1993, this parasite was found in gut contents of 6 of 168 (3.6 percent) mainstem adult humpback chub treated with a nonlethal stomach pump, for an average of 6.7 tapeworms per infected fish (range, 1–28; Valdez and Ryel 1997). Clarkson et al. (1997) found Asian tapeworms in 28 percent of sacrificed humpback chub examined from the Little Colorado River in 1990–94. They also reported the parasite in intestines of common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), speckled dace (*Rhinichthys osculus*), and plains killifish (*Fundulus zebrinus*). Brouder and Hoffnagle (1997) also found Asian tapeworms in humpback chub (22.5 percent) from the LCR in 1994, as well as in plains killifish (10.3 percent), speckled dace (3.8 percent), and fathead minnow (2.2 percent). They reported that nearly all (66.7–100 percent) of infected fish were captured near the Little Colorado River, although the parasite was found as far downstream as Kanab Creek, 132 km downstream of the LCR. During 1996–1997, the internal Asian tapeworm occurred in 31.6-84.2 percent of humpback chub examined in the LCR and 8.8–26.7 percent in the Colorado

River (Hoffnagle et al. 2000); *Lernaea cyprinacea* was found on 5.3–47.6 percent of chubs in the Little Colorado River and 0–6.7 percent in the Colorado River; the trematode (*Ornithodiplostomum* sp.) in 50 percent; and the nematode (*Rhabodochona* sp.) in 5.3 percent. Markedly lower infestation rates of most parasites in the Colorado River in Grand Canyon demonstrate the detrimental effect of cold temperatures on most fish parasites of the Colorado River System.

Infection of humpback chub by the Asian tapeworm is a concern because of possible stress and death to the host and widespread infestation during periods of stress. This parasite is able to complete its life cycle in the LCR where the temperature requirement of >20 °C is met (Granath and Esch 1983), and although unable to complete its life cycle in the mainstem, it is apparently able to survive in a fish host in the cold temperatures. Meretsky et al. (2000) hypothesized that an observed decline in condition of adult humpback chub in Grand Canyon was a result of recent infestation by the internal Asian tapeworm.

2.4.2 Razorback Sucker

Legal Status

The razorback sucker (X*yrauchen texanus*) was listed as "endangered" under the Endangered Species Act of 1973, as amended, on October 23, 1991 (56 FR 54957). A recovery plan was approved on December 23, 1998 (FWS 1998) and Recovery Goals were approved on August 1, 2002 (FWS 2002b). The final rule for determination of critical habitat was published on March 21, 1994 (59 FR 13374), and the final designation became effective on April 20, 1994. Designated critical habitat includes the Colorado River and its 100-year floodplain from the Paria River downstream through Marble and Grand canyons to Hoover Dam, including the full pool elevation of Lake Mead. Primary threats to razorback sucker populations are streamflow regulation and habitat modification and fragmentation (including cold-water dam releases, habitat loss, and blockage of migration corridors); competition with and predation by non-native fish species; and pesticides and pollutants (Bestgen 1990, Minckley 1991; FWS 2002b).

Historical and Current Range

The razorback sucker is endemic to the Colorado River system. Historically, it occupied the mainstem Colorado River and many of its tributaries from northern Mexico through Arizona and Utah into Wyoming, Colorado, and New Mexico. In the late 19th and early 20th centuries, it was reported as abundant in the Lower Colorado River Basin and common in parts of the Upper Colorado River Basin, with numbers apparently declining with distance upstream (Jordan and Evermann 1896; Minckley et al. 1991; Mueller 2006). Distribution and abundance of razorback sucker declined throughout the 20th century over all of its historic range, and the species now exists naturally only in a few small, discontiguous populations or as dispersed individuals. The razorback sucker has exhibited little natural recruitment in the last 40–50 years and wild populations are comprised primarily of aging adults, with steep declines in numbers. Reproduction occurs, but few juveniles are found. Razorback sucker in the lower Colorado River basin persist primarily in reservoirs, including Lakes Mohave and Mead (Minckley 1983). Few and decreasing numbers of wild fish have also been caught in Lake Havasu, at several other locations along the river, and in water diversion facilities (Bozek et al. 1991; Minckley et al. 1991).

Currently, the group of razorback sucker in Lake Mohave is the largest remaining in the entire Colorado River system. Observers reported these fish as being common to abundant when the reservoir was filling in the 1950s, with the number of adults appearing to remain fairly stable through the 1970's and 1980's (Minckley et al. 1991). No verified natural recruitment has been found in Lake Mohave despite documented spawning and the presence of larval fish (Minckley 1983; Marsh 1994). This failure to recruit has been attributed primarily to predation by non-native fishes (Minckley et al. 1991; Burke 1994; Horn 1996; Pacey and Marsh 1998b). Estimates of the wild stock in Lake Mohave, now old and senescent, have dropped precipitously in recent years from 60,000 in 1989 (Marsh and Minckley 1989) to 25,000 in 1993 (Marsh 1993; Holden 1994) and to about 9,000 in 2000 (personal communication, T. Burke, U.S. Bureau of Reclamation).

A major repatriation effort to conserve the gene pool of razorback sucker in Lake Mohave was initiated by the Native Fish Work Group in 1991, in which naturally hatched larvae are captured and raised to juveniles under protection from predators in isolated coves (Minckley et al. 1991; Clarkson et al. 1993; Burke 1994; Pacey and Marsh 1998b; Jahrke and Clark 2000). More than 23,000 repatriated juveniles were released into Lake Mohave between 1992 and 1998. A total of 212 repatriated fish had been recaptured from 1992 through 1999, representing about 1 percent of the total number of juveniles released. Using the wild adult population estimate of 9,087 and catch summaries from 1998 and 1999, Pacey and Marsh (1999) determined that the percentage of repatriated juveniles among total recaptures is about 34 percent. An estimate of the repatriated juvenile population size is thus 3,104 with a 13 percent survival. They estimate that there are currently 12,000 razorback sucker in Lake Mohave, 75 percent are wild adults and 25 percent are repatriated juveniles. Intensive management in some locations has helped to offset the decline of the razorback sucker, such as the capture and protective rearing of larvae in Lake Mohave for release at larger sizes, and raising of young in predator-free environments in Cibola High Levee Pond; a 2-ha pond containing approximately 3,000 razorback suckers with reproduction and recruitment (Marsh 2000). It is also estimated that there are more than 1,000 razorback sucker in the 60-mile reach of the lower Colorado River between Davis Dam (impounds Lake Mohave) and Lake Havasu, with evidence of reproduction (Mueller 2001). These individuals do not include small numbers of fish in Lake Havasu.

A second razorback sucker population of approximately 500 individuals occurs in Lake Mead. The species was reported as common in Lake Mead into the 1960's, but numbers were noticeably reduced by the 1970's, and the species was considered rare (Minckley 1973; Bozek et al. 1991). The Lake Mead population is the only known recruiting population of razorback sucker in the Lower Colorado River Basin (Holden et al. 2000; Abate et al. 2002; Albrecht and Holden 2005). Recent age-growth data showed fish at about 20–25 years of age, indicating recent recruitment (Ruppert et al. 1999). The majority of the fish are found in Las Vegas Bay and Echo Bay, where spawning has been documented over alluvial deposits and rock outcrops. The population in Lake Mead has been studied since 1996 (Holden et al. 2000). During the first four years, 115 individuals were collected, not counting larvae. In August 1999, an adult was found in upper Lake Mead at the western side of the mouth of Grand Wash. This discovery was followed in 2000 by collection of larval razorback sucker in the far eastern part of Lake Mead. Holden et al. (2000) concluded that “spawning occurred in the lake, either near the Colorado River inflow area or in the actual Colorado River before it enters the lake.” Limited and sporadic captures of naturally occurring fish occur throughout the remainder of the lower Colorado River basin

(Abate et al. 2002; Holden et al. 1997, 1999, 2000a, 2000b, 2001; Marsh and Minckley 1989; Welker and Holden 2003, 2004).

Between 1981 and 1990, more than 13 million hatchery-produced razorback sucker were released at 57 sites into historic habitat in Arizona, primarily in the Verde, Gila, and Salt rivers and their tributaries, where the natural population had been extirpated (Hendrickson 1994). Low short-term survival and no long-term survival was reported from these releases, primarily because of predation by non-native fishes, although 14 adults were recently reported from Fossil Creek. Since 1994, 17,371 razorback sucker have been stocked into the Verde River. Numerous fish have been recaptured and survival up to 2 years has been documented. In addition, ripe males have been encountered in the Verde River, but no evidence of reproduction or recruitment has been found (personal communication, D. Shroufe, Arizona Game and Fish Department).

The razorback sucker appear to be a highly diverse species, displaying many mitochondrial DNA (mtDNA) genotypes. Based on restriction endonuclease analysis of mtDNA, it was determined that fish from Lake Mohave displayed the highest degree of genetic variability of all remaining populations of razorback sucker. Moving from south to north, populations appear to be progressively less diverse and possess fewer unique genotypes. Most fish sampled exhibited genotypes identical to those in the Lake Mohave fish; unique genotypes were similar and rarely found (Dowling and Minckley 1993). Hybridization between razorback sucker and flannelmouth sucker was identified as early as 1889 (Hubbs and Miller 1953) and has been reported for many years (Hubbs and Miller 1953; Suttkus et al 1976; Kidd 1977; McAda and Wydoski 1980; Maddux et al. 1987; Valdez and Ryel 1995; Douglas and Marsh 1998).

Populations within the Action Area

The razorback sucker has not been reported from Grand Canyon since 1990, and only 10 adults were reported between 1944 and 1995 (Valdez 1996; Gloss et al. 2005). Carothers and Minckley (1981) reported four adults from the Paria River in 1978-1979. Maddux et al. (1987) reported one blind female razorback sucker at Upper Bass Camp (Colorado River Mile 107.5) in 1984, and Minckley (1991) reported five adults in the lower Little Colorado River from 1989-1990. Putative hybrids with flannelmouth sucker (*Catostomus latipinnis*) have been reported from the Little Colorado River (Suttkus and Clemmer 1979, Carothers and Minckley 1981; Valdez and Ryel 1995). Douglas and Marsh (1998) confirmed the presence of such hybrids and estimated their numbers between 8 and 136. Although hybridization between these species has been reported for many years (Hubbs and Miller 1953; McAda and Wydoski 1980), the incidence in Grand Canyon appears high relative to the number of razorback suckers, especially in the Little Colorado River where these fish concentrate during spawning.

Douglas and Douglas (2000) reported a larval razorback sucker identified by the Colorado State University Larval Fish Laboratory from collections made at the mouth of Havasu Creek in Grand Canyon. They admitted the possibility that this could have been of a hybrid between razorback sucker and flannelmouth sucker, but noted that all known hybrids occur considerably higher in the system, in Marble Canyon and the Little Colorado River. Douglas and Marsh (1996a) contend that razorback suckers were never abundant in Grand Canyon, noting that remains were not found at Stanton’s Cave, where non-fossilized bones of five other native species were discovered. They suggest that razorback suckers were not residents of Grand Canyon, but transients, moving between more desirable habitats upstream and downstream.

A small number of hatchery adult razorback sucker equipped with radio transmitters were released in the Lake Mead inflow (Zimmerman and Leibfried 1997). After nearly two months of tracking, these tagged razorback sucker apparently left the area and were not relocated either up-river in the lower 40 miles of the Grand Canyon or down-lake in Gregg Basin or Virgin Basin (Abate et al. 2002; Holden et al. 1999). The migration of these fish out of the Colorado River inflow area, combined with the fact that no razorback sucker larvae were found in the area in 2002, suggests that decreasing lake levels altered habitat in this area and may have caused wild razorback sucker to move out of this vicinity.

Reproduction

Razorback suckers are warm-water species that spawn over a broad time span in late winter and spring, depending on latitude. In upper basin riverine environments, razorback sucker in reproductive condition and newly hatched larvae generally have been captured from mid-April through June on the ascending limb of the hydrograph (Modde and Wick 1997; Muth et al. 1998; McAda and Wydoski 1980; Osmundson and Kaeding 1989; Tyus and Karp 1989, 1990; Snyder and Muth 1990; Osmundson and Kaeding 1991; Tyus 1987; Valdez et al. 1982;). Further downstream, in Lake Mead, spawning takes place earlier, from mid-February to early June, peaking in March–April (Jonez and Sumner 1954; Holden et al. 1999a). Spawning occurs even earlier further downstream in Lake Mohave, beginning as early as November and continuing as late as May (Bozek et al. 1990, 1991; Burke and Mueller 1993; Minckley et al.1991; Schrader 1991). Activity appears to peak in January–March, with only scattered individuals in spawning condition found in May (Bozek et al. 1991).

Razorback suckers also have a wide temperature range for spawning, incubation, and rearing. The generally require about 12-22ºC for spawning with an optimum of 18ºC; and 14-25ºC with an optimum of 19ºC for egg incubation (Valdez 2006). The optimal thermal range for the razorback sucker is 22-25 °C (Bulkley and Pimentel 1983); however, the species occurs in widely varying temperatures. In the Upper Colorado River Basin, habitats are ice-covered during winter, while temperatures of mainstream habitats in the Lower Colorado River exceed 32^{o}C in summer (Dill 1944). Evidence of spawning in the Green River has been observed at water temperatures of 6–19 °C (McAda and Wydoski 1980; Tyus and Karp 1990; Snyder and Muth 1990; Muth et al. 1998), with an average of about 15 °C reported by Tyus and Karp (1990). Spawning in Lake Mohave has occurred at water temperatures between 9.5 °C and 22 °C (Minckley et al. 1991; Schrader 1991; Bozek et al. 1991; Burke and Mueller 1993). Gorman et al. (1999) observed spawning in the tailwaters of Hoover Dam at water temperatures of 11–12 °C. The population was characterized by a preponderance of spent/non-ripe males and gravid females, an unusual condition for suckers so late in the spawning season and possible evidence of retarded ovulation due to the cold dam tailwaters. Optimal water temperature for hatching success is around 20 °C; extreme limits of hatching are 10 °C and 30 °C (Marsh and Minckley 1985). Snyder and Muth (1990) found that eggs incubated at 18–20 °C hatch in 6–7 days, swim up in 12–13 days, and swim down in 27 days; eggs incubated at 15 °C hatch in 11 days, swim up in 17–21 days, and swim down in 38 days. Bozek et al. (1984) reported that eggs incubated at 10 °C hatched in 17.5–22.1 days, whereas Toney (1974) reported high mortality for eggs incubated at 11.7 °C. Marsh (1985) demonstrated in the laboratory that the highest successful hatching percentage for razorback suckers occurs at 20 °C, and that the hatch declines considerably at 15 °C with complete mortality at 10 °C.

Razorback sucker have high reproductive potential. McAda and Wydoski (1980) reported an average fecundity (N=10) of 46,740 eggs/fish (27,614–76,576), or about 39,600 eggs/kg. Inslee (1981) reported an average of 103,000 eggs/fish. Razorback sucker are broadcast spawners that scatter adhesive eggs over cobble substrate. Eggs incubate in interstitial spaces, and larvae must hatch and emerge from cobble substrates before being suffocated by deposited silt/sand (Minckley 1983; Minckley et al. 1991; Wick 1997). Adults make no effort to guard the nest sites (Jonez and Sumner 1954).

Survival of newly hatched larvae appears to be the limiting factor for razorback suckers in the Upper Colorado River Basin and may be dependent on availability of nursery areas in riverside floodplains (Bestgen 1990; Tyus 1998; Tyus and Karp 1990). Riverine spawning typically occurs in shallow water over gravelly substrates, often in areas of inflowing streams or on large cobble bars where gravel sorting has occurred (Minckley 1983; Mueller 1989). In riverine situations in the Upper Basin, spawning begins on the rising limb of the spring hydrograph (April-May) and continues for an extended period through the spring runoff when riverside nursery floodplains are available. Larval razorback suckers drift downstream from spawning sites and become entrained in these nursery floodplains where they may remain for several years. The timing of floodplain inundation, food availability, and arrival of larvae are critical to the survival of these young fish (Modde et al. 1996).

Habitat and Movement

The razorback sucker evolved in warm-water reaches of larger rivers of the Colorado River system from Mexico to Wyoming. Adults in rivers use deep runs, eddies, backwaters, and flooded off-channel environments in spring; runs and pools often in shallow water associated with submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter. Spring migrations of adult razorback sucker were associated with spawning in historic accounts and a variety of local and long-distance movements and habitat-use patterns have been documented. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and water temperatures and spawning in reservoirs takes place over rocky shoals and shorelines. Young require nursery environments with quiet, warm, shallow water such as tributary mouths, backwaters, or inundated floodplains in rivers, and coves or shorelines in reservoirs.

Adult razorback sucker tend to occupy different habitats seasonally (Osmundson et al. 1995), and can do well in both lotic and lentic environments (Minckley et al. 1991). In rivers, they usually are captured in lower velocity currents, more rarely in turbulent canyon reaches (Minckley et al. 1991; Bestgen 1990; Tyus and Karp 1990; Lanigan and Tyus 1989; Tyus 1987). An exception may be in the San Juan River, where hatchery-reared, radio-tagged adults preferred swifter mid-channel currents during summer–autumn base-flow periods (Ryden 2000). In the upper basin, bottomlands, low-lying wetlands, and oxbow channels flooded and ephemerally connected to the main channel by high spring flows appear to be important habitats for all life stages of razorback sucker (Modde et al. 1996; Muth et al. 2000). These areas provide warmwater temperatures, low-velocity flows, and increased food availability (Tyus and Karp 1990; Modde 1997; Wydoski and Wick 1998). For example, in Old Charlie Wash, a managed wetland on the middle Green River, spring–summer water temperatures were 2–8 °C higher than in the adjacent river (Modde 1996, 1997), density of benthos was 41 times greater than in other sampled habitats, and densities of zooplankton were 29 times greater than in backwaters and 157 times greater than in the main channel (Mabey and Shiozawa 1993). Many floodplain habitats comparable to Old Charlie Wash were available in the Green and Colorado River systems before dams, channelization, and levees altered large segments of the ecosystem (Tyus and Karp 1990; Osmundson and Kaeding 1991; Wydoski and Wick 1998). The loss of such habitats has been implicated in the decline of the species, but to some degree gravel pits and other artificial, relatively warm off-channel ponds are used as a substitute (Valdez and Wick 1983; Wick 1997; Maddux et al. 1993; Minckley et al. 1991).

During non-reproductive times of the year (summer–winter), adult razorback sucker in lotic environments have been found in deeper eddies, slow runs, backwaters, and other types of pool habitats with silt or sand substrate, depths ranging from 0.6 to 3.4 m, and velocities ranging from 0.3 to 0.4 m/s (Osmundson et al. 1995; Minckley et al. 1991; Tyus and Karp 1990; Valdez et al. 1982; Tyus 1987; Tyus et al. 1987). In summer, Osmundson and Kaeding (1989) captured adults in pools and runs 1.62 to 1.65 m deep. Tyus and Karp (1990) also found them in the vicinity of midchannel sandbars. In winter, Osmundson and Kaeding (1989) captured adults in pools and slow eddies 1.83 to 2.16 m deep, and Valdez and Masslich (1989) found them in slow runs, slack water, and eddies 0.6 to 1.4 m deep.

Hatchery-reared adults in the San Juan River generally moved out of the main channel and into edge pools during low winter base flows, using these habitats exclusively in January, the coldest month of the study (Ryden 2000). During the other winter months, fish ventured into the main channel during the warmest part of the day, presumably to feed. In the Verde River, adult razorback sucker were found in deeper pools and glides, at depths generally less than those reported in the upper basin (Clarkson et al. 1993; Creef et al. 1992). This difference was attributed to generally shallower conditions and possibly to hatchery conditioning (Clarkson et al. 1993). In the Gila River, Marsh and Minckley (1991) captured razorback sucker in flatwater, pools, and eddies.

In reservoirs in the lower basin, adult razorback sucker are pelagic at varying depths, except in breeding season, when they congregate in shallower, nearshore areas (Pacey and Marsh 1998b). Spawning takes place near shore in shallow water at temperatures of 10–21 °C, over flat, gravel and gravel mix substrate (Bozek et al. 1991; Minckley 1983; Schrader 1991; Burke and Mueller 1993). These areas tend to be located on outwash fans, along shorelines or on shoals that are swept free of silt by currents, wave action, and spawning activity. Larvae remain near shore for a few weeks before disappearing (Burke and Mueller 1993; Bozek et al. 1990, 1991; Minckley et al. 1991; Schrader 1991; Marsh and Minckley 1989). What happens to them is unknown; they may be dispersing to deeper water, but the near absence of juveniles suggests mortality at the larval stage, probably as a result of predation (Marsh and Langhorst 1988; Minckley et al. 1991; Horn 1996). Five tagged juveniles in Lake Mohave moved throughout the pelagic zones for the first week after release but then tended to occupy vegetated areas near the shore (Mueller et al. 1998). In the mixed channelized, lacustrine, and backwater environment of the Imperial Division of the Lower Colorado River, Bradford et al. (1999) tracked 58 fish with ultra-sonic tags and found that the main channel was used less frequently in proportion to availability; side channels were used in proportion to availability; backwaters were used slightly more relative to availability; and the reservoir was used more frequently in proportion to availability.

Growth

Adult razorback suckers attain a maximum size of about 1 m and can live to be 44 years old (McCarthy and Minckley 1987; Minckley 1973). Growth among individuals in the same cohort is highly variable (Minckley et al. 1991), and this variation may represent divergent strategies in this long-lived fish for dealing with the highly unpredictable environment of desert rivers in southwestern U.S. Growth is rapid for approximately the first six years, but then it slows dramatically (McCarthy and Minckley 1987). Based on analysis of bony structures, including otoliths from 70 razorback sucker from Lake Mohave, McCarthy and Minckley (1987) estimated ages ranging from 24 to 44 years. The relatively large size of wild adults in both the upper and lower basins, coupled with high incidences of blindness, external parasitism, tumors, and infections suggests that most populations are composed primarily of old fish (Valdez et al. 1982; Minckley 1983; Bozek et al. 1984; McCarthy and Minckley 1987). Razorback sucker in Lake Mead appear to be an exception. Ruppert et al. (1999) measured an annual average growth rate of 17.28 mm for wild (unstocked) razorback sucker in Lake Mead. This rapid growth is typical of young catostomids. Holden et al. (1999b) reported a lower annual growth rate (10 mm) from Lake Mead, but this is still three times the reported rate for both Lake Mohave and upper basin populations. Based on 10 years of data from Lake Mohave, Pacey and Marsh (1999) calculated an average monthly growth near zero (0.2–1.5 mm for females and 0.1–2.2 mm for males). In the upper basin, Modde et al. (1996) analyzed data from 1975–1992 and found the average growth rate to be only 1.66 mm/year.

Razorback sucker in the upper basin tend to be smaller than those in the lower basin, and grow more slowly (Minckley et al. 1991; Modde et al. 1996; Holden et al. 1999b). First-year growth of up to 400 mm was measured in the lower basin (Mueller et al. 1993), whereas average first-year growth of wild fish in the middle Green River was closer to 100 mm (Modde and Wydoski 1995). McAda and Wydoski (1980) reported that fish in upper basin riverine habitats mature after three to six growing seasons. In the lower basin, males usually reach maturity in their second year; females in their third year (U.S. Bureau of Reclamation 1996). Within the Green River, larvae in the upper river grew 6–21 percent faster than those in the lower river (Muth et al. 1998). Among stocked razorback sucker in the San Juan River, no difference was seen in growth between female and male fish, but, as expected, smaller fish grew faster than larger fish (Ryden 2000).

Rapid growth to adult size is correlated with food-rich, warm environments (Osmundson and Kaeding 1989; Minckley et al. 1991; Mueller 1995). Age-0 razorback sucker collected from Old Charlie Wash, a food-rich managed wetland adjacent to the middle Green River, grew 67 percent faster than larvae in hatchery ponds, and 29 percent faster than larvae in off-channel habitats (Muth et al. 1998). Enhanced growth is thought to increase survivorship, in part by reducing vulnerability to predation (Modde et al. 1999b). In laboratory experiments, slower larval growth of another native fish, Colorado pikeminnow, correlated to increased mortality due to predation (Bestgen et al. 1997).

Diet

All life stages of razorback sucker consume insects, zooplankton, phytoplankton, algae, and detritus; however, diet varies by age and habitat (Bestgen 1990, Muth et al. 2000). Within days of hatching, razorback sucker larvae (10–11 mm TL) begin to feed on plankton (Muth et al. 2000). As their terminal mouth migrates to a sub-terminal position, larvae begin feeding on benthos as well (Marsh and Minckley 1985). Razorback sucker diet composition is highly dependant upon life stage, habitat, and food availability. Upon hatching, razorback sucker larvae have terminal mouths and shortened gut lengths (less than 1 body length) which in combination, appears to facilitate and necessitate selection of a wide variety of food types. Exogenous feeding occurs at approximately 10 mm TL (approximately 8-19 days old), after which larvae from lentic systems feed mainly on phytoplankton and small zooplankton, while riverine inhabiting larvae are assumed to feed largely on chironomids and other benthic insects (Minckley and Gustafson 1982, Marsh and Langhorst 1988, Bestgen 1990, Papoulias and Minckley 1990, FWS 1998b). Papoulias and Minckley (1992) reared larval razorback sucker in three different ponds containing different densities of food resources to demonstrate that increased growth was positively related to invertebrate densities, suggesting the importance of larval food switching from algal and detrital food items to a diet enriched with invertebrates. Papoulias and Minckley (1990) showed that larval mortality is minimized when food levels are within the range of 50-1,000 organisms/L. In riverine environments in the upper basin, Muth et al. (1998) reported that cladocerans, rotifers, and algae decreased in importance as larvae grew larger, but chironomids remained the dominant food item at all lengths. Chironomids are among most common benthic invertebrates in riverine nursery habitats of the upper basin.

In Lake Mohave, Marsh and Langhorst (1988) reported a somewhat different diet for larvae < 21 mm TL. Larvae along a shoreline consumed primarily cladocerans, rotifers, or copepods; those in an adjacent backwater had a similar diet, but ate larval chironomids and trichopterans as well. When compared to hatchery larvae, wild specimens had a significantly greater frequency of empty guts, and guts with food contained significantly fewer organisms. Zooplankton densities are relatively low and variable in Lake Mohave, but primary productivity is high. Minckley et al. (1991) reported that nutritional levels appear to be high enough in most years to support the new year class, but Horn (1996) concluded that nutritional limitations in the reservoir may contribute to mortality of larvae directly through starvation or indirectly through reduced growth, which prolongs their susceptibility to predation. In a study of razorback sucker diet in Lake Mohave, Marsh (1987) found that the combination of planktonic crustaceans, rotifers, diatoms, detritus, and filamentous algae occurred in 44 percent of digestive tracts. *Bosmina* sp. was the most abundant item (100 percent of fish); followed by diatoms, primarily Fragillaria crotenensis (nearly 90 percent); and *Daphnia* sp. (72 percent). Rotifers, benthic ostracods, copepods, and chironomid dipteran larvae were found in 53 percent, 53 percent, 34 percent, and 3 percent of fish, respectively, but numbers were low, except for rotifers. Detrital organic matter and inorganic matter was found in 56 percent and 16 percent of digestive tracts, respectively.

Parasites
There is no evidence that disease is a significant factor in the decline and status of the razorback sucker. In a survey of pathogens recovered from endangered fishes in the Upper Colorado River Basin, Flagg (1982) reported the bacteria *Erysipelothrix rhysiopathiae*, the protozoan *Myxobolus* sp., and the parasitic copepod *Lernaea cyprinacea* in razorback sucker. The protozoan parasite *Myxobolus* can invade the eye tissue and eventually cause blindness, an ailment commonly reported in older specimens (Minckley 1983). Based on incidence of infection and condition of fish, Flagg (1982) concluded that parasitic infestation was not likely to be a contributing factor to mortality of native fish in the upper basin.

In the lower basin, *Lernaea* spp., the pathogenic protozoans *Myxobolus* and *Ichtyophthirius*, an internal monogenetic trematode of the suborder Polyopistocotyles, the cestode *Isoglaridacris bulbocirrus*, and nematodes of the genus *Dacnitoides* have all been reported from razorback sucker from Lake Mohave (Minckley 1983; Bozek et al. 1984). Mpoame (1981) reported a low rate of parasitism for the Lake Mohave razorback sucker. This contrasts with hatchery-reared razorback sucker recaptured after introduction into the Verde and Salt rivers, which exhibited extremely heavy infestations by *Lernaea*, particularly in summer and fall (Clarkson et al. 1993; Creef and Clarkson 1993; Hendrickson 1994). The heavily infected fish (several dozen parasites per individual) were pale and emaciated, and two of them exhibited partial loss of equilibrium (Hendrickson 1994). Hendrickson (1994) concluded that razorback sucker may be more susceptible to *Lernaea* infection than other species in the stocked areas, and that *Lernaea* and other exotic parasites may have been a factor in the decline of native fish in the lower basin. *Lernaea* was not present or was very rare in Arizona before the 1930's, but had increased significantly by the 1960's (James 1968). Researchers monitoring reintroduced razorback sucker in the Verde and Salt rivers continued to observe *Lernaea* infestation on this species in 1999; however, the incidence appears to have decreased from previously reported levels (personal communication, E. Jahrke, Arizona Game and Fish Department).

2.4.3 Kanab Ambersnail

Legal Status

The Kanab ambersnail, *Oxyloma haydeni kanabensis*, was listed as endangered in 1992 (FWS 1992) with a recovery plan completed in 1995 (FWS 1995). Fully mature snails are brown with an elongated first whorl and measure about 23 mm in shell size (Sorensen 2007). Kanab ambersnail are pulmonate or air-breathing mollusks, but are able to survive underwater for up to 32 hours in cold, highly oxygenated water (Pilsbry 1948). This adaptation may have allowed for dispersal of the species to new sites. Kanab ambersnail feeds on plant tissue, bacteria, fungi and algae. It scrapes this food off of plants by means of a radula or rasp tongue.

Historical and Current Range

Kanab ambersnail populations in the Southwest are believed to be relict populations from the late Pleistocene, when springs, seeps, and wetland habitat were more abundant (Spamer 1993; Szabo 1990). Historically, the region may have harbored many populations of ambersnails, but today the Kanab ambersnail occurs at only three springs: one at Three Lakes near Kanab, Utah; two in Grand Canyon National Park: one at Vaseys Paradise, a spring and hanging garden at the right bank at RM 31.8 and a translocated population at Upper Elves Chasm, at the left bank at RM 116.6 (Gloss et al. 2005). At Three Lakes near Kanab, two populations once existed, but one was extirpated by desiccation of its habitat. The remaining population at Three Lakes is located on private lands at several small spring-fed ponds dominated by cattail (Clarke 1991).

Through analysis of historic photographs, an increase in the vegetative cover along the river in Grand Canyon has occurred since the completion of Glen Canyon Dam in 1963 (Turner and Karpiscak 1980). The increase in cover, reduction in beach-scouring flows, and introduction of non-native water-cress, *Nasturtium officinale*, has lead to a >40 percent increase in suitable Kanab ambersnail habitat area at Vaseys Paradise from pre-dam conditions (Stevens et al 1997a).

Populations in the Action Area
Intensive searches at more than 150 springs and seeps in tributaries to the Colorado River between 1991 through 2000 found no additional Kanab ambersnail (Meretsky 2000; Meretsky and Wegner 1999; Sorensen and Kubly 1997, 1998; Webb and Fridell 2000). In September 1998, three springs along the Colorado River were stocked with young snails (AGFD 1998). Release sites were selected above the historic flood elevation (~100,000 cfs) and where populations would be unaffected by dam operations. One translocation site, Upper Elves Chasm, has established as a new population. Continued monitoring has detected numerous Kanab ambersnail persisting and reproducing at the initial release area, including migration into suitable adjacent habitat (Gloss et al. 2005).

Reproduction
Kanab ambersnail live approximately 12-15 months and are hermaphroditic and capable of self-fertilization (Clarke 1991; Pilsbry 1948). Mature Kanab ambersnail mate and reproduce May-August and deposit clear, gelatinous egg masses on undersides of moist to wet live stems, on the roots of watercress, and on dead stems of crimson monkey-flower (Nelson and Sorensen 2001; Stevens et al. 1997a). In warm winters, more than one reproductive period can occur. Adult mortality increases in late summer and autumn leaving the overwintering population dominated by subadults. Young snails enter dormancy in October-November and typically become active again in March-April. Over-winter mortality of Kanab ambersnail can range between 25 and 80 percent (KAIMG 1997; Stevens et al. 1997a). Populations fluctuate widely throughout the year due to variation in reproduction, survival, and recruitment (Stevens et al. 1997a). The number of ambersnails at Vaseys Paradise has remained stable since 1998 (Ralston 2005), although flows greater than 45,026 cfs (1275 cms) are thought to decrease the population by up to 17 percent in the short-term (Stevens et al. 1997a, 1998b).

Habitat
Vaseys Paradise is a small, spring-fed riparian area adjacent to the Colorado River at RM 31.8 (Stevens 1990). Ambersnails are found in the vegetation associated with this spring, which includes native crimson monkey-flower, *Mimulus cardinalis* Dougl. ex Benth., native water sedge, *Carex aquatilis* Wahlenb., and non-native water-cress, *Nasturtium officinale* L. Stevens et al. (1997a,b) found Kanab ambersnail at Vaseys Paradise predominantly use crimson monkeyflower and water-cress for food and shelter. They identified these two species as key habitat components for Kanab ambersnail. The other Grand Canyon habitat at Upper Elves Chasm is predominated by crimson monkeyflower and maidenhair fern, *Adiantum capillus-veneris*, with lesser amounts of sedges, *Carex aquatilis*, rushes, *Juncus* spp., cattails, water-cress, helleborine orchids, *Epipactis gigantean*, and grasses (Nelson 2001; Nelson and Sorensen 2002). From evidence collected under controlled laboratory conditions, microclimatic conditions such as higher humidity and lower air temperatures relative to the surrounding environments and high vegetative cover may be important habitat features related to Kanab ambersnail survival (Sorenson and Nelson 2002).

Threats
Current threats to Kanab ambersnail include loss and adverse modification of wetland habitats, which are scarce in this semi-arid region (FWS 1995). The Three Lakes population is at risk due to commercial development by the private landowner. Historically, the Grand Canyon often

experienced annual floods of 90,000 cfs (2,550 cms) or greater and Kanab ambersnail were likely swept downstream and drowned (Stevens et a. 1997a). Today, Glen Canyon Dam limits such floods, although numerous high flows (>45,000 cfs; 1,275 cms) have occurred in the last 30 years. For example, during the March 1996 high flow in the Grand Canyon, up to 16 percent of Kanab ambersnail habitat at Vaseys Paradise was lost or degraded and hundreds of snails were lost. Recovery of this habitat to pre-flood conditions required over two years (IKAMT 1998; Stevens et al. 1997b).

On a lesser scale, vegetation trampling and flash floods from the talus slope above Vaseys Paradise also contribute to habitat loss and direct Kanab ambersnail mortality. Due to steep slopes and a dense cover of poison ivy at this location, the impacts from river runners and hikers are reduced. Additionally, plateau-origin flash floods are rare in the region (Stevens et al. 1997a).

Parasites

Evidence exists that a small number of Kanab ambersnails at Vaseys Paradise were parasitized by a trematode, tentatively identified as *Leucochloridium* sp. (Stevens et al. 1997b). Potential vertebrate predators include rainbow trout in the stream mouth, Say's and black phoebe, *Savornis savi* and *S. niaricans*, canyon wren, *Catherpes mexicanus*, American dipper, *Cinclus mexicanus*, and canyon mice, *Peromyscus crinitus* (Stevens et al. 1997b; FWS 1995). Direct evidence of Kanab ambersnail consumption and predation rates by birds and mice are not available, but analysis of mice feces suggests that snails are not regularly eaten by rodents (Meretsky and Wegner 1999). Another natural threat is bighorn sheep, *Ovis canadensis*, which can consume water sedge, a source of forage for bighorn sheep, especially during droughts. With increased growth of water sedge, the springs at Vaseys Paradise are now habitually visited by bighorn sheep, resulting in vegetation used by the snails being regularly trampled and consumed (Gloss et al. 2005).

2.4.4 Southwestern Willow Flycatcher

Legal Status

The Southwestern willow flycatcher, *Empidonax traillii extimus,* (SWFL) was designated by the FWS (1995a) as endangered on February 27, 1995. A final recovery plan was completed in August 2002 (FWS 2002c). Critical habitat was initially designated in 1997 (62 FR 39129), but was rescinded by court order in 2001. Designation of critical habitat was finalized in October 2005 (FWS 2005b). The affected environment for this action does not include any critical habitat.

The SWFL is about 15 cm long, and weighs approximately 11 grams. It has a grayish-green back and wings, whitish throat, light grey-olive breast, and pale yellow belly. Two distinct wing bars are visible on the greater coverts, and an eye-ring is either absent or very faint. The upper mandible is dark, while the lower mandible is pale to yellowish (Phillips et al. 1964; FWS 2002c). Recognition of the different subspecies in the field is nearly impossible and is mainly based on differences in color and morphology using museum specimens (Paxton 2000; Unitt 1987). The SWFL may be distinguished from other *Empidonax* species by its primary song and its location on its breeding grounds only after spring migration is over (Sogge et al. 1997a,b).

Historic and Current Range

The historic breeding range of the SWFL included southern California, southern Nevada, southern Utah, Arizona, New Mexico, western Texas, southwestern Colorado, and extreme northwestern Mexico (Browning 1993; Paxton 2000; FWS 2002c; Unitt 1987). When the SWFL was listed as endangered in 1995, populations were estimated at 350 territories (FWS 2002c). Through increased surveys that number has increased to over 1,000 territories (Durst et al. 2005). Arizona Game and Fish documented 883 resident flycatchers at 483 territories in 47 sites in 2005 (English et al. 2006). Approximately 73 territories were documented in 2005 along the lower Colorado River and at sites in Nevada and the lower Grand Canyon (Koronkiewicz et al. 2006).

Another important component in the distribution of SWFL is its migration routes and migration stopover habitats. This neotropical migrant travels between breeding areas in the US to wintering grounds in Central and South America (FWS 2005b). Migration flyways include major rivers such as the Colorado (English et al. 2006; Koronkiewicz et al. 2006; Moore 2005; FWS 2005b; Yong and Finch 1997). Over 600 individual birds have been located during migration along the lower Colorado River near Yuma, Arizona (McLeod et al. 2005).

Wintering grounds for the SWFL are believed to include central America and northern South America. Surveys have been conducted in Costa Rica, Ecuador, El Salvador, Guatemala, Mexico, Nicaragua, and Panama (Koronkiewicz and Sogge 2000; Koronkiewicz and Whitfield 1999; Lynn and Whitfield 2002, Lynn et al. 2003; Nishida and Whitfield 2004). It is suspected that all subspecies may winter in similar locations, but because it is difficult to identify subspecies, specific areas where they winter are not well-known at this time.

In the Southwestern US, some 100 sites have been surveyed for SWFL including the Virgin River, Pahranagat National Wildlife Refuge, Grand Canyon, and the lower Colorado River from Lake Mead to Mexico. These surveys indicate the main breeding populations occur along the Virgin River from north of Mesquite, Nevada to the Virgin River delta with Lake Mead, at Pahranagat National Wildlife Refuge, at Topock Marsh near Needles, California, and on the Bill Williams National Wildlife Refuge, Arizona. Presence-absence surveys and life history studies of the SWFL have been conducted along the Colorado River since 1996 (Koronkiewicz et al. 2004, 2006a; McKernan and Braden 1997, 1998, 1999, 2001a, 2002, 2006a,b; McLeod 2005). These studies show the bird has consistently nested along the river in Grand Canyon from Separation Canyon to the delta of Lake Mead, as new riparian habitat, primarily tamarisk, has developed in response to regulated river flows (Gloss et al. 2005). The expansion of riparian vegetation in Grand Canyon may have provided additional habitat for the SWFL, but birds in the upper river corridor persist at a very low level at only one or two sites.

Populations in the Action Area

Southwestern willow flycatchers are not present around Lake Powell, but they have been documented along the Colorado River between RM 47 and RM 54, at RM 71, and at RM 259 (Sogge et. al. 1995; Tibbets and Johnson 1999, 2000; Unitt 1987). Population numbers have fluctuated between five breeding pairs and three territorial, but non-breeding pairs in 1995, to one single breeding pair more recently. The year 2004 marked the sixth consecutive year in which surveys located a single breeding pair at the upper sites, the lowest population level since surveys began in 1982. Given these low numbers, the continued presence of the SWWF in Grand Canyon appears tenuous.

The SWWF has been detected within lower Grand Canyon-upper Lake Mead since surveys began in 1997 with breeding flycatchers detected in 1999–2001, but not in 2002 or 2003. A single breeding pair was detected in 2004 and an unpaired male occupied this same area in 2005 (Koronkiewicz et al. 2006a). Two nests were detected during the 2006 breeding season (Koronkiewicz et al. 2006a). Due to extreme drops in water levels that started in 2000, much of the occupied habitat of the 1990s is now dead or dying. More recently, new stands of vegetation have been developing in areas exposed by receding water and this vegetation is now developing into suitable flycatcher habitat.

Reproduction

The SWFL breeds across the lower Southwest from May through August. SWFL typically arrive on breeding grounds between early May and early June. Males generally arrive first to set up territories, with females arriving a week or two later. Males are highly territorial and will defend their territory through counter singing and aggressive interaction. Flycatchers often clump together in one area of the habitat patch, which leads to an indication that this species is semi-colonial. Males are usually monogamous, but polygyny occurs at approximately 10-20 percent (Pearson 2002; FWS 2002c). Genetic evidence suggests extra-pair copulation exists by either mated or unmated males with females in neighboring territories (FWS 2002).

Dense riparian vegetation near surface water or saturated soil, across a large elevational and geographic area is the dominant habitat for breeding SWFLs (FWS 2002c; Sogge et al. 1997a). Dominant plant species consist of large riparian trees such as Coyote willow (*Salix exigua*), Goodding willow (*Salix gooddingii*), Fremont cottonwood (*Populus fremontii)*, boxelder (*Acer negundo)*, tamarisk, and Russian olive (*Elaeagnus angustifolia)* (FWS 2002c).

Occupied sites vary in size and shape but all have dense vegetation with some open areas, and are usually associated with open or standing water. Occupied patches can be as small as two acres and as large as several hundred acres, but are typically greater than 10 m wide. Although most of the sites are associated with open water, marshy seeps, or saturated soil where the nest tree can be in standing water, hydrologic conditions can change drastically during the breeding season and between years (Koronkiewicz et al. 2006a; FWS 2002c; Sogge et al. 1997a; Sogge and Marshall 2000). Because birds are exposed to extreme environmental conditions throughout the desert southwest, dense vegetation and moist soils at the nest may be needed to provide a more suitable microclimate for raising young by increasing humidity within the site (Allison et al. 2003; Koronkiewicz et al. 2006a; Sogge and Marshall 2000).

Vegetation analysis for occupied SWFL sites suggests that flycatchers breed in a wide variety of habitats throughout the region (Koronkiewicz et al. 2006a; McKernan and Braden 2002). These areas contain relatively homogenous, contiguous stands of riparian vegetation that differ from each other both structurally and compositionally. Preliminary nest productivity, as related to vegetation type (e.g., non-native versus native), shows no significant difference (McKernan and Braden 2002), but further analysis is planned.

Nest building usually begins three to seven days after pair formulation. The SWFL build open cup nests that are approximately 7 cm high and wide with dangling material below. Nests are typically placed within the fork of branches with the nest cup supported by several stems. Nest height varies and can be anywhere from ground height to several meters high, depending on height of nest tree. Typical nest height is around 2-7 m. (Sogge et al. 1997a). Flycatchers nest in various tree species including Goodding's willow, coyote willow, cottonwood, tamarisk, boxelder, and other native and non-native tree species. Along the lower Colorado River, main nest substrates include Goodding's willow (20-30 percent), coyote willow (5-15 percent), Fremont cottonwood (5 percent), and tamarisk (50 percent-70 percent). In some areas, such as Topock Marsh, nearly 100 percent of the nests are in tamarisk (Koronkiewicz et al. 2004, 2006a; McKernan and Braden 2001; McLeod et al. 2005). On average, one egg is laid per day, with a typical clutch size of four eggs laid within five days. Egg laying can start as early as late May, but is usually in early to mid-June (Sogge et al. 1997a, b). Upon completion of egg laying, the female usually incubates the eggs for approximately 12 days, and all eggs usually hatch within 24-48 hours of one another. Nestlings fledge usually within 12-15 days (Paxton and Owen 2002). Chicks are usually present from mid-June through early August. The SWFL will re-nest, either after the first nest fledges or after failure, and have been documented to have up to four nesting attempts and three clutches (Koronkiewicz et al. 2006a; McKernan and Braden 2001b; Sferra et al. 1997,). Adults depart from breeding territories as early as mid-August, but may stay until mid-September if nesting was late. Fledglings usually leave the breeding areas a week or two after adults (Sogge et al. 1997a).

Nest success averaged from 40-50 percent through all years of study along the lower Colorado River (Koronkiewicz et al. 2004, 2006a; McKernan and Braden 1997, 1998, 1999, 2001, 2002, 2006; McLeod 2005) and approximately 25-70 percent over the complete range of the SWFL (FWS 2002b,c). Predation was the leading cause of nest failure at many study sites throughout the range (FWS 2002b,c, McKernan and Braden 2001b and 2002, Koronkiewicz et al. 2004, 2006a, McLeod 2005). Predation has averaged 33-65 percent along the lower Colorado River from 1996 through 2005 (Koronkiewicz et al. 2004, 2006a; McKernan and Braden 2001, 2006; McLeod 2005). For Arizona statewide surveys in 2005, approximately 77 percent of failed nests were due to depredation (English et al. 2006). Although these numbers are within the typical range for open-cup nesting passerine birds (FWS 2002c), this amount of predation increases the stress on a species already endangered.

Habitat

At most sites along the Colorado River and tributaries, occupied habitats usually have high canopy closure with no distinct understory, overstory, or structural layers (Koronkiewicz et al. 2006a). High vegetation volume may be more important than specific tree species type or habitat structure. High vegetation volume and high foliage density at nest sites and within breeding patches has been reported in other willow flycatcher breeding areas (Allison et al. 2003; Paradzick 2005; Sedgwick and Knopf 1992; Sogge and Marshall 2000; Stoleson and Finch 2003). This factor, along with the presence of water, was consistent throughout the range.

The presence of water is an important component of SWFL habitat (FWS 2002c; Sogge and Marshall 2000). Studies indicate that SWFL nest sites are usually closer to water than non-use sites (Koronkiewicz et al. 2006a; Paradzick 2005; Stoleson and Finch 2003). Nest sites are usually located within 200 m of open or standing water and usually contain soils that are higher in water content than non-use sites (Koronkiewicz et al. 2006a; McKernan and Braden 2002; Paradzick 2005; Stoleson and Finch 2003). Water or moist soils help regulate temperature and relative humidity within the stand, produce the right conditions for insect development and survival, and are associated with creating a greater foliage density (Koronkiewicz et al. 2006a; Paradzick 2005; FWS 2002c).

Diet

The SWFL is an insectivore that hawks insects while in flight, gleans insects from foliage, and occasionally captures them from the ground (FWS 2002c). Flycatchers forage from within the habitat or above the canopy, above water, or glean from trees and herbaceous cover (McCabe 1991; FWS 2002c; Sogge 2000,). The main diet of the flycatcher consists of small to medium size insects such as true bugs, Hemiptera, wasps and bees, Hymenoptera, flies, Diptera, beetles, Coleoptera, butterflies and caterpillars, Lepidoptera, and spiders, Araneae (DeLay et al. 2002; Drost et al. 1998, 2001; Durst 2004; McCabe 1991; Sogge 2000). Berries and small fruits have also been reported but are typically rare (McCabe 1991). The flycatcher can exploit a diverse array of insects depending on availability within the habitat (DeLay et al. 2002; Drost et al. 1998, 2001, 2003; Durst 2004). Diet may differ between sites and between years depending on abundance and availability of insects in and near the breeding habitat (DeLay et al. 2002; Drost et al. 2003; Durst 2004). Although there were differences in prey types consumed by the flycatcher among different habitats (e.g., native versus non-native), there was no significant differences in the abundance of insects available between habitats (Durst 2004) and there was no evidence that physiological condition of flycatchers was lower in saltcedar habitats (Owen et al. 2002).

Threats and Parasites

Habitat alteration, as well as loss and fragmentation are considered one of the greatest threats to the SWFL (Marshall and Stoleson 2000). Riparian habitats in the Southwest are naturally patchy and subject to periodic disturbance. Factors contributing to habitat loss include water management, such as dams and reservoirs, diversions and groundwater pumping, channelization and bank stabilization, agricultural development, livestock grazing, phreatophyte control, increased recreation, and urbanization. All of these cause loss of habitat, habitat fragmentation, loss of water underneath stands, and human disturbance (Marshall and Stoleson 2000).

Although the SWFL now nests in tamarisk, this has some disadvantages. Tamarisk exudes salts and creates soils that are too salty for other native species to propagate, thus reducing diversity in the stand which may affect prey base for flycatchers. Tamarisk also is much more adapted to disturbance (floods, fire) and reestablishes more readily than native species, thus changing the composition of the stand, and increasing the chance of greater habitat loss and degradation. Deep root systems and extended production and proliferation of seeds from March through October gives tamarisk selective advantage over natives under stressed conditions and may reduce soil moisture and standing water conditions needed for flycatcher habitat (Marshall and Stoleson 2000).

Parasitism by brown-headed cowbirds is another cause of nest failure. Cowbird parasitism may impact some SWFL populations enough to warrant management actions. The cowbird lays it eggs in the nest of the host species, and the host then incubates the cowbird eggs, which typically hatch prior to the hosts own young. Parasitism rates have ranged from 0-75 percent in some areas, with the average parasitism rate in 2005 at 32 percent for all sites (Koronkiewicz et al. 2006a). The Arizona statewide average for 2005 was 7 percent (English et al. 2006).

The SWFL has evolved with predation and cowbird parasitism, but increased populations of predators and cowbirds has become a major threat to some local populations. Predation is the leading cause of nest failure in many populations of SWFL (Marshall and Stoleson 2000; FWS 2002c), including those along the Colorado River and its tributaries (Koronkiewicz et al. 2006a; McKernan and Braden 2002). Known and suspected nest predators include snakes, predatory birds such as raptors, corvids, grackles and cowbirds, small mammals, and even ants (Marshall and Stoleson 2000). Cowbird populations have expanded greatly with the expansion of livestock grazing, agriculture, and deforestation (Marshall and Stoleson 2000; Siegle and Ahlers 2004).

Little is known of diseases and parasites within the SWFL population. McCabe (1991) reported a mite infestation in several willow flycatcher nests in Maryland, subsequently identified as *Ornithonyssus sylviarum*, the northern fowl mite. The SWFL is also known to host blood parasites such as Hemoproteus, Leucocytozoon, Microfilaria, Tyrpanosoma, and Plasmodium (FWS 2002c). Other parasites identified include blow fly, *Protocalliphora* sp., and nasal mites (FWS 2002c). It is unknown what effects these parasites have on the SWFL, but McCabe (1991) noted no significant effects from the mite infestations.

3 Sufficient Progress and New Information

3.1 Actions Taken in Response to the 1995 Biological Opinion

The RPA of the 1995 biological opinion included the following elements, which are followed in turn by a discussion of actions taken by Reclamation to date in response to the biological opinion:

3.1.1 Element 1: Development of an Adaptive Management Program

Progress to date

A common element of the 1995 EIS and a central theme of the 1995 biological opinion was an adaptive management program. The AMP was developed and implemented under the Federal Advisory Committee Act in 1997. The AMP retains the same organizational structure as presented in the fourth sufficient progress communication. The AMP Charter was renewed in 2006. New and continuing representatives to the Adaptive Management Work Group (AMWG) were confirmed by the Secretary of the Interior during 2004–2007; the Federation of Fly Fishers replaced Trout Unlimited and Grand Canyon Wildlands Council replaced Southwest Rivers.

A number of ad hoc committees have been formed under the AMP that address specific issues regarding dam operations and conservation of humpback chub. In response to a discovery that the endangered humpback chub population in Grand Canyon was in decline, the AMWG directed in January 2003 that an ad hoc committee be formed with the responsibility of developing a comprehensive plan for future research, monitoring, and management of the endangered fish. In August 2003, the HBC Ad Hoc Committee delivered the plan to the Science

Advisors (GCDAMP Science Advisors 2003) and then to AMWG (Humpback Chub Ad Hoc Committee 2003), and the plan was used to fund projects in the 2004 and 2005 fiscal years. The plan is presently being revised by the HBC Ad Hoc Committee and will be resubmitted to AMWG after projects are assessed by an AMWG ad hoc committee to determine which of them would be recommended for inclusion in the AMP.

The adaptive management program necessitated integration of scientific information into an ecosystem-based science program. This need was partially fulfilled through development of a conceptual model of the Colorado River ecosystem in the Grand Canyon region (Walters et al. 2000). During 2003 the TWG used knowledge gained from the conceptual model to evaluate a program of potential future experimental actions through a multi-attribute tradeoff analysis (Failing et al. 2003). A complimentary exercise has been the development of the AMP Strategic Plan, which was adopted by the AMWG and is available at http://www.usbr.gov/uc/envprog/amp/ strategic_plan.html.

Other aspects of the adaptive management planning process for humpback chub include development of a Strategic Science Plan, Core Monitoring Plan, several Beach Habitat Building Science Plans, a study plan for the 2000 Low Steady Summer Flows (Fritzinger et al. 2000) and Non-native Fish Mechanical Removal protocols (Coggins et al. 2002). Many of these efforts are presently ongoing.

In May and July of 2005, workshops to assess the knowledge gained through the AMP were conducted in Phoenix and Flagstaff, AZ, respectively (Melis et al. 2005). At the workshops all aspects of the Program were evaluated and assessed for the level of science and knowledge that had been gained to date. The workshops and resulting publication also helped to define and refine research questions and to prioritize research projects in the future.

Results of science investigations conducted under the auspices of the AMP were presented at a science symposium on October 25–27, 2005 , (Gloss et al. 2005), see also [online] http://www.gcmrc.gov/library/reports/synthesis/score2005.pdf. This publication is the second synthesis of research and monitoring in the Colorado River ecosystem and covers the years 1991-2004, though results regarding particular areas of investigation varied from resource to resource. For example, information for the endangered humpback chub was only referenced through 2001.

The FWS is a key stakeholder within the existing AMP and the FWS has previously concurred with Reclamation that sufficient progress has been made in the implementation of the AMP. Reclamation notes that the AMP currently retains the same organizational structure as presented in the fourth sufficient progress communication.

3.1.2 Element 1A: Program of Experimental Flows

Progress to date

This element was intended to continue research through the AMP to identify the effects of Glen Canyon Dam release patterns on listed species, and was "…to include high steady flows in the spring and low steady summer flows in summer and fall during [8.23 MAF] years…studies of high steady flows in the spring may include studies of habitat building and habitat maintenance flows..." Following the 1995 biological opinion and the 1996 ROD, Reclamation helped the AMP to coordinate a series of experimental flows on Glen Canyon Dam. The first large experiment was a week-long, 45,000 cfs beach habitat-building flow that occurred in March-April 1996. Objectives were to rebuild high-elevation sandbars, restore backwater channels, retain fine silts and clays, restore the pre-dam disturbance regime, preserve and restore camping beaches, displace non-native fishes, scour vegetation from camping beaches, and protect cultural resources, all without significant adverse impacts to endangered species, cultural resources, the Lees Ferry trout fishery, or hydropower production. Results of the 1996 experimental flood were documented by Webb et al. (1999).

In 1997 a fall flow test consisting of a powerplant release of 31,000 cfs for 48 hours was conducted. This action received its own consultation, however it is also consistent with RPA element 1A. While powerplant capacity releases were described in the 1995 EIS as Habitat Maintenance Flows, such a test in the fall was not addressed in the 1995 FEIS, which necessitated additional ESA consultation.

The steady flow requirement identified by the FWS was evaluated in the year 2000. In 1999 Reclamation funded a contractor to convene a panel of experts to develop a program of experimental flows for endangered and native fishes of the Colorado River in Grand Canyon (Valdez et al. 2000). As part of this program, the third large experiment conducted by the AMP was an experimental flow for native fishes from March-September 2000. Flow components included: (1) short-term 8,000 cfs initiating the study for aerial photography; (2) stable, spring flows of 14,000-19,000 cfs to measure hydraulics and water temperatures at the mouth of the Little Colorado River; (3) spring and autumn powerplant capacity spike flows; (4) an extended period of 8,000 cfs during May, June, July, and August; and (5) a period of 8,000 cfs steady flows following the autumn spike flow to measure its effects and to conduct a second round of aerial photography. In October 2003 GCMRC convened a science symposium that was largely directed at presentation of results from the low summer steady flows (LSSF) research and monitoring. Effects of the experiment on fish populations were documented by Trammell et al. (2002), Rogers et al. (2003) and Speas et al. (2004b; see Section 3.2.6).

In January 2002 the AMWG directed the Grand Canyon Monitoring and Research Center (GCMRC), in consultation with the Technical Work Group (TWG), to design an experiment to test how dam operations might be modified and other management actions taken to better conserve sediment and to benefit native fish. On March 25, 2002, the GCMRC provided a draft proposal for the requested experimental flows and management actions that formed the basis of the September 2002 Environmental Assessment on Proposed Experimental Releases from Glen Canyon Dam and Removal of Non-Native Fish (Reclamation, NPS and USGS 2002).

Mechanical removal of non-native fish from the Colorado River above and below the LCR was started in January 2003 (Coggins and others 2002, Coggins and Yard 2003) and was continued through 2006. Rainbow trout and brown trout were removed from a 10-mile reach adjacent to the LCR. Non-native suppression releases from Glen Canyon Dam were implemented from January to March 2003 to test the effectiveness of high fluctuating flows on limiting the recruitment of non-native fish (Davis and Batham 2003, Korman et al. 2003). The high fluctuating flows for non-native suppression were continued in 2004 and 2005.

In November 2004 a second high flow experiment was conducted. The duration of this release was reduced to 60 hours on peak and the magnitude was reduced to 41,500 cfs due to repairs being made on one of the dam turbines. Another important difference with the 1996 high flow experiment was that the 2004 release occurred only after sediment input triggers, based largely on antecedent input from the Paria River, had been met. The trigger required that at least 1 million metric tons of fine sediment had been received by the Colorado River prior to the high release.

In September and October of 2005, a series of two-week dam releases occurred that alternated between steady and fluctuating releases. The purpose of this short-term experiment was to examine the effects of daily fluctuations on water quality parameters and biotic constituents (phytoplankton, macroinvertebrates, and fishes) of associated shoreline habitats (Ralston et al. 2007).

In 2006, Reclamation initiated development of a long-term experimental plan which was proposed to include both dam releases and other management actions. This effort originated with a science planning group that produced four options which were recommended by the AMWG to the Secretary of the Interior. GCMRC provided an assessment of the effects of the four options (GCMRC 2006). Reclamation conducted public scoping meetings in December 2006 and January 2007 and identified the purpose and need for the Proposed Action as improving the understanding of the Colorado River ecosystem below Glen Canyon Dam and protection of key resources (humpback chub, sediment, and cultural resources). In April 2007, GCMRC convened a science workshop to evaluate the four options for their use in development of EIS alternatives. Workshop participants also developed a fifth alternative for consideration by Reclamation and its cooperating agencies.

In summary, Reclamation has, through the adaptive management program, conducted a series of experiments that featured varied dam operations in conjunction with non-flow actions (e.g., non-native fish removal, translocation of humpback chub and Kanab ambersnail). These experiments were conducted in an effort to improve the status of the humpback chub and increase our understanding of the relationship between dam releases, sediment conservation and humpback chub population dynamics. Reclamation believes that implementation of these experiments through adaptive management is in concert with the directive to develop a program of experimental flows and has contributed substantially to the new information presented in this biological assessment.

3.1.3 Element 1B: Feasibility Analysis of a Selective Withdrawal Program for Glen Canyon Dam

Progress to date

In January 1999, Reclamation released a draft environmental assessment on a temperature control device (TCD) for Glen Canyon Dam. Such a device is also referred to as a selective withdrawal structure as its utility extends to other water quality issues as well as temperature control. The preferred alterative was a single inlet, fixed elevation design with an estimated cost of $15,000,000. Sufficient concern was evidenced in the review of the environmental assessment (Mueller et al. 1999) for unintended negative effects (i.e., non-native fish proliferation) as a result of the operation of a TCD, as well as the lack of a detailed science plan to measure those effects, that the environmental assessment was withdrawn and not finalized. In 1999 and in 2001, Reclamation convened workshops at Saguaro Lake, AZ of scientists to evaluate the feasibility of a temperature control device and to further develop research and monitoring for evaluating ecosystem responses to warmer temperatures. One outcome of the 1999 workshop was the discovery that native fish data had not been brought together and analyzed. Opinions of native fish biologists on the status of endangered humpback chub differed sufficiently to make obvious the need for the analysis.

During development of the Interim Surplus Criteria EIS in 2000, Reclamation discovered that projections for utilization of the preferred alternative design for the temperature control device, previously estimated at 85 out of 100 years, were considerably overestimated and were closer to 45-50 percent of those years. This discovery prompted re-evaluation of the engineering designs for the temperature control device.

Another milestone in the feasibility assessment was a survey of operators of dams having selective withdrawal devices, including TCDs, to determine whether concerns evidenced by scientists and managers for effects of the Glen Canyon Dam TCD have been experienced at other facilities. Results of this survey and other related investigations were presented to the AMWG at their July 2002 meeting and were subsequently published in Vermeyen (2003). No major environmental complications were identified in the survey results; however, there was little dedicated evaluation of the biological efficacy of the TCDs from which to draw conclusions.

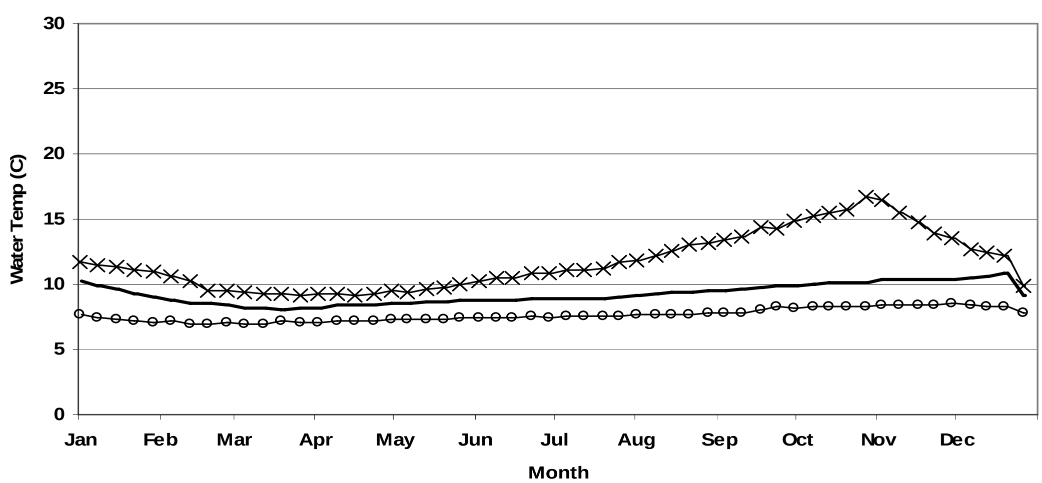
In summer 2002, the AMWG recommended that Reclamation should solicit a risk assessment of the Glen Canyon Dam TCD proposal from the AMP Science Advisors. Subsequently, the Advisors produced a report on their findings of risk assessment (Garrett and others 2003) which recommended the installation of a TCD for Glen Canyon Dam as soon as possible and the construction of a pilot TCD in the interim. The Science Advisors further recommended a strong leadership role from AMWG, TWG, and GCMRC related to the installation and operation of a TCD along with a commitment from all parties to incorporating the TCD into the AMP and the research required to evaluate the TCDs effects. At the August 13–14, 2003 meeting, the AMWG recommended to the Secretary of the Interior that Reclamation should initiate environmental compliance associated with the construction of a TCD. Reclamation initiated a feasibility-level construction design assessment for the TCD in spring of 2006, which was completed in November 2007.

Reclamation has continued to work on the feasibility assessment since the decision was made to rescind the draft environmental assessment on the proposed TCD released in January 1999 (Reclamation 1999). In our 2004 sufficient progress letter, Reclamation indicated to FWS that following the results of scientific investigations, expert workshops, a risk assessment by the AMP Science Advisors, and a recommendation by AMWG, it was justified to proceed with environmental compliance on a selective withdrawal device for Glen Canyon Dam. In 2005 Reclamation initiated development of a new environmental assessment to provide NEPA compliance on a 2-unit selective withdrawal. This effort was discontinued when the decision was made to include compliance for a TCD within the Long-Term Experimental Plan EIS.
Several designs were considered for the selective withdrawal, including uncontrolled and controlled overdraw and internal and external frame devices. Based on projections for lower future reservoir levels arising from modeling in the Interim Surplus Criteria EIS and an extended

drought beginning in 1999, Reclamation chose an external frame design that would allow release of warmer water over a wide range of reservoir elevations from 3700 feet (full reservoir) down to 3520 feet elevation, 30 feet above the level of the penstocks (3490 feet elevation). The range of operation increased to 180 feet or 6 times that of the design proposed in 1999. Each of the two selective withdrawal devices would be 48 feet wide (cross canyon direction), 50 feet deep (stream direction) and 280 feet high. The external frame selective withdrawal devices would contain three sliding gates that would control the level of water withdrawal from the reservoir. They would be mounted to the upstream face of the dam by rigid frames attached near the top of the dam and guide girders connected to the dam along each side of the trashracks. The two generating units designed for placement of selective withdrawal are numbers 4 and 6, which lie near the center of the dam.

To evaluate the effectiveness and capability of this TCD design, Reclamation used the U.S. Army Corps of Engineers' CE-QUAL-W2 model (Cole and Wells 2000) to model Glen Canyon Dam release temperatures, the 1-D Generalized Environmental Modeling System for Surface waters model (GEMSS; Kolluru and Fichera 2003) to model flow temperatures from Glen Canyon Dam to Separation Canyon, and the 3-D GEMSS model to model backwaters below the confluence of the LCR. These models were calibrated for water temperature using temperature data at fixed stations in the reservoir and river.

Historic water temperature data during the period of 1990 to 2005 were used to calibrate and model dam release temperatures, with historic dam release temperatures varying from 8 °C to 16 °C. Graphical results of the historic data are displayed in Figure 6. The temperature of water released from Lake Powell (Figure 6 top) tended to approach ambient water temperature as it traveled downstream to Lake Mead. The rate at which the water increased in temperature depended on release temperature, flow magnitude, and atmospheric conditions. Water temperatures below the confluence of the Little Colorado River varied from 7 °C to 17 °C (Figure 6 middle) and were between 4 °C and 25 °C at the inflow to Lake Mead (Figure 6 lower) during this period of record.



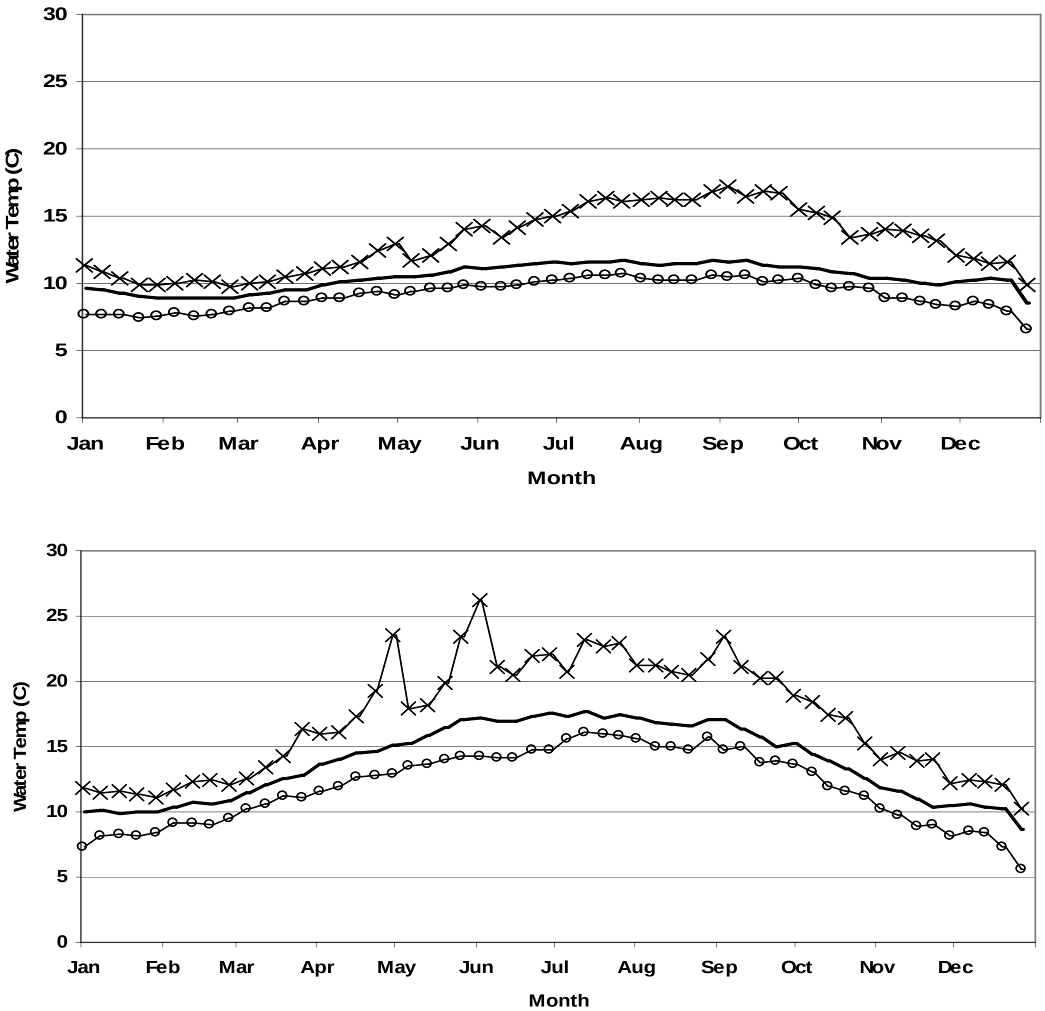


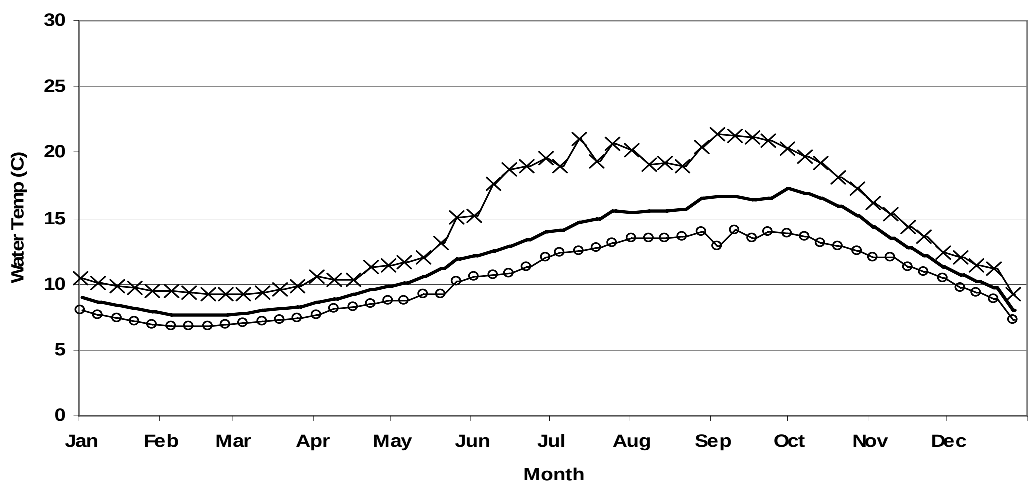
Figure 6. Upper, median, and lower bounds of 7-day moving average temperatures for Glen Canyon Dam releases (top), LCR confluence (middle), and Separation Canyon (lower) sites.

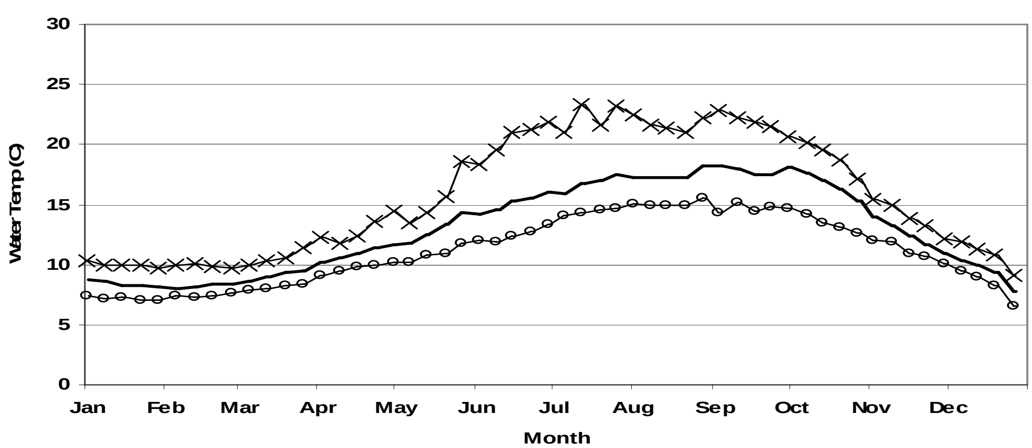
A 2-unit external frame TCD would allow releases to be selected at any elevation within the water column between 3,700-3,520 feet (Reclamation 2005). A maximum of 4,000 cfs could be released from each penstock fitted with a TCD, therefore releases above 8,000 cfs would require blending of water with releases from the remaining penstocks. When reservoir elevations dropped below 3,520 feet, releases would return to the current penstock intakes under the proposed TCD design. Below 3,490 feet elevation releases would have to be made from the hollow jet tubes, also known as the river outlet works. All TCD releases would be constrained using a 30-foot submergence criteria for the intake to avoid surface vortex formation (Reclamation 2005).

Using the period of record from 1990 to 2005 to model the effects of the two-unit TCD, CE-QUAL-W2 modeling predicted Glen Canyon dam release water temperatures would vary from 7 °C to 21 °C (Figure 7 top). Using the output from the CE-QUAL-W2 modeling, water temperatures were routed downstream using the GEMSS model. Water temperatures at the Little

Colorado River varied from 7 °C to 23 °C (Figure 7 middle) and 4 °C to 28 °C at the inflow to Lake Mead (Figure 7 lower) using a two-unit TCD. The analysis showed an average increase in release temperature of about 3 °C with installation of a 2-unit TCD. A better idea of the differences can be gained by assessing the variation among months (Figure 8). Considering the differences in median temperatures with and without a 2-unit TCD, positive deviations with the 2-unit TCD begin in late April, peak in late summer to early autumn at about 7° C, and remain positive until the end of November. The relationship between release temperature and downstream temperature is nonlinear and is limited by the ambient atmospheric conditions. During colder months release temperatures would cool as dam release waters moved downstream.

Releasing water from higher in the water column of a reservoir will reduce the heat budget within that body of water. Modeling impacts of a two-unit TCD showed an average temperature decrease of 2 °C for Lake Powell both at the surface and at a depth of 50 feet.





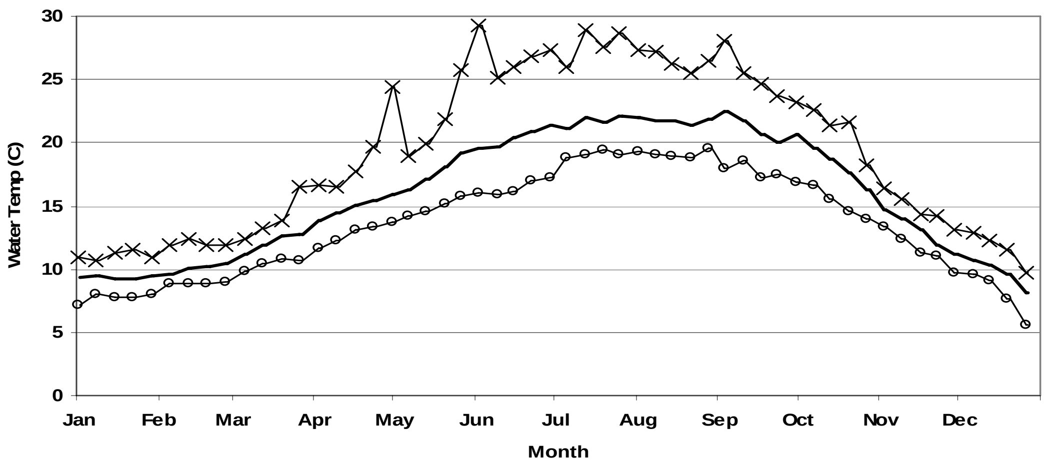


Figure 7. Upper, median, and lower bounds of 7-day moving average temperatures for Glen Canyon Dam releases (top), LCR confluence (middle), and Separation Canyon (lower) sites with a 2-unit TCD.

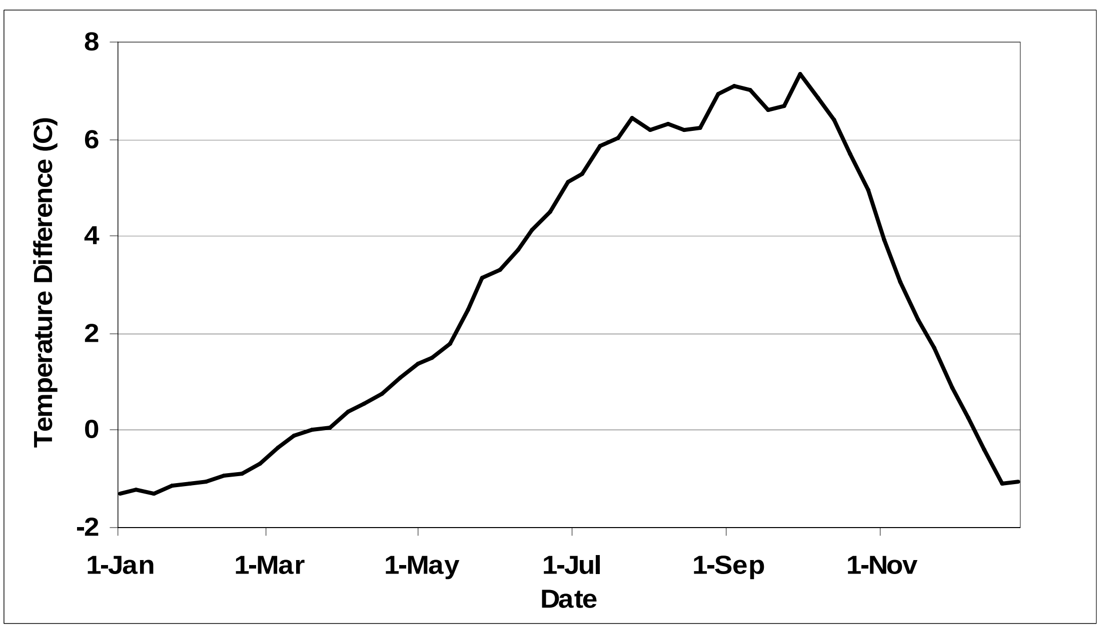


Figure 8. Absolute differences (ºC) in median release temperatures with a 2-unit TCD at Glen Canyon Dam over the course of an annual cycle.

Reclamation also completed a risk assessment to help evaluate responses of aquatic resources in Grand Canyon to the construction and implementation of a TCD (Valdez and Speas 2007). The risk assessment utilized standard EPA protocols (CENR 1999; NRC 1983; RAM 1998; USEPA 2000, 2005, 2006). A mathematical model was used as a tool to quantify risks and benefits to fish, fish parasites, zooplankton, and macroinvertebrates from water temperature changes resulting from modification of 2 of the 8 generation units on the dam. All taxa present or with known potential to access the area were inventoried for each of six regions, including lower Lake

Powell, Glen Canyon Dam to Paria River, Paria River to LCR, LCR to Bridge Canyon, and Bridge Canyon to Pearce Ferry.

The median, minimum, and maximum temperature results from the GEMSS modeling were used in this risk assessment evaluation, assuming both with and without a 2-unit TCD. Temperature degree days were computed for spawning, incubation, and growth for fish and life history requirements for other taxa and compared with the predicted water temperatures to determine if the temperature change would benefit particular taxa. Risk assessment scores were computed based on degree day accumulation and then calibrated for fish by comparing modeled fish composition with composition from four prior surveys reflecting a range of thermal regimes from the pre-dam era through recent years.

Results suggested benefits to all native fishes, but correspondingly higher benefits to many non-native fish species that may compete with or prey upon native species. Fish species carrying the highest risk for benefiting from warmer water were rainbow trout, brown trout, common carp, fathead minnow, red shiner, channel catfish, and smallmouth bass. Preliminary results also show more suitable conditions for warm-water fish parasites, including *Lernea* and Asian fish tapeworm *Bothriocephalus acheilognathi.*

Results also predicted an increase in periphyton biomass and diversity with warmer water, which could lead to increased food and/or substrate for epiphytes, aquatic invertebrates, fish, and waterfowl. Warm water impacts to macroinvertebrates include minor shifts in relative abundance of existing taxa with the possibility of increased taxa richness, which could be beneficial if limited to insect taxa. However, increased potential for invasion by crayfish and other nuisance species is significant.

In light of these concerns and with the recommendation of an independent scientist panel convened in April 2007 to discuss long-term experimental planning, Reclamation also briefly investigated whether construction of a TCD with both warm and cold water release capability is possible and under what circumstances cold water would be available for release. Due to the high cost of design investigation, no specific design work or feasibility analysis was completed on this option, pending a decision by FWS on whether to proceed with construction of a TCD as designed.

For the warm and cold water TCD to be viable, sufficient cold water must be available lower in Lake Powell when dam releases naturally warm due to drought induced draw down. CE-QUAL-W2 modeling was used to determine the reservoir elevation at which cold release temperatures persist when the river outlet works are operated. Model results indicate that at elevation 3530 feet, which is 10 feet above the lower cutoff elevation for TCD operation, release water temperatures from the level of the river outlet works (elevation 3370 feet) are colder, with July temperatures of 9 °C, September temperatures of 12.5 °C, and November temperatures of 16 °C. When the reservoir is at or above elevation 3530 feet sustained release of cold or cool water may be possible.

There is a slight probability (<0.5 percent) of Lake Powell elevation dropping below 3490 feet when the external frame TCD, as presently designed, would no longer be operable. Below this elevation water would be released through the river outlet works. Lake Powell’s capacity at this elevation is approximately 2.5 maf. Based on modeling with CE-QUAL-W2, dam release temperatures from the river outlet works below elevation 3490 would be about 13 °C in July, 20 °C in August, and 23 °C in September. The water temperature of Lake Powell would quickly increase in the spring and summer at this elevation as a result of the small reservoir capacity, directly affecting dam release temperatures.

The external frame design described above has undergone a full engineering and budget review by Reclamation's Denver Technical Services Center. The review has included a Value Engineering Study (June 2006), a Design, Engineering, and Cost Estimating Review (July 2006) and a Constructability Review (August 2006). The review process passed the 60 Percent Design Decision point in January 2007 and the final design specifications and drawings were completed in November 2007. Estimated cost (construction and non-construction) for installing a 2-unit warm water TCD was approximately $100 million in 2009 dollars.

If the decision is made to proceed, testing of the selective withdrawal would occur under the auspices of the AMP using a science plan developed by GCMRC, cooperating scientists, and the Technical Work Group. This would be accomplished by modifying two penstocks on Glen Canyon Dam and operating the dam for a minimum period of 3-4 years with assessment through the AMP before a subsequent decision is made on any potential further modification. Testing would be the next phase in the feasibility assessment called for by the FWS. Although many potential positive and negative effects of a TCD on endangered fish and other Colorado River resources have been postulated during investigations conducted to date, few of these projected outcomes can be known with certainty without specific testing through a research and monitoring program.

Reclamation engineers and managers now believe that a TCD designed to allow warmer water to be released downstream is technically feasible. With this consultation, Reclamation is reporting to the FWS that a TCD is technically feasible, but Reclamation is seeking the biological opinion of the FWS whether the risks of warming the water by modifying the dam's penstocks (as identified above regarding potential parasites and warm-water non-native enhancement) are worthwhile given the current status of listed species and their habitat below the dam. The question for the FWS is whether the potential benefits to the endangered fish of operating a TCD and warming the water outweigh the potential adverse effects from potential increases in non-native predators, parasites and diseases, or other unintended, systemic interactions in the downstream environment.

3.1.4 Element 1C: Determination of Native Fish Responses to Various Temperature and Flow Conditions

Progress to date

Various studies have addressed fish response to different temperature and flow conditions that are applicable to the Colorado River in Glen and Grand canyons. Ward et al. (2002) evaluated the effects of temperature, fish length, and exercise on swimming performance of age-0 flannelmouth sucker, and Ward and Bonar (2003) examined the effects of cold water on susceptibility of age-0 flannelmouth sucker to predation by rainbow trout. Vernieu (2003) evaluated warming of mainstem and nearshore habitats during the low steady flows of summer 2000. Rogers et al. (2003b) measured drift and benthic biomass under the low steady flows and powerplant-capacity spike flows in the steady flow experiment. Trammell et al. (2003) investigated responses of native fishes to the same low steady and spike flows. A report on the mechanical removal of non-natives coincident to warmer releases from Glen Canyon Dam in 2004-2005 was submitted by Coggins (2007). Rogers et al. (2003a) examined non-native salmonid distribution and abundance from RM 12 to 218. Johnstone and others (2003) reported on native fish monitoring efforts and made recommendations for approaches to setting up a standardized monitoring program with emphasis on shoreline and backwater fish communities. Ralston et al. (2007) compared the effects of steady and fluctuating flows on water quality parameters and biotic constituents (phytoplankton, macroinvertebrates, and fishes) of associated shoreline habitats. Petersen and Paukert (2005) developed a bioenergetics model for humpback chub and evaluated the effects of water temperature changes on energetic demand for the species.

One of the impediments to identifying responses of native fish to changes in water temperature regimes and river flows has been the lack of a consistent monitoring plan and assessment analysis. Under the auspices of GCMRC, with the aid of Dr. Carl Walters, University of British Columbia, an age-structured mark-recapture (ASMR) model was developed for both humpback chub and flannelmouth sucker. The ASMR uses the history of marks and recaptures for all PIT-tagged fish in the population and determines the population size for adults (age 4+) using variable mortality and constant mortality models.

Concern within the AMP arose over the controversy surrounding the different methods and models used to assess humpback chub populations in both the Upper Basin and in the Grand Canyon. In response to this concern, GCMRC convened a Panel of Independent Reviewers to meet with representatives of ongoing programs in the Upper Basin and Grand Canyon. The goal of this panel was to review current methods and make recommendations to improve the accuracy and precision associated with the parameter estimates (i.e., abundance, population growth rate, and recruitment) from the various models being used. The Panel of Independent Reviewers found that the competing models used in the Upper Basin and Grand Canyon were appropriate for their respective locations and made recommendations to improve their use in the future (Kitchell et al. 2003). A series of meetings was proposed to examine data on humpback chub collected in both the Upper Basin and in the Grand Canyon. An investigation into population estimation techniques was conducted and recommendations were made for the AMP by Dr. Otis of Iowa State University. A recent compilation of results of this work (Coggins 2007) addresses these concerns and is described in detail in Section 2.4.1.

Research and monitoring of native fishes in Grand Canyon, as well as their predators, competitors, diseases, and parasites is being carried out largely under the auspices of the GCMRC with funding provided to the AMP. Much of the research and monitoring work accomplished through GCMRC is accomplished through competitive proposals that are peer-reviewed by independent scientists. Results of this work are presented on a regular basis at TWG and AMWG meetings, and are published as reports and peer-reviewed articles in technical journals.

3.1.5 Element 2: Protection of the Humpback Chub Spawning Population in the Little Colorado River

Progress to date

Reclamation accepted this element of the RPA, despite lacking legal jurisdiction or discretionary authority over the LCR or surrounding lands and tributaries. Reclamation clearly identified the limits to the jurisdiction of the action agency with respect to this sub-element of the Biological Opinion in a letter to the FWS dated April 6, 1995. Moreover it is essential to emphasize that no single agency or entity has the authority or responsibility to implement a management plan that would protect the endangered humpback chub and its critical habitat from threats arising throughout the LCR basin. The LCR watershed is the second largest in Arizona, encompassing approximately 27,000 square miles in both Arizona and New Mexico. It crosses two state boundaries, seven counties, many local, state and federal agency jurisdictions, and three Native American Indian Reservations. Land ownership in the watershed includes 48 percent Indian Reservations, 19 percent federally owned, 10 percent State Trust Lands, and 23 percent privately owned.

The Little Colorado River Multi-Objective Management Watershed Group (LCRMOM) was formed in 1996 and as an umbrella watershed group having as members LCR basin subwatershed groups, Native American tribes, and city, county, state, and federal agencies. A draft Little Colorado River Management Plan was prepared in 1999 (SWCA 1999), reviewed by the FWS, and revised. A revised draft was completed (SWCA 2005) but not finalized given several changes and developments in the organization of groups involved in management of the Little Colorado River watershed. In March 2002, Reclamation made a presentation to the LCR-MOM on the need for a management plan for humpback chub and our efforts in that endeavor. At the meeting, LCR-MOM representatives indicated that they were interested in partnering with Reclamation and the FWS in the development of the management plan. Since that time, the LCR-MOM has become less active and other organizations have formed to coordinate water management activities in the LCR.

Currently, there is a Statewide Water Resources Advisory Group that provides technical assistance and advice to interested parties. The Little Colorado River Plateau Resources Conservation and Development (RC&D) is focused on implementing a strategic plan developed by sponsors and Council Members with the priority goal of formulating and publishing an all inclusive watershed management plan. There are 32 participants in the RC&D. The Little Colorado River watershed Coordinating Council operates under the umbrella of the RC&D and is developing the Little Colorado River Watershed Management Plan. The Bureau of Reclamation Lower Colorado Region has committed to fund 50 percent of the estimated $600,000 to develop the plan with the other 50 percent coming from the non-federal stakeholders. In addition, several partnerships have become established, including the Upper Little Colorado River Watershed Partnership and the Show Low Creek Enhancement Partnership to monitor, restore, and protect natural resources within the Upper Little Colorado River Watershed to enhance the quality of life in accordance with the diverse interests of the watershed residents.

Reclamation will continue to work with these organizations to better understand how to affect land and water management in the LCR watershed in a manner that conserves water quantity and quality to benefit the endangered humpback chub. Reclamation will continue to assist in developing a watershed management plan, emphasizing actions that could be accomplished to address the threats to the endangered humpback chub arising in the Little Colorado River Basin and the potential roles to be taken by various participants and watershed organizations. Because this is the extent of our authority regarding this element, Reclamation believes it has fulfilled this element of the 1995 biological opinion.

3.1.6 Element 3: Sponsor a Workshop for Development of a Razorback Sucker Management Plan for the Grand Canyon

Progress to date

Reclamation sponsored a workshop on the endangered razorback sucker on January 11 and 12, 1996. Workshop participants generally agreed that the razorback sucker was probably historically a transient through Grand Canyon between more suitable meandering river reaches located upstream and downstream (Wegner 1996; Valdez 1996). The workshop participants also recognized that the inflow of the Colorado River into Lake Mead provided the best potential habitat for the razorback sucker in Grand Canyon with its expansive areas of inundated and emergent vegetation and a complex channel with backwaters and embayments.

The results of the workshop (Wegner 1996) were sent to participants, including the FWS, on February 12, 1996. The FWS has not initiated development of the Memorandum of Understanding for razorback sucker management. In the FWS response to Reclamation's third progress evaluation, dated May 27, 1999, several action items of interest to the FWS were identified. Because the only known extant population of razorback sucker above Hoover Dam is in Lake Mead (Holden and others 2000), these actions should be addressed primarily by the Lower Colorado River Multi-species Conservation Program. However, we are partially addressing two of the actions—non-native fish control and provision of experimental flows that could affect habitat of razorback sucker in upper Lake Mead—through the AMP. In May of 1997, Hualapai Tribe biologists implanted 15 razorback sucker with radio transmitters for release at three locations of the Colorado River below Diamond Creek (Zimmerman and Leibfried 1999); Separation Canyon (RM 240), Spencer Creek (RM 246), and Quartermaster Creek (RM 260). The fish remained in their original locations and then gradually moved toward Lake Mead. Several radio-tagged fish remained in the inflow region, but eventually all fish moved into Lake Mead and contact was lost. None moved upstream into Grand Canyon proper. The AMWG recommended in 2004 that GCMRC develop a non-native fish control program in Grand Canyon working with the Technical Work Group. Reclamation has agreed to assist in the development of this non-native fish control program.

Reclamation has completed the workshop. It is our understanding that the next step is for the FWS to recommend a course of action and to develop a Memorandum of Understanding with Reclamation and other entities who may wish to participate.

3.1.7 Element 4: Establishment of a Second Spawning Aggregation of Humpback Chub Downstream of Glen Canyon Dam

Progress to date

In 1999, Reclamation funded a contractor to convene a panel of experts and develop a plan for establishing a second population of humpback chub in Grand Canyon. The plan evaluated four alternatives: (1) existing mainstem aggregation, (2) metapopulation approach, (3) tributaries, and (4) tributary and mainstem (Valdez et al. 2000). Preliminary habitat analyses showed that genetic criteria (i.e., target population size and structure) are unlikely to be met in a tributary, but may be met in two contiguous mainstem aggregations (Stephen Aisle/Middle Granite Gorge) or in the mainstem taken as a whole (the metapopulation concept). The metapopulation concept was thought to represent the greatest likelihood for success in establishing a new, genetically viable population of humpback chub in Grand Canyon if suitable conditions of flow, temperature, and low predator loads could be achieved. Reclamation has initiated investigations and actions to establish a second population of humpback chub as identified by Valdez et al. (2000). Reclamation believes that, in the aggregate, all of these activities represent a system-wide approach at improving humpback chub viability throughout the Grand Canyon ecosystem.

Impediments to establishment of a second spawning aggregation of humpback chub in the Colorado River include unsuitable environmental conditions, e.g., cold water temperature, and the presence of non-native competitors and predators. As indicated above, under element 1B (Section 3.1.3), Reclamation made an initial determination on feasibility of the TCD for Glen Canyon Dam in 2002 after a risk assessment (Garrett and others 2003) and AMWG recommendation to initiate environmental compliance necessary for the construction and testing of a TCD at Glen Canyon Dam. Brown trout control in Bright Angel Creek and a feasibility assessment of non-native control in other tributaries were conducted by GCNP (Leibfried et al. 2003) and Reclamation funded a project conducted by the Arizona Game and Fish Department to evaluate sampling gear for capture of channel catfish and carp in the LCR. Rogers et al. (2003a) evaluated the abundance and distribution of non-native predators related to mechanical removal efforts.

In 2003 the FWS began a translocation program funded by Reclamation for humpback chub above Chute Falls in the LCR and GCNP is examining other tributaries to the Colorado River in the park to assess their suitability for translocations. During 2003-05, a total of 1,150 YOY humpback chub were translocated from the lower LCR to the LCR above Chute Falls. Preliminary results indicate that translocated fish survival and growth rates are high; limited reproduction and downstream movement to below Chute Falls has also been documented (Sponholtz et al. 2005; Stone 2006, 2007).

The use of Glen Canyon Dam releases to negatively impact non-native fish has been assessed in the AMP (Davis and Batham 2003; Korman and others 2003). The use of high experimental flows for this purpose, in addition to directly improving habitat for native fish, has been incorporated into the development of a program of experimental flows to satisfy the needs of element 1A. Another impediment to establishment of a second spawning aggregation is the determination of genetic relatedness among aggregations of humpback chub in Grand Canyon. Valdez and Ryel (1995) established the presence of nine aggregations of humpback chub, including the individuals in the LCR. Genetic evaluations by Colorado State University (Douglas and Douglas 2003a, 2003b; Douglas and Douglas 2007) on the entire taxon and by the FWS on humpback chub collected in the LCR and held at Willow Beach National Fish Hatchery will provide important information in making these determinations.

Evaluating the feasibility of increasing the temperature of water released from Glen Canyon Dam was a common element in the Glen Canyon Dam EIS and one of the elements of the reasonable and prudent alternative in the 1995 biological opinion of that document. In 1999, Reclamation issued an environmental assessment regarding potential modification of Glen Canyon Dam to construct a selective withdrawal structure, and has subsequently continued to investigate various structural designs. The recent drought-induced drawdown of Lake Powell has resulted in warmer release temperatures, providing an opportunity to monitor and evaluate the effects on habitat, reproduction and recruitment.

Monitoring of fish populations since 2002 during MLFF releases shows that the numbers of young humpback chub in the mainstem have increased, most likely as a result of warmer releases from Glen Canyon Dam and/or mechanical removal of trout, though the cause is uncertain (USGS 2007). Further monitoring and investigation is needed of the mainstem aggregations of humpback chub to determine if a second self-sustaining population is becoming established outside of the LCR aggregation.

3.2 New Information Gathered Since the 1995 Biological Opinion

3.2.1 Fluvial Geomorphology and High Flow Tests

Glen Canyon Dam and Lake Powell traps most of the sediment transported by the Colorado River. Tributaries downstream of the dam are now the only renewable sediment source to Glen, Marble, and Grand canyons. The dam and reservoir have also reduced annual flood peaks and increased moderate flows. The altered flow releases from the dam have less capacity to transport sand and coarser sized sediments than under pre-dam conditions with frequent floods.

Sandbars, debris fans, and rapids are the most prominent geomorphic features in the Colorado River corridor. Sandbars in particular are inherently linked to the magnitude and timing of sediment supplied from the Paria and Little Colorado rivers, lesser tributaries, and the mainstream river channel; and to the magnitude and frequency of river flows (Griffiths et al., 2004; Melis 1997; Webb et al. 1999). Sandbars are formed in eddies, which are commonly associated with tributary debris fans (Schmidt and Graf 1990; Schmidt and Rubin 1995). These debris fans form the rapids of Grand Canyon (Griffiths et al. 2004; Webb et al. 2005; Melis 1997; Melis et al. 1994; Webb et al. 1989). Nearly all sandbars in Grand Canyon are associated with recirculation zones that consist of one or more eddies. Sandbars are highly valued for their role as camping beaches and their occurrence is frequently accompanied by backwaters in the eddy return channel. Backwaters are important rearing habitat for native fish due to low water velocity, warm water and high levels of biological productivity.

The 1995 EIS predicted that sediment would eventually accumulate over multiyear timescales in the eddies and other depositional areas of the Colorado River below the Paria River, and that the relationship between sediment transport and river discharge was constant through time. Both assumptions were refuted in the years following the 1996 high flow test and resulted in an entirely new paradigm of sediment transport and conservation. The assumption in the 1995 EIS of a constant relationship between river discharge and sediment transport has recently been determined incorrect (Topping et al. 2000a, b); instead, sediment transport rates vary significantly with river bed grain size, which in turn varies with tributary input of fine sediment. Dam releases under existing operating criteria, have typically resulted in little to no multiyear accumulated sand storage during years of average to below-average tributary sediment supply and less opportunity for sandbar deposition (Rubin et al. 2002; Schmidt et al. 2004; Wright et al. 2005). Sand supplied during tributary floods tends to accumulate in eddies only during low-flow periods (9,000 cfs or less; Topping et al. 2000a, b).

Sandbars between the 20,000- and 30,000-cfs levels have eroded and not been rebuilt, riparian vegetation encroached into the 20,000 to 30,000-cfs zone, and backwater habitats have filled with silt. The sand mass balance remained negative during water years 2000 through 2004, despite five consecutive years in which minimal release volumes (8.23 maf) from Lake Powell occurred during prolonged drought in the upper Colorado River Basin (Wright et al. 2005). These measurements and calculations of sand transport also show that tributary inputs are typically transported downstream and out of the canyon within a few months under typical ROD operations (Rubin et al. 2002).

One of the questions raised by geomorphologists (Andrews 1991; Goeking et al. 2003; Howard and Dolan 1981 Schmidt 1999; Schmidt and Goeking 2003) is what flow magnitude and duration is needed to resuspend sediment and create and maintain sandbars. One hypothesis is that without occasional periods of sustained high releases (powerplant capacity and above), high elevation sandbars will erode and not rebuild (Andrews 199l). In 1997, a habitat maintenance flow was conducted that indicated flows less than or equal to powerplant capacity could be used to redistribute sediment. Future experiments may include habitat maintenance flows (of lesser magnitude and duration), depending upon the results of the proposed experimental high flow in 2008.

The high flow tests of 1996 and 2004 were found effective at building or rebuilding sandbars, although persistence of the sandbars is variable. The 1996 beach/habitat-building flow deposited more sandbars and at a faster rate than predicted. Webb et al. (1999) contains a series of scientific articles that describe finding of the 1996 beach/habitat-building flow. Repeat topographic and hydrographic mapping of 33 sandbar-eddy complexes showed that the 1996 beach/habitat-building flow rebuilt previously eroded high-elevation sandbar, regardless of location, bar type, or canyon width (Hazel et al. 1999). More than half of the sand deposited at higher elevations was taken from the lower portions of the sandbars (Schmidt 1999) rather than being derived from tributary sand supplies accumulated on the channel bed, as originally hypothesized in the 1995 EIS (Wright et al.2005). Over time, however, this resulted in a net decrease in total eddy-sandbar area and volume (Topping et al. 2004); many sandbars built during the 1996 high flow test eroded in as little as several days following the experiment.

In contrast to the 1996 high flow test, the 2004 high flow test was strategically timed to take advantage of highly sediment-enriched conditions (Wiele et al. 2005). Suspended sediment concentrations during the 2004 experiment were 60 to 240 percent of those measured during the 1996 experiment, although there was less sand in suspension below RM 42 (Topping et al. 2004). This resulted in creation of larger sandbars than those observed during the 1996 experiment in Marble Canyon, but area and volume of sandbars downstream of RM 42 actually decreased due to comparatively less sand in that area in 2004 than in 1996. Thus, it was clear from results of the 2004 high flow test that high flows conducted under sediment-depleted conditions (such as 1996) cannot be used to sustain sandbar area and volume (Topping et al.

2004); additionally, it became evident that more sand would be needed during future high flow tests to restore sandbars throughout Marble and upper Grand canyons.

In 2007, sand inputs from the Paria River were at least 2.5 million metric tons, or about 2.5 times the historic average (Topping and Melis, 2007). Together with inputs from the Little Colorado River in 2006 and unexpected retention of sediment from both tributaries during 2006 (USGS 2006b), sand inputs are currently at least 3 times the amount that triggered the 2004 high flow test, and greater than since at least 1998. This presents a unique opportunity to evaluate effects of a high flow test under sand-enriched conditions greater than ever tested before.

Finally, as noted by Magirl et al. (2005), the water-surface profile in Grand Canyon has only been measured twice, once by USGS in 1923 and the second time as part of the experimental flow program of the AMP in 2000. Important new information from the USGS's comparison of 1923 with 2000 is that the profiles do not differ at the scale of the full length of the canyon and some rapids and other geomorphic features exhibit no change over time. However, changes in specific geomorphic features may be of importance within the overall critical habitat for endangered fish. One of the observed changes is that 66 percent of the drop in elevation occurs in 9 percent of the total river length, whereas in 1923, 50 percent of the cumulative drop through the river corridor occurred in the same 9 percent distance. This change has resulted in an enhanced pool-and-rapid morphology in the eastern portion of the canyon where humpback chub occur. The largest rise in elevation is at House Rock Rapid (+2.0 m), followed by Badger Rapid with a 1.8 m rise. While stability or change in individual rapids such as Badger or House Rock does not directly affect endangered fish, related changes in sandbars and debris fans associated with the rapids are important as fish habitat.

3.2.2 Backwaters

Backwaters are thought to be important rearing habitat for native fish due to low water velocity, warm water and high levels of biological productivity. They are created as water velocity in eddy return channels decline to near zero with falling river discharge, leaving an area of stagnant water surrounded on three sides by sand deposits and open to the mainchannel environment on the fourth side. Reattachment sandbars are the primary geomorphic feature which functions to isolate nearshore habitats from the cold, high velocity mainchannel environment.

Backwater numbers vary spatially among geomorphic reaches in Grand Canyon and tend to occur in greatest number in river reaches with the greatest active channel width, including the reach immediately downstream from the LCR (RM 61.5-77; McGuinn-Robbins 1995). Numbers and size also vary temporally as a function of sediment availability and hydrology, and their size can vary within a year at a given site. On short time scales (i.e., from one year to the next; Dr. John C. Schmidt, personal communication) backwater numbers appear to respond readily to sudden high sediment inputs and high flows regardless of antecedent sediment conditions. Backwaters declined in number from 1990 to 1992 under experimental high fluctuating flows and MLFF, but a rapid but short lived increase in backwater numbers resulted from high inputs and flows from the LCR in 1993 (Beus et al. 1994; McGuinn-Robbins 1995). Backwaters created in 1993 declined in 1994 under more average sediment and flow conditions (McGuinn-Robbins 1995). Backwater number can also vary tremendously depending on flow elevation during sampling and tend to be greatest at low flow elevations. Hoffnagle and Stevens (1999) noted that backwater numbers and area were reduced at flows greater than 10,000 cfs at any given point in time. McGuinn-Robbins found more backwaters during 1990 at the 5,000 cfs level than at the 8,000 cfs level, although area was greatest at the 8,000 cfs level.

Persistence of backwaters created during the 1996 high flow test appeared to be strongly influenced by post-high flow dam operations. Whereas the 1996 test resulted in creation of 26 percent more backwaters, potentially available as rearing areas for Grand Canyon fishes, most of these newly created habitats disappeared within two weeks due to reattachment bar erosion (Brouder et al. 1999; Hazel et al. 1999; Parnell et al. 1997; Schmidt et al. 2004). Nearly half of the total sediment aggradation in recirculation zones had eroded away during the 10 months following the experiment and was associated in part with relatively high fluctuating flows of 15,000-20,000 cfs (Hazel et al. 1999).

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

Biologically, the 1996 high flow caused an immediate reduction in benthic invertebrate numbers and fine particulate organic matter (FPOM) through scouring (Brouder et al. 1999; Parnell et al. 1999). Invertebrates had rebounded to pre-test levels by September 1996, but it is thought that the rate of recolonization was hindered by a lack of FPOM. Still, recovery of key benthic taxa such as chironomids and other Diptera was relatively rapid (3 months), certainly rapid enough for use as food by the following summer's cohort of YOY native fish (Brouder et al. 1999). Also during the 1996 high flow test, Parnell et al. (1999) documented burial of autochthonous vegetation during reattachment bar aggradation, which resulted in increased levels of dissolved organic carbon, nitrogen and phosphorus in sandbar ground water and in adjacent backwaters. These nutrients are thus available for uptake by aquatic or emergent vegetation in the backwater.

In a study conducted in the upper Colorado River basin (middle Green River, Utah) Grand et al (2005) 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. 2005). Potential geomorphic differences between the Grand Canyon and the Upper Colorado River basin underline the need for additional research investigation.

An outstanding information need for management of Grand Canyon backwaters is the relationship between backwater bathymetry and suitability as fish habitat, specifically the relationship between depth, area, volume and thermal characteristics. Goeking et al. (2003) point out large backwaters may not incur as many benefits to young native fish as smaller backwaters because the latter will warm faster and thus remain warmer over time than larger backwaters; however, due to their depth, they may be more frequently available as fish habitat over a greater range of flows. In the Upper Colorado River basin, Colorado pikeminnow were found to utilize backwaters with average depths greater than 0.3 m (Trammell and Chart 1999) and average areas of 992 m^2 (Dey et al 1999). The issue of backwater depth is a research need from the standpoint that while greater depths afford more availability over a wide range of flows (Muth et al. 2000), the concurrent increase in volume with depth may slow warming rates.

3.2.3 Water Temperature and Flow Regime

Glen Canyon Dam releases hypolimnetic water (the deeper layer of the reservoir) with a relatively constant temperature which ranges from 6-8 °C at high reservoir levels. In the summer, the surface layer (epilimnion) of Lake Powell warms to nearly 30 °C as a result of warm inflows, ambient air temperature, wind mixing and solar radiation. However, while release temperatures remain relatively constant, they are influenced by lake elevation, inflow hydrology, and to a lesser extent, release volumes and meteorological conditions. Release temperatures have varied from 7 to 16 °C through 2006 (Figure 9). Between 1999 and 2005, Lake Powell elevations dropped more than 140 feet as a result of a basin-wide drought. While winter release temperatures remained cold, Glen Canyon Dam release temperatures increased to 16 °C in the fall of 2005. The drop in Lake Powell elevation resulted in warmer releases because the epilimnion was closer to the penstock withdrawal zone. Release temperatures from Glen Canyon Dam during 2004 and 2005 were the highest since August 1971 when the reservoir was filling.

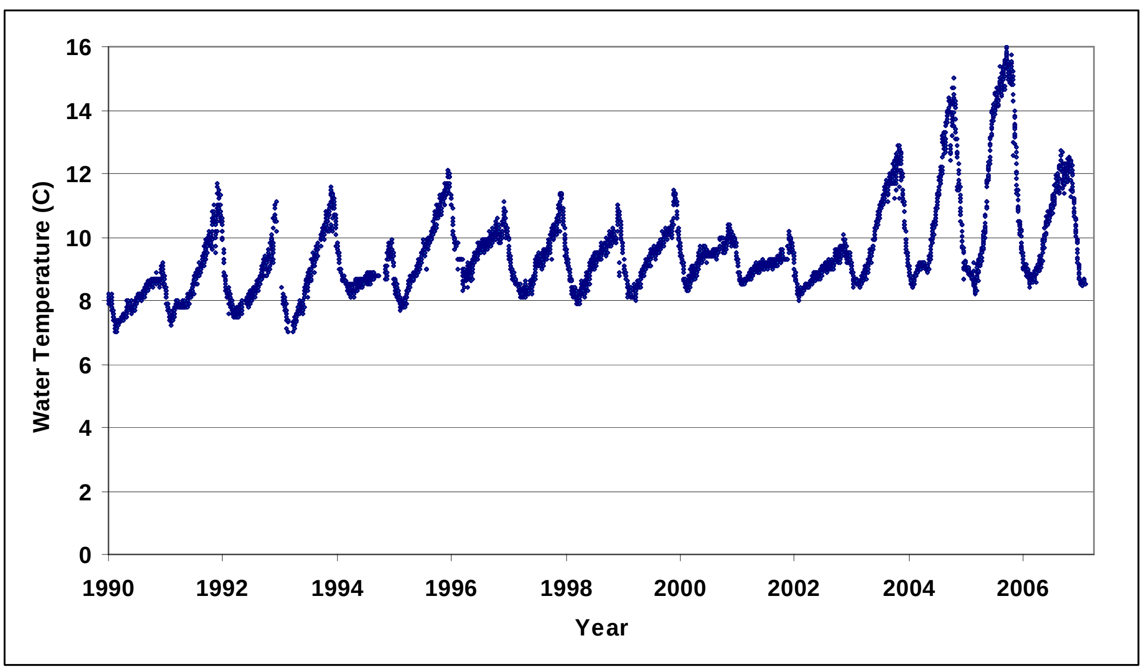


Figure 9. Release water temperature data from Glen Canyon Dam, AZ from 1990 to 2007.

As water travels downstream from Glen Canyon Dam to Lake Mead the water temperature increases by an average of 9 °C during summer months. The amount of warming is directly affected by seasonal air temperature, winds and water velocity, with highest warming rates occurring in mid-summer at low release volumes (Vernieu et. al. 2005). Generally, as air temperatures decrease during late fall, water released from Glen Canyon Dam cools as it moves downstream towards Diamond Creek. River temperatures across the channel are nearly uniform due to turbulence and mixing, but nearshore areas typically exhibit higher water temperatures during summer and early autumn months (Vernieu et al. 2005). Temperature differences between mainchannel and nearshore habitats are especially pronounced in backwaters and other low velocity areas. The amount of warming that occurs in backwaters is affected by daily fluctuations, which cause mixing with cold mainchannel waters (Arizona Game and Fish Department 1996).

Hoffnagle (1996) found that mean, minimum, maximum and diel 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. Similar results were documented by Trammell et al. (2002), who found backwater temperatures during the 2000 low steady summer flow experiment to be 2-4 °C above those during 1991-1994 under fluctuating flows.

Korman et al (2006) also found warmer backwater temperatures under steady flow conditions, concluding that backwaters were cooler during fluctuations because of the daily influx of cold main channel water. These effects were documented during the months of August and September, but not October, when cooler air temperatures caused backwaters to be about 1 °C cooler than the mainchannel. However, they also noted that the extent of the effect was variable and depended on the timing of daily minimum and maximum flows, the difference between air and water temperatures, and the topography and orientation of the backwater.

Perhaps more importantly, Korman et al. (2006) also noted that nearshore areas affected by fluctuating flows (i.e., in the varial zone) warmed substantially for brief periods each day, which posits an ecological trade-off for fish utilizing these areas. On the one hand, fish may choose to exploit the warmer temperatures of the fluctuating zone on a daily basis and simply sustain any bioenergetic disadvantages of acclimating to rapidly changing discharge; or they may choose to remain in permanently wetted zone which is always wetted, but colder than the immediate near shore margin.

In a separate study, Korman et al (2005) observed that slightly more than half of observed YOY rainbow trout in the Lees Ferry reach maintained their position as flows fluctuated rather than follow the stream margin up slope. Thus, for trout, it appears that the bioenergetic cost of changing stream position with fluctuations in discharge perhaps outweighs the benefits of exploiting the slightly warmer stream margins. It is clear from this work that understanding the trade-off between temperature and fluctuating flows as it affects growth and survival of early life stages of Grand Canyon fish (native and non-native) is an important research question.

To assess the likelihood of water temperatures during the Proposed Action without a TCD installed on Glen Canyon Dam, the probabilities of cold (<11 °C), cool (>11 C - 17 °C) and warm (>17 °C) releases from the dam in July were estimated for the five-year period beginning in 2009. The analysis was based on 1,700 separate data points of reservoir elevations using sequential incremental methodology of calculating elevation with a given starting elevation.

Projected reservoir release temperatures were identified based on previous empirical data and modeling outputs. Reservoir elevation was used as the driving variable most affecting release temperature with consideration for the affects of runoff volume in affecting the depth of the reservoir thermocline. Larger runoff volumes deepen the epilimnion creating a larger, deeper body of warm water that is relatively closer to the penstocks at a given reservoir elevation, and therefore available to be released, than do smaller runoff volumes. Using this approach, the following elevations were determined likely to produce the associated dam release temperatures:

- > 3600 feet elevation produced cold releases
- > 3550 and < 3599 feet elevation produced cool releases
- > 3490 and < 3550 feet elevation produced warm releases

The overall probabilities for these three temperature ranges over the long term in the month of July were: (<11 °C) = 75 percent; (>11 °C and <17 °C) = 21 percent; and (> 17 °C) = 4 percent. Thus, the modeling output predicts that release temperatures in 3 out of 4 years in the time period of the Proposed Action will be cold.

To further differentiate the prospective release temperatures in the five-year period identified for the Proposed Action, we estimated the probabilities of delivering cold, cool, and warm waters for 2-5 year successive periods. Probabilities for the first two years using all combinations of cold, cool, and warm releases show that by far the highest likelihood is for two successive years of cold water, with the lowest probability being for a cold release year followed by a warm release year (Table 6).

Table 6. Probabilities of water temperatures for two succeeding years (2 years total)

	Succeeding Years Temperature (Probabilities in percent)		
Initial Water Temperature	Cold	Cool	Warm
Cold	90.9	8.9	0.2
Cool	32.6	52.8	14.5
Warm	4.2	63.8	31.9

The probabilities for the remaining three years are provided for cold to cold, cool to cool and warm to warm release temperatures (Table 7). Again, the highest probability is for release water remaining cold during the five year period and the lowest probabilities are for successive years of warm water. Based on this analysis, we predict that waters released from Glen Canyon Dam during the period 2009-2013 without selective withdrawal will most likely be cold (< 11 °C).

Table 7. Probabilities of similar water temperatures for two, three and four succeeding years when year one releases are cold, cool or warm

		Succeeding Years Temperature		
Initial Water Temperature	Succeeding Year	Cold	Cool	Warm
Cold	3	82.6		
	4	75.1		
	5	68.3		
Cool	3		27.9	
	4		14.7	
	5		7.8	
Warm	3			10.2
	4			3.3
	5			1.1

3.2.4 Humpback Chub

An overview of the information on the life history and ecology of the humpback chub in the action area is provided in Section 2.4.1, Species Accounts, Humpback Chub. The humpback chub presently occurs as nine aggregations within the action area. The largest aggregation is the LCR population which is self-sustaining and had an estimated 5,300-6,800 adults in 2006. Fish in the LCR aggregation spawn in the LCR in the spring. Evidence of reproduction was reported for the 30-Mile aggregation in 1994. At the time of the 1995 biological opinion, the distribution of humpback chub aggregation had just been reported and little was known about the habitat use of especially the young fish along shoreline habitats and their response to various flow regimes.

A considerable amount of new information has been gathered on the humpback chub since the 1995 biological opinion. This information has been summarized in various documents including Valdez and Carothers (1998), Gloss and Coggins (2005), and Coggins (2007). This new information has provided more reliable and precise estimates and trends of the humpback chub population in Grand Canyon, use of shoreline habitats by young humpback chub and their response to flow experiments such as high flow tests and steady summer flows, as well as the genetic character of humpback chub aggregations in Grand Canyon. There is also new information that suggests mainstem reproduction by humpback chub in one or more of the mainstem aggregations. Also, the nature of the Lake Mead inflow area, Lake Mead elevation, and the fish community has also changed considerably.

Apparent recruitment failure through the mid 1990s resulted in decline of the Little Colorado River humpback chub adult population to a low in 2001 of between 2,400 and 4,400 age 4+ fish (Gloss and Coggins 2005; Coggins et al. 2006). The population has since increased by approximately 20-25 percent and in 2006 consisted of about 6,000 individuals (Coggins 2007). This increase has previously been attributed in part to the results of non-native fish mechanical removal, increases in temperature due to lower reservoir elevations and inflow events, the 2000 low steady summer flow experiment, or other experimental flows (USGS 2006a). However, the most recent population modeling indicates that the increase was actually due to increased recruitment rates as early as 1996 but no later than 1999 (Coggins 2007). Thus, the increase in recruitment under MLFF began at least four and as many as nine years prior to implementation of non-native fish control, incidence of warmer water temperatures, the 2000 steady flow experiment, and the 2004 high flow test. To date, no analysis of humpback chub recruitment dynamics has been conducted during the early years of MLFF, and the reason for increased recruitment during those years is uncertain.

New information also shows greater numbers of young humpback chub in the mainstem than in previous years. During 2002-2006, a total of 442 humpback chub <100 mm TL was captured upstream of the Little Colorado River inflow (RM 61.3) as far upstream as RM 30.7 (Ackmerman 2007). Of the 442 fish, 225 (13-66 mm TL) were caught between RM 30 and RM 50. The 30-Mile aggregation is located 31 miles upstream of the Little Colorado River inflow and it is unlikely that the young humpback chub swam upstream for that distance, especially in the cool mainstem temperatures. Furthermore, the distribution of these fish, as well as averages size above (mean = 38 mm TL) and below the LCR (mean = 67 mm TL), indicate that the natal source is upstream of RM 50 and not from the LCR.

Young-of-year and juvenile humpback chub observed outside the LCR aggregation were most abundant at RM 110-130 (Stephen Aisle and Middle Granite Gorge aggregations) during 2000 and 2004 and RM 160-200 during 2000 (Ackerman 2007; AGFD 1996; Johnstone and Lauretta 2004, 2007; Trammell et al. 2002). However, seine catches of all young-of-year humpback chub outside the nine aggregations during 2004 were at their highest in 21 years (Johnstone and Lauretta 2007). Four humpback chub were also collected at Separation Canyon (RM 239.5) in 2005 (Ackerman et al. 2006). The Middle Granite Gorge aggregation (which includes adults) has been stable or increasing in size since 1993 (Trammell et al. 2002) and may be sustained via immigration from the LCR aggregation, as well as local reproduction. Valdez et al. (2000a) identified this aggregation as the most likely candidate for a second spawning population in the mainchannel given favorable conditions (mainly temperature). No humpback chub have been caught at the Havasu Inflow and Pumpkin Spring aggregations since 2000 (Ackerman 2007). Population estimates have not been made for other mainstream aggregations since 1993 (Trammell et al. 2002).

Studies to assess habitat of young humpback chub have revealed important information to help determine suitable flows for the species. Converse et al. (1998) identified shoreline habitats used by subadult humpback chub and related spatial habitat variability with flow regulation. Most humpback chub utilized talus, debris fans or vegetated shorelines in depths of water less than 1 m and velocities of 0.1 to 0.2 m/s, and that these parameters covaried by geomorphic reach. Korman et al. (2004) found that habitat stability as determined by flow was important to minimize displacement of young humpback chub. They also found that humpback chub suitable habitat (depth and velocity as based on Converse et al. 1998, among others) declines by about 78 percent as discharge increases from 3,000 to 32,000 cfs, but tends to increase slightly at higher elevations (Korman et al. 2004). As the role of backwaters and near shore areas in humpback chub survival and recruitment is presently unclear, this remains an important resource question to be addressed through the Proposed Action and ongoing monitoring and research.

There is also new information on our ability to translocate humpback chub, their survival, growth, and reproduction. As a conservation measure for humpback chub (Interior 2002), Reclamation, NPS, and USGS proposed to implement translocation of young humpback chub above Chute Falls in the Little Colorado River (ca. 16 km from the confluence). In August 2003, nearly 300 young humpback chub were translocated above a natural barrier in the Little Colorado River located 16 km above the confluence. This translocation was followed by another 300 fish in July 2004, and finally by another 567 fish in July 2005 (Sponholtz et al. 2005; Stone 2006). Results indicated that translocated fish survival and growth rates were high. Reproduction and downstream movement below Chute Falls has also been documented (Sponholtz et al. 2005; Stone 2006). The Chute Falls aggregation now appears to be a source of recruitment to the lower portions of the Little Colorado River and the mainstem Colorado River (Stone 2007).

Non-native removal has been conducted in Bright Angel Creek (Leibfried and others 2003) and the feasibility of extending this work to other tributaries to the Colorado River in Grand Canyon National Park (GCNP) is being investigated by NPS (Leibfried et al. 2006). If non-native removal is successful and suitable, additional translocations can be contemplated. Moving young HBC to other tributaries as *in-situ* refugia would decrease the risk of catastrophic events to the LCR humpback chub population and allow opportunities for translocated humpback chub to grow prior to migrating to the mainstream. The NPS is also exploring the possibility of translocating humpback chub to other tributaries, such as Shinumo Creek (SWCA and GCWC 2007).

Studies of effects of high experimental flows on young-of-year humpback chub dispersal rates have yielded conflicting results. Based largely on catch rate information, abundance of humpback chub and other native fish species did not differ following the 1996 experimental flow (Hoffnagle et al. 1999). Trammell et al. (2002) showed similar results during 2000 when habitat maintenance flows (ca. 30,000-31,000 cfs) were conducted during the month of September, although reinvasion of non-native fathead minnow was relatively rapid. Catch rates of humpback chub in hoopnets declined following the 2004 high flow test, however, and suggested that humpback chub may be vulnerable to displacement by such flows, at least for the smallest individuals during late autumn-early winter months (GCMRC, unpublished data). This apparent decline in humpback chub catch rates in 2004 may be partially attributed to variable capture probabilities between sample periods (turbid vs. clear water) (Lew Coggins, GCMRC, personal communication). Differences between the 1996 high flow and the 2004 high flow test may also be attributed to the time of year in which the high flow test occurred. The 1996 high flow was in April when the fish were about 10 months old and the 2004 high flow test was conducted in September when the fish were about 5 months of age and perhaps less able to maintain their position in the channel or adjust to more suitable water depths and velocities.

Significant information has also come forth recently on the genetic structure of humpback chub in Grand Canyon. Douglas and Douglas (2007) concluded that some differences among the Marble and Grand Canyon ‘aggregates’ of *G. cypha* were difficult to distinguish at the microsatellite level. Aggregates appeared to be connected by geneflow, suggesting downstream drift of larvae and juveniles as a likely scenario. The Little Colorado River population would be the primary source, but contribution from occasional local reproduction by mainstem aggregates cannot be excluded. The *G. cypha* population at 30-mile in Marble Canyon was recorded as having two individuals with *G. elegans* haplotypes, and the microsatellite profile for this population was intermediate between genotypes found in Desolation Canyon (a hypothesized hybrid population) and Grand Canyon. Although reproduction has been documented for the 30-mile population, it suffers from chronic low numbers (at least chronic low numbers of catchable fish). However, this is the only population in Grand Canyon that is upstream from the Little

Colorado River and is least likely to receive migrants from downstream locations. Douglas and Douglas (2007) recommended further study of the 30-mile aggregation to evaluate the potential distinctiveness of these fish.

Studies in western Grand Canyon show that the Lake Mead inflow has changed considerably with lower lake levels such that the former inflow has transformed from an expansive area of inundated vegetation to a narrow sand bed river. The lake fish community reported by Valdez (1994) and Valdez et al. (1995) in this inflow region is now a riverine community (Ackerman et al. 2006). Studies and monitoring should continue to evaluate the effect of this changed community on the fish community further upstream in Grand Canyon.

New information was also reported for infestation rates of Asian tapeworm and effects of this parasite on fish. Infestation rates were reported by Hoffnagle et al. (2006), Cole et al. (2002), and Choudhoury et al. (2001). Meretsky et al. (2000) reported a decline in condition factor of adult humpback chub not in immediate spawning condition from the Little Colorado River confluence from 1978 to 1996, hypothesizing that the decline could be caused by one or more factors; e.g., a recent invasion of the Asian tapeworm (*Bothriocephalus acheilognathi*), researcher variation in weighing fish, or natural population variation. Hoffnagle (2000) reported that condition and abdominal fat were greater in the mainstem Colorado River than in the Little Colorado River during 1996, 1998, and 1999 possibly because of an increased prevalence and abundance of parasites (especially *Lernaea cyprinacea* and *Bothriocephalus acheilognathi*) in the LCR fish and/or greater food availability in the Colorado River.

3.2.5 Non-Listed Native and Non-native Fish

Background. The Lee's Ferry Reach (dam to Paria River) supports a self-sustaining fishery of rainbow trout, *Oncorhynchus mykiss,* whose population and food base are influenced by dam operations (McKinney et al. 1999b; McKinney and Persons 1999; McKinney et al. 2001; Speas et al. 2004a, 2004b; Korman et al. 2005). Brown trout, *Salmo trutta,* occasionally move into the reach between the dam and the Paria River from downstream populations, but is not managed as part of the sport fishery and is not a desired species in this reach. The Lee's Ferry Reach also supports small numbers of flannelmouth suckers, bluehead suckers, and speckled dace. The flannelmouth sucker spawns in this reach (McIvor and Thieme 2000; McKinney et al. 1999c; Thieme 1998), although the water generally is too cold for survival of eggs and larvae. The flannelmouth sucker also spawns in the Paria River (Weiss 1993), where the inflow serves as a nursery habitat when impounded by mainstem flows above 11,866 cfs (Thieme 1998).

The 61-mile reach of the Colorado River from the Paria River to the Little Colorado River supports low to moderate numbers of flannelmouth suckers, bluehead suckers, speckled dace, and humpback chub. Most native fish in the mainstem are large juveniles and adults. Earlier life stages rely extensively on more protected nearshore habitats throughout the river, primarily backwaters (AGFD 1996; Lauretta and Serrato 2006; Maddux et al. 1987; Trammel et al. 2002). Native fish spawning may occur in warm springs at RM 30-32 (Valdez and Masslich 1999). Although their abundance has declined significantly over the last seven years, rainbow trout are still the dominant non-native species between the Paria River and the Little Colorado River (Ackerman 2007; Johnstone and Lauretta 2007). Other non-native species sporadically found in that reach include brown trout, common carp, channel catfish and fathead minnow, *Pimephales* *promelas*. Invasion of non-native fish from the upper LCR has recently been documented (Stone et al. 2007)

The 174 miles from the LCR confluence to Bridge Canyon has six major tributaries and supports a diverse fish fauna of cool- to warm-water species to about Havasu Creek, including the three non-listed native species and seven known aggregations of humpback chub (Section 2.4.1). Non-listed native fish are also well represented in Bright Angel, Shinumo, Tapeats, Kanab, and Havasu creeks (Leibfried et al. 2006), especially during spawning periods. The Little Colorado River supports comparatively large populations of the three non-listed species and the largest aggregation of humpback chub, all of which also inhabit the main channel near the LCR in comparable densities.

Below the Little Colorado River, rainbow trout numbers drop dramatically, although brown trout are common near Bright Angel Creek where they spawn and maintain a resident tributary population. Warm water species such as common carp, channel catfish, and fathead minnow increase in numbers downstream of the Little Colorado River and are most abundant between Shinumo and Diamond creeks. (Ackerman 2007). Red shiner and plains killifish, *Fundulus zebrinus*, are common in backwaters immediately below the Little Colorado River and occur sporadically downstream from that point (Johnstone and Lauretta 2007; Lauretta and Serrato 2006).

The 45-mi. reach of the Colorado River from Bridge Canyon to Pearce Ferry is flat and muddy due to high lake elevation sediment deposition on the old river channel. Abundance of flannelmouth suckers, speckled dace, and bluehead suckers are generally limited due to lack of spawning habitat and large numbers of predators (Valdez 1994; Valdez et al. 1995).

Distribution of fish parasites found in Grand Canyon fishes is related to thermal tolerances of host species along the longitudinal gradient of the river. *Trittaedacnitis truttae*, Nematoda, specifically affects rainbow trout and is prevalent in the Lees Ferry reach of the Colorado River below Glen Canyon Dam (McKinney et al. 2001). Whirling disease was discovered in the rainbow trout population below Glen Canyon Dam in June of 2007. Asian fish tapeworm, *Bothriocephalus acheilognathi*, and anchor worm, *Lernaea cyprinacea*, may pose threats to native fish below Glen Canyon Dam. Asian tapeworm is currently the most abundant fish parasite in the Little Colorado River, infecting 23-51 percent of all humpback chub (AGFD 1996; Choudhury et al. 2004; Clarkson et al. 1997) and also a variety of cyprinids. Main channel infestation rates are much lower and may be temperature-limited (4-22 percent) (AGFD 1996; Valdez and Ryel 1995). Optimal *B. acheilognathi* development occurs at 20-30 °C (Granath and Esch 1983). Choudhury et al. (2004) hypothesized that infection rates were positively related to both fish host and copepod density in the Little Colorado and parasitic fauna found there have diversified through invasion of non-native host fish species. *Lernae cyprinacea* infects humpback chub at a higher rate than other species of fish in Grand Canyon (Hoffnagle 2000) and favors temperatures greater than 18 °C (Grabda 1963), with 23-30 °C being optimum (Bulow et al. 1979). Post-dam mainstream temperatures have prevented *L. cyprinacea* from completing its life cycle and limited its distribution to warmer backwaters. Infestation apparently does not increase fish mortality in the Upper Colorado Basin (Valdez and Ryel 1995).

The Grand Canyon fish community has shifted over the past five years from one dominated by non-native salmonids to one dominated by native species (Ackerman 2007; AGFD 2006; Johnstone et al. 2003; Lauretta and Serrato 2006; Trammell et al. 2002). Electrofishing catch rates of flannelmouth and bluehead suckers have increased four to six-fold in the past seven years, whereas trout catch rates have correspondingly declined (AGFD 2006); a similar trend is evident from trammel net data (Johnstone et al. 2003; Lauretta and Serrato 2006). Riverwide, young flannelmouth suckers were more abundant in 2004 than the previous 16 years (Johnstone and Lauretta 2007) and speckled dace are abundant in hoop net and seining samples, particularly in downstream reaches (Ackerman 2007). It is hypothesized that the recent shift from non-native to native fish is due in part to warmer than average water temperatures, although the decline of coldwater salmonid competitors (due to mechanical removal or temperature increases) also has been implicated (Ackerman 2007; Persons and Rogers 2006; USGS 2006a). Population size of humpback chub has also increased from about 4,500 – 5,700 in 2001 to an estimated 5,300 – 6,800 adult fish in 2006 (Figure 26 in Coggins 2007; see Section 2.4.1).

The increase in native fish abundance apparently began about the year 2000 although increases in humpback chub abundance appear to have begun earlier (Section 3.2.4). Relative abundance of young-of-year (YOY) flannelmouth suckers was higher during the summer 2000 steady flow experiment than at any point during the previous 10 years, which was thought to be directly related to warmer than average temperatures associated with the steady flow experiment (Trammell et al. 2002). A similar trend was identified for fathead minnow, however, although both their abundance and that of flannelmouth sucker were subsequently reduced by a 30,000 cfs habitat maintenance flow in September 2000. Young bluehead sucker catch rates during 2000 were also among the highest on record (Johnstone and Lauretta 2007). Speckled dace catch rates have been variable over the past two decades or so, with no apparent trend (Johnstone and Lauretta 2007). Mainchannel YOY and juvenile flannelmouth suckers have remained abundant since 2000 in association with warmer water (Johnstone and Lauretta 2007; Lauretta and Seratto 2006). Catch rates of speckled dace in recent years have been generally higher than historical levels and were highest in the vicinity of tributaries. Juvenile and adult bluehead suckers continued to occur in low numbers, usually in association with tributaries.

Recent declines in trout abundance in the Lees Ferry tailwater are attributed less to increased daily fluctuations during 2003-2005 and more to increased water temperatures and trout metabolic demands coupled with a static or declining food base, periodic oxygen deficiencies and nuisance aquatic invertebrates (New Zealand mudsnails; AGFD unpublished; Persons and Rogers 2006). Concurrent with these declines in abundance, however, trout condition (a measure of plumpness or optimal proportionality of weight to fish length) has increased, reflecting a strongly density dependent fish population where growth and condition are inversely related to fish abundance (McKinney and Speas 2001; McKinney et al. 2001).

Whirling disease was discovered in the rainbow trout population below Glen Canyon Dam in June of 2007. Additionally, highly invasive quagga mussels (*Dreissena* sp.) were discovered in Lake Powell during the summer of 2007. Because of their high filtration and reproductive rates, quagga mussels frequently alter aquatic food webs and damage water supply infrastructure. Kennedy (2006) performed a risk assessment on establishment potential of quagga mussels in the Colorado River below Glen Canyon Dam, concluding that there is low risk of these mussels becoming established in high densities in the Colorado River or its tributaries below Lees Ferry.

In contrast, conditions in the clear tailwater reach below the dam appear more suitable for establishment of this species.

Korman et al. (2005) and Korman and Kaplinski (in preparation) documented increased mortality of rainbow trout eggs due to increased flow fluctuations (15,000 cfs/day) in 2003-2005, however survival rates of hatched fish compensated for these losses and did not affect abundance of young-of-year trout. Korman et al. (2005) and Korman and Campana (in preparation) also noted improved young-of-year growth rates during periods of stable daily flows due to lower water velocities and warmer temperatures at stream margins.

Korman et al. (2005) and Korman and Kaplinski (in preparation) also determined that most YOY rainbow trout maintained their position in the streambed as flows increased during the daily hydropower generation cycle. They hypothesized that during the 24 hour power generation cycle, fish are essentially faced with a series of choices imposed by hourly changes in discharge. Maintaining one's position in the streambed during fluctuating discharge ensures minimal bioenergetic expenditure in searching for a new stream position. While bioenergetic costs of maintaining stream position are uncertain, it is assumed that the larger proportion of fish which did move indicates a bioenergetic advantage to maintaining position. However, maintaining position also precludes fish from exploiting slightly warmer temperatures at the stream margins, which occur at higher elevations in the water column at peak discharge; this would require searching and movement.

The non-native fish fauna of the Lees Ferry reach historically included less frequent taxa including common carp, largemouth bass, golden shiner, *Notemigonus crysoleucas*, redside shiner, *Richardsonius balteatus*, striped bass, and threadfin shad (GCMRC unpublished data). In more recent years, however, YOY green sunfish, *Lepomis cyanellus*, smallmouth bass, brown trout, and channel catfish have been collected in this reach; mature smallmouth bass and walleye have also been collected (GCMRC unpublished data). Sources of these fish are unknown, but the closest source containing green sunfish, catfish and smallmouth bass would be Lake Powell; means of introduction is unknown, but Reclamation is currently assessing risk potential for entrainment of Lake Powell fish through the dam penstocks.

Recently, a few smallmouth bass and striped bass were collected in the vicinity of the Little Colorado River (GCMRC unpublished data), but no population-level establishment has been documented to date. There are also recent records of green sunfish, black bullhead, yellow bullhead, red shiner, plains killifish and largemouth bass downstream of the Little Colorado River, usually associated with warm springs, tributaries, and backwaters (Johnstone and Lauretta 2007; GCMRC unpublished data). Striped bass are found in relatively low numbers below Lava Falls (Ackerman 2007; Valdez and Leibfried 1999).

Stone et al. (2007) reported common carp, fathead minnow and red shiner below Grand Falls (an ephemeral reach of the river), which indicates that the LCR is a viable conduit for introduction of non-native fish from areas higher in the watershed. Other non-native fish documented in the upstream reaches of the Little Colorado River basin include golden shiner, black bullhead, yellow bullhead, channel catfish, rock bass *Ambloplites rupestris*, bluegill, green sunfish, smallmouth bass, and largemouth bass (Stone et al. 2007); thus these species could eventually occur in Grand Canyon.

Fish samples collected below Diamond Creek in 2005 (Ackerman et al. 2006) were comprised primarily of red shiner (28 percent), channel catfish (18 percent), common carp (12 percent), and striped bass (9 percent); smallmouth bass, mosquitofish, *Gambusia affinis*, and fathead minnow were also present in low numbers. Bridge Canyon Rapid impedes upstream movement of most fish species, except for the striped bass, walleye, and channel catfish (Valdez 1994; Valdez et al. 1995; Valdez and Leibfried 1999). Non-native fish species increased from 11 above to 18 below the rapid (Valdez 1994; Valdez et al. 1995). Above Bridge Canyon Rapid, the red shiner was absent, but below the rapid it comprised 50 percent and 72 percent of all fish captured in tributaries and the mainstream, respectively (Valdez 1994; Valdez et al. 1995). Other common fish species found below Bridge Canyon Rapid include the common carp, fathead minnow, and channel catfish; however, very little fish habitat exists in this reach due to declining elevations of Lake Mead and subsequent downcutting of accumulated deltaic sediments in inflow areas. Flannelmouth suckers comprised about 15 percent of the total catch from this reach during 2005 (Ackerman et al. 2006), several times greater than the 1.3 percent observed during 1992-1995 (Valdez et al. 1995). Percentage of speckled dace in the reach has not changed appreciably over the last decade, and no bluehead suckers were collected during 2005 (Ackerman et al. 2006; Valdez et al. 1995).

3.2.6 Non-native Fish Control Undertaken 2003-2006

In an attempt to benefit native species, mechanical removal targeted at non-native salmonid species in the mainchannel Colorado River and tributaries in Grand Canyon took place during 2003-2006 (Interior 2002; Coggins and Yard 2003). Removal of salmonids and other non-native fish (black bullhead, fathead minnow, common carp, brown trout) in the vicinity of the Little Colorado River by electrofishing contributed to a 90 percent reduction in rainbow trout over a four year period, although part of the decline is attributed to warmer main channel temperatures and higher flow daily fluctuations (GCMRC unpublished data). Main channel water temperatures during the removal period were as high as 6 °C above the 1990-2002 average. At the same time, electrofishing catch rates of YOY and age 1 flannelmouth sucker, bluehead sucker, and humpback increased by as much as a factor of ten; catch rates of speckled dace also increased.

Mechanical removal of spawning brown trout through weir operations in Bright Angel creek yielded inconclusive results. During operations in 2002 (November—January), over 400 brown trout were removed from Bright Angel Creek and euthanized (Leibfried et al. 2005). When a similar removal effort was conducted in November—January of 2006, only 54 brown trout were removed, and a rainbow trout catches were decreased by a similar proportion (Sponholtz and VanHaverbeke 2007). The decline cannot be attributed to weir operations alone, however, as both trout species experienced a considerable system-wide decline in abundance between the two removal periods.

Most brown trout from Bright Angel Creek were captured during the spawning period between late November and mid-December. The onset of rainbow trout spawning was documented in mid-January. For both species of trout, short term increases in water temperature (over the course of a week or less) were often associated with increases in catch rates. Returns of tagging data indicate that most spawning brown trout move 10 miles or less to access Bright Angel Creek, however some individuals were tagged over 32 river miles away.

Multi-pass backpack electrofishing was also evaluated as a mechanical control technique in Bright Angel and Shinumo Creeks. In a 3.35 km reach of Bright Angel Creek, approximately 55 percent and 57 percent of the brown and rainbow trout populations, respectively, were removed through as many as 4 electrofishing passes. At Shinumo Creek, 35 to 85 percent of rainbow trout were removed through similar methods (Leibfried et al. 2006). In both creeks, however, recolonization rates from upstream and downstream have not been evaluated.

Recently, GCMRC has proposed to implement a strategy to reduce warmwater non-native fish (including crayfish) abundance and negative impacts to native fish found in the Colorado River in Grand Canyon (Hilwig et al., in review). This strategy would very likely be needed to offset potential undesirable positive responses of non-native fish to artificial or natural increases in river temperatures. The draft plan consists of short-term (ca. 1-2 y) fulfillment of baseline information needs followed by implementation of longer-term (8+ y) non-native fish control and management programs.

The initial phase of the draft management plan (1-2 y) would identify the geographic extent of non-native fish occurrence in the watershed immediately surrounding the Colorado River below Glen Canyon Dam, assign risks posed by individual species, evaluate efficacy of current monitoring methods to detect changes, identify effective management methodologies, and assess feasibility of management options. “High risk” species are those (1) currently residing within the immediate Grand Canyon watershed with the strong potential for expansion during warm water periods; (2) possessing a strong proclivity for predation or aggressive behavior; and (3) displaying considerable spatiotemporal overlap with native species of concern. This assessment would likely be informed through bioenergetic investigations (e.g., Petersen and Paukert 2005) and be complemented by investigations into environmental tolerances, life histories and habits of problem species. Management options for high-risk species would include conventional “mechanical” approaches as well as hypothetical use of Glen Canyon Dam operations specifically targeted at disadvantaging non-native fish. Additionally, a more comprehensive system for reporting non-native fish would be developed to allow better information sharing and timelier reporting of new species occurrences to managers. Management of coldwater species (rainbow trout) would be reinitiated and used as an interim methodology to track warmwater occurrence in the Little Colorado River inflow reach.

The long-term aspects of the draft management plan would implement actions identified in the initial phase. Effective strategies for the control of high risk species would be developed and implemented. Considerable emphasis would be placed on implementation of cost-effective, sustainable management strategies. Control measures would focus on exploiting weaknesses of non-native fish life histories, which would likely involve recommendations for specific dam operations. As control measures are undetermined at this time, additional environmental compliance would likely be needed in the future. Management strategies would also be implemented to prevent invasions by source populations of non-native fish, particularly via the Little Colorado River watershed. Results of all management efforts (including response of native fish) would be evaluated at the population level.

4 Effects Analysis

4.1 Humpback chub analytical approach and assumptions

We identified five hypothetical mechanisms by which we expect the Proposed Action to affect humpback chub, two associated with the high flow test and three associated with steady fall flows. The mechanisms are listed below, followed by a description of the analytical approach and assumptions we made in their evaluation.

4.1.1 Displacement of young-of-year humpback chub by high flow tests

Small-bodied humpback chub may be vulnerable to displacement by high flows conducted during periods of cold dam releases (8-10 °C), when their swimming performance is reduced (Bulkley et al. 1982). Likewise, adverse effects of high flow tests on humpback chub during November-December was a concern of the FWS in their 2005 biological opinion and provisions for incidental take were made in the 1995 biological opinion. The high flow test proposed for 2008 wouldn't occur until March, which historically has been viewed as the timeframe posing the least amount of risk to a number of species, including humpback chub (Hoffnagle et al. 1999; Reclamation 1995), the young of which are generally thought to utilize deeper eddies and shoreline cover in the fall and winter months (Valdez and Ryel 1995). However as in 2004, the Colorado River currently supports high numbers of young-of-year humpback chub (Ackerman 2007; Andersen 2007) which would theoretically be vulnerable to displacement by high flow tests, and for that reason we present the following analysis.

Effects of high flows were evaluated by comparing retention rates (i.e., the opposite of displacement, or percentage of fish able to maintain their position in a given reach) expected during a high flow test to those predicted for the median monthly flow in March under MLFF. Retention rates over a range of flows was modeled using a particle tracking algorithm in conjunction with velocity predictions from a 2-D hydrodynamic model developed by Korman et al. (2004). This model was developed using channel bathymetry from seven transects located from RM 61.5 to 66.5, below the LCR confluence. The model contains four assumptions of fish swimming behavior: 1) passive, no swimming behavior; 2) rheotactic, in which particles (or "fish") swim toward lower velocity currents at 0.1 to 0.2 m/s; 3) geotactic, in which particles swim toward the closest bank at 0.2 m/s; and 4) upstream, in which the particle attempts to move upstream at 0.2 m/s. Temperature of the Colorado River in the LCR inflow reach during the proposed time period for high flow tests (early March) typically ranges from 8 to 10 °C (AGFD 1996). At these levels, subadults and young of year may fatigue rapidly and may be unable to withstand swift currents, forage efficiently, or escape predators. Bulkley et al. (1982) reported that swimming ability of juvenile humpback chub (73–134 mm TL) in a laboratory swimming tunnel was positively and significantly related to temperature. Humpback chub forced to swim at a velocity of 0.51 m/sec fatigued after an average of 85 minutes at 20 °C, but fatigued after only 2 minutes at 14 °C, a reduction in time to fatigue by 98 percent. Time to fatigue is presumably further reduced below 14 °C, especially for the smallest individuals. For these reasons, and also to identify the "worst case scenario" of fish displacement, we focused primarily on results for passive swimming behavior in this analysis.

4.1.2 Creation or Improvement of Backwater Habitats

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

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

4.1.3 Creation of More Persistent Suitable Habitat Conditions

The 2-D hydrodynamic model was used to predict two-dimensional fields of depth and velocity over the range of daily flow fluctuations and monthly volumes proposed under the various alternatives (Korman et al. 2004). Specifically, the model evaluated YOY fish habitat availability and suitable habitat persistence in Grand Canyon under MLFF and the Proposed Action. Depth and velocity at seven transects in the first 10 km below the LCR were modeled over the range of flows proposed in the alternative. This model was developed using channel bathymetry from seven transects located from RM 61.5 to 66.5 (Wiele et al. 1996, 1999; Wiele, 1998; Appendix A). Transects ranged from 253 to 993 m in length and represented the full range of shoreline types typically utilized by YOY humpback chub: talus slopes, debris fans, vegetated shorelines, cobble bars, bedrock and sandbars. Descriptions of these shoreline types can be found in Converse et al. (1998). The hydrodynamic model was used successfully to predict patterns of sand deposition following the 1993 flood from the Little Colorado River and during and after the 1996 high flow test (Wiele et al. 1999; Wiele 1998; Wiele et al. 1996). Accuracy of these predictions of erosion and deposition provide a sensitive test of the accuracy of calculated flow fields.

The amount of total suitable habitat at a given flow elevation was computed by summing the total wetted area of each reach where velocity was less than or equal to critical values. Two criteria were evaluated for suitable water velocity: < 0.25 m/s and <0.10 m/s. The first criterion was a composite of several field and laboratory studies published previously, including Bulkley et al. (1982), Valdez et al. (1990) and Converse et al. (1998) (Figure 10). The second criterion was selected to be more representative of a suite of non-native species currently found in the

Little Colorado River or the adjacent mainchannel Colorado River (Table 8; see also Meffe and Minckley 1987; Minckley and Meffe 1987). Depths of <1 m (maximum depth of most HBC habitats sampled in Converse et al. 1998) were used to further restrict predictions on suitable HBC and non-native fish habitat. To further simulate YOY habitat availability, we limited habitat predictions to areas which intersected the streambed and computed habitat over shoreline types.

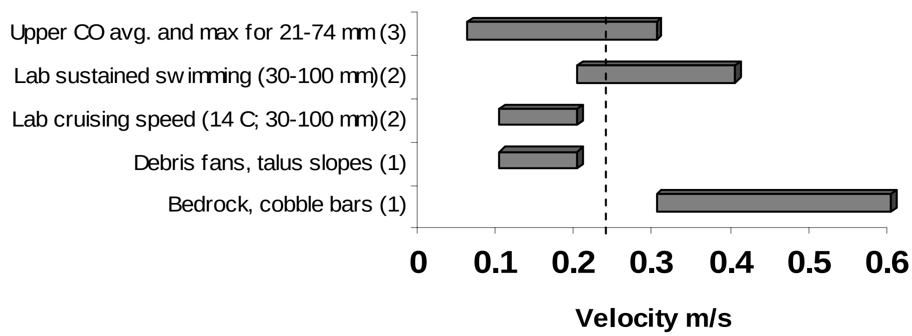


Figure 10. Velocity preference criteria for humpback chub in the Colorado River, Grand Canyon. Sources include (1) Converse et al 1998; (2) Bulkley et al. 1982; and (3) Valdez et al. 1990.

Persistent suitable habitat was used to determine the area of suitable habitat that is stable across daily ranges in discharge (Bowen et al. 1998; Freeman et al. 2001; Korman et al. 2004). The suitable habitat areas at 5,000 cfs, 8,000 cfs, and 15,000 cfs were calculated for each transect. The total area of habitat common to flow elevations is referred to as the amount of "persistent suitable habitat."

Table 8. Preferred water velocities (m/s) for non-native fish found in the vicinity of the Little Colorado River

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

Habitat predictions for discrete flow elevations during September and October were not available, so we used previously published predictions for flows to approximate effects of the Proposed Action (Korman et al. 2004). The assumption is that predictions for habitat persistence at a steady release of 8,000 cfs would approximate September and October steady releases in the Proposed Action (8,000 or 9,000 to 10,000 cfs per day), and that daily ranges between 5,000 cfs and 8,000 cfs would approximate MLLF conditions for the same period (5,000 to 12,000 cfs/day). Higher fluctuations of 8,000 cfs to 20,000 cfs were used to approximate fluctuations at higher flow elevations such as those in July and August. This demonstrated relationships across a range of flows.

We also present absolute values for suitable habitat specific to discrete shoreline types to show habitat availability over a range of discharge found in the Proposed Action and MLFF. We considered the three shoreline types most commonly utilized by humpback chub (talus, vegetated shorelines, debris fans) as well as the total habitat area (<0.25 m/s, <1 m depth) intersecting all shoreline types.

4.1.4 Creation of Warmer Nearshore Habitats

We hypothesized that young-of-year humpback chub growth rates would vary as a function of water temperatures, which in turn vary with flow regime (monthly volume, steady and fluctuating flows during September and October). Since monthly volumes in the Proposed Action and the MLFF are the same, we considered only steady versus fluctuating flows in this analysis. Both mainchannel and backwater temperatures were considered.

We analyzed effects of steady and fluctuating flows using modeled data and empirical backwater and mainchannel temperatures reported in Trammell et al. (2002) in relation to young-of-year humpback chub growth rates (Figure 11). We derived a relationship between water temperature and humpback chub growth rates (mm/day) using observations from laboratory and field studies (Peterson and Paukert 2005; Gorman and VanHoosen 2000; Clarkson and Childs 2000; Lupher and Clarkson 1995; Valdez and Ryel 1995). Test subjects in laboratory studies ranged from about 10 to 80 mm total length at the onset of each study. Growth rates were plotted against temperatures evaluated in each study and fitted the data with a logarithmic regression line (Figure 12). We then evaluated total growth during the month of September by substituting backwater and mainchannel temperatures into the equation shown in Figure 12.

We modeled water temperatures of nearshore habitats, including backwaters, using a 3-D temperature model (Generalized Environmental Modeling System for Surface waters model, or GEMSS; Kolluru and Fichera 2003) in conjunction with reservoir temperature predictions (CE-QUAL-W2; Cole and Wells 2000) routed through the Colorado River in Grand Canyon with a 1-D GEMMS model. The 3-D model focused on nearshore habitats in the Colorado River immediately below the LCR. We evaluated output from the 1-D model, which predicts mainchannel thalweg water temperatures for the LCR inflow reach (approximately RM 61.5).

The 3-D model underestimated water temperatures when compared with empirical observations (AGFD 1996; Trammell et al. 2002) and results are not presented here. This was due to the large cell size in the model (25 m X 25 m). These large cells are too large for fine-scale water temperature predictions, which were shown by Korman et al. (2006) to occur mainly in the zone of flow fluctuations as they intersect the backwater shoreline any backwater in stretch of river below the Little Colorado River. This is a fairly small spatial scale (1-10 m) which will require smaller model cell sizes and additional data collection for calibration.

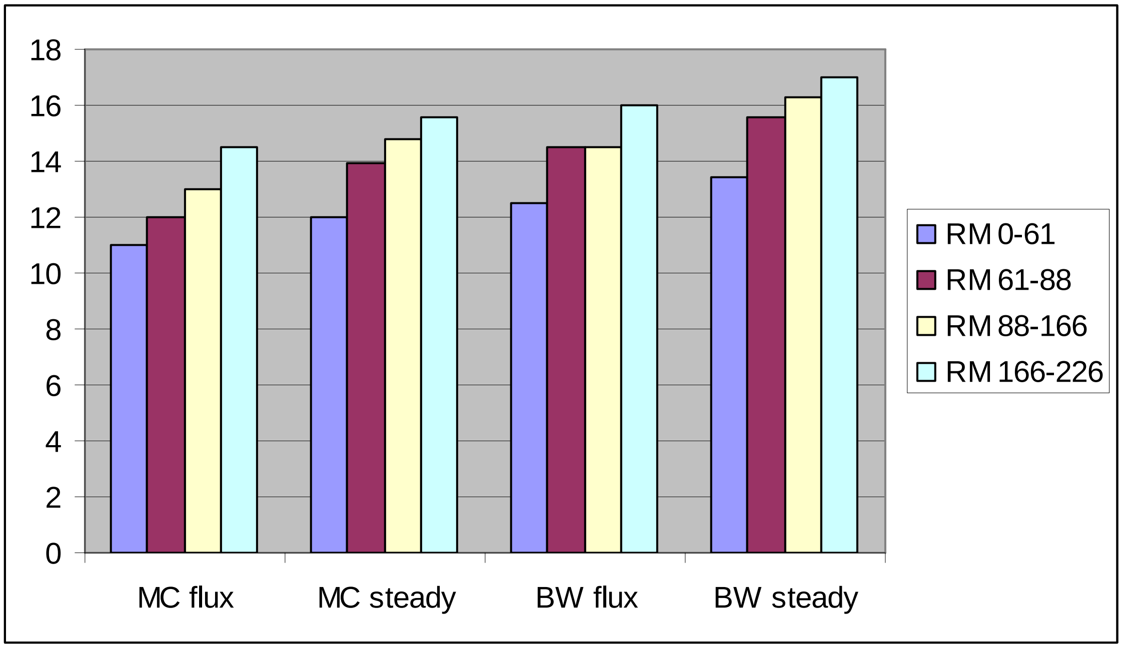


Figure 11. Average river temperatures in the mainchannel Colorado River (MC) and backwaters (BW) under fluctuating discharge ("flux") and steady releases ("steady"). Fluctuating flow data are from 1991-1994 (AGFD, in Trammell et al. 2002) and steady flow observations are from 2000 (Trammell et al. 2002).

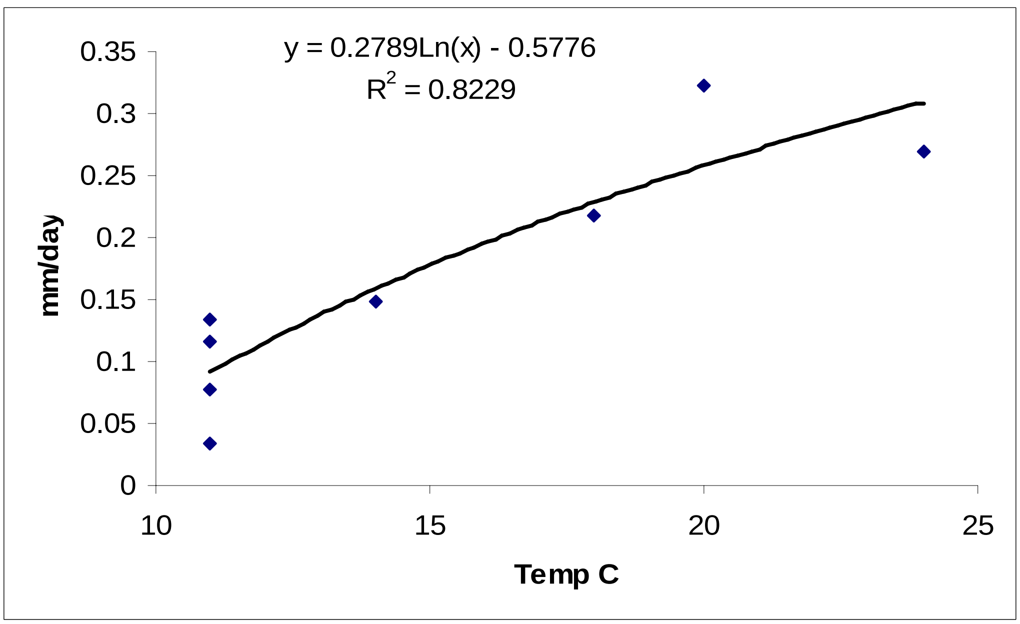


Figure 12. Growth rate of humpback chub (10-80 mm total length) in relation to temperature. Regression line is statistically significant ($P < 0.01$).

4.1.5 Creation of More Productive Nearshore Environments

The effects of the Proposed Action on the availability of invertebrate prey in backwater habitats is evaluated qualitatively in the following sections using existing literature. No modeling was performed for this part of the analysis.

4.2 Humpback Chub Effects Analysis

4.2.1 High Flow Tests and Displacement

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

Korman et al. (2004) predicted that retention rates of small-bodied fish in the Colorado River immediately below the LCR will decrease with increased discharge, but that this pattern tended to vary considerably with reach geomorphology and assumptions on swimming behavior of the fish. Passively drifting fish were the most susceptible to displacement, but also the least sensitive to the effects of variable discharge magnitude. Assuming that passively drifting fish can be used to represent the poor swimming ability of humpback chub at low temperatures, then we would expect that about 21 percent of these fish would be able to maintain their position within a given river reach during high flow tests of 41,500 (Korman et al. 2004) (Figure 13). The retention rate at mean monthly flows for March under MLFF (about 9,400 cfs), by contrast, is predicted to be about 36 percent. Therefore we would expect retention to decrease by 15 percentage points during the Proposed Action; absolute numbers of fish swept downstream would be dependent on young of year population size during March 2008, although this information is unlikely to be available.

Total suitable habitat would also be at a low level across the continuum of flow elevations (Figure 14). However, available habitat over talus and debris fan substrates is not expected to change during high flows as compared to regular MLFF releases (about 9,700 cfs), and area of vegetated shorelines would actually be near its maximum predicted values. Thus if the fish could exploit these unchanged or improved habitats as refuge from high flows, displacement could be minimized (see also Converse et al. 1998).

Conducting a high flow test during the month of March nevertheless appears to pose the fewest risks to young-of-year humpback chub. During this period, occurrence of larval humpback chub in the Colorado River should be minimal or nonexistent. In contrast to the November 2004 high flow test, humpback chub would be about 10 months old in March (as opposed to 5 months), and presumably stronger and better able to adjust position with varying flows. Depending on habitat use and growth rate assumptions, humpback chub should be from 5 to 20 mm larger in March than in November at 8-12 °C (Petersen and Paukert 2005; Gorman and VanHoosen 2000; Valdez and Ryel 1995; Lupher and Clarkson 1994). Hoffnagle et al. (1999) reported no statistically significant change in catch rates of young humpback chub along shorelines before and after the March-April 1996 controlled flood of 45,000 cfs, although catch rates may have declined in 2004 (GCMRC, unpublished).

It is also very likely that non-native fish will experience negative impacts of the high flow tests, perhaps more so than humpback chub due to their preferences for lower water velocities (Table 8). Hoffnagle et al. (1999) noted that the 1996 test had few discernable effects on native fish, but reduced numbers of fathead minnow and plains killifish, presumably by downstream displacement. Trammell et al. (2002) found similar results for fathead minnow during the September 2000 habitat maintenance flow.

Predictions made in Korman et al. (2004) have not been validated via empirical data, so displacement rates of young-of-year humpback chub over a range of operational and experimental flows remain uncertain and should be evaluated. Furthermore, the fate of these fish in downstream reaches is unknown, as neither the exact river reaches they are likely to arrive at nor habitat conditions therein are known. Also, the exact number of fish displaced by high flows will vary markedly by the distribution of fish among discrete shoreline types, as certain shoreline types afford more refuge from high flow velocities than others (i.e., talus slopes as compared to sandbars, etc.). Downstream displacement could provide positive effects for some humpback chub if they are carried to downstream aggregations, survive, and increase the size of these groups.

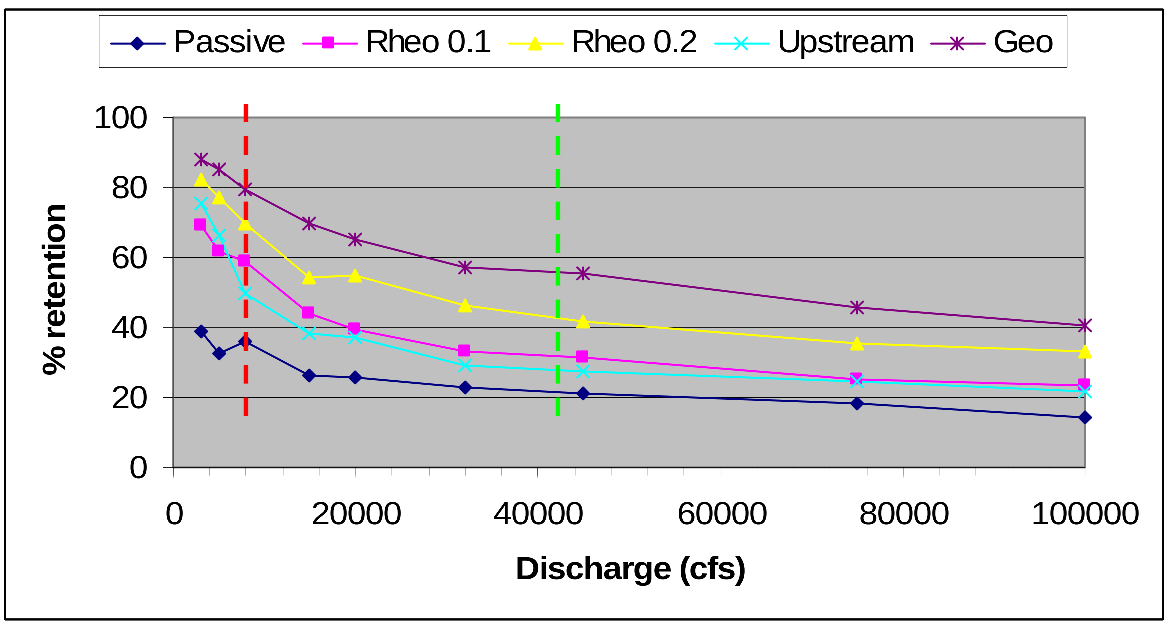


Figure 13. Average percent of simulated young-of-year fish retained within a given river reach over a range of river flows and swimming behavior assumptions. Red vertical line indicates mean flow for MLFF; the green vertical line indicates mean flow during a high flow test. Legend refers to swimming performance assumptions (see text). Data are from Korman et al. 2004.

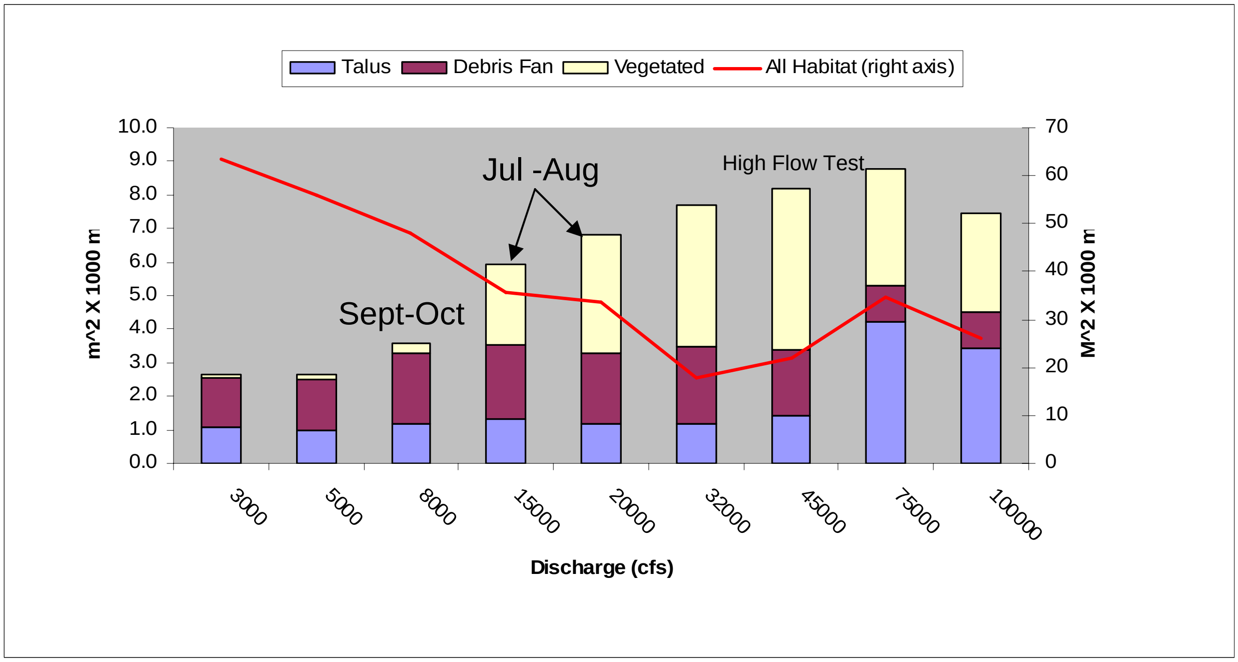


Figure 14. Total suitable habitat (line) and breakdown by shoreline types used by humpback chub. Not shown are habitat areas for cobble bars, sand and bedrock and unmapped portions of transects. 8,000 cfs and 15,000-20,000 cfs estimates approximate habitat conditions for July-August and September-October for both MLFF and the Proposed Action.

High flow tests and backwaters

Immediate physical impacts of high flow tests on backwater habitats include increased relief of bed topography, increased elevation of reattachment bars and deepened return current channels (Andrews et al. 1999). Biologically, the 1996 test significantly reduced backwater macroinvertebrate standing stocks due to scouring of the return current channel, but key taxa (i.e., chironomids) recovered to pre-flood levels within three months (Brouder et al. 1999). Nutrient enrichment due to burial and decomposition of organic matter during the high flow test (Parnell et al. 1999) probably enhanced recovery of benthic macroinvertebrates. As a result, reductions of invertebrate prey had little or no impact on food availability to fish (McKinney et al. 1999; Valdez and Hoffnagle 1999). Finally, since humpback chub probably do not commonly utilize backwaters in March (Valdez and Ryel 1995; proposed time frame for the 2008 high flow test), we do not expect negative effects due to reduced food availability.

One goal of test flows conducted during 1996 and 2004 was redistribution of channel bottom sediment to the channel margins to establish and maintain habitats for young life stages of humpback chub in the mainstream. The chief difference between the proposed 2008 high flow test and previous experiments is that the amount of fine sediment in the system is about 3 times greater than that which triggered the 2004 high flow test. We perceive no significant negative impact on humpback chub from this change. Instead, we anticipate that greater sediment availability during 2008 should lead to more widespread construction of sandbars (Schmidt 1999; Topping et al. 2006), which should increase the likelihood of backwater formation and more nursery habitat for humpback chub. This assumption is an uncertainty that should be framed as a research question and tested.

An outstanding information need for management of Grand Canyon backwaters is the relationship between backwater bathymetry and suitability as fish habitat, specifically the relationship between dam operations, depth, area, volume and thermal characteristics. Goeking et al (2003) point out that large backwaters may not incur as many benefits to young native fish as smaller backwaters because the latter will warm faster and thus remain warmer over time than larger backwaters; however, due to their depth, they may be more frequently available as fish habitat over a greater range of flows. In the Upper Colorado River basin, Colorado pikeminnow were found to utilize backwaters with average depths greater than 0.3 m (Trammell and Chart 1999) and average areas of 992 m^2 (Day et al 1999). The issue of backwater depth is a research need from the standpoint that while greater depths afford more availability over a wide range of flows (Muth et al. 2000), the concurrent increase in volume with depth may slow warming rates.

Persistence of backwaters created during 1996 appeared to be strongly governed by post-high flow dam operations. Whereas the 1996 test resulted in creation of 26 percent more backwaters available as rearing areas for Grand Canyon fishes, most of these newly created habitats disappeared within two weeks due to reattachment bar erosion (Brouder et al. 1999; Hazel et al. 1999; Parnell et al. 1997; Schmidt et al. 2004). Nearly half of the total sediment aggradation in recirculation zones had eroded away during the 10 months following the experiment and was associated in part with relatively high fluctuating flows of 15,000-20,000 cfs (Hazel et al. 1999). Post-test flow regimes to minimize erosion have yet to be developed and tested.

Steady flows and persistent suitable habitat

The net effect of steady flows during September and October on habitat persistence is most likely to be positive. Depending on river location, the amount of persistent habitat increases by 63 to 400 percent when flows are held steady at 8,000 cfs as compared to fluctuations between 5,000 and 8,000 cfs (Korman et al. 2004) (Figure 15). The increase is even more dramatic when compared to higher fluctuations (8,000 to 20,000 cfs), so we assume that the predictions for persistent habitat for flows included under the Proposed Action are similar (i.e., relatively steady flows of 9,000-10,000 cfs as compared to fluctuations between 5,000 to 12,000 cfs per day).

The same benefits of a more stabilized nearshore environment would be accrued for non-native fish; however, their general preference for slightly lower water velocities restricts them to a smaller area than for humpback chub and perhaps other native fish, which tend to be more tolerant of higher velocities (Meffe and Minckley 1987; Minckley and Meffe 1987; Table 8; Figure 16). Depending on the transect, humpback chub have available for their use at any given point under steady flows 16 to 34 percent more habitat than non-native fish, which presumably translates into a competitive advantage for humpback chub and other native fish. Similar trends for both humpback chub and non-native fish are expected during dry years (7.48 maf).

During wet years and years of high reservoir elevation, flow volumes during the transition from September to October could diminish by over 50 percent depending on real-time dam operations decisions; similar transitions could occur between August and September. With that change comes a dramatic decrease in daily minimum flows, which is expected to increase available habitat for humpback chub (Figure 14). However, the rate at which this shift is expected to occur is very rapid and may entail bioenergetic costs to humpback chub forced to relocate in favorable habitat at low velocities. This effect could be exacerbated, for example, if chub are using the vegetated portion of the channel inundated at high flows but then need to readjust at the lower elevations (talus, debris fans; Figure 14). The risk of stranding is also appreciable, so more gradual transitions from one water year to the next during wet years may have important benefits (Section 1.4.1).

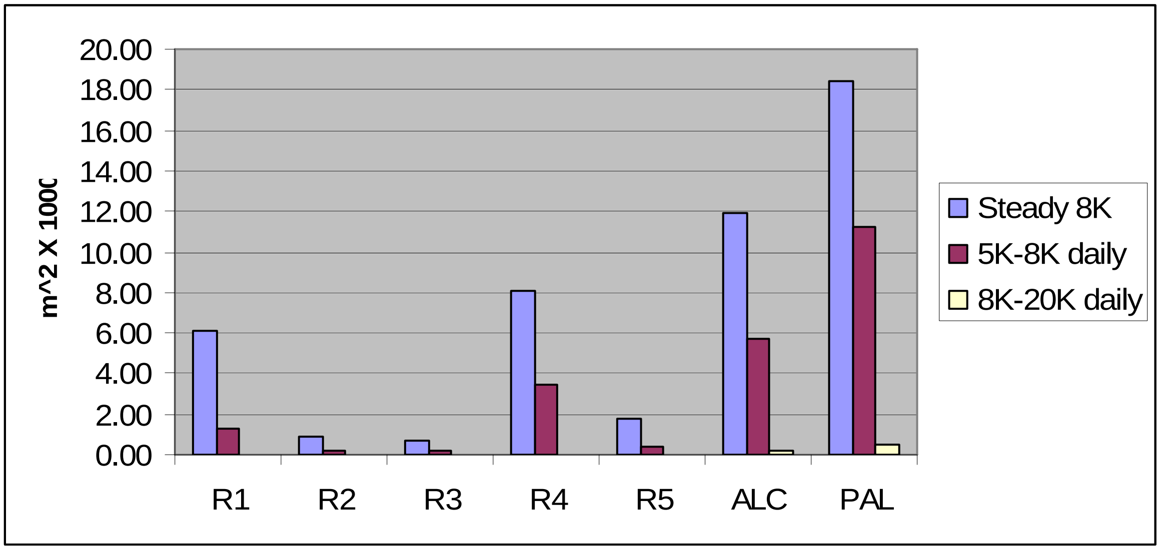


Figure 15. Predicted habitat persistence (m^2 X 1000) for humpback chub suitable habitat among transacts immediately below the Little Colorado River confluence under steady flow conditions (8K), low fluctuating flows (5,000-8,000 cfs daily) and high fluctuating flows (8,000-20,000 cfs). See Figure A.1 for locations of transects. Predictions are from Korman et al. 2004.

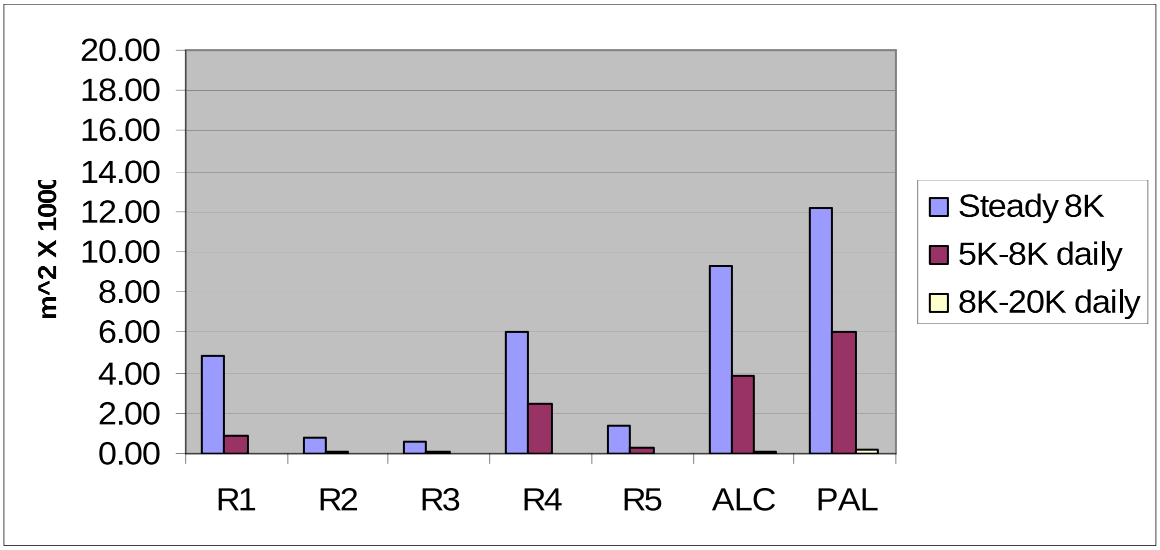


Figure 16. Predicted habitat persistence (m^2 X 1000) for non-native fish suitable habitat among transacts immediately below the Little Colorado River confluence under steady flow conditions (8K), low fluctuating flows (5,000-8,000 cfs daily) and high fluctuating flows (8,000-20,000 cfs). See Figure A.1 for locations of transects. Predictions are from Korman et al. 2004.

Steady flows and temperature

Based on historic data (Trammell et al. 2002), mainchannel water temperatures in September are predicted to be 1-2 °C warmer under steady flow conditions than under fluctuating flows, and backwater temperatures are predicted to be 0.9 to 1.8 °C warmer than the mainchannel. Depending on river reach, humpback chub growth rates during the month of September are predicted to increase by 12 to 36 percent in the mainchannel environment and 9 to 19 percent more in backwaters (Table 9). This increase in growth due solely to changes in temperature could be augmented by any bioenergetic benefits accrued through increased habitat stability and increased abundance in prey. No assessment was possible for October due to lack of information, although Korman et al. (2005) found backwaters to be about 1 °C cooler than the mainchannel during that period.

Modeling results predict much more modest increases in temperature under steady flows than under fluctuating flows, and mostly during the month of October (Figure 17). Thus, the actual warming rate of both the thalweg and backwaters is an uncertainty that should be addressed through monitoring and model validation.

Table 9. Expected changes in mainchannel and backwater temperatures and young-of-year humpback chub growth rates (mm/month) under MLFF and the Proposed Action among river reaches

	Mainchannel					Backwaters				
River Mile	Temperatures Sept 1991-94 (Fluctuating)	Expected growth (mm) under Fluctuating Flows	Temperatures in 2000 under Steady Flows	Expected growth (mm) under Steady Flows	Growth difference (percent), Increase under Steady Flows	Temperatures Sept 1991-94 (Fluctuating)	Expected growth (mm) under Fluctuating Flows	Temperatures in 2000 under Steady Flows	Expected growth (mm) under Steady Flows	Growth difference (percent), Increase under Steady Flows
0-61	11.0	2.7	12.0	3.5	26.6	12.5	3.8	13.4	4.4	15.3
61-88	12.0	3.5	13.9	4.7	35.5	14.5	5.0	15.6	5.7	12.1
88-166	13.0	4.1	14.8	5.2	26.3	14.5	5.0	16.3	6.0	19.4
166-226	14.5	5.0	15.6	5.7	12.1	16.0	5.9	17.0	6.4	8.6

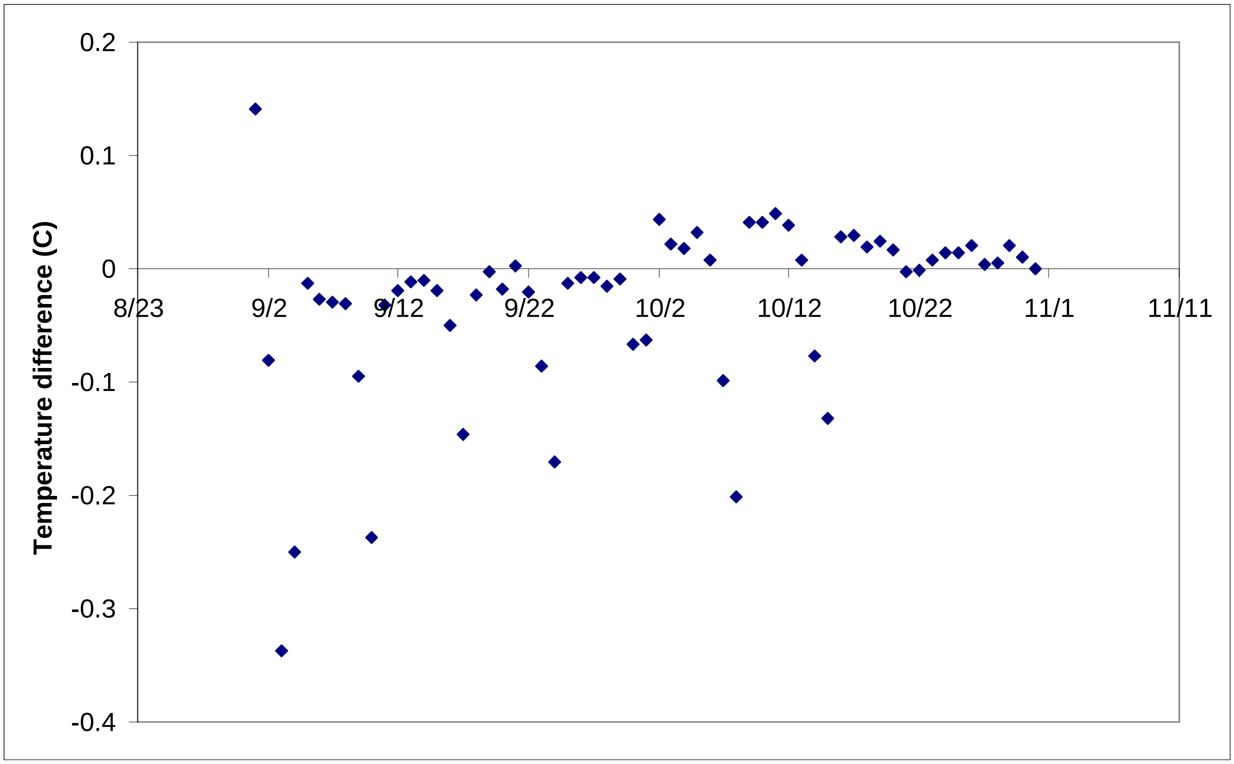


Figure 17. Difference in modeled mainchannel (thalweg) water temperatures between No Action and the Proposed Action at the LCR inflow reach (RM 61.5).

Steady flows and backwater prey availability

In a study conducted in the upper Colorado River basin (middle Green River, Utah) Grand et al (2005) 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 increase, so to does the proportion of backwater water volume, which results in a net export in as much as 30 percent of daily invertebrate production. Potential geomorphic differences between the Grand Canyon and the Upper Colorado River basin underline the need for additional research investigation.

Prey availability may be further enhanced by the creation and improvement of new backwaters from the proposed high flow tests in March 2008. Arizona Game and Fish Department (1996) hypothesized that the 1993 Little Colorado River flood expanded the availability of stable backwater habitats, which coincided with increases of benthic invertebrate standing stocks the following year. Also, Parnell et al. (1999) documented burial of autochthonous vegetation during reattachment bar aggradation, which resulted in increased levels of dissolved organic carbon, nitrogen and phosphorus in sandbar ground water and in adjacent backwaters. These nutrients are thus available for uptake by aquatic or emergent vegetation in the backwater.

Steady flows would occur during a period when benthic invertebrate standing stocks are declining to low winter levels (AGFD 1996). Thus, increases in benthic standing stocks during that period caused by stable flows (and perhaps greater availability of backwaters) would be beneficial to humpback chub as their potential for added growth prior to the onset of winter would be enhanced.

The role of non-native fish management

While effects of increased temperature and invertebrate prey availability are thought to benefit humpback chub, the same could be said of non-native fish, primarily small-bodied cyprinids which utilize the same backwater habitats as humpback chub. Thus, in order for the Proposed Action to be most beneficial to humpback chub, a non-native fish control plan (coldwater and warmwater) would need to be developed and implemented. Progress to this end is being made at this time by GCMRC, and active management of warm water non-native fish should begin as soon as possible.

In the Upper Colorado Basin, Trammell et al. (2004) investigated the feasibility of using mechanical removal to reduce non-native cyprinid fish species in backwater habitats. They concluded that their ability to reduce non-native cyprinid species was limited to short-lived, site-specific reductions in abundance. However, they concluded that such programs could be beneficial to native fish if efficiency was improved and reductions were made just as endangered fish begin to use backwaters in the early summer. They also recommended that additional efforts be conducted in the fall to reduce over-winter competition and suppress non-native fish abundance during the following spring. Finally, they recommended evaluation of additional methods including chemical treatment.

Backwaters tend to concentrate all Grand Canyon fishes. Investigations usually indicate that fish density in backwaters is invariably higher than adjacent mainchannel environments (AGFD 1996; Parnell et al. 1997). This relationship contrasts with the Upper Colorado River basin in that backwater temperatures are often very similar to the mainchannel, so non-native fish are not necessarily restricted to backwaters and, if removed, can recolonize these habitats rapidly. Thus, if sources of non-native fish for recolonization of backwaters in Grand Canyon are relatively infrequent, vulnerability of small-bodied non-native fish to mechanical or chemical renovation of backwaters could be high, and reductions through these means could be longer-lived than in the Upper Basin.

4.2.2 Summary of Effects: Humpback Chub

Some aspects of dam operations contained in the 1996 and 2007 RODs will continue (i.e., daily ramp rates, fluctuation ranges, etc.). The most recent and best available science (Coggins 2007) indicates that there has been increased recruitment into the population from some year classes starting in the mid- to late-1990s, during the period of MLFF operations. This improvement has added credibility to the estimates and contributed to a better understanding of the status and trends of the population. This increase has previously been attributed in part to the results of non-native fish mechanical removal, increases in temperature due to lower reservoir elevations and inflow events, the 2000 low steady summer flow experiment, and/or other experimental flows (USGS 2006a). However, the most recent population modeling indicates the increase was due to increased recruitment as early as 1996 but no later than 1999 (Coggins 2007). The increase in recruitment began at least four and as many as nine years prior to implementation of non-native fish control, incidence of warmer water temperatures, the 2000 low steady summer flow experiment, and the 2004 high flow test. It is also unclear as to whether this increase is attributable to conditions in the mainstem or in the LCR. Population dynamics of non-native fish, humpback chub, hydrology, and other environmental variables in the LCR may have influenced the observed recruitment trends. Nevertheless, we hypothesize that recent changes in non-native fish abundance, temperature, and habitat conditions resulting from natural and experimental actions will likely be beneficial to humpback chub, and the proposed experimental action should provide opportunities to test this hypothesis.

In the absence of conclusive information on factors governing humpback chub recruitment, Reclamation believes that those operational aspects of Glen Canyon Dam of the Proposed Action will not adversely affect humpback chub and hypothesize that the Proposed Action, when tested alongside current operational parameters from the 1996 and 2007 RODs, should actually cause further increases in humpback chub recruitment and abundance.

Table 10. Summary of effects on humpback chub expected to result from the Proposed Action

Proposed Action	Mechanism	Net result*	Duration
High flow test	displacement	negative	60 hours
High flow test	habitat improvement	positive	60 hours
Steady flows	stable habitat	positive	2 months/yr for 5 years
Steady flows	temperature	positive	2 months/yr for 5 years
Steady flows	prey abundance	positive	2 months/yr for 5 years

*assumes that non-native fish control actions are developed, implemented as necessary, and effective

With respect to the Proposed Action, there could be potential take associated with downstream transport of humpback chub during the high flow test; therefore, Reclamation’s finding is the Proposed Action may affect, and is likely to adversely affect humpback chub. The Proposed Action is not expected to adversely modify or destroy critical habitat of humpback chub.

Adverse effects are likely to be short-term and outweighed by benefits derived over longer timeframes. The long-term effects on humpback chub from creation and improvement of rearing habitats are expected to be positive. Effects of the fall steady flows are expected to be positive and result in improved growth and survival of young-of-year humpback chub prior to the onset of winter. Beneficial effects of steady flows in fall months should be especially pronounced during the first few years following the 2008 high flow test. Creation and improvement of backwater rearing habitats expected from the high flow test would expand habitat spatial extent, and steady flow would improve overall habitat stability (persistence) and quality (temperature, prey availability). Implementation of conservation measures identified in the Shortage biological opinion (FWS 2007) is also expected to be positive.

4.2.3 Risks, Uncertainties, and Monitoring

The preceding analysis raises a number of uncertainties associated with the Proposed Action. These uncertainties need to be evaluated through the AMP. These include:

1) Relationship between antecedent sediment availability and backwater formation following a high flow test, including return channel depth and sandbar elevation.

2) Relationship between (1) and suitability of backwaters as humpback chub rearing habitat.

3) Persistence of backwaters created by a high flow test in relation to the post-test flow regime (downramp rates, daily fluctuations, steady fall flows, etc.), including erosion and sedimentation rates.

4) Response of young-of-year humpback chub to steady and fluctuating flows in terms of growth, bioenergetics, survival, behavior and habitat use.

5) Warming rates of mainchannel and nearshore habitats (including backwaters) under steady and fluctuating flows and response of native and non-native fishes.

6) Backwater primary and secondary production and standing mass under steady and fluctuating flows.

7) Future climatic changes throughout the Upper Colorado River basin are uncertain. Responses to increased duration or intensity of droughts are discussed in the Shortage EIS (Appendix N).

Risks have also been identified that are related to uncertainties and unknown responses. These include:

1) Responses by non-native fish to warmer releases from a TCD, or conversely, responses by non-native fish to cold releases in the absence of a TCD.

2) Displacement of humpback chub during high flows.

4.3 Razorback Sucker Effects Analysis

Razorback suckers have not been reported from the action area since 1995, and prior to that time, only 10 confirmed fish had been reported from Grand Canyon (Valdez 1996). The recent absence of wild razorback sucker in the action area has precluded studies of the species in the system and a better understanding of their ecology and life history, as well as habitat needs. The nearest occurrence of the species is downstream in Lake Mead proper with specimens rarely caught in the inflow. Radiotagged fish released in spring of 1997 in the Lake Mead inflow eventually moved into the reservoir and no specimens have been reported from the inflow in recent surveys (Ackerman et al. 2006; Van Haverbeke et al. 2007).

Based on what is known of the razorback sucker from other parts of the Colorado River system, the species has variable habitat requirements. Adults in rivers use deep runs, eddies, backwaters, and flooded off-channel environments in spring; runs and pools often in shallow water associated with submerged sandbars in summer; and low-velocity runs, pools, and eddies in winter. These habitats are limited in Grand Canyon and the lack of suitable habitat is probably responsible for the low numbers of historical captures.

Spring migrations of adult razorback sucker were associated with spawning in historic accounts and a variety of local and long-distance movements and habitat-use patterns have been documented. Spawning in rivers occurs over bars of cobble, gravel, and sand substrates during spring runoff at widely ranging flows and water temperatures and spawning in reservoirs takes place over rocky shoals and shorelines. Spawning habitat may be available for razorback suckers in Grand Canyon, but cool temperatures could limit spawning. Young razorback suckers require nursery environments with quiet, warm, shallow water such as tributary mouths, backwaters, or inundated floodplains in rivers, and coves or shorelines in reservoirs. These habitats are not readily and reliable available in Grand Canyon. In the upper basin, floodplains that become inundated with spring runoff are vital habitat for larvae and young.

High flow test and displacement

The high flow is not expected to affect razorback suckers because there are probably few, if any, fish in the action area. Nevertheless, if adults were in the action area, they would not be affected and should be able to sustain their position because they are regularly exposed to variable flows. Newly hatched razorback suckers typically become transported downstream with spring flows following emergence as larvae. This is part of the natural life history of the species and downstream transport is not considered detrimental. However, there are few if any floodplain habitats in Grand Canyon that provide quiet food-rich habitats for the young fish. Hence, if larvae were present, downstream transport would probably carry the young fish into Lake Mead. This is unlikely since reproduction in Grand Canyon is unlikely.

Steady median flows and persistent habitat

Fall steady flows are not likely to adversely affect razorback suckers in the action area. If young are in the area, they would be several months old and would likely benefit from the stable flows and possibly warm, productive shoreline habitats. Adults, if they were present in the action area, would also likely not be adversely affected by the steady flows, but could benefit from the more stable habitat.

In summary, the Proposed Action is not likely to adversely affect razorback sucker or adversely modify or destroy critical habitat.

4.4 Kanab Ambersnail Effects Analysis

Based on the following analysis, there is potential for take of individual ambersnail and Reclamation has concluded the Proposed Action may affect and is likely to adversely affect the Kanab ambersnail.

The Proposed Action will have no effect on the water flow from the side canyon spring that maintains wetland and aquatic habitat at Vasey's paradise. Kanab ambersnail habitat can be adversely affected by scouring at Colorado River flows exceeding 17,000 cfs. The high flow test will increase flows to 41,500 cfs. These flows will inundate Kanab ambersnail habitat and likely scour the vegetation and carry the snails downstream. During the March 1996 high flow test (45,000 cfs) in the Grand Canyon, up to 17 percent of Kanab ambersnail habitat at Vaseys Paradise was lost or degraded, hundreds of snails were lost, and it took over two years for the habitat to recover to pre-flood conditions (IKAMT 1998; Stevens et al. 1997b). In 2004 during the high flow test, 120 m^2 of the habitat was temporarily removed previous to the high release and replaced following the high flow.

4.5 Southwestern Willow Flycatcher Effects Analysis

The Proposed Action may affect, but is not likely to adversely affect the southwestern willow flycatcher. Critical habitat for the Southwestern willow flycatcher is located beyond the action area. The northern boundary of the critical habitat forms the southern boundary for the action area. Downstream flows as a result of the Proposed Action are not expected to have adverse effects below Separation Canyon.

Southwestern willow flycatchers are known to nest in tamarisk along the Colorado River in the Grand Canyon. The southwestern willow flycatcher can be affected by high flows through scouring and destruction of willow-tamarisk shrub nesting habitat or wetland foraging habitat. Conversely, a reduction in flows could have adverse effects on riparian and marsh vegetation, which could adversely affect southwestern willow flycatcher. Willow flycatcher nests in the Grand Canyon are typically above the 45,000 cfs stage (Gloss et al. 2005), which will not be exceeded for the high-flow test. Furthermore, the time frame for the planned high-flow test is outside of the nesting period for southwestern willow flycatchers. Southwestern willow flycatcher nest in primarily tamarisk shrub in the lower Grand Canyon which is quite common along the Colorado River in the Grand Canyon. Tamarisk is not an obligate phreatophtye and is capable of surviving lowered water levels. Therefore, the potentially lower flows in September and October associated with the Proposed Action are not expected to kill tamarisk and thus no loss of southwestern willow flycatcher nesting habitat is anticipated.

An important element of flycatcher nesting habitat is the presence of moist surface soil conditions. Moist surface soil conditions are maintained by overbank flow or high groundwater elevations supported by river stage. During September and October steady flow periods flows will likely be lower than those found under the no-action peak releases. The potential exists for groundwater elevations adjacent to the channel to decline through the steady flows, which could desiccate nesting habitat and result in take of southwestern willow flycatcher. The probability for such take is considered to be low since the period for the Proposed Action is outside of the normal nesting period for southwestern willow flycatcher and the level of any such take would be low because only a few nest sites are known from this reach of the Colorado River and. The level of this effect is not expected to substantively affect the abundance or distribution of southwestern willow flycatcher in the action area or regionally.

4.6 Effects of Climate Change

The Fourth Assessment Report (Summary for Policymakers) of the Intergovernmental Panel on Climate Change (IPCC 2007), presented a selection of key findings regarding projected changes in precipitation and other climate variables as a result of a range of unmitigated climate changes projected over the next century. Although annual average river runoff and water availability are projected to decrease by 10-30 percent over some dry regions at mid-latitudes, information with regard to potential impacts on specific river basins is not included. Recently published projections of potential reductions in natural flow on the Colorado River Basin by the mid 21st century range from approximately 45 percent by Hoerling and Eischeid (2006), to approximately 6 percent by Christensen and Lettenmaier (2006), but, as documented in the Shortage EIS (Appendix N), these projections are not at the spatial scale needed for CRSS, the model used to project future flows.

The hydrologic model, CRSS, used as the primary basis of the effects analysis does not project future flows or take into consideration projections such as those cited above, but rather relies on the historic record of the Colorado River Basin to analyze a range of possible future flows. Using CRSS, projections of future Lake Powell reservoir elevations are probabilistic, based on the 100-year historic record. This record includes periods of drought and periods with above average flow. However, studies of proxy records, in particular analyses of tree-rings throughout the upper Colorado River Basin indicate that droughts lasting 15-20 years are not uncommon in the late Holocene. Such findings, when coupled with today's understanding of decadal cycles brought on by ENSO and PDO (and upstream consumptive use), suggest that the current drought could continue for several more years, or the current dry conditions could shift to wetter conditions at any time (Webb et al. 2005). Thus, the action period may include wetter or drier conditions than today. An analysis of hydrologic variability and potential alternative climate scenarios is more thoroughly discussed in the Shortage EIS (Appendix N) and is incorporated by reference here.

Although precise estimates of the future impacts of climate change throughout the Colorado River Basin at appropriate spatial scales are not currently available, these impacts may include decreased mean annual inflow to Lake Powell, including more frequent and more severe droughts. Such droughts may decrease the average storage level of Lake Powell, which could correspondingly increase the temperature of dam releases. Increased release temperatures have been cited as one potential factor in the recent increase of juvenile humpback chub (USGS Fact Sheet 2007) but concerns also exist that warmer aquatic habitat will also increase the risk of warm water non-native fish predation. To allay this risk if such warming occurs, in the Shortage biological opinion Reclamation has committed to the monitoring and control of non-native fish as necessary, in coordination with other Department of the Interior agencies and working through the AMP (FWS 2007).

5 Incidental Take

The Reasonable and Prudent alternative of the 1995 biological opinion (FWS 1995) includes habitat/beach building flows; however, the FWS determined some humpback chub and Kanab ambersnail would be taken during such an event. Similar judgments accompanied the 2004 high flow test. The discussion of incidental take in the 1995 biological opinion considers testing and studies to determine impacts of flows on young humpback chub. We anticipate a similar requirement for take under the current Proposed Action to evaluate the fate of humpback chub and Kanab ambersnail displaced by high flow tests, including numbers displaced and final disposition (location and habitat availability) of surviving humpback chub individuals.

6 Conservation Measures

Reclamation recognizes that conservation measures contained in the Shortage biological opinion (Section 2.1.5) will materially contribute to the conservation and protection of listed species in the action area. In addition, Reclamation offers the following conservation measures to enhance humpback chub conservation and reduce incidental take of Kanab ambersnail.

Humpback chub

In addition to the anticipated positive benefits to humpback chub conservation that have been used to develop the Proposed Action, during the five year experimental period, Reclamation will also use its available discretion in determining monthly release volumes so that monthly releases during the proposed steady flow months of September and October remain fairly similar. Our ability to achieve this transition depends not only on the state of the reservoir and on any need for equalization releases, but also the official inflow forecast received from the Colorado River Forecast Center throughout the water year and consultation within the Colorado River Management Work Group. A more gradual transition in the dam release volumes of those months should minimize sudden changes in humpback chub habitat type and any bioenergetic costs associated with their adaptation to the change. Notwithstanding the potential for modest variation in the monthly volumes during September and October, Reclamation will implement the steady flow element of the Proposed Action set forth in Section 1.3.1 above.

Kanab ambersnail

Prior to the high flow test, Reclamation proposes to move approximately 25 percent of the area of Kanab ambersnail habitat (150 m^2; watercress, monkeyflower, and other plants) and the ambersnails living in that habitat at Vaseys Paradise from below the zone of inundation prior to an above power plant capacity experimental flow. This action would be conducted only during March 2008 under the current proposal. The habitat and ambersnails would be held locally above the level of inundation until the experimental flow, which has an expected duration of 60 hours, has receded. At that time, the habitat and associated ambersnails would be replaced in such a manner as to facilitate the regrowth of the vegetation forming the habitat for the ambersnails. Past experience gained during the 1996 high flow test (45,000 cfs) revealed that nearly all vegetation and ambersnails below the level of inundation were scoured and carried downstream. This experience also indicated that, without supplementation, it took approximately two years for the vegetation to reach its former area and volume. The proposed conservation measure is designed decrease the incidental take from mortality during experimental flows, which will be particularly important if the action agencies and the AMP propose even higher experimental flows in the future. Subsequent monitoring of the effects of this action conducted under the auspices of the GCMRC would be used to determine the survivorship of ambersnails and the rate of regrowth of the replaced vegetation.

A second potential agency action for Kanab ambersnail, which was identified in the September 2002 environmental assessment/biological assessment, was to augment the Elves Chasm population that was established by translocation of individuals from Vaseys Paradise in 1998. Periodic augmentation of translocated populations by Kanab ambersnails from Vaseys Paradise was identified in the biological opinion on the 1998 translocation as an action that the National Park Service may undertake. The primary purpose of augmentation would be to help ensure that the genetic identity of the translocated population does not deviate from the source population at Vaseys Paradise.

The Elves Chasm translocation was one of three undertaken by the National Park Service, AGFD and cooperators in an attempt to achieve a goal of redundant populations in the recovery plan and to address a reasonable and prudent measure in the February 1996 biological opinion on the 1996 high flow test. Reclamation has supported monitoring of both Vaseys Paradise and Elves Chasm populations of Kanab ambersnail through the AMP. This reasonable and prudent measure was removed by the FWS on July 12, 2000, pursuant to their discovery that the level of incidental take for the beach habitat building flow had been underestimated.

In addition, the FWS is in the process of evaluating the genetic status of the Vaseys Paradise population of ambersnail. Reclamation suggests that at the conclusion of this work that Reclamation and the FWS discuss what measures, if any, should be taken with respect to the Elves Chasm population of ambersnail.

7 Literature Cited

Aadland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790-806

Abate, P. D., T. Welker, and P.B. Holden. 2002. Razorback sucker studies on Lake Mead, Nevada and Arizona 2001 - 2002 annual report PR 578-6. Department of Resources; Southern Nevada Water Authority, Las Vegas, NV.

Ackmerman, M. W. 2007. Native fish monitoring activities in the Colorado River, Grand Canyon. Draft Report to Grand Canyon Monitoring and Research Center from SWCA, Inc., Flagstaff, Arizona.

Ackerman, M. W., D. Ward, T. Hunt, R. S. Rogers, D. R. VanHaverbeke, A. Morgan, and C. Cannon. 2006. 2006 Grand Canyon long-term fish monitoring in the Colorado River, Diamond Creek to Lake Mead. Annual report to the Grand Canyon Monitoring and Research Center, Flagstaff.

Ackmerman, M. W. 2007. 2006 native fish monitoring activities in the Colorado River, Grand Canyon. Draft Report to Grand Canyon Monitoring and Research Center from SWCA, Inc., Flagstaff, Arizona.

Albrecht, B., and P. B. Holden. 2006. Razorback Sucker studies on Lake Mead, Nevada and Arizona. 2005-2006 Annual Report. Prepared for the Department of Resources, Southern Nevada Water Authority. Prepared by Bio-West, Inc. Logan, Utah. PR-977-1.

Allison, L. J., C. E. Paradzick, J. W. Rourke, and T. D. McCarthey. 2003. A Characterization of Vegetation in Nesting and Non-Nesting Plots for Southwestern Willow Flycatchers in Central Arizona. Studies in Avian Biology 26:81-90.

Andersen, M. E. 2007. Preliminary data regarding young humpback chub in Marble Canyon. Letter to the GCDAMP Technical Work Group. Grand Canyon Monitoring and Research Center, Flagstaff.

Andrews, E. D. 1991. Sediment transport in the Colorado River basin. Pp. 54-74 in Marzolf, G.R. and others, Colorado River ecology and dam management. National Academy Press, Washington DC. 276 p.

Andrews, E. D., C. E. Johnston, J. C. Schmidt, and M. Gonzales. 1999. Topographic evolution of sandbars. Pages 117-130 in Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez, eds., The controlled flood in Grand Canyon. American Geophysical Union monograph 110.

Archer, D. L., L. R. Kaeding, B. D. Burdick, and C. W. McAda. 1985. A study of the endangered fishes of the upper Colorado River. Final Report of U.S. Fish and Wildlife Service, Grand Junction, Colorado, to Northern Colorado Water Conservancy District.

Arizona Game and Fish Department. 1994. Glen Canyon Environmental Studies Phase II, 1993. Draft Annual Report to U.S. Bureau of Reclamation, Upper Colorado Region, Glen Canyon Environmental Studies, Flagstaff, Arizona.

Arizona Game and Fish Department. 1996a. The ecology of Grand Canyon backwaters. Final Report to U.S. Bureau of Reclamation, Upper Colorado Region, Glen Canyon Environmental Studies, Flagstaff, Arizona.

Arizona Game and Fish Department. 1996b. The effects of an experimental flood on the aquatic biota and their habitats in the Colorado River, Grand Canyon, Arizona. Final Report. Arizona Game and Fish Department, Phoenix.

Arizona Game and Fish Department. 1996c. Ecology of Grand Canyon backwaters. report to Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, AZ. 155 pp.

Arizona Game and Fish Department AGFD. 1998. Environmental Assessment: Establishment of new populations of Kanab ambersnail in Grand Canyon (Coconino County , Arizona). Prepared by AGFD for the National Park Service.

Arizona Game and Fish Department. 2006. Development of fish monitoring (electrofishing) and recent trends in the Grand Canon fish community. Presentation to the GCDAMP Technical Work Group, November 2006. cited December 17, 2007. Available from http://www.usbr.gov/uc/rm/amp/twg/mtgs/06nov08/Attach_07.pdf

Baltz, D. M., B. Vondracek, L. R. Brouwn, and P. B. Moyle. 1991. Seasonal changes in microhabitat selection by rainbow trout in a small stream. Transactions of the American Fisheries Society 120:166-176.

Bestgen, K. R. 1990. Status review of the razorback sucker, *Xyrauchen texanus*. Final Report of Colorado State University Larval Fish Laboratory to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Bestgen, K. R., D. W. Beyers, G. B. Haines, and J. A. Rice. 1997. Recruitment models for Colorado squawfish: tools for evaluating relative importance of natural and managed processes. Final Report of Colorado State University Larval Fish Laboratory to U.S. National Park Service Cooperative Parks Study Unit and U.S. Geological Survey Midcontinent Ecological Science Center, Fort Collins, Colorado.

Beus, S. S., M. A. Kaplinksi, J. E. Hazel, and L. Kearsley. 1994. Monitoring the effects of interim flows from Glen Canyon Dam on sand bar dynamics and campsite size in the Colorado River corridor, Grand Canyon National Park, AZ. Draft final report submitted to Glen Canyon Environmental Studies, U.S. Bureau of Reclamation.

Blinn, W. J. P. Shannon, L. E. Stevens and J. P. Carder. 1995. Consequences of fluctuating discharge for lotic communities. Journal of the North American Benthological Society 14(2):233-248.

Bowen, Z. K., M. C. Freeman, and K. D. Bovee. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. Transactions of the American Fisheries Society 127:455-468.

Bozek, M. A., L. J. Paulson, and J. E. Deacon. 1984. Factors affecting reproductive success of bonytail chubs and razorback suckers in Lake Mohave. Technical Report No. 12. Lake Mead Limnological Research Center, Department of Biological Sciences, University of Nevada, Las Vegas.

Bozek, M. A., L. J. Paulson, and J. E. Deacon. 1991. Spawning season of the razorback sucker, *Xyrauchen texanus*, in Lake Mohave, Arizona and Nevada. Journal of Freshwater Ecology 6:61–73.

Bozek, M. A., L. J. Paulson, and G. R. Wilde. 1990. Effects of ambient Lake Mohave temperatures on development, oxygen consumption, and hatching success of the razorback sucker. Environmental Biology of Fishes 27:255–263.

Bradford, R. H., S. D. Gurtin, and B. R. Vlach. 1999. Habitat use by razorback suckers, *Xyrauchen texanus*, implanted with ultra-sonic transmitters and released into the Imperial Division, Lower Colorado River. Proceedings of the Desert Fishes Council 29:4.

Brouder, M. J. 1997. Glen Canyon Environmental Studies Colorado River native fish study, 1995 annual report. Arizona, Arizona Game and Fish Department. Research Branch, Phoenix, AZ.

Brouder, M. J. 1999. Paria River native fish monitoring 1996-98. Annual report. Arizona Game and Fish Department. Research Branch, Phoenix, AZ.

Brouder, M. J., D. W. Speas and T. L. Hoffnagle. 1999. Changes in number, sediment composition and benthic invertebrates of backwaters. Pages 241-248 in Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez, eds., The controlled flood in Grand Canyon. American Geophysical Union monograph 110.

Brouder, M. J., and T. L. Hoffnagle. 1997. Distribution and prevalence of the Asian tapeworm, *Bothriocephalus acheilognathi*, in the Colorado River and tributaries, Grand Canyon, Arizona, including two new host records. Journal of Helminthological Society of Washington 64:219–226.

Browning, M. R. 1993. Comments on the Taxonomy of *empidonax traillii* (Willow Flycatcher). *Western Birds* 24:241-57.

Bulkley, R. V., C. R. Berry, R. Pimental, T. Black. 1982. Tolerance and preferences of Colorado River endangered fishes to selected habitat parameters. Colorado River Fishery Project Final Report Part 3. Bureau of Reclamation, Salt Lake City.

Bulkley, R. V., C. R. Berry, R. Pimentel, and T. Black. 1981. Tolerance and preferences of Colorado River endangered fishes to selected habitat parameters. Pages 185–241 in Part

3, Colorado River Fishery Project, Final Report. U.S. Fish and Wildlife Service and Bureau of Reclamation, Contracted Studies, Salt Lake City, Utah.

Bulkley, R. V., and R. Pimentel. 1983. Temperature preference and avoidance by adult razorback suckers. Transactions of the American Fisheries Society 112:601–607.

Bulow, F. J., J. R. Winningham, and R. C. Hooper. 1979. Occurrence of copepod parasite *Lernaea cyprinacea* in a stream fish population. Transactions of the American Fisheries Society 108:100–102.

Burke, T. 1994. Lake Mohave native fish rearing program. U.S. Bureau of Reclamation, Boulder City, Nevada.

Burke, T., and G. Mueller. 1993. Native Fish Work Group, 1992 Annual Report. U.S. Bureau of Reclamation, Boulder City, Nevada.

Carothers, S. W., and C. O. Minckley. 1981. A survey of the fishes, aquatic invertebrates and aquatic plants of the Colorado River and selected tributaries from Lees Ferry to Separation Rapids. Final Report to U.S. Bureau of Reclamation, Museum of Northern Arizona, Flagstaff.

CENR (Committee on Environment and Natural Resources). 1999. Ecological risk assessment in the federal government. Executive Office of the President of the United States, National Science and Technology Council, Report CENR/5-99/001, Washington, D.C.

Childs, M.R., R.W. Clarkson, and A.T. Robinson. 1998. Resource use by larval and early juvenile native fishes in the Little Colorado River, Grand Canyon, Arizona. Transactions of the American Fisheries Society 127:620–629.

Choudhury, A., T.L. Hoffnagle, and R.A. Cole. 2003. Parasites of Native and Non-native Fishes of Lower Little Colorado River, Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Choudhoury, A., T. L. Hoffnagle, and R. A. Cole. 2001. Parasites of Native and Non-native Fishes of the Little Colorado River, Grand Canyon, Arizona. Journal of Parasitology 90 (5):1042-1053.

Choudhury, A., T. L. Hoffnagle, and R. A. Cole. 2004. Parasites of Native and Non-Native Fishes of the Little Colorado River, Grand Canyon, Arizona. Journal of Parasitology 90:1042-53.

Christensen, N. and D. P. Lettenmaier. 2006. A multimodel ensemble approach to assessment of climate change impacts on the hydrology and water resources of the Colorado River basin, Hydrology and Earth System Sciences Discussion 3:1-44.

Clarke, A. H. 1991. Status Survey of Selected Land and Freshwater Gastropods in Utah. Denver, CO: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

Clarkson, R. W. 1993. Unpublished data on fecundity of humpback chub in the Little Colorado River, Grand Canyon, Arizona. Arizona Game and Fish Department, Phoenix.

Clarkson, R. W., A. T. Robinson, and T. L. Hoffnagle. 1997. Asian tapeworm, *Bothriocephalus acheilognathi*, in native fishes from the Little Colorado River, Grand Canyon, Arizona. Great Basin Naturalist 57:66–69.

Clarkson, R. W., E. D. Creef, and D. K. McGuinn-Robbins. 1993. Movements and habitat utilization of reintroduced razorback suckers (*Xyrauchen texanus*) and Colorado squawfish (*Ptychocheilus lucius*) in the Verde River, Arizona. Special Report. Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix.

Clarkson, R. W. and M. R. Childs. 2000. Temperature effects of hypolimnial-release dams on early life stages of Colorado River basin big-river fishes. Copeia 2000(2):402-412.

Coggins, L. G. 2007. Abundance trends and status of the Little Colorado River population of humpback chub: an update considering 1989-2006 data. United States Geological Survey open file report 2007-1402.

Coggins, L., C. Walters, C. Paukert, and S. Gloss. 2003. An overview of status and trend information for the Grand Canyon population of the humpback chub, Gila cypha. [online] http://www.gcmrc.gov/library/reports/biological/Fish_studies/GCMRC/coggins2003a.pdf.

Coggins, L.G., Jr., and D.R. Van Haverbeke. 2001. Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2000. Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Coggins, L. and M. Yard. 2003. Non-native fish removal efforts in Grand Canyon: A proposed modification to ongoing activities. Grand Canyon Monitoring and Research Center, Flagstaff.

Coggins, L., and M. Yard. 2003. Mechanical removal of non-native fishes in the Colorado River in Grand Canyon: update of winter operations and findings. U.S. Geological survey, Flagstaff, AZ. [online] http://www.gcmrc.gov/library/reports/biological/Fish_studies/GCMRC/coggins2003.pdf.

Coggins, L., M. Yard, and C. Paukert. 2002. Piscivory by non-native salmonids in the Colorado River and an evaluation of the efficacy of mechanical removal of non-native salmonids. Grand Canyon Monitoring and Research Center, Flagstaff, AZ. [online] http://www.usbr.gov/uc/ envprog/amp/amwg/mtgs/03mar28/lc_mod_fishremprop_attach10.pdf.

Coggins, L. G., W. E. Pine III, C. J. Walters, and S. J. D. Martell. 2006. Age-Structured Mark-Recapture Analysis: A Virtual-Population-Analysis-Based Model for Analyzing Age-Structured Capture-Recapture Data. North American Journal of Fisheries Management 26:201-205.

Coggins, L. G., W. E. Pine III, C. J. Walters D. R. Van Haverbeke, D. Ward, and H. C. Johnstone. 2006. Abundance Trends and Status of the Little Colorado River Population of Humpback Chub. North American Journal of Fisheries Management 26:233-245.

Cole, R. A., A. Choudhury, and T. L. Hoffnagle. 2002. Parasites of Native and Non-native Fishes of Lower Little Colorado River, Arizona. National Wildlife Health Center, Biological Resources Division, USGS, Madison, Wisconsin.

Cole, T.M. and S. Wells. 2000. CE-QUAL-W2: A Two-Dimensional, Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.

Converse, Y. K., C. P. Hawkins, and R. A. Valdez. 1998. Habitat Relationships of Subadult Humpback Chub in the Colorado River through Grand Canyon: Spatial Variability and Implications of Flow Regulation. Regulated Rivers 14(3):267-284.

Creef, E. D., R. W. Clarkson, and D. K. McGuinn-Robbins. 1992. Razorback sucker (*Xyrauchen texanus*) and Colorado squawfish (*Ptychocheilus lucius*) reintroduction and monitoring, Salt and Verde Rivers, Arizona, 1991–1992. Arizona Game and Fish Department, Research Branch Completion Report to U.S. Fish and Wildlife Service, Office of Endangered Species, Albuquerque, New Mexico.

Davis, E., and W. W. Batham. 2003. Stranding of rainbow trout during experimental fluctuating releases from Glen Canyon Dam on the Colorado River. Final Report. EcoPlan Associates, Inc., Mesa, AZ. [online] http://www.gcmrc.gov/library/reports/biological/Fish_studies/Ecoplan/Davisw2003.pdf.

Day, K. S. K. D. Christopherson, and C. Crosby. 1999. An assessment of young-of-year Colorado pikeminnow *Ptychocheilus lucius* use of backwater habitats in the Green River, Utah. Report B in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report to Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City.

DeLay, L. S., S. H. Stoleson, and M. Farnsworth. 2002. A Quantitative Analysis of the Diet of Southwestern Willow Flycatchers in the Gila Valley, New Mexico. Cortaro, AZ: T&E Inc. 13 pp.

Dill, W. A. 1944. The fishery of the lower Colorado River. California Fish and Game 30(2):109–211.

Douglas M. R., M. E. Douglas M.E. 2000. Late season reproduction by big river Catostomidae in Grand Canyon. Copeia, 2000:238—244.

Douglas, M. R. and M. E. Douglas. 2003a. Genetic interrelationships of *Gila cypha* in the Colorado River ecosystem. Abstract, The Colorado River: an ecosystem science symposium. Tucson, AZ, October 28-30, 2003. Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Douglas, M. E. and M. R. Douglas. 2003b. Effective population sizes for *Gila cypha* in the Colorado River ecosystem. Abstract, The Colorado River: an ecosystem science symposium. Tucson, AZ, October 28-30, 2003. Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Douglas, M. R., and M. E. Douglas. 2007. Genetic structure of humpback chub Gila cypha and roundtail chub G. robusta in the Colorado River ecosystem. Final Report to Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Douglas M. E., and P. C. Marsh. 1996. Population estimates/ population movements of Gila cypha, an endangered cyprinid fish in the Grand Canyon region of Arizona. Copeia, 1996, 15-28.

Douglas, M. E., and P. C. Marsh. 1998. Population and survival estimates of *Catostomus latipinnis* in northern Grand Canyon, with distribution and abundance of hybrids with *Xyrauchen texanus*. Copeia 1998:915–925.

Dowling, T. E., and W. L. Minckley. 1993. Mitochondrial DNA diversity within and among populations of the razorback sucker, *Xyrauchen texanus.* Proceedings of the Desert Fishes Council 24: 64.

Drost, C. A., E. H. Paxton, M. K. Sogge, and M. J. Whitfield. 2001. Food Habitats of the Endangered Southwestern Willow Flycatcher." In final report to the U.S. Bureau of Reclamation, 24. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Colorado Plateau Field Station.

Drost, C. A., E. H. Paxton, M. K. Sogge, and M. J. Whitfield. 2003. Food Habitats of the Southwestern Willow Flycatcher During the Nesting Season. Studies in Avian Biology 26:96-103.

Drost, C. A., M. K. Sogge, and E. Paxton. 1998. Preliminary Diet Study of the Endangered Southwestern Willow Flycatcher. Phoenix, AZ: U.S. Department of the Interior, U.S. Geological Survey, Colorado Plateau Research Station.

Durst, S. L. 2004. Southwestern Willow Flycatcher Potential Prey Base and Diet in Native and Exotic Habitats. M.S. Thesis, Northern Arizona University.

Durst, S. L., M. K. Sogge, H. C. English, S. O. Williams III, B. E. Kus, and S. J. Sferra. 2005. Southwestern Willow Flycatcher Breeding Site and Territory Summary – 2004. In report to U.S. Bureau of Reclamation, 18. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Southwest Biological Science Center, Colorado Plateau Research Station.

Edwards, R. J. 1997. Ecological profiles for selected stream-dwelling Texas freshwater fishes. Report to the Texas Water Development Board. University of Texas-Pan American, Edinburg.

English, H. C., A. E. Graber, S. D. Stump, H. E. Telle, and L. A. Ellis. 2006. Southwestern Willow Flycatcher 2005 Survey and Nest Monitoring Report. In Nongame and Endangered Wildlife Program Technical Report 248. Phoenix, AZ: Arizona Game and Fish Department.

Failing, L., J. Korman, and C. Walters. 2003. Summary of results from AMP TWG multi-attribute evaluation workshop. Ecometrics, Inc., Vancouver, British Columbia. 24 p.

Flagg, R. 1982. Disease survey of the Colorado River fishes. Pages 177–184 *in* Colorado River Fishery Project, Final Report, Part 3: Contracted Studies. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Freeman, M. C., Z. H. Bowen, K. D. Bovee, and E. R. Irwin. 2001. Flow and habitat effects on juvenile fish abundance in natural and altered flow regimes. Ecological Applications 11(1):179-190.

Garrett, D., J. Baron, V. Dale, L. Gunderson, A. Howard, D. Hulse, J. Kitchell, J. Loomis, M. Palmer, R. Parker, D. Robertson, D. Schwartz, and J. Watkins. 2003. Evaluating a Glen Canyon Dam temperature control device to enhance native fish habitat in the Colorado River: a risk assessment by Adaptive Management Program Science Advisors. July 2003.

GCDAMP (Glen Canyon Dam Adaptive Management Program) Science Advisors. 2003. Grand Canyon Dam Adaptive Management Program Science Advisor review comments on the report; "Status and management strategy for humpback chub in Grand Canyon." Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ and Bureau of Reclamation, Salt Lake City, UT. July 2003.

Gloss, S. P., and L. G. Coggins. 2005. Fishes of Grand Canyon. Pages 33-56 in Gloss, S.P., J.E. Lovich, and T.S. Melis (editors). The state of the Colorado River ecosystem in Grand Canyon. A report of the Grand Canyon Monitoring and Research Center 1991-2004. USGS Circular 1282. U.S. Geological Survey, Flagstaff, Arizona.

Gloss, S. P., J. E. Lovich, and T. S. Melis (editors). 2005. The state of the Colorado River ecosystem in Grand Canyon. A report of the Grand Canyon Monitoring and Research Center 1991-2004. USGS Circular 1282. U.S. Geological Survey, Flagstaff, Arizona.

Goeking, S. A., J. C. Schmidt and M. K. Webb. 2003. Spatial and temporal trends in the size and number of backwaters between 1935 and 2000, Marble and Grand Canyons, AZ. Progress report submitted to Grand Canyon Monitoring and Research Center. Department of Aquatic, Watershed and Earth Resources, Utah State University, Logan.

Gorman, O. T. 1994. Habitat use by humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Glen Canyon Environmental Studies Phase II Final Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Flagstaff, Arizona.

Gorman, O. T., D. M. Stone, and J. M. Seals. 1999. Ecology of razorback sucker during early spring in upper Lake Mohave, 1994–1997. Proceedings of the Desert Fishes Council 29:17–18.

Gorman, O., and L. Coggins. 2000. Status and trends of native and non-native fishes of the Colorado River in Grand Canyon 1990-2000. Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Gorman, O., and L. Coggins. 1999. Ecology of spawning humpback chub, Gila cypha, in the Little Colorado River near Grand Canyon, Arizona. Environmental Biology of Fishes 55:115-133

Gorman, O. T., R. G. Bramblett, R. M. Hervin, D. R. VanHaverbeke, and D. M. Stone. 2005. Distribution and Abundance of native and non-native fishes of the Colorado River Ecosystem in Grand Canyon, Arizona : pages 78-94 in M.J. Brouder, C. L. Springer and S. C. Leon, editors. Proceedings of two symposia: Restoring native fish to the lower Colorado River: interactions of native and non-native fishes. July 13-14, 1999, Las Vegas, NV.

Gorman, O. T. and R. R. VanHoosen. 2000. Experimental growth of four native Colorado River fishes at temperatures of 12, 18 and 24 °C. Draft final report submitted to Grand Canyon Monitoring and Research Center, Flagstaff. U.S. Fish and Wildlife Service, Willow Beach AZ.

Grabda, J. 1963. Life cycle and morphogenesis of *Lernaea cyprinacea* L. Acta Parasitologica Polonica XI:169–199.

Grabowski, S. J., and S. D. Hiebert. 1989. Some aspects of trophic interactions in selected backwaters and the main channel of the Green River, Utah, 1987–1988. U.S. Bureau of Reclamation, Salt Lake City, Utah.

Granath, W. O., Jr., and G. W. Esch. 1983. Seasonal dynamics of *Bothriocephalus acheilognathi* in ambient and thermally altered areas of a North Carolina cooling reservoir. Proceedings of the Helminthological Society Washington 50:205–218.

Grand Canyon Monitoring and Research Center. 2007. Draft USGS workshop on scientific aspects of a long-term experimental plan for Glen Canyon Dam, April 10–11, 2007, Flagstaff, Arizona: U.S. Geological Survey Scientific Investigations Report 2007–xxx, 60 p.

Grand Canyon Protection Act of 1992. Public Law No. 102-575.

Grand, T. C. S. F. Railsback, J. W. Hayse and K. E. LaGory. 2006. A physical habitat model for predicting the effects of flow fluctuations in nursery habitats of the endangered Colorado pikeminnow *Ptychocheilus lucius*. River Research and Applications 22:1125-1142.

Grannath, W. O., and G. W. Esch. 1983. Seasonal Dynamics of bothriocephalus acheilognathi in Ambient and Thermally Altered Areas of a North Carolina Cooling Reservoir. Proceedings of the Helminthological Society of Washington 50:205-18.

Griffiths, P. G., R. H. Webb and T. S. Melis. 2004. Frequency and initiation of debris flows in Grand Canyon, AZ. Journal of Geophysical Research 109: F04002

Hamman, R.L. 1982. Spawning and culture of humpback chub. Progressive Fish-Culturist 44:213–216.

Hazel, J. E., M. Kaplinksi, R. Parnell, M. Manone and A. Dale. 1999. Topographic and bathymetric changes at thirty-three long-term study sites. P 161-183 in Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez, eds., The controlled flood in Grand Canyon. American Geophysical Union monograph 110.

Heggenes, J. A. Brabrand and S. J. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. Transactions of the American Fisheries Society 119:101-111.

Hoerling, M. and J. Eischeid. 2006. Past Peak Water in the Southwest. Southwest Hydrology 6(1).

Hendrickson, D. A. 1993. Progress report on study of the utility of data obtainable from otoliths to management of humpback chub (*Gila cypha*) in the Grand Canyon. Non-Game and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix.

Hendrickson, D. A. 1994. Evaluation of the razorback sucker (*Xyrauchen texanus*) and Colorado squawfish (*Ptychocheilus lucius*) reintroduction programs in central Arizona based on surveys of fish populations in the Salt and Verde rivers from 1986–1990. Final Report. Non-Game and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix.

Hoffnagle, T. L. 1996. Changes in water quality parameters and fish usage of backwaters during fluctuating vs. short-term steady flows in the Colorado River, Grand Canyon. Arizona Game and Fish Dept. Prepared for Glen Canyon Environmental Studies, U.S. Bureau of Reclamation.

Hoffnagle, T. L. 1999. Paria River native fish monitoring. 1998 annual report. Arizona Game and Fish Department. Research Branch, Phoenix, AZ.

Hoffnagle, T. L., 2000. Spring Fish Monitoring in the Little Colorado River, Grand Canyon. Draft Final Report, Arizona Game and Fish Department.

Hoffnagle, T. L. 2000. Humpback chub *Gila cypha* health and parasites, 1998–1999. Final Report of Arizona Game and Fish Department to Grand Canyon Fishery Resource Office, U.S. Fish and Wildlife Service, Flagstaff, Arizona.

Hoffnagle, T. L., A. Choudhury, and R. A. Cole. 2006. Parasitism and Body Condition in Humpback Chub from the Colorado and Little Colorado Rivers, Grand Canyon, Arizona. Journal of Aquatic Animal Health 18:184-193.

Hoffnagle, T. L., R. A. Cole, and A. Choudhury. 2000. Parasites of native and non-native fishes of the lower Little Colorado River, Arizona. 1999 Annual Report. National Wildlife Health Center, U.S. Geological Survey - Biological Resources Division, Madison, Wisconsin, and Arizona Game and Fish Department, Phoenix.

Hoffnagle, T. L., R. A. Cole, and A. Choudhury. 2000. Parasites of Native and Non-native Fishes of Lower Little Colorado River, Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Hoffnagle, T. L., R. A. Valdez, and D. W. Speas. 1999. Fish abundance, distribution, and habitat use. Pages 273–287 *in* R.H. Webb, J.C. Schmidt, G.R. Marzolf, and R.A. Valdez (eds.). The controlled flood in Grand Canyon. Geophysical Monograph 110, The American Geophysical Union, Washington, D.C.

Holden, P. B. 1994. Razorback sucker investigations in Lake Mead, 1994. Report of Bio/West, Inc., Logan, Utah, to Southern Nevada Water Authority.

Holden, P. B., P. D. Abate, and J. B. Ruppert. 1997. Razorback sucker studies on Lake Mead, Nevada, 1996–97. Annual Report PR-578-1, Bio/West, Inc., Logan, Utah.

Holden, P. B., P. D. Abate, J. B. Ruppert, and J.E. Heinrich. 1999a. Razorback sucker studies on Lake Mead, Nevada, 1996–97. Proceedings of the Desert Fishes Council 29:25–26.

Holden, P. B., P. D. Abate, J. B. Ruppert, and J. E. Heinrich. 1999b. Razorback sucker studies on Lake Mead, Nevada, 1997–98. Proceedings of the Desert Fishes Council 30:20–21.

Holden, P. B., P. D. Abate, and J. B. Ruppert. 2000. Razorback sucker studies on Lake Mead, Nevada. 1998-1999 Annual Report PR-578-3 to Southern Nevada Water Authority, Las Vegas. 49 pp.

Horn, M. J. 1996. Nutritional limitation of recruitment in the razorback sucker (*Xyrauchen texanus*). Doctoral Dissertation. Arizona State University, Tempe.

Howard, A., and R. Dolan. 1981. Geomorphology of the Colorado River in the Grand Canyon. Journal of Geology 89:269-298.

Hubbs, C. L., and R. . Miller. 1953. Hybridization in nature between the fish genera *Catostomus* and *Xyrauchen.* Papers of the Michigan Academy of Arts, Science and Letters 38:207–233.

Humpback Chub Ad Hoc Committee. 2003. Status and management strategy for humpback chub in Grand Canyon. Draft report to Adaptive Management Work Group, Glen Canyon Dam Adaptive Management Program. May 22, 2003. [online] http://www.usbr.gov/uc/envprog/amp/amwg/mtgs/03mar28/HBC_Rpt_may22.pdf

IKAMT, Interagency Kanab Ambersnail Monitoring Team. 1998. The Endangered Kanab Ambersnail at Vaseys Paradise, Grand Canyon, Arizona: 1997 Final Report. In final report. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Intergovernmental Panel on Climate Change (IPCC). 2007. IPCC Fourth Assessment Report: Climate Change 2007, Climate Change Impacts, Adaptation and Vulnerability - Summary for Policymakers.

Jahrke, E., and D. A. Clark. 2000. Razorback sucker and Colorado pikeminnow (formerly squawfish) reintroduction and monitoring in the Salt and Verde Rivers. Paper presented at the 33rd Joint Annual Meeting of the Arizona/New Mexico Chapter of the American Fisheries Society and Arizona and New Mexico Chapters of The Wildlife Society, February 3–5, 2000, Sierra Vista, Arizona.

James, A. E. 1968. *Lernaea* (Copepod) infection of three native fishes from the Salt River basin, Arizona. Master's Thesis. Arizona State University, Tempe.

Johnstone, H. C., and M. Lauretta. 2004. Native Fish Monitoring Activities in the Colorado River within Grand Canyon during 2003. Final Report to Grand Canyon Monitoring and Research Center from SWCA Environmental Consultants, Flagstaff, AZ.

Johnstone, H. C., and M. V. Lauretta. 2007. Native Fish Monitoring Activities in the Colorado River within Grand Canyon during 2004. Final Report to the Grand Canyon Monitoring and Research Center. SWCA Environmental Consultants, Flagstaff.

Johnstone, H. C., M. Lauretta, and M. Trammell. 2003. Native Fish Monitoring Activities in the Colorado River within Grand Canyon during 2002. Final Report to Grand Canyon Monitoring and Research Center from SWCA Environmental Consultants, Flagstaff, AZ. [online] http://www.gcmrc.gov/library/reports/biological/Fish_studies/swca/01WRAG0046/johnstone2003.pdf

Jonez, A., and R. C. Sumner. 1954. Lakes Mead and Mohave investigations: a comparative study of an established reservoir as related to a newly created impoundment. Final Report. Federal Aid Wildlife Restoration (Dingell-Johnson) Project F-l-R, Nevada Game and Fish Commission, Carson City.

Jordan, D. S., and B. W. Evermann. 1896. The fishes of North and Middle America. Bulletin of the U.S. National Museum 47:1–1240.

Kaeding, L. R., B. D. Burdick, P. A. Schrader, and C. W. McAda. 1990. Temporal and spatial relationships between the spawning of humpback chub and roundtail chub in the Upper Colorado River. Transactions of the American Fisheries Society 119:135-144.

Kaeding, L. R., and M. A. Zimmerman. 1982. Life history and population ecology of the humpback chub in the Little Colorado and Colorado rivers of the Grand Canyon, Arizona. Pages 281-365 in U.S. Fish and Wildlife Service. Colorado River Fishery Project Final Report, Field Investigations. U.S. Fish and Wildlife Service, Utah.

Kaeding, L. R., and M. A. Zimmerman. 1983. Life history and ecology of the humpback chub in the Little Colorado and Colorado Rivers of the Grand Canyon. Transactions of the American Fisheries Society 112:577–594.

KAIMG. 1997. The Impacts of an Experimental Flood from Glen Canyon Dam on the Endangered Kanab Ambersnail at Vaseys Paradise, Grand Canyon, Arizona: Final Report. I*n final report*, 43. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Karp, C. A., and Tyus, H. M. 1990. Humpback chub (*Gila cypha*) in the Yampa and Green Rivers, Dinosaur National Monument, with observations on roundtail chub (*G. robusta*) and other sympatric fishes. Great Basin Naturalist 50:257–264.

Kennedy, T. A. 2007. A *Dreissena* Risk Assessment for the Colorado River ecosystem. United States Geological Survey open file report 2007-1085.

Kidd, G. 1977. An investigation of endangered and threatened fish species in the upper Colorado River as related to Bureau of Reclamation Projects. Final Report of Northwest Fisheries Research, Clifton, Colorado, to U.S. Bureau of Reclamation.

Kitchell, J. F., C. Grimes, S. T. Lindley, D. Otis, and C. Schwartz. 2003. An independent review of ongoing proposed scientific methods to assess the status & trends of the Grand Canyon population of the humpback chub. Report to the Adaptive Management Work Group: Glen Canyon Dam Adaptive Management Program. Grand Canyon Monitoring and Research Center, Flagstaff, AZ. December 2003.

Kolluru, V. and M. Fichera. 2003. Development and Application of Combined 1-D and 3-D Modeling System for TMDL Studies. Reprinted from Estuarine and Coastal Modeling Proceedings of the Eight International Conference American Society of Civil Engineers, Monterey, CA.

Kolok, A. S. and J. T. Otis. 1995. The relationship between specific growth rate and swimming performance in male fathead minnows *Pimephales promelas*. Canadian Journal of Zoology 73:2165-2167.

Korman, J., M. Kaplinski and J. Buszowski. 2006. Effects of Air and Mainstem Water Temperatures, Hydraulic Isolation, and Fluctuating Flows From Glen Canyon Dam on Water Temperatures in Shoreline Environments of the Colorado River in Grand Canyon. Final Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Korman, J., M. Kaplinski, and J. Hazel, Jr. 2003. Spatial and temporal patterns in rainbow trout redds and fry in the Lees Ferry reach of the Colorado River: implications for fluctuating flows from Glen Canyon Dam. Abstract, The Colorado River: an ecosystem science symposium. Tucson, AZ, October 28-30, 2003. Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Korman, J., M. Kaplinski, J. E. Hazel III, and T. S. Melis. 2005. Effects of the Experimental Fluctuating Flows from Glen Canyon Dam in 2003 and 2004 on the Early Life History

Stages of Rainbow Trout in the Colorado River. Final Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Korman, J., M. Yard, and D. Speas. 2006. An Evaluation of the Utility of Snorkel Surveys for Estimating Population Size and Tracking Trends in Relative Abundance of Rainbow Trout in the Lee's Ferry Reach of the Colorado River. Final Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Korman, J., M. Yard, and D. Speas. 2006. An Evaluation of the Utility of Snorkel Surveys for Estimating Population Size and Tracking Trends in Relative Abundance of Rainbow Trout in the Lee's Ferry Reach of the Colorado River. Final Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Korman, J., and P.S. Higgins. 1997. Utility of escapement time series data for monitoring the response of salmon populations to habitat alteration. Canadian Journal of Fisheries and Aquatic Sciences 54(9):2058-2067.

Korman, J., S. M. Wiele, and M. Torizzo. 2004. Modeling Effects of Discharge on Habitat Quality and Dispersal of Juvenile Humpback Chub (*Gila cypha*) in the Colorado River, Grand Canyon. Regulated Rivers 20:379-400.

Koronkiewicz, J. J., M. A. McLeod, B. T. Brown, and S. W. Carothers. 2004. Southwestern Willow Flycatcher Surveys, Demography, and Ecology Along the Lower Colorado River and Tributaries, 2003. In report from SWCA Environmental Consultants Inc. Boulder City, NV: U.S. Department of the Interior, Bureau of Reclamation. 125 pp.

Koronkiewicz, T. J. and M. J. Whitfield. 1999. Surveys for Wintering Willow Flycatchers (E*mpidonax traillii*) in Costa Rica and Panama. In *Canadian Journal of Zoology*, 91. Phoenix, AZ: U.S. Department of the Interior, Bureau of Reclamation.

Koronkiewicz, T. J. and M. K. Sogge. 2000. Willow Flycatcher (E*mpidonax traillii*) Winter Ecology in Costa Rica: 1999/2000. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Forest and Rangeland Ecosystem Science Center, Colorado Plateau Field Station. 28 pp.

Koronkiewicz, T. J., M. A. McLeod, B. T. Brown, and S. W. Carothers. 2006a. Southwestern Willow Flycatcher Surveys, Demography, and Ecology Along the Lower Colorado River and Tributaries, 2005. In report from SWCA Environmental Consultants Inc., 176. Boulder City, NV: U.S. Department of the Interior, Bureau of Reclamation.

Koronkiewicz, T. J., M. K. Sogge, C. Van Riper III, and E. H. Paxton. 2006b. Territoriality, Site Fidelity, and Survivorship of Willow Flycatchers Wintering in Costa Rica. Condor 108:558-70.

Kubly, D. M. 1990. The endangered humpback chub (*Gila cypha*) in Arizona: a review of past studies and suggestions for future research. Arizona Game and Fish Department, Phoenix.

Lanigan, S. H., and H. M. Tyus. 1989. Population size and status of razorback sucker in the Green River basin, Utah and Colorado. North American Journal of Fisheries Management 9:68–73.

Lauretta, M. V. and K. M. Serrato. 2006. Native Fish Monitoring Activities in the Colorado River within Grand Canyon During 2005. In Draft annual report. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Leonard, P. M. and D. J. Orth. 1988. Use of habitat guilds of fishes to determine instream flow requirements. North American Journal of Fisheries Management 8:399-409.

Leibfried, W. C., H. Johnstone, S. Rhodes, and M. Lauretta. 2003. A study to determine the efficacy of removing brown trout in Bright Angel Creek, Grand Canyon, Arizona. Report submitted to Grand Canyon National Park Science Center. SWCA Environmental Consultants, Inc., Flagstaff, AZ.

Leibfried, W.C., H. Johnstone, S. Rhodes, and M. Lauretta. 2005. Feasibility study to determine the efficacy of using a weir in Bright Angel Creek to capture brown trout. Final Report to Grand Canyon Monitoring and Research Center from SWCA Environmental Consultants, Flagstaff, AZ.

Liebfried, B., K. Hilwig, K. Serrato, and M. Lauretta. 2006. Restoring native fish habitat in selected tributaries of Grand Canyon National Park. Draft Report to the National Park Service from SWCA, Inc., Flagstaff, Arizona.

Lupher, M. L., and R. W. Clarkson. 1994. Temperature tolerance of humpback chub (*Gila cypha*) and Colorado squawfish (*Ptychocheilus lucius*), with a description of culture methods for humpback chub. Glen Canyon Environmental Studies phase II 1993 annual report. Arizona Game and Fish Department, Phoenix.

Lynn, J. C. and M. J. Whitfield. 2002. Winter Distribution of the Willow Flycatcher (E*mpidonax traillii*) in Mexico. Weldon, CA: Southern Sierra Research Station. 45 pp.

Lynn, J. C., T. J. Koronkiewicz, M. J. Whitfield, and M. K. Sogge. 2003. Willow Flycatcher Winter Habitat in El Salvador, Costa Rica, and Panama: Characteristics and Threats. Studies in Avian Biology 26:41-51.

Mabey, L. W., and D. K. Shiozawa. 1993. Planktonic and benthic microcrustaceans from floodplain and river habitats of the Ouray Refuge on the Green River, Utah. Department of Zoology, Brigham Young University, Provo, Utah.

Maddux, H. R, D. M. Kubly, J. C. deVos, W. R. Persons, R. Staedicke, and R. L. Wright. 1987. Evaluation of varied flow regimes on aquatic resources of Glen and Grand Canyon. Final Report of Arizona Game and Fish Department to U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Salt Lake City, Utah.

Maddux, H. R., L. A. Fitzpatrick, W. R. Noonon. 1993. Colorado River endangered fishes critical habitat. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Magirl, C. S., R. H. Webb, and P. G. Griffiths. 2005. Changes in the Water Surface Profile of the Colorado River in Grand Canyon, Arizona, between 1923 and 2000. Water Resources Research 41: W05021.

Marsh, P. C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. Southwestern Naturalist 30:129–140.

Marsh, P. C. 1987. Food of adult razorback sucker in Lake Mohave, Arizona-Nevada. Transactions of the American Fisheries Society 116:117–119.

Marsh, P. C. 1993. Draft biological assessment on the impact of the Basin and Range Geoscientific Experiment (BARGE) on federally listed fish species in Lake Mead, Arizona and Nevada. Arizona State University, Center for Environmental Studies, Tempe, Arizona.

Marsh, P. C. 2000. Fish population status and evaluation in the Cibola High Levee Pond. Final Report to U.S. Bureau of Reclamation, Boulder City, Nevada.

Marsh, P. C. 1994. Abundance, movements, and status of adult razorback sucker in Lake Mohave, Arizona-Nevada. Proceedings of the Desert Fishes Council 25:35–36.

Marsh, P. C., and M.E. Douglas. 1997. Predation by introduced fishes on endangered humpback chub and other native species in the Little Colorado River, Arizona. Transactions of the American Fisheries Society 126:343–346.

Marsh, P. C., and D. R. Langhorst. 1988. Feeding and fate of wild larval razorback sucker. Environmental Biology of Fishes 21:59–67.

Marsh, P. C., and W. L. Minckley. 1989. Observations on recruitment and ecology of razorback sucker: Lower Colorado River, Arizona-California-Nevada. Great Basin Naturalist 49:71–78.

Marshall, R. M. and S. H. Stoleson. 2000. Status, Ecology, and Conservation of the Southwestern Willow Flycatcher. edited by D. Finch and S. Stoleson. Albuquerque, NM.

McAda, C. W., and R. S. Wydoski. 1980. The razorback sucker, *Xyrauchen texanus*, in the Upper Colorado River Basin, 1974-76. Technical Papers of the U.S. Fish and Wildlife Service 99. U.S. Fish and Wildlife Service, Washington, D.C.

McCarthy, M. S., and W. L. Minckley. 1987. Age estimation for razorback sucker (Pisces: Catostomidae) from Lake Mohave, Arizona and Nevada. Journal of the Arizona-Nevada Academy of Science 21:87–97.

McCabe, R. A. 1991. The Little Green Bird, Ecology of the Willow Flycatcher. Madison, Wisconsin.

McGuinn-Robbins, D. K. 1995. Comparisons in the number and area of backwaters associated with the Colorado River in Glen, Marble and Grand Canyons, AZ. Draft report to Glen Canyon Environmental Studies, U.S. Bureau of Reclamation. Arizona Game and Fish Department, Phoenix.

McIvor, C. C., and M. L. Thieme. 1999. Flannelmouth Suckers: Movement in the Glen Canyon Reach and Spawning in the Paria River. In The Controlled Flood in Grand Canyon. pages 289-296 in Geophysical Monograph 110, J. C. Schmidt R. H. Webb, G. R. Marzolf, and R. A. Valdez, (eds). The American Geophysical Union, Washington, DC.

McKernan, R. L and G. Braden. 1997. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 2 – 1997. In report to Bureau of Reclamation, Lower Colorado River Region and U.S. Fish and Wildlife Service. Redlands, CA: San Bernardino County Museum. 64 pp.

McKernan, R. L and G. Braden. 1998. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 3 – 1998. In report to U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and U.S. Bureau of Land Management. Redlands, CA: San Bernardino County Museum. 94 pp.

McKernan, R. L. and G. Braden. 1999. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 4 – 1999. In report to U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and U.S. Bureau of Land Management. Redlands, CA: San Bernardino County Museum. 83 pp.

McKernan, R. L and G. Braden. 2001. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 5 – 2000. In report to U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and U.S. Bureau of Land Management. Redlands, CA: San Bernardino County Museum. 86 pp.

McKernan, R. L and G. Braden. 2006a. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 6 – 2001. In report to U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service and U.S. Bureau of Land Management. Redlands, CA: San Bernardino County Museum. 58 pp.

McKernan, R. L and G. Braden. 2006b. Status, Distribution, and Habitat Affinities of the Southwestern Willow Flycatcher Along the Lower Colorado River Year 7 – 2002: Final Report - Revised. In report to U.S. Bureau of Reclamation and U.S. Fish and Wildlife Service. Redlands, CA: San Bernardino County Museum. 93 pp.

McKinney, T. and D. W. Speas. 2001. Observations of size-regulated asymmetries in diet and energy intake of rainbow trout in a regulated river Environmental Biology of Fishes 61: 435-444

McKinney, T., D. W. Speas, R. S. Rogers and W. R. Persons. 1999b. Rainbow trout in the Lees Ferry recreational fishery below Glen Canyon Dam, Arizona, following establishment of minimum flow requirements. Final report submitted to Grand Canyon Monitoring and Research Center. Arizona Game and Fish Department, Phoenix.

McKinney, T., D. W. Speas, R. S. Rogers and W. R. Persons. 2001. Rainbow trout in a regulated river below Glen Canyon Dam, Arizona, following increased minimum flows and reduced discharge variability. North American Journal of Fisheries Management 21:216-222.

McKinney, T., R. S. Rogers, A. D. Ayers and W.R. Persons. 1999a. Lotic community responses in the Lees Ferry reach. Pages 249-258 in Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez, eds., The controlled flood in Grand Canyon. American Geophysical Union monograph 110.

McKinney, T., and W. R. Persons. 1999. Rainbow Trout and Lower Trophic Levels in the Lee's Ferry Tailwater Below Glen Canyon Dam, Arizona: A Review. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

McKinney, T., W. R. Persons, and R. S. Rogers. 1999. Ecology of Flannelmouth Sucker in the Lee's Ferry Tailwater, Colorado River, Arizona. Great Basin Naturalist 59:259-65.

McLeod, M. A., T. J. Koronkiewicz, B. T. Brown, and S. W. Carothers. 2005. Southwestern Willow Flycatcher Surveys, Demography, and Ecology Along the Lower Colorado River and Tributaries, 2004. In annual report SWCA Environmental Consultants Inc., 155. Flagstaff, AZ: U.S. Department of the Interior, Bureau of Reclamation.

Meffe, G. K., and W. L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. American Midland Naturalist. 117:177-191.

Meko, D., Woodhouse, C., Baisan, C., Knight, T., Lukas, J., Hughes, M., and Salzer, M., 2007. Medieval Drought in the Upper Colorado River Basin. Geophysical Research Letters. Vol 34, L10705.

Melis, T. S. 1997. Geomorphology of debris flows and alluvial fans in Grand Canyon National Park and their influence on the Colorado River below Glen Canyon Dam, AZ. PhD thesis, University of Arizona. 490 p.

Melis, T. S., J. Korman, and C. J. Walters. 2005. Active Adaptive Management of the Colorado River Ecosystem Below Glen Canyon Dam, USA: Using Modeling and Experimental Design to Resolve Uncertainty in Large-River Management. Proceeding of the International Conference on Reservoir Operations & River Management, Guangzhou, China, September 18-23, 2005.

Melis, T. S., R. H., Webb, P. G. Griffiths, and T. J. Wise. 1994. Magnitude and frequency data for historic debris flows in Grand Canyon National Park and vicinity, AZ. U.S. Geological Survey Water Resources Investigations Report 94-4214. 285 p.

Melis, T. S., S. A. Wright, B. E. Ralston, H. C. Fairley, T. A. Kennedy, M. E. Andersen, and L. G. Coggins, Jr. 2005. 2005. Knowledge Assessment of the Effects of Glen Canyon Dam on the Colorado River Ecosystem: An Experimental Planning Support Document   Grand Canyon Monitoring and Research Center, Flagstaff.

Melis, T. S., W. M. Phillips, R. H. Webb, and D. J. Bills. 1997a. When the Blue-Green Waters Turn Red: Historical Flooding in Havasu Creek, Arizona. In Water Resources Investigations Report #96-4115. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey 85 pp.

Melis, T. S., W. M. Phillips, R. H. Webb, and D. J. Bills. 1997b. Geomorphology of Debris Flows and Alluvial Fans in Grand Canyon National Park and Their Influence on the Colorado River Below Glen Canyon Dam, Arizona. University of Arizona Press. 490 pp.

Melis T. S., S. A. Wright, B. E. Ralston, H. C. Fairley, T. A. Kennedy, M. E. Andersen, and L. G. Coggins, Jr. 2005. Knowledge Assessment of the Effects of Glen Canyon Dam on the Colorado River Ecosystem : An Experimental Planning Support Document. Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Meretsky, V. 2000. Population Ecology and Management for Oxyloma in Kanab Canyon, Kane Co., Utah. In report to the Bureau of Land Management. Kanab, UT: U.S. Department of the Interior, Bureau of Land Management.

Meretsky, V. and D. Wegner. 1999. Kanab Ambersnail at Vaseys Paradise, Grand Canyon National Park, 1998 Monitoring and Research. In report SWCA Environmental Consultants Inc., 9. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey.

Meretsky, V. J., R. A. Valdez, M. E. Douglas, M. J. Brouder, O. T. Gorman and P. C. Marsh. 2000. Spatiotemporal variation in length-weight relationships of endangered humpback chub: implications for conservations and management. Transactions of the American Fisheries Society 129:418-429.

Miller, R. R. 1946. *Gila cypha*, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona. Journal of the Washington Academy of Sciences 36:409–415.

Minckley, W. L. 1983. Status of the razorback sucker, *Xyrauchen texanus* (Abbott), in the Lower Colorado River Basin. Southwestern Naturalist 28:165–187.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Sims Printing Company, Inc., Phoenix.

Minckley, W. L. and G. K. Meffe. 1987. Differential selection for native fishes by flooding in streams of the arid American Southwest. P. 93-104 in W.J. Matthews and D.C. Heins, eds., Ecology and Evolution of North American Stream Fish Communities. University of Oklahoma Press, Norman.

Minckley, W. L. 1991. Native fishes of the Grand Canyon region: an obituary? Pages 124–177 *in* National Research Council Committee (eds.). Colorado River ecology and dam management. Proceedings of a symposium, May 24–25, 1990, Santa Fe, New Mexico, National Academy Press, Washington, D.C.

Minckley, W. L., P. C. Marsh, J. E. Brooks, J. E. Johnson, and B. L. Jensen. 1991. Management toward recovery of the razorback sucker. Pages 303–357 in W.L. Minckley and J.E. Deacon (eds.). Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Minckley, C. O. 1992. Observed growth and movement in individuals of the Little Colorado population of the humpback chub (*Gila cypha*). Proceedings of the Desert Fishes Council 22:35–36.

Minckley, C. O. 1996. Observations on the biology of the humpback chub in the Colorado River Basin, 1908–1990. Doctoral Dissertation. Northern Arizona University, Flagstaff.

Modde, T., and D. Wydoski. 1995. *Xyrauchen texanus*, razorback sucker/matalote jorobado, catostomidae - suckers. Desert Fish Council website http://www.utexas.edu/depts/tnhc/. www/fish/dfc/na/catostom/xyrauche/xtexanus/xtexanus.html (accessed March 22, 2000)

Modde, T., and E. J. Wick. 1997. Investigations of razorback sucker distribution movements and habitats used during spring in the Green River, Utah. Final Report of U.S. Fish and Wildlife Service, Vernal, Utah, to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Modde, T., K.P. Burnham, and E.J. Wick. 1996. Population status of the razorback sucker in the middle Green River. Conservation Biology 10:110–119.

Modde, T., R. T. Muth, and G. B. Haines. 1999b. Floodplain wetlands as nursery habitat for razorback suckers in the middle Green River. Proceedings of the Desert Fishes Council 30:30.

Moore, D. 2005. Status and Monitoring of Southwestern Willow Flycatchers within Elephant Butte Reservoir, New Mexico. In report from Denver Technical Service Center, prepared for Albuquerque Area Office, 34. Albuquerque, NM: U.S. Department of the Interior, Bureau of Reclamation.

Moyle, P. B. and D. M. Baltz. 1985. Microhabitat use by an assemblage of California stream fishes: developing criteria for instream flow determinations. Transactions of the American Fisheries Society 114:695-704.

Mpoame, M. 1981. Parasites of some fishes native to Arizona and New Mexico, with ecological notes. Doctoral Dissertation. Arizona State University, Tempe.

Mueller, G. 1995. A program for maintaining the razorback sucker in Lake Mohave. American Fisheries Symposium 15:127–135.

Mueller, G. 1995. Scientific panel eview of the Glen Canyon Dam modifications to control downstream temperatures, plan and draft environmental assessment (EA) / Gordon

Mueller, Carl Walters, Paul Holden, Pete Walker, Jerry Landye and Brett Johnson. Report prepared for Grand Canyon Monitoring and Research Center. 5 pp. Accessed December 17, 2007. online http://www.gcmrc.gov/library/reports/synthesis/Mueller1999.pdf

Mueller, G., T. Burke, and M. Horn. 1993. A program to maintain the endangered razorback sucker in a highly modified riverine habitat. Pages 77–85 in W. O. Deason and S. S. Anderson (eds.). Environmental enhancement of water projects. U.S. Committee on Irrigation and Drainage, Denver, Colorado.

Mueller, G. A. 2006. Ecology of bonytail and razorback sucker and the role of off-channel habitats in their recovery. U.S. Geological Survey Investigations Report 2006-5-65.

Mueller, G., P. C. Marsh, and G. W. Knowles. 1998. Distribution, migratory behavior, and habitat use of razorback sucker (*Xyrauchen texanus*), in Lake Mohave, Arizona-Nevada. U.S. Geological Survey, Biological Resources Division, Denver, Colorado.

Mueller, G. 1999. Scientific Panel Review of the Glen Canyon Dam Modifications to Control Downstream Temperatures, Plan and Draft Environmental Assessment (EA) / Gordon Mueller, Carl Walters, Paul Holden, Pete Walker, Jerry Landye and Brett Johnson. Bureau of Reclamation, Salt Lake City, Utah.

Muth, R. T. 1990. Ontogeny and taxonomy of humpback chub, bonytail, and roundtail chub larvae and early juveniles. Doctoral Dissertation. Colorado State University, Fort Collins.

Muth, R. T., L. W. Crist, K. E. LaGory, J. W. Hayse, K. R. Bestgen, T. P. Ryan, J. K. Lyons, and R. A. Valdez. 2000. Flow and temperature recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Final Report to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Muth, R. T., G. B. Haines, S. M. Meismer, E. J. Wick, T. E. Chart, D. E. Chart, D. E. Snyder, and J. M. Bundy. 1998. Reproduction and early life history of razorback sucker in the Green River, Utah and Colorado, 1992–1996. Final Report of Colorado State University Larval Fish Laboratory to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

Nelson, C. 2001. Life history of the Kanab ambersnail on native and non-native host plants in Grand Canyon, Arizona. M. S. Thesis, Northern Arizona University, Flagstaff. 98 pp.

Nelson, C. B. and J. A. Sorensen. 2002. Investigations of the Endangered Kanab Ambersnail: Monitoring of Translocated Populations and Surveys of Additional Habitat. In Nongame and Endangered Wildlife Program Technical Report 200. Phoenix, AZ: Arizona Game and Fish Department.

Nishida, C. and M. J. Whitfield. 2004. Winter Distribution of the Willow Flycatcher (E*mpidonax traillii*) in Ecuador and Southern Mexico. In Canadian Journal of Zoology, 70. Phoenix, AZ.

NRC (National Research Council). 1983. Risk Assessment in the Federal Government: Managing the Process. National Academy Press, Washington, DC.

Osmundson, D. B., and L. R. Kaeding. 1989. Studies of Colorado squawfish and razorback sucker use of the “15-Mile Reach” of the upper Colorado River as part of conservation measures for the Green Mountain and Ruedi Reservoir water sales. Final Report. U.S. Fish and Wildlife Service, Colorado River Fishery Project. Grand Junction, Colorado.

Osmundson, D. B., P. Nelson, K. Fenton, and D. W. Ryden. 1995. Relationships between flow and rare fish habitat in the ‘15-Mile Reach’ of the upper Colorado River. Final Report. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

Owen, J. C., M. K. Sogge, and M. D. Kern. 2002. Habitat and Sex Differences in Physiological Condition of Breeding Southwestern Willow Flycatchers (*empidonax traillii extimus*). *The Auk* 122: 1261-70.

Pacey, C. A., and P. C. Marsh. 1998a. Resource use by native and non-native fishes of the Lower Colorado River: literature review, summary, and assessment of relative roles of biotic and abiotic factors in management of an imperiled indigenous icthyofauna. Final Report of Arizona State University, to U.S. Bureau of Reclamation, Boulder City, Nevada.

Pacey, C. A., and P. C. Marsh. 1998b. Growth of wild adult razorback suckers in Lake Mohave, Arizona-Nevada. Proceedings of the Desert Fishes Council 30:31–32.

Pacey, C. A., and P. C. Marsh. 1999. A decade of managed and natural population change for razorback sucker in Lake Mohave, Colorado River, Arizona and Nevada. Report to the Native Fish Work Group, Arizona State University, Tempe.

Papoulias, D., and W. L. Minckley. 1990. Food limited survival of larval razorback sucker, *Xyrauchen texanus*, in the laboratory. Environmental Biology of Fishes 29:73–78.

Papoulias, D., and W. L. Minckley. 1992. Effects of food availability on survival and growth of larval razorback suckers in ponds. Transactions of the American Fisheries Society 121:340–355.

Paradzick, C. E. 2005. Southwestern Willow flycatcher habitat selection along the Gila and Lower San Pedro Rivers, Arizona: Vegetation and Hydrogeomorphic Considerations. M.S. Thesis, Arizona State University.

Parnell, R. A. Springer and L. Stevens. 1997. Flood-induced backwater rejuvenation along the Colorado River n Grand Canyon, AZ: 1996 final report. Northern Arizona University, Flagstaff. 67 p.

Parnell, R. A. and J. B. Bennet. 1999. Mineralization of riparian vegetation buried by the 1996 controlled flood. Pages 225-239 in Webb, R. H., J. C. Schmidt, G. R. Marzolf, and R. A. Valdez, eds., The controlled flood in Grand Canyon. American Geophysical Union monograph 110.

Paukert, C. P., L. G. Coggins, Jr., and C. E. Flaccus. 2006. Distribution and Movement of Humpback Chub in the Colorado River, Grand Canyon, Based on Recaptures. Transactions of the American Fisheries Society 135 (1):539-544

Paukert, C. P., and R. S. Rogers. 2004. Factors Affecting Condition of Flannelmouth Suckers in the Colorado River, Grand Canyon, Arizona. North American Journal of Fisheries Management 24:648-653.

Paxton, E. H. 2000. Molecular genetic structuring and demographic history of the willow flycatcher (*Empidonax traillii*).Master's Thesis. Northern Arizona University, Flagstaff. May 2000. 42 pp.

Paxton E. H. and J. C. Owen. 2002. An aging guide for willow flycatcher nestlings. Colorado Plateau Field Station, Northern Arizona University, Flagstaff, AZ. 18 pp.

Persons, W. R. and R. S. Rogers. 2006. Lees Ferry trout fishery status and trends update January 2006. Presentation to the GCDAMP Technical Work Group. Available at http://www.usbr.gov/uc/rm/amp/twg/mtgs/06jan25/Attach_07b.pdf (accessed 12/07).

Pearson, T. 2002. Polygyny and Extra-Pair Paternity in a Population of Southwestern Willow Flycatchers (E*mpidonax traillii extimus*). M.S. Thesis, Northern Arizona University.

Peterson, J. H., and C. P. Paukert. 2005. Development of a Bioenergetics Model for Humpback Chub and Evaluation of Water Temperature changes in the Grand Canyon, Colorado River. Transactions of the American Fisheries Society 134: 960-974

Peterson, R. V. 2002. Memorandum on conservation measures for the Proposed Action of mechanical removal of non-native fish and experimental flows in the Colorado River below Glen Canyon Dam. Memorandum to Field Supervisor, U.S. Fish and Wildlife Service, Phoenix, AZ. December 6, 2002.

Peterson, R. V. 2003. Memorandum on reinitiation of Section 7 consultation. Memorandum to Field Supervisor, U.S. Fish and Wildlife Service, Phoenix, AZ. March 17, 2003.

Phillips, A. J., J. Marshall, and G. Monson. 1964. The Birds of Arizona. University of Arizona Press. 212 pp.

Pilsbry, H. A. 1948. Land Mollusca of North America. The Academy of Natural Sciences of Philadelphia Monographs II: 521-1113.

Rakowski, C. L., and J. C. Schmidt. 1999. The geomorphic basis of Colorado pikeminnow nursery habitat in the Green River near Ouray, Utah. Report A in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report to Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City.

Ralston, B. E. 2005. Riparian vegetation and associated wildlife. Pages 103-122, in Gloss, S. P., J. E. Lovich, and T. S. Melis. (eds), The state of the Colorado River ecosystem in Grand Canyon. U.S. Geological Survey, USGS Circular 1282.

Ralston, B. E., M. V. Loretta, and T. A. Kennedy. 2007. Draft report on comparisons of water quality and biological variables from Colorado River shoreline habitats in Grand Canyon, Arizona, under steady and fluctuating discharges from Glen Canyon Dam. Grand Canyon Monitoring and Research Center, Flagstaff, AZ. 29 pp.

RAM (Risk Assessment and Management) Committee. 1998. Generic nonindigenous aquatic organisms risk analysis review process (for estimating risk associated with the introduction of nonindigenous aquatic organisms and how to manage for that risk). Report to the Aquatic Nuisance Species Task Force. U.S. Government Printing Office, 1998—693-132/62087, Region No. 10, Washington, D.C. Available: www.anstaskforce.gov/gennasrev.htm. (April 2004). (Front cover with date of October 1996, actual year of publication 1998).

Reclamation, U.S. Bureau of. 1995a. Biological assessment of the potential effects of a one-time test of a beach/habitat building flow from Glen Canyon Dam. U.S. Bureau of Reclamation, Salt Lake City.

Reclamation, U.S. Bureau of. 1995b. "Operation of Glen Canyon Dam. In Final Environmental Impact Statement. Salt Lake City, UT: U.S. Department of the Interior, Bureau of Reclamation.

Reclamation, U.S. Bureau of. 1995c. Response letter to final Biological Opinion on Operations of Glen Canyon Dam EIS. U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, UT.

Reclamation, U.S. Bureau of. 1996a. Description and Assessment of Operations, Maintenance, and Sensitive Species of the Lower Colorado River: Final Biological Assessment. In report U.S. Fish and Wildlife Service and Lower Colorado River Multi-Species Conservation Program. Lower Colorado Region. Salt Lake City, UT: U.S. Department of the Interior, Bureau of Reclamation.

Reclamation, U.S. Bureau of. 1996b Record of Decision on the Operation of Glen Canyon Dam. In *Final Environmental Impact Statement*. Salt Lake City, UT: U.S. Department of the Interior, Bureau of Reclamation.

Reclamation, U.S. Bureau of. 2002. Proposed Experimental Releases from Glen Canyon Dam and Removal of Non-Native Fish. Salt Lake City, UT: U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region.

Reclamation, U.S. Bureau of. 2004. Supplement to the feasibility design report Glen Canyon Dam temperature control device. U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, UT. 22 pp + appendices.

Reclamation, U.S. Bureau of. 2005. Supplement to the feasibility design report Glen Canyon Dam temperature control device. U.S. Department of the Interior, Bureau of Reclamation, Denver, CO. 22 pp + appendices.

Reclamation, U.S. Bureau of. 2007a. Colorado River interim guidelines for Lower Basin shortages and coordinated operations for Lake Powell and Lake Mead: Final Environmental Impact Statement. U.S. Department of the Interior, Bureau of Reclamation, Boulder City, NV.

Reclamation, U.S. Bureau of. 2007b. Record of Decision on Colorado River interim guidelines for Lower Basin shortages and coordinated operations for Lake Powell and Lake Mead: Final Environmental Impact Statement. U.S. Department of the Interior, Bureau of Reclamation, Boulder City, NV.

Reclamation, National Park Service, and US Geological Survey. 2002. Finding of No Significant Impact (FONSI) for proposed experimental releases from Glen Canyon Dam and removal of non-native fish.

Reclamation, National Park Service, and US Geological Survey. 2003. Finding of No Significant Impact (FONSI) for proposed modification to removal of non-native fish from the Colorado River in Grand Canyon.

Reclamation, National Park Service, and US Geological Survey. 2004. Supplemental environmental assessment for proposed experimental actions for water years 2005-2006, Colorado River, Arizona, in Glen Canyon National Recreation Area and Grand Canyon National Park. 26 pp.

Robinson, A. T. and M. R. Childs. 2001. Juvenile growth of native fishes in the Little Colorado River and in a thermally modified portion of the Colorado River. North American Journal of Fisheries Management 21:809-815.

Robinson, A. T., R. W. Clarkson, and R. E. Forrest. 1998. Dispersal of larval fishes in a regulated river tributary. Transactions of The American Fisheries Society 127:722–786.

Rogers, R. S., D. W. Speas, D. L. Ward, and A. S. Makinster. 2003a. Grand Canyon long-term non-native fish monitoring, 2002 annual report. Cooperative Agreement # 02WRAG0030. Arizona Game and Fish Department, Flagstaff, AZ. [online] http://www.gcmrc.gov/library/reports/biological/fish_studies/AZGame&Fish/2003/Rogers2003a.pdf.

Rogers, R. S., W. R. Persons, and T. McKinney. 2003b. Effects of a 31,000-cfs spike flow and low steady flow on benthic biomass and drift composition in the Lees Ferry tailwater. Cooperative Agreement 1425-98-FC-40-22690 (mod3). Arizona Game and Fish Department, Flagstaff, AZ. [online] http://www.gcmrc.gov/library/reports/foodbase/Rogers2003.pdf

Rubin, D. M., D. J. Topping, J. C. Schmidt, J. Hazel, K. Kaplinski, and T. S. Melis. 2002. Recent Sediment Studies Refute Glen Canyon Dam Hypothesis. EOS, Transactions, American Geophysical Union 83, no. 25: 273, 77-78.

Ruppert, J. B., P. B. Holden, and P. D. Abate. 1999. Age estimation and growth of razorback sucker, *Xyrauchen texanus*, in Lake Mead, Nevada. Proceedings of the Desert Fishes Council 30:40–41.

Ryden, D. W. 2000. Monitoring of experimentally stocked razorback sucker in the San Juan River: March 1994 through October 1997. U.S. Fish and Wildlife Service, Colorado River Fishery Project, Grand Junction, Colorado.

Schmidt, J. C. 1999. Summary and synthesis of geomorphic studies conducted during the 1996 controlled flood in Grand Canyon. P 329-342 in Webb, R.H., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez, eds., The Controlled Flood in Grand Canyon. American Geophysical Union monograph 110.

Schmidt, J. C., D. J. Topping, P. E. Grams, and J. E. Hazel. 2004. System wide changes in the distribution of fine sediment in the Colorado River corridor between Glen Canyon Dam and Bright Angel Creek, AZ. Final Report of the Fluvial Geomorphology Laboratory, Utah State University, Logan. 99 p.

Schmidt, J. C., and D. M. Rubin. 1995. Regulated streamflow, fine-grained deposits, and effective discharge in canyons with abundant debris fans. Pages 177-195 in J. E. Costa, A. J. Miller, K. W. Potter, and P. R. Wilcox (eds.). Natural and anthropogenic influences in fluvial geomorphology. American Geophysical Union Monograph 89.

Schmidt, J. C. and J. B. Graf. 1990. Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona. U.S. Geological Survey Professional Paper 1493. 74 p.

Schmidt., J. C. and S. A. Goeking. 2003. Stream flow and sediment data collected to determine the effects of low summer steady flows and habitat maintenance flows in 2000 on the Colorado River between Lees Ferry and Bright Angel Creek, AZ. Draft report to the Grand Canyon Monitoring and Research Center, Flagstaff. Department of Aquatic, Watershed and Earth Resources, Utah State University, Logan.

Schrader, P. A. 1991. Endangered and threatened wildlife and plants: the razorback sucker (*Xyrauchen texanus*) determined to be an endangered species. Federal Register 56:54957–54967.

Sedgwick, J. A. and F. L. Knopf. 1992. Describing Willow Flycatcher Habitats: Scale Perspectives and Gender Differences. Condor 94:720-33.

Sferra, S. J., T. E. Corman, C. E. Paradzick, J. W. Rourke, J. A. Spencer, and M .W. Sumner. 1997. Arizona Partners in Flight Southwestern Willow Flycatcher Survey: 1993-1996 Summary Report. In Nongame and Endangered Wildlife Program Technical Report 113. Phoenix, AZ: Arizona Game and Fish Department.

Siegle, R. and D. Ahlers. 2004. Brown-Headed Cowbird Management Techniques Manual. Denver, CO: U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center. 58 pp.

Snyder, D. E., and R. T. Muth. 1990. Descriptions and identification of razorback, flannelmouth, white, Utah, bluehead, and mountain sucker larvae and early juveniles. Colorado Division of Wildlife, Technical Publication No. 38.

Sogge, M. K. "Breeding Season Ecology. 2000. In Status, Ecology, and Conservation of the Southwestern Willow Flycatcher, edited by D. Finch and S. Stoleson. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sogge, M. K. and R. M. Marshall. 2000. A Survey of Current Breeding Habitats. In Status, Ecology, and Conservation of the Southwestern Willow Flycatcher, edited by D. Finch and S. Stoleson. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Sogge, M. K., R. M. Marshall, S. J. Sferra, and T. J. Tibbitts. 1997a. A Southwestern Willow Flycatcher Natural History Summary and Survey Protocol. In National Park Service Technical Report NPS/NAUCPRS/NRTR-97/12, 37: U.S. Department of the Interior, NPS.

Sogge, M. K., T. J. Tibbitts, C. Van Riper III, and T. May. 1995. Status of the southwestern willow flycatcher along the Colorado River in Grand Canyon National Park - 1995. Summary Report. National Biological Service Colorado Plateau Research Station/Northern Arizona University. 26 pp.

Sogge, M. K., T. J. Tibbitts, and J. R. Petterson. 1997b. Status and Breeding Ecology of the Southwestern Willow Flycatcher in the Grand Canyon. Western Birds 28:142-57.

Sorensen, J. 2007. Kanab Ambersnail *(oxyloma haydeni kanabensis)* Arizona Game and Fish Department. [cited December 17, 2007]. Available from http://www.azgfd.gov/w_c/nongame_kanab_ambersnail.shtml.

Sorensen, J. A. and C. B. Nelson. 2002. Interim Conservation Plan for Oxyloma (haydeni) kanabensis complex and related ambersnails in Arizona and Utah . Nongame and Endangered Wildlife Program Technical Report 192. Arizona Game and Fish Department, Phoenix , Arizona .

Sorensen, J. A. and D. M. Kubly. 1997. Investigations of the Endangered Kanab Ambersnail: Monitoring, Genetic Studies, and Habitat Evaluation in Grand Canyon and Northern Arizona. In Nongame and Endangered Wildlife Program Technical Report 122. Phoenix, AZ: Arizona Game and Fish Department.

Sorensen, J. A. and D. M. Kubly. 1998. Monitoring and Habitat Surveys of the Endangered Kanab Ambersnail in Grand Canyon and Northern Arizona. In Nongame and Endangered Wildlife Program Technical Report 125. Phoenix, AZ: Arizona Game and Fish Department.

Spamer, E. E. and A. E. Bogan. 1993. Mollusca of the Grand Canyon and Vicinity, Arizona: New and Revised Data on Diversity and Distributions with Notes on Pleistocene-Holocene Mollusks of the Grand Canyon. Academy of Natural Sciences of Philadelphia 144: 21-68.

Speas, D. W. 2004. Effects of Low Steady Summer Flows on Rainbow Trout in the Lee's Ferry Tailwater, 2000. Flagstaff, AZ: Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Speas, D. W., W. R. Persons, R. S. Rogers, D. L. Ward, A. S. Makinster, and J. E. Slaughter, IV. 2004. 2001 Fish Investigations in the Lee's Ferry Tailwater. U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Sponholtz, P. J., D. M. Stone and J. David. 2005. Monitoring for Humpback Chub (G*ila cypha*) above Chute Falls, Little Colorado River. In Presentation to the GCAMP Technical Work Group. Phoenix, AZ.

Sponholtz, P. J. and D. R. VanHaverbeke. 2007. Bright Angel Creek Trout Reduction Project. In Summary report on fall 2006 weir and electrofishing efforts. U.S. Department of the Interior, National Park Service, Grand Canyon, AZ.

Stevens, L. 1983. The Colorado River in Grand Canyon. A Guide. 5th ed. Flagstaff, AZ: Red Lake Books.

Stevens, L. E. 1996. Flood-induced backwater rejuvenation, along the Colorado River in Grand Canyon, Arizona. 1996 draft final report. Submitted to: Terry May, Sponsored Projects Office, Northern Arizona University, Flagstaff, AZ.

Stevens, L. E., F. R. Protiva, D. M. Kubly, V. J. Meretsky and J. Petterson. 1997a. The Ecology of Kanab Ambersnail (*succineidae: oxyloma haydeni kanabensis pilsbry*, 1948) at Vaseys Paradise, Grand Canyon, Arizona: 1995 Final Report. edited by Glen Canyon Environmental Studies Program Report. Flagstaff, AZ: U.S. Department of the Interior, Bureau of Reclamation, Glen Canyon Environmental Studies Program Report.

Stevens, L. E., J. P. Shannon and D. W. Blinn. 1997b. Colorado River Benthic Ecology in Grand Canyon Arizona: USA; Dam, Tributary and Geomorphic Influences. Regulated Rivers 13:129-49.

Stevens, L. E., and T. L. Hoffnagle. 1999. Spatio-Temporal Changes in Colorado River Backwaters Downstream from Glen Canyon Dam, Arizona, 1965-1997. Report to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Stoleson, S. H. and D. M. Finch. 2003. Microhabitat Use by Breeding Southwestern Willow Flycatchers on the Gila River, New Mexico. Studies in Avian Biology 26:91-95.

Stone, D. M. 1999. Ecology of Humpback Chub (Gila cypha) in the Little Colorado River, near Grand Canyon, Arizona. M. S. Thesis. Northern Arizona University, Flagstaff, AZ.

Stone, D. M. 2006. Monitoring of Humpback Chub (*gila cypha*) and Other Fishes above Lower Atomizer Falls of the Little Colorado River, Arizona. U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Stone, D. 2007. Fall monitoring of humpback chub Gila cypha and other fishes in the lower 13.57 km of the Little Colorado River, Arizona. Trip Report submitted to Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Stone, D. M., and O. T. Gorman. 2006. Ontogenesis of Endangered Humpback Chub (Gila cypha) in the Little Colorado River. American Midland Naturalist 155 (1):123-135.

Stone, D., and P. Sponholtz. 2003. Translocation of young-of-year humpback chub above Chute Falls in the Little Colorado River, AZ: 2003 Interim Report. Prepared for Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office-Flagstaff. AZFRO Document # USFWS-AZFRO-FL-04-006. 20 pp.

Stone, D., and P. Sponholtz. 2004. Translocation of young-of-year humpback chub above Chute Falls in the Little Colorado River, AZ: 2004 Interim Report. Prepared for Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fishery Resources Office-Flagstaff. AZFRO Document # USFWS-AZFRO-FL-05-002. 23 pp.

Stone, D. M., D. R. VanHaverbeke, D. L. Ward, and T. A. Hunt. 2007. Dispersal of non-native fishes and parasites in the intermittent Little Colorado River, Arizona. Southwestern Naturalist 52(1):130-137.

Suttkus, R. D., G. H. Clemmer, C. Jones, and C. Shoop. 1976. Survey of the fishes, mammals and herpetofauna of the Colorado River in Grand Canyon. Colorado River Research Series Contribution 34. Grand Canyon National Park, Grand Canyon, Arizona.

SWCA, Inc. Environmental Consultants. 1999. Strategies for developing the Little Colorado River management plan. SWCA, Inc. Environmental Consultants, Flagstaff, Arizona.

SWCA, Inc. Environmental Consultants. 2005. Little Colorado River management plan. SWCA, Inc. Environmental Consultants, Flagstaff, Arizona.

SWCA, Inc. and Grand Canyon Wildlands Council (GCWC). 2007. A proposal to translocate humpback chub into Shinumo Creek, Grand Canyon. Draft Report to National Park Service, Grand Canyon, Arizona.

Szabo, B. J. 1990. Age of Travertine Deposits in Eastern Grand Canyon National Park, Arizona. *Quaternary Research* 34:24-32.

Tibbitts, T. J. and M. J. Johnson. 1999. Southwestern willow flycatcher inventory and monitoring along the Colorado River in Grand Canyon National Park. 1998 Summary Report. USGS Biological Resources Division, Colorado Plateau Field Station, Northern Arizona University, Flagstaff. 17 pp.

Tibbitts, T. J. and M. J. Johnson. 2000. Southwestern willow flycatcher inventory and monitoring along the Colorado River in Grand Canyon National Park. 1999 Summary Report. USGS Biological Resources Division, Colorado Plateau Field Station, Northern Arizona University, Flagstaff. 19 pp.

Toney, D. P. 1974. Observations on the propagation and rearing of two endangered fish species in a hatchery environment. Proceedings of the Annual Conference of the Western Association of State Game and Fish Commissions 54:252–259.

Topping, D. J., D. M. Rubin, J. C. Schmidt, J. E. Hazel, Jr., T. S. Melis, S. A. Wright, M. Kaplinski, A. E. Draut, and M. J. Breedlove. Comparison of Sediment-Transport and Bar-Response Results from the 1996 and 2004 Controlled-Flood Experiments on the Colorado River in Grand Canyon. Paper presented at the CD-ROM Proceedings of the 8th Federal Inter-Agency Sedimentation Conference, Reno, NV, April 2-6 2006.

Topping, D. J., D. M. Rubin, J. M. Nelson, P. J. Kinzel, III, and I. C. Corson. 2000b. Colorado River Sediment Transport 2. Systematic Bed-Elevation and Grain-Size Effects of Sand Supply Limitation. Water Resources Research 36:543-70.

Topping, D. J., D. M. Rubin, and L. E. Vierra, Jr. 2000a. Colorado River Sediment Transport 1. Natural Sediment Supply Limitation and the Influence of Glen Canyon Dam. Water Resources Research 36:515-42.

Trammell, M. A., D. W. Speas, and S. Meismer. 2004. Non-native cyprinid removal in the lower Green and Colorado rivers, Utah. Final report to the Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City.

Trammell, M. A. and T. E. Chart. 1999.Colorado pikeminnow young-of-year habitat use, Green River, Utah, 1992-1996. Report C in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report to Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City.

Trammell, M. A., R. A. Valdez, S. W. Carothers, and R. J. Ryel. 2002. Effects of a Low Steady Summer Flow Experiment in the Grand Canyon, Arizona. In Final report SWCA Consultants Inc. U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Topping, D. J., and T. S. Melis. 2007. Summary of water year 2007 sand supply below Glen Canyon Dam. Presentation to the GCDAMP Technical Working Group, October 2007.

Topping, D. J., T. S. Melis, D. M. Rubin, and S. A. Wright. 2004. High-Resolution Monitoring of Suspended-Sediment Concentration and Grain Size in the Colorado River in Grand Canyon Using a Laser-Acoustic System. In Proceedings of the Ninth International Symposium on River Sedimentation, edited by C. Hu, and Tan, Y, 2507-14. Yichang, China: People’s Republic of China, Tsinghua University Press.

Trammell, M. and R. Valdez. 2003. Native fish monitoring activities in the Colorado River within Grand Canyon during 2001. SWCA Environmental Consultants, Flagstaff, Arizona.

Trammell, M. A., R. A. Valdez, S. W. Carothers, and R. J. Ryel. 2002. Effects of a Low Steady Summer Flow Experiment in the Grand Canyon, Arizona. In Final report SWCA Consultants Inc. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Trammell, M. A. and T. E. Chart. 1999.Colorado pikeminnow young-of-year habitat use, Green River, Utah, 1992-1996. Report C in Flaming Gorge Studies: Assessment of Colorado pikeminnow nursery habitat in the Green River. Final Report to Upper Colorado River Endangered Fish Recovery Program. Utah Division of Wildlife Resources, Salt Lake City.

Turner, R. M. and M. M. Karpiscak. 1980. Recent Vegetation Changes Along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. In professional paper 1132. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey.

Tyus, H. M. 1998. Early records of the endangered fish *Gila cypha* Miller from the Yampa River of the Colorado with notes on its decline. Copeia 1998:190–193.

Tyus, H. M. 1987. Distribution, reproduction, and habitat use of the razorback sucker in the Green River, Utah, 1979-1986. Transactions of the American Fisheries Society 116:111–116.

Tyus, H. M., and C. A. Karp. 1989. Habitat use and streamflow needs of rare and endangered fishes, Yampa River, Colorado and Utah. U.S. Fish and Wildlife Service Biological Report 89:1–27.

Tyus, H. M., and C. A. Karp. 1990. Spawning and movements of razorback sucker, *Xyrauchen texanus*, in the Green River Basin of Colorado and Utah. Southwestern Naturalist 35:427–433.

Unitt, P. "E*mpidonax traillii extimus*: An Endangered Subspecies." *Western Birds* 18, no. 3 (1987): 137-62.

U.S. Department of the Interior. 2002. Proposed experimental releases from Glen Canyon Dam and removal of non-native fish. Environmental Assessment. Prepared by Bureau of Reclamation, National Park Service, and US Geological Survey. Salt Lake City, UT. September 2002.

U.S. Department of the Interior. 2007. Record of Decision on Colorado River interim guidelines for Lower Basin shortages and the coordinated operations for Lake Powell and Lake Mead. U.S. Department of Interior, Bureau of Reclamation, Boulder City, NV. 59 pp.

USEPA (U.S. Environmental Protection Agency). 2000. Ecological Risk Assessment: Federal Guidelines. U.S. Environmental Protection Agency. Government Institutes, Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2005. Environmental Protection Agency Risk Assessment Values (RAVs) or Standards. Washington, D.C. http://www.scorecard.org/chemical-profiles/def/rav_us.html.

USEPA (U.S. Environmental Protection Agency). 2006. Integrated Risk Assessment (IRIS). Office of Research and Development, National Center for Environmental Assessment, U.S. Environmental Protection Agency. Washington, D.C. http://www.epa.gov/iris/intro.htm.

USFWS, U.S. Fish and Wildlife Service. 1990a. Humpback chub recovery plan, 2nd revision. Report of Colorado River Fishes Recovery Team to U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS, U.S. Fish and Wildlife Service. 1992. Endangered and threatened wildlife and plants, final rule to list the Kanab ambersnail as endangered. Federal Register 57 (75): 13657-13661.

USFWS, U.S. Fish and Wildlife Service. 1995. Kanab ambersnail (*Oxyloma haydeni kanabensis*) recovery plan. U.S. Fish and Wildlife Service, Denver, Colorado. 21 pp.

USFWS, U.S. Fish and Wildlife Service. 1998. Razorback sucker recovery plan. U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

USFWS, U.S. Fish and Wildlife Service. 2002a. Humpback chub (*Gila cypha*) Recovery Goals: amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

USFWS, U.S. Fish and Wildlife Service. 2002b. Razorback sucker (*Xyrauchen texanus*) Recovery Goals: amendment and supplement to the Razorback Sucker Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

USFWS, U.S. Fish and Wildlife Service. 2002c. Southwestern Willow Flycatcher Recovery Plan. Albuquerque, New Mexico. i-ix + 210 pp., Appendices A-O.

USFWS, U.S. Fish and Wildlife Service. 2002d. Biological Opinion of Section 7 consultation of proposed experimental releases from Glen Canyon Dam and removal of non-native fish. Memorandum (Consultation # 02-21-03-F-016) to Regional Director, Bureau of Reclamation, Salt Lake City, UT; Superintendent, Grand Canyon National Park, Grand Canyon, AZ; Superintendent, Glen Canyon National Recreation Area, Page, AZ; Chief, Grand Canyon Monitoring and Research Center, USGS, Flagstaff, AZ. December 6, 2002.

USFWS, U.S. Fish and Wildlife Service. 2003a. Biological Opinion of Reinitiation of Section 7 consultation on proposed experimental releases from Glen Canyon Dam and removal of non-native fish. Memorandum (Consultation # 02-21-03-F-0016) to Regional Director, Bureau of Reclamation, Salt Lake City, UT; Superintendent, Grand Canyon National Park, Grand Canyon, AZ; Superintendent, Glen Canyon National Recreation Area, Page, AZ; Chief, Grand Canyon Monitoring and Research Center, USGS, Flagstaff, AZ. July 12, 2003.

USFWS, U.S. Fish and Wildlife Service. 2003b. Biological Opinion of Reinitiation of Section 7 consultation on proposed experimental releases from Glen Canyon Dam and removal of non-native fish. Memorandum (Consultation # 02-21-03-F-0016-R1) to Regional Director, Bureau of Reclamation, Salt Lake City, UT; Superintendent, Grand Canyon National Park, Grand Canyon, AZ; Superintendent, Glen Canyon National Recreation Area, Page, AZ; Chief, Grand Canyon Monitoring and Research Center, USGS, Flagstaff, AZ. August 12, 2003.

USFWS, U.S. Fish and Wildlife Service. 2005a. Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Southwestern Willow Flycatcher (e*mpidonax traillii extimus*); Final Rule. 50 cfr Part 17. In *Federal Register 70:60886-61009*: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

USFWS, U.S. Fish and Wildlife Service. 2005b. Biological and Conference Opinion on the Lower Colorado River Multi-Species Conservation Program, Arizona, California, and Nevada. U.S. Fish and Wildlife Service, Phoenix, AZ. 214 pp.

USGS, United States Geological Survey. 2004. Climatic fluctuations, drought, and flow in the Colorado River Basin. United States Geological Survey fact sheet 2004-3062. 8 pp.

USGS, United States Geological Survey. 2006a. Grand Canyon humpback chub population stabilizing. United States Geological Survey fact sheet 2006-3109.

USGS, United States Geological Survey. 2006b. Status of Sand Supplies in the Colorado River Below GCD. Presentation to the GCDAMP Technical Work Group, November 2006. available at http://www.usbr.gov/uc/rm/amp/twg/mtgs/06nov08/Attach_14.pdf (accessed 12/07).

USGS, United States Geological Survey. 2006c. Assessment of the estimated effects of four experimental options on resources below Glen Canyon Dam. United States Geological Survey, Grand Canyon Research and Monitoring Center, Flagstaff, AZ. 210 pp.

USGS, United States Geological Survey. 2007. Grand Canyon humpback chub population improving. Fact Sheet 2007-3113. U.S. Geological Survey, Flagstaff, Arizona.

Valdez, R. A. 1990. The endangered fish of Cataract Canyon. Final Report of Bio/West, Inc., Logan, Utah, to U.S. Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R. A. 1994. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead: Phase I, final report to Glen Canyon Environmental Studies from Bio/West, Inc., Logan, UT.

Valdez, R. A. 1996. Synopsis of the razorback sucker in Grand Canyon. Paper presented at the Razorback Sucker Workshop, January 11–12, 1996, Laughlin, Nevada. Sponsored by U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona.

Valdez, R. A. 1999. Possible responses by the fishes of the Colorado River in Grand Canyon to warmed releases from a multi-level intake structure on Glen Canyon Dam.

Valdez, R. A., B. R. Cowdell, and E. Pratts. 1995. Effects of interim flows from Glen Canyon Dam on the aquatic resources of the lower Colorado River from Diamond Creek to Lake Mead: Phase II, final report to Glen Canyon Environmental Studies from Bio/West, Inc., Logan, UT.

Valdez, R. A., and B. R. Cowdell. 1996. Effect of Glen Canyon Dam beach/habitat-building flows on fish assemblages in Glen and Grand Canyons, Arizona. Project completion report submitted to Arizona Game and Fish Dept. and Glen Canyon Environmental Studies from Bio/West, Inc., Logan, UT.

Valdez, R. A., and D. W. Speas. 2007. A risk assessment model to evaluate risks and benefits to aquatic resources from a selective withdrawal structure on Glen Canyon Dam. Bureau of Reclamation, Salt Lake City, Utah.

Valdez, R.A., and E.J. Wick. 1983. Natural vs. manmade backwaters as native fish habitat. Pages 519–536 *in* V.D. Adams and V.A. Lamarra (eds.). Aquatic resources management of the Colorado River ecosystem. Ann Arbor Science, Ann Arbor, Michigan.

Valdez, R. A., and G. C. Clemmer. 1982. Life history and prospects for recovery of the humpback chub and bonytail chub. Pages 109–119 *in* W.H. Miller, H.M. Tyus, and C.A. Carlson (eds.). Fishes of the upper Colorado River system: present and future. Western Division, American Fisheries Society, Bethesda, Maryland.

Valdez, R. A., P. B. Holden, and T. B. Hardy. 1990. Habitat suitability index curves for humpback chub of the upper Colorado River Basin. Rivers 1(1):31-42.

Valdez, R. A., P. Mangan, R. Smith, B. Nilson. 1982. Upper Colorado River investigations (Rifle, Colorado to Lake Powell, Utah). Pages 100–279 *in* U.S. Fish and Wildlife Service. Colorado River Fishery Project, Final Report, Part 2: Field Investigations. U.S. Fish and Wildlife Service, Salt Lake City, Utah.

Valdez, R. A., and R. J. Ryel. 1995. Life history and ecology of the humpback chub (*gila cypha*), in the Colorado River, Grand Canyon, Arizona: final report. [online] http://www.gcmrc.gov/library/reports/biological/Fish_studies/gces/valdez1995f.pdf.

Valdez, R. A., and R. J. Ryel. 1997. Life history and ecology of the humpback chub in the Colorado River in Grand Canyon, Arizona. Pages 3–31 *in* C. van Riper, III and E.T. Deshler (eds.). Proceedings of the Third Biennial Conference of Research on the Colorado Plateau. National Park Service Transactions and Proceedings Series 97/12.

Valdez, R. A. and S. W. Carothers. 1998. The aquatic ecosystem of the Colorado River in Grand Canyon. Final report to the Bureau of Reclamation, Salt Lake City

Valdez, R. A., S. W. Carothers, M. E. Douglas, M. Douglas, R .J. Ryel, K. R. Bestgen, and D. L. Wegner. 2000b. Research and Implementation Plan for Establishing a Second Population of Humpback Chub in Grand Canyon. In final report. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey, Grand Canyon Monitoring and Research Center.

Valdez, R. A., S. W. Carothers, D. A. House, M. E. Douglas, M. Douglas, R. J. Ryel, K. R. Bestgen, and D. L. Wegner. 2000a. A program of Experimental Flows for Endangered and Native Fishes of the Colorado River in Grand Canyon. Report to Grand Canyon Monitoring and Research Center from SWCA Environmental Consultants, Flagstaff, AZ.

Valdez, R. A., and T. L. Hoffnagle. 1999. Movement, habitat use, and diet of adult humpback chub. Pages 297–307 *in* R.H. Webb, J.C. Schmidt, G.R. Marzolf, and R.A. Valdez (eds.). The controlled flood in Grand Canyon. Geophysical Monograph 110. American Geophysical Union, San Francisco, California.

Valdez, R. A., T. L. Hoffnagle, C. C. McIvor, T. McKinney, and W. L. Leibfried. 2001. Effects of a Test Flood on Fishes of the Colorado River in Grand Canyon, Arizona. Ecological Applications 11(3):686-700.

Valdez, R. A., and T. L. Hoffnagle. 1999. Movement, Habitat Use, and Diet of Adult Humpback Chub. In The Controlled Flood in the Grand Canyon; Geophysical Monograph 110, American Geophysical Union.

Valdez, R. A., T. L. Hoffnagle, C. D. McIvor, T. McKinney, and W. C. Leibfried. 2001. Effects of a test flood on fishes of the Colorado River in Grand Canyon, Arizona. Ecological Applications 11:686–700.

Valdez, R. A., and W. J. Masslich. 1999. Evidence of reproduction by humpback chub in a warm spring of the Colorado River in Grand Canyon, Arizona. Southwestern Naturalist 44(3):384-387.

Van Haverbeke, D. 2003. Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2001. Final Report, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Van Haverbeke, D. R. 2003. Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2002. Final Report, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Van Haverbeke, D. R. 2004. Stock Assessment and Fisheries Monitoring Activities in the Little Colorado River within Grand Canyon During 2003. Final Report, Grand Canyon Monitoring and Research Center, Flagstaff, AZ.

Van Haverbeke, D. R., R. S. Rogers, M. V. Lauretta, and K. Christensen. 2007. 2005 Grand Canyon Long-Term Fish Monitoring Colorado River, Diamond Creek to Lake Mead.

2005 Annual Report to Grand Canyon Monitoring and Research Center from U.S. Fish and Wildlife Service, Hualapai Tribe, and SWCA Environmental Consultants, Flagstaff, AZ.

Vermeyen, T. C., DeMoyer, W. Delzer, and D. Kubly. 2003. A survey of selective withdrawal systems. Denver Technical Service Center Water Resource Services, Bureau of Reclamation, Denver, CO. 15 p. + 2 appendices.

Vernieu, W. 2003. Warming of the Colorado River under low steady flows. Abstract. Grand Canyon Monitoring and Research Center Science Symposium, Tucson, AZ. October 29, 2003.

Vernieu, W. S., S. J. Hueftle, and S. P. Gloss. 2005. Water Quality in Lake Powell and the Colorado River. pages 68-85 in The State of the Colorado River Ecosystem in Grand Canyon, Circular 1282, edited by J. E. Lovich S. P. Gloss, and T. S. Melis, Department of the Interior, U.S. Geological Survey. Reston, VA: U.S.

Walters, C., and J. Korman. 1999. Cross-Scale Modeling of Riparian Ecosystem Responses to Hydrologic Management. Ecosystems 5(2):411-421.

Walters, C., J. Korman, L. E. Stevens, and B. Gold. 2000. Ecosystem modeling for evaluation of adaptive management policies in the Grand Canyon. Conservation Ecology 4(2):1. [online] http://www.consecol.org/vol4/iss2/art1.

Ward, D. L 2001. Effects of reduced water temperature on swimming performance and predation vulnerability of age-0 flannelmouth sucker (*Catostomus latipinnis*). Thesis (M.S.), University of Arizona.

Ward, D. L, A. A. Schultz, and P. G. Matson. 2003. Differences in swimming ability and behavior in response to high water velocities among native and non-native fishes. Journal Environmental Biology of Fishes 68(1):1573-5133.

Ward. D. L., O. E. Maughan, S. A. Bonar, and W. J. Matter. 2002. Effects of temperature, fish length, and exercise on swimming performance of age-0 flannelmouth sucker. Transaction of the American Fisheries Society 131:492-497.

Ward, D.L, and S.A. Bonar. 2003. Effects of cold water on susceptibility of age-O flannelmouth sucker to predation by rainbow trout. The Southwestern Naturalist 48(1):43-46.

Webb, R. H. G. J. McAbe, R. Hereford, and C. Wilkowske. 2004. Climatic fluctuations, drought, and flow in the Colorado River Basin. U.S. Geological Survey Fact Sheet 2004-3062.4 pp.

Webb, R. H., J. C. Schmidt, G. R. Marzolf, and R. A. Valdez. 1999. The controlled flood in Grand Canyon. American Geophysical Union monograph 110. 367 p.

Webb, R. H., J. C. Schmidt, G. R. Marzolf, and R. A. Valdez (editors). 2000. The controlled flood in Grand Canyon. Geophysical monograph 110, American Geophysical Union, Washington, D.C.

Webb, M. A. and R. A. Fridell. 2000. Kanab Ambersnail Distribution Surveys in the East Fork of the Virgin River, Upper Parunuweap Canyon, Utah. In Publication No. 00-29. Salt Lake City, UT: Utah Division of Wildlife Resources.

Webb, R. H., J.C. Schmidt, G. R. Marzolf, and R. A. Valdez (editors). 2000. The controlled flood in Grand Canyon. Geophysical monograph 110, American Geophysical Union, Washington, D.C

Webb, R. H., P. G. Griffiths. 2001. Sediment Delivery by Ungaged Tributaries of the Colorado River in Grand Canyon, Arizona. U.S. Geological Survey Fact Sheet 018-01. 6 pp.

Webb, R. H., P. G. Griffiths, C. S. Magirl, and T. C. Hanks. 2005. Debris flows in Grand Canyon and the rapids of the Colorado River. Pages 139-152 in Gloss, S.P., J.E. Lovich, and T.S. Melis (editors). The state of the Colorado River ecosystem in Grand Canyon. A report of the Grand Canyon Monitoring and Research Center 1991-2004. USGS Circular 1282. U.S. Geological Survey, Flagstaff, Arizona.

Webb, R. H., P. G. Griffiths, T. S. Melis, and D. R. Hartley. 2000. Sediment Delivery by Ungaged Tributaries of the Colorado River in Grand Canyon, Arizona. In Water Resources investigation report # 00-4055. Grand Canyon, AZ: U.S. Department of the Interior, U.S. Geological Survey. 67 pp.

Webb, R. H., P. T. Pringle, and G. R. Rink. 1989. Debris flows from tributaries of the Colorado River, Grand Canyon National Park, AZ. U.S. Geological Survey Professional Paper 1492. 39 p.

Webb, R. H., R. Hereford, and G. J. McCabe. 2005. Climatic fluctuations, drought, and flow in the Colorado River Basin. *In* S.P. Gloss, J.E. Lovich, and T.S. Melis, editors. The State of the Colorado River Ecosystem in Grand Canyon. US Geological Survey Circular 1282, pp. 59-69.

Wegner, D. 1996. Proceedings of Razorback Sucker Workshop, January 11–12, 1996, Laughlin, Nevada. Sponsored by U.S. Bureau of Reclamation, Glen Canyon Environmental Studies, Flagstaff, Arizona.

Weiss, S. J. 1993. Spawning, Movement and Population Structure of Flannelmouth Sucker in the Paria River. M.S. Thesis, Department of Biology, University of Arizona, Tucson, AZ.

Welker, T. L, and P. B. Holden. 2004. Razorback sucker studies on Lake Meade, Nevada and Arizona. 2003-2004 annual report. BIO/WEST report PR-578-8. Submitted to Department of Resources, Southern Nevada Water Authority, Las Vegas, NV.

Wick, E. J. 1997. Physical processes and habitat critical to the endangered razorback sucker on the Green River, Utah. Doctoral Dissertation. Colorado State University, Fort Collins.

Wiele, S. M. 1997. Modeling of flood-deposited sand distribution for a reach of the Colorado River below the Little Colorado River, Grand Canyon, AZ. U.S. Geological Survey Water Resources Investigation Report 97-4168.

Wiele, S. M., E. D. Andrews, and E. R. Griffin. 1999. The Effect of Sand Concentration on Depositional Rate, Magnitude, and Location in the Colorado River Below the Little Colorado River. pages 131-145 In The Controlled Flood in Grand Canyon, edited by J.C. Schmidt R.H. Webb, G.R. Marzolf, and R.A. Valdez. Geophysical Monograph 110.

Wiele, S. M., J. B. Graf, and J. D. Smith. 1996. Sand Deposition in the Colorado River in the Grand Canyon from Flooding of the Little Colorado River. Water Resources Research 32:3579-96.

Wiele, S. M., and M. Torizzo. 2005. Modeling of Sand Deposition in Archaeologically Significant Reaches of the Colorado River in Grand Canyon, USA. pages 357-94 In Computational Fluid Dynamics: Applications in Environmental Hydraulics, edited by S.N. Lane P.D. Bates, and R.I. Ferguson.

Woudhouse, C. A., S. T. Gray, and D. M. Meko. 2006. Updated streamflow reconstructions for the Upper Colorado River Basin. Water Resources Research 42:W05415.

Wright, S. A., T. S. Melis, D. J. Topping, and D. M. Rubin. 2005. Influence of Glen Canyon Dam Operations on Downstream Sand Resources of the Colorado River in Grand Canyon, Circular 1282. In The State of the Colorado River Ecosystem in Grand Canyon, edited by S.P. Gloss, Lovich, J.E., and Melis, T.S., pp. 17-31. Flagstaff, AZ: U.S. Department of the Interior, U.S. Geological Survey.

Wydoski, R. S., and E. J. Wick. 1998. Ecological value of floodplain habitats to razorback suckers in the Colorado River Basin. Final Report of U.S. Fish and Wildlife Service and National Park Service to Upper Colorado River Endangered Fish Recovery Program, Denver, Colorado.

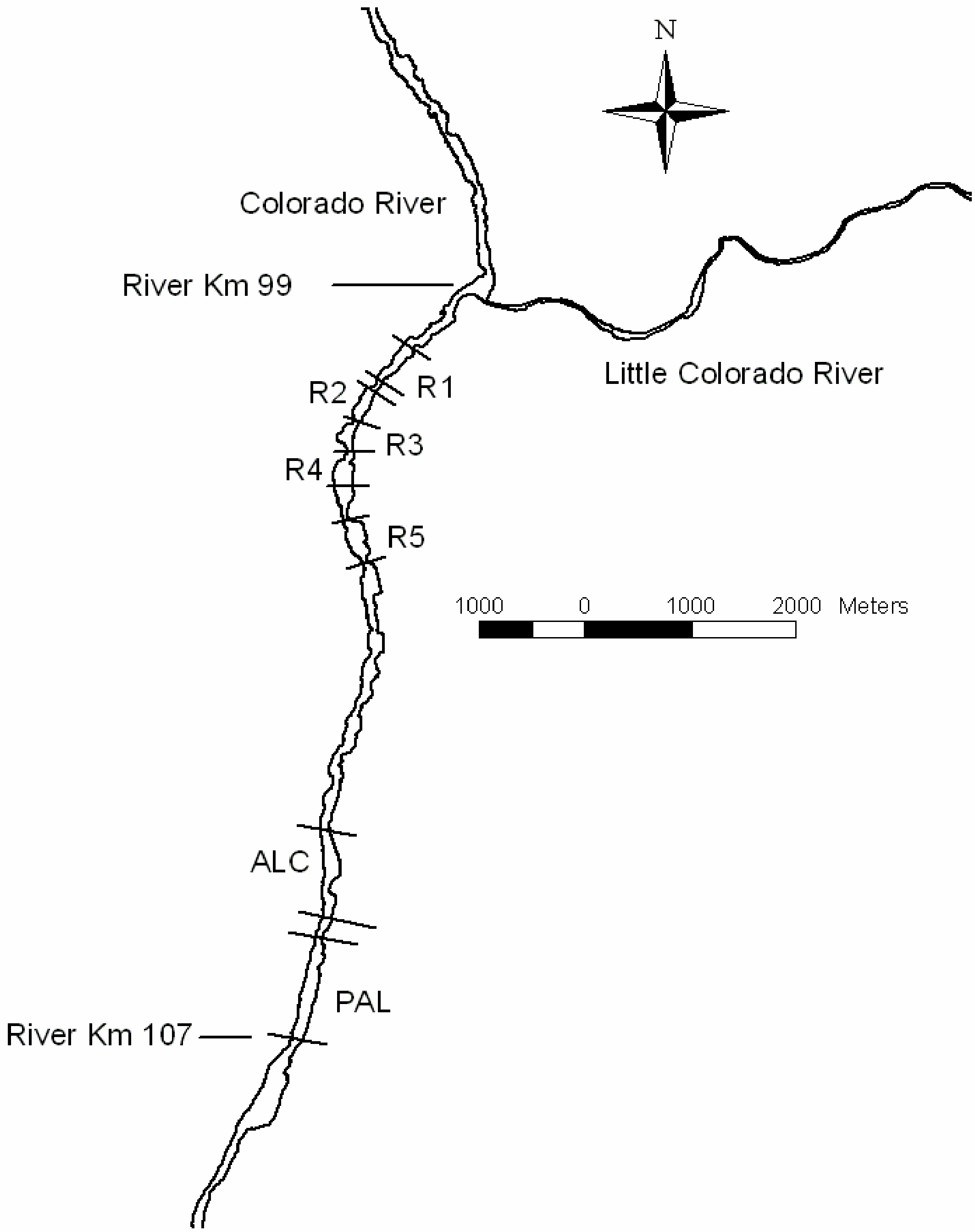
Yong, W. and D. M. Finch. 1997. Migration of the Willow Flycatcher Along the Middle Rio Grande. *Wilson Bulletin* 109:253-68.

Yu, Shyi-Liang and E. J. Peters. 2002. Diel and seasonal habitat use by red shiner (Cyprinella lutrensis). Zoological Studies 41(3):229-235.

Zimmerman, B., and W. Leibfried. 1999. Preliminary results of radio-telemetry of razorback suckers in the Colorado River, Western Grand Canyon. Page 74 in Hendrickson, D.A., and G.P. Garrett (editors). Proceedings of the Desert Fishes Council, Volume 29, 1997 Annual Symposium, Death Valley, California.

8 Appendix A

Figure A1. Transects used in 2-D hydrodynamic model (Korman et al. 2004).



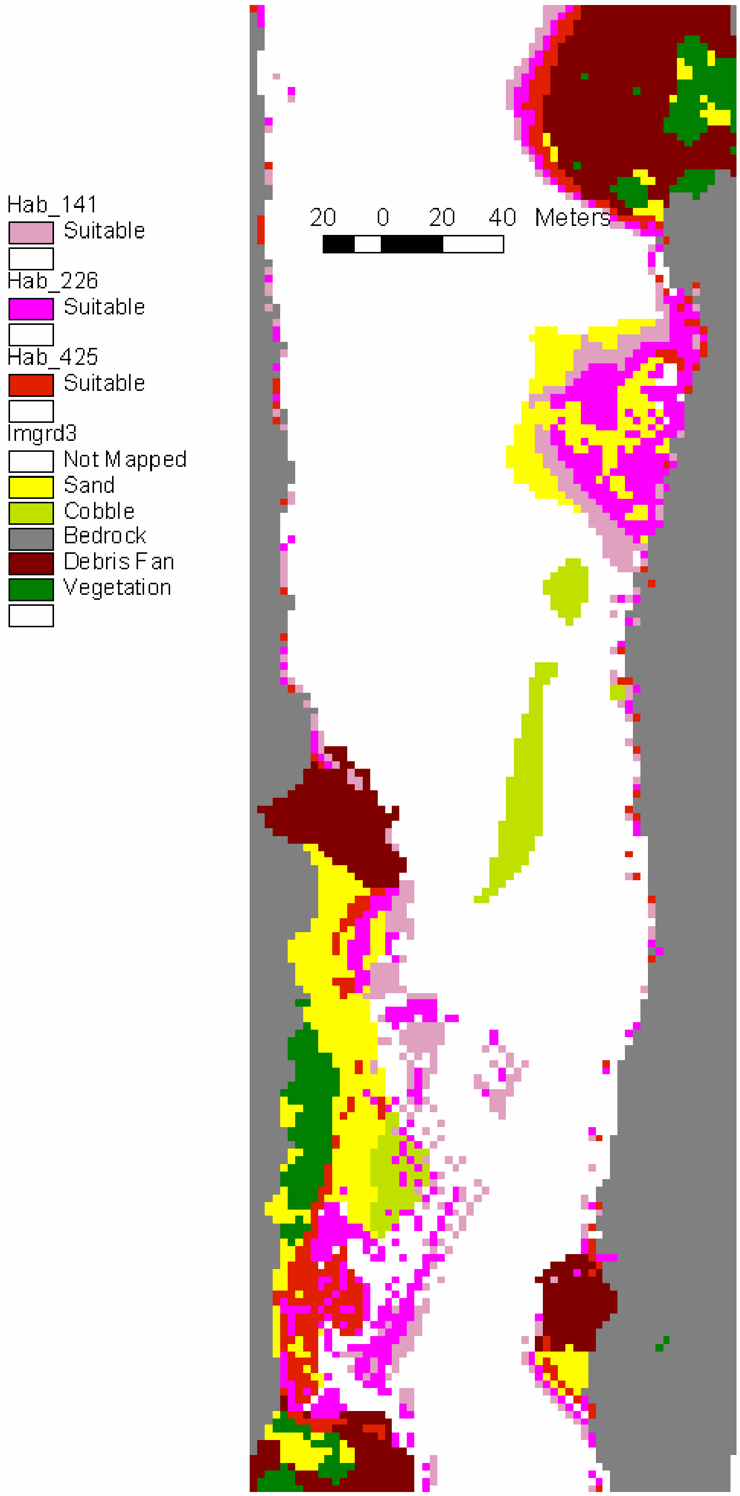


Figure A2. Transect R-1 from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

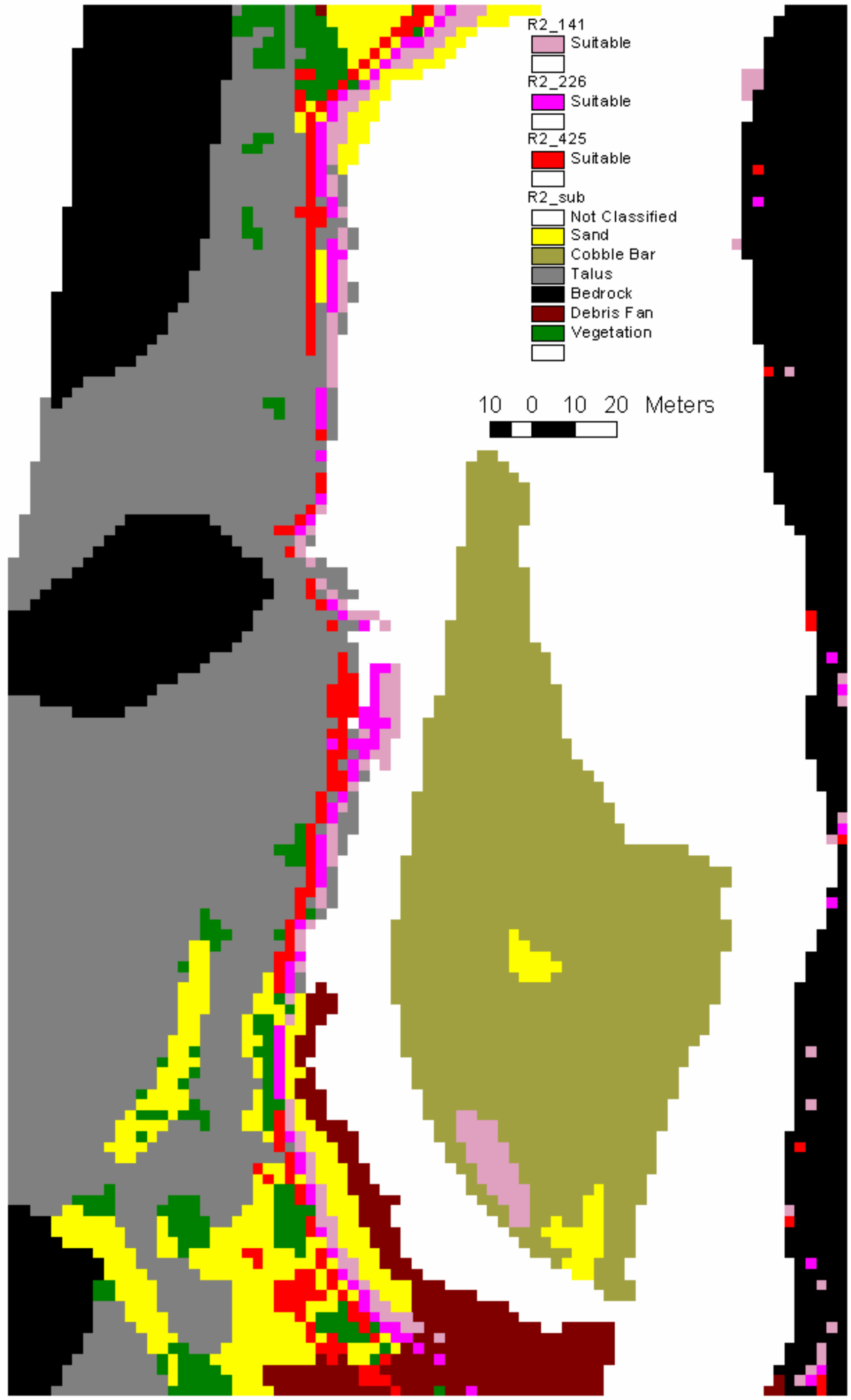


Figure A3. Transect R-2 from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

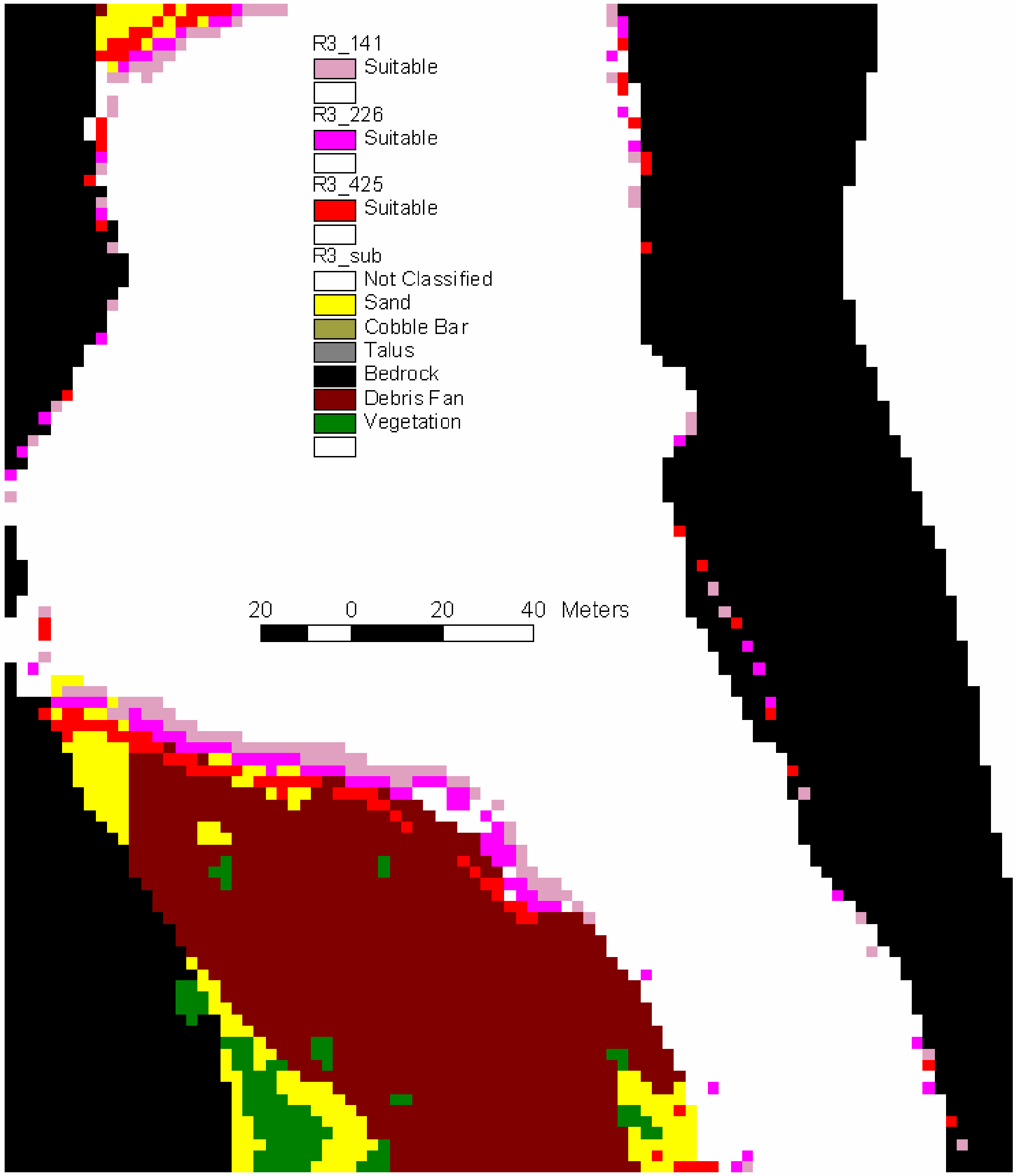


Figure A4. Transect R-3 from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

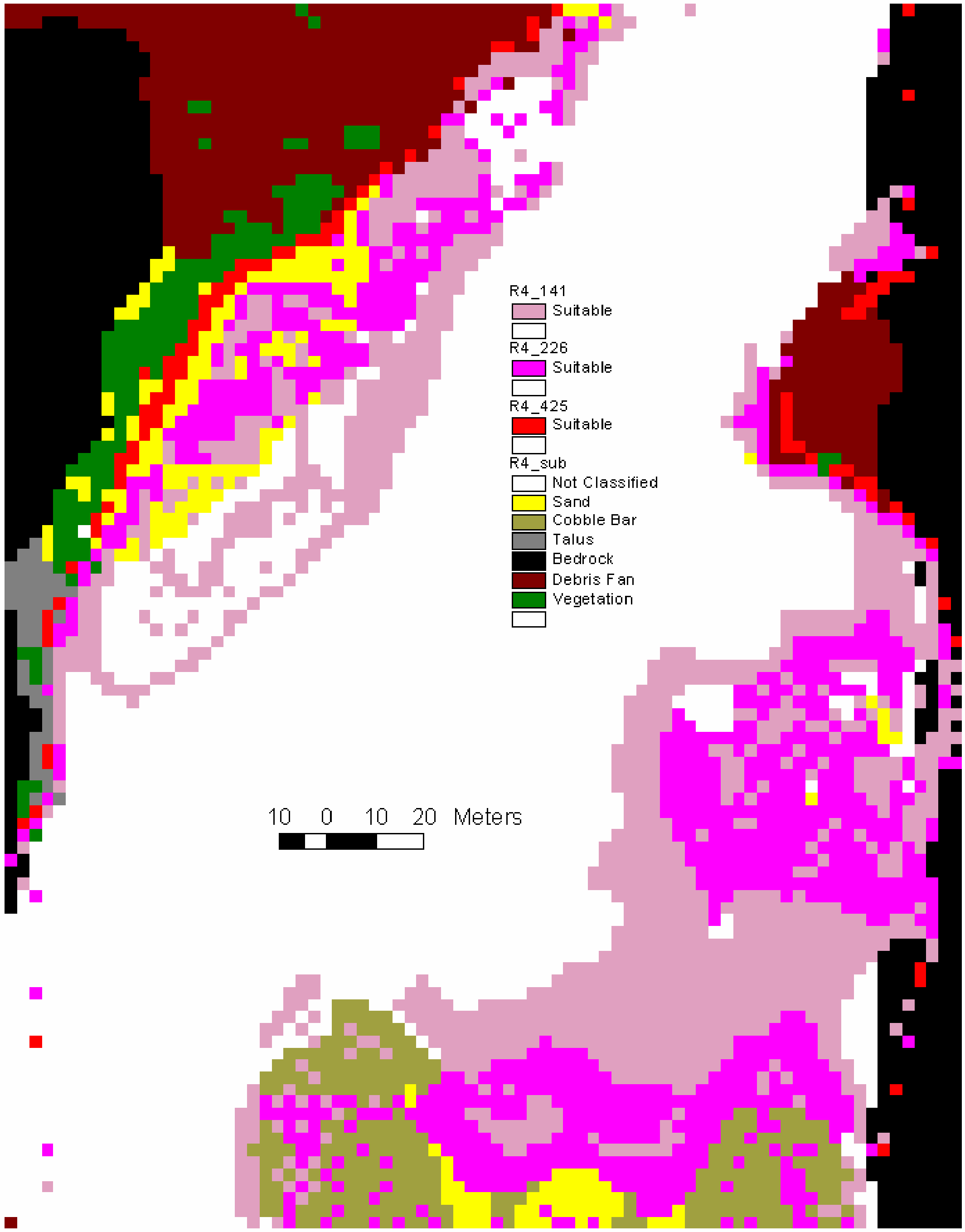


Figure A5. Transect R-4 from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

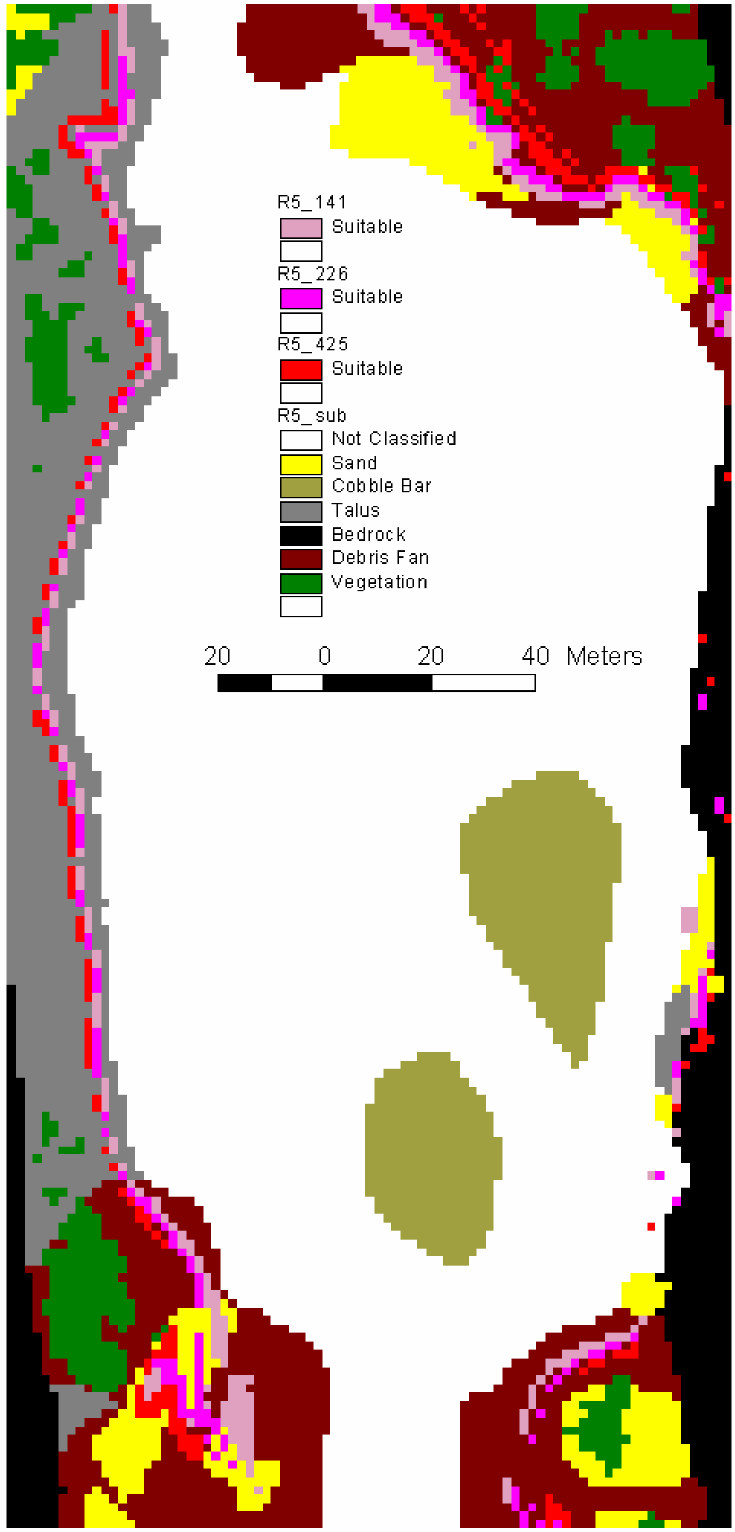


Figure A6. Transect R-5 from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

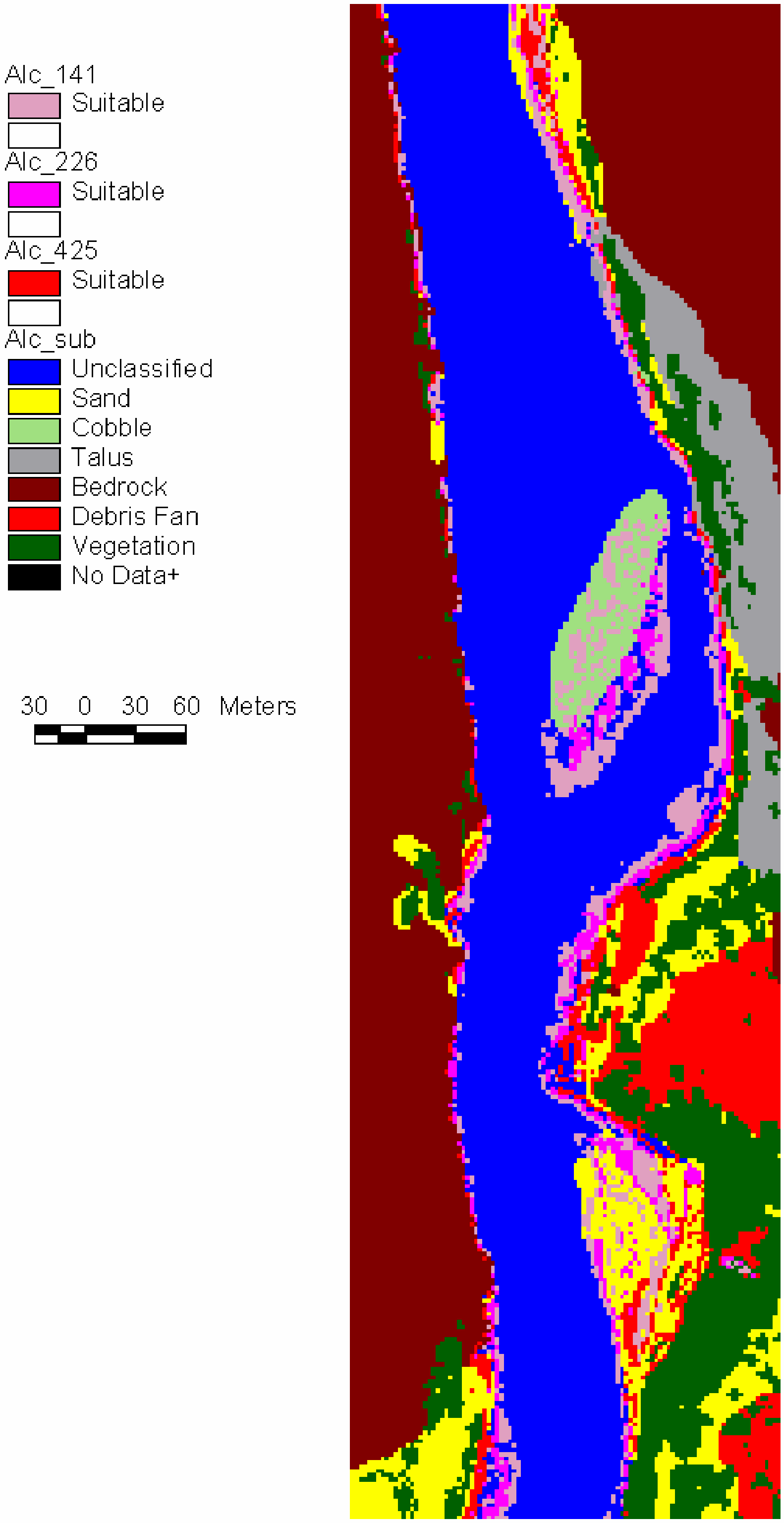


Figure A7. Transect ALC from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.

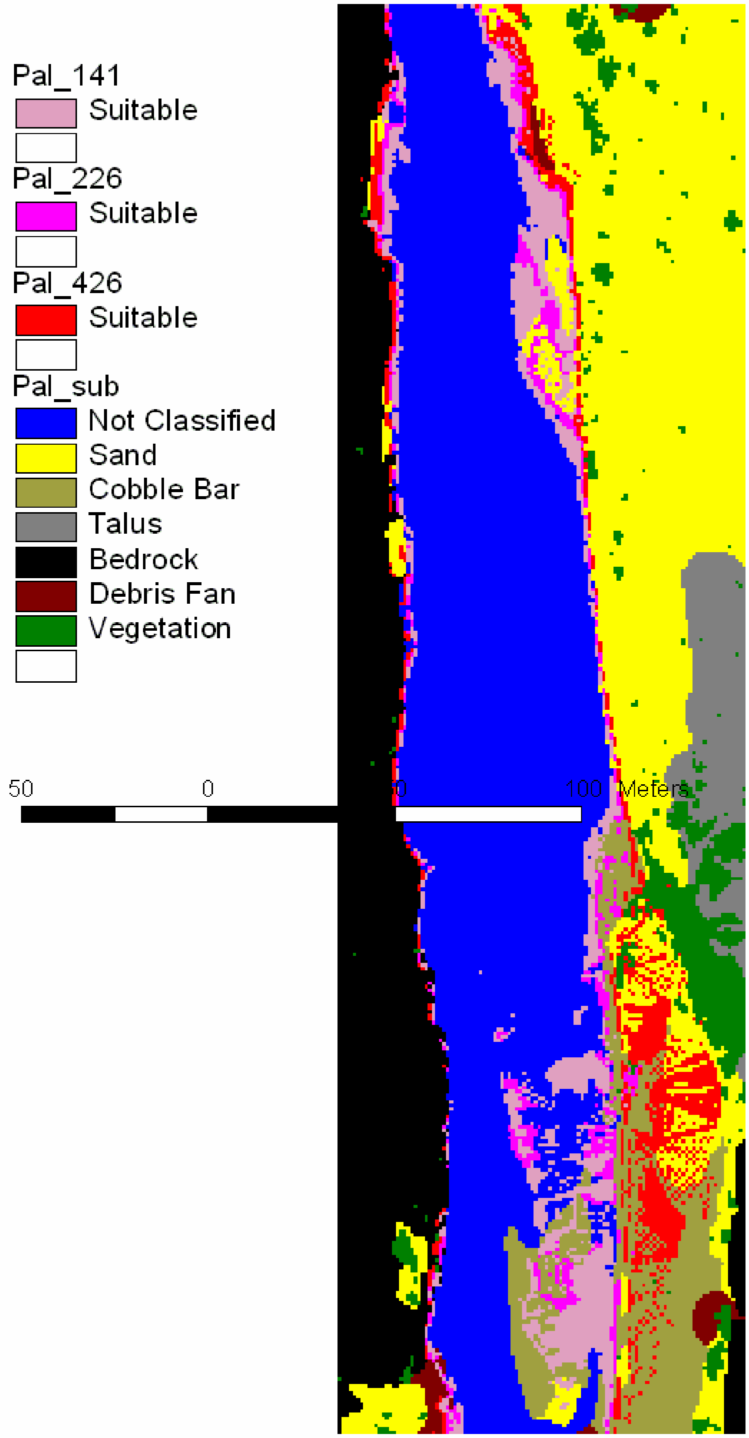


Figure A8. Transect PAL from Korman et al (2004; see Figure A-1). Upstream direction is toward the top of the figure. HAB_141 refers to suitable habitat at 5,000 cfs, HAB_226 refers to 8,000 cfs, HAB_425 refers to 15,000 cfs.