FINAL

A PROGRAM OF EXPERIMENTAL FLOWS FOR ENDANGERED AND NATIVE FISHES OF THE COLORADO RIVER IN GRAND CANYON

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EXECUTIVE SUMMARY

In 1994, the U.S. Fish and Wildlife Service issued a Biological Opinion (Opinion) on the operation of Glen Canyon Dam stating that the modified low fluctuating flow (MLFF), the preferred alternative of the Final Environmental Impact Statement on the operation of the dam, is likely to jeopardize the continued existence of two endangered Colorado River fishes (i.e., humpback chub [*Gila cypha*] and razorback sucker [*Xyrauchen texanus*] and is likely to destroy or adversely modify designated critical habitat. Contained in that Opinion is a reasonable and prudent alternative (RPA), one element of which directs the U.S. Bureau of Reclamation (Reclamation) to initiate a program of experimental dam releases consisting of high steady spring flows and low steady summer flows. The purpose for implementing this and other elements of the RPA is to remove the risk of further jeopardizing these endangered fishes. The experimental flows would be released only in low-water years, when approximately 8.23 million acre-feet (maf) of water is forecast to be delivered at the compact point near Lees Ferry, located 24 km downstream of Glen Canyon Dam.

This document contains a description of a proposed 3-year program of experimental flows (EF) that will satisfy this element of the RPA. The program consists of 1 year of MLFF at 8.23 maf ($MLFF_{8.23}$), as a baseline, followed by 2 years of the EF hydrograph at 8.23 maf ($EF_{8.23}$), as independent treatments. The EF hydrograph for each treatment extends for 1 year and consists of a high steady release of 21,400 cubic feet per second (cfs) from mid-March through May with a 4-day spike of 33,000 cfs in late April. This is followed by a low steady release of 8,000 cfs from June through February with a 4-day spike of 33,000 cfs in late September. Ramping rates of 4,000 cfs/hr up and 1,500 cfs/hr down are applied to the two spike releases. Based on the pattern of dam releases from 1964 to 1998, the probability of a release of 8.5 maf, or less, is about 46%, and the probability of consecutive years of 8.5 maf, or less, is only about 26%. Hence, consecutive years of approximately 8.23 maf releases are unlikely to occur, and the study design considers each $EF_{8.23}$ as an independent treatment for comparison against the 1-year baseline of $MLFF_{8.23}$, supplemented with data from previous studies. The $MLFF_{8.23}$ must precede the treatments of $EF_{8.23}$, and if Glen Canyon Dam is modified to control downstream temperatures before the program of experimental flows is implemented, the temperature control device must be implemented equally during both the baseline and treatment years. Other experimental releases from Glen Canyon Dam (e.g., beach/habitat building flows, test floods) should not be implemented during the 3-year program of EF in order to avoid confounding results of the EF. However, if water volume is available, the 4-day spike can be allowed to exceed 33,000 cfs.

The EF hydrograph targets life history requirements of primarily the humpback chub, with the ecological perspective of providing suitable conditions for native fishes in general, and unsuitable conditions for non-native fishes to minimize the adverse effects of predation and competition. The native fish species, in addition to humpback chub, are flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), and speckled dace (*Rhinichthys osculus*). The razorback sucker is very rare, and possibly extirpated from Grand Canyon. The two primary hypotheses to be tested are that no significant changes will occur in life history parameters (growth, survival, recruitment, and condition) of native fishes (Ho I) or life history parameters of non-native fishes (Ho II) as a result of the experimental flows. Other parameters to be tested under these hypotheses include density and distribution of sub-adults and adults. These hypotheses will test the response of these parameters, as measured near the beginning, middle, and end of each treatment. Causal relationships will be more difficult to evaluate because of a lack of replication and controls. The Grand Canyon conceptual model and a "weight-of-evidence" approach (causal inference based on a series of logical arguments) will be used to better understand cause-and-effect relationships.

The hydrograph is expected, or hypothesized, to have several ecological benefits and risks, when compared to present dam operations of MLFF. Anticipated benefits of the high steady release are ponding of tributary inflows as warm refuges for recently hatched larval native fishes descending to the colder mainstem, and flooded and destabilized shoreline habitats to disadvantage non-native fishes. The April spike is expected to redistribute nutrients and may scour eddy return-current channels, which form backwater habitats used as nurseries and rearing areas by native fishes during subsequent lower flows. The low steady summer flow is expected to provide stable, warm, sheltered shorelines and backwaters for young native fishes with potential increases in growth, survival, recruitment, and condition. The low flow may increase primary and secondary production as food resources for fish by increasing water clarity and nearshore water temperatures, but it is also expected to increase numbers of non-native fishes that will profit from the same conditions that benefit native species. The September spike is designed and timed to counter the expected increase of non-native fishes by displacing them from sheltered shoreline habitats into more unfavorable mid-channel conditions, particularly newly hatched young and small-bodied forms. This spike may also resuspend and store sediment and sand from recent monsoonal storm events from tributaries; this sediment can provide the foundation for future development of fish habitat associated with sand bars and eddy complexes, and is laden with organic material that will spiral through the food chain.

The principal risk of the EF is reproductive success and increased abundance of non-native fishes which may result in increased competition and predation on native fishes. Other risks include desiccation of productive shorelines and reduction in wetted perimeter, which could reduce the aquatic food base, particularly for the tailwater trout population, as well as decreased drift of food materials for fish. Reduced flows will result in a loss of thermal plume entrainment at an aggregation of humpback chub that appear to have spawned successfully in a riverside spring (but with no evidence of recruitment) in past years about 72 km downstream of Glen Canyon Dam.

Recommended field sampling to evaluate the EF includes trips in late June, October, and February, all at a dam release of 8,000 cfs to minimize sampling variability from high or variable river flows. Each sample trip would be about 20 days long and would require guides, support boats, food packs, and logistical support. Six biologists are recommended per trip together with two motorized sample boats (1 electrofishing, 1 netting) and sample gear. Sample trips are recommended for June to measure parameters immediately following the high steady release and at the beginning of the low steady release; for October to measure parameters immediately following the spike flow and midway through the experiment and to evaluate the effectiveness of the spike in reducing non-native fishes; and for February as the measurement of parameters at the end of the experiment. This sample schedule evaluates short-term responses and assumes that an ongoing monitoring program will be in place to measure parameters during years between treatments and to evaluate the long-term effects of this program of experimental flows within the context of dam operations.

Safeguards and criteria for terminating a treatment or for discontinuing the program of experimental flows are recommended. It may be necessary to terminate a treatment if human safety (i.e., increased rafting accidents) and/or human health (i.e., water quality) of recreationists are compromised. A treatment may also be terminated if an undesirable biological response (e.g., massive invasion of non-native predatory fish, widespread disease outbreak with potentially significant population loss) is observed or measured that is considered to be irreversible and ecologically damaging. It may also be necessary to discontinue the program of experimental flows if negative biological responses outweigh positive responses or if no significant positive responses occur. The decision to either terminate a treatment or discontinue the program should be made as part of the adaptive management process. This program should be viewed as an experiment that should be allowed to run through at least the 1-year $MLFF_{8.23}$ baseline and two 1-year $EF_{8.23}$ treatments.

Estimated cost of the experimental flows program (baseline and two treatments) is $400,000-450,000 per year. This includes developing requests for proposals, reviewing proposals, conducting three field sample trips per year, data entry and analysis, and reports. The program of experimental flows consists of a minimum of 1 year of baseline and 2 years of treatments. Although baseline and treatments are not likely to occur in consecutive years, evaluation studies should be conducted by the same researchers to provide continuity and reduce sample variability. These costs include only evaluation of fish assemblages. Studies to evaluate other resources will constitute additional costs, and loss of power revenues are not included in this estimate.

1.0 INTRODUCTION

This document describes a program of experimental flows (EF) for releases from Glen Canyon Dam designed to benefit endangered and other native fishes. These flows potentially affect 470 km of the Colorado River from the dam downstream to the Lake Mead inflow in northwestern Arizona (Figure 1). The program was developed to fulfill an agreement between the U.S. Bureau of Reclamation (Reclamation) and SWCA, Inc., Environmental Consultants (see Appendix A for the Request for Proposals that initiated this project). This document is organized into the following sections:

- **1.0 Introduction –** describes the justification and need for the program, purpose and objectives, a paradigm for EF, the fishes, and Glen Canyon Dam operations.
- **2.0 The Experimental Flows –** identifies specific components of an EF hydrograph and the rationale for each component, coordination with related actions, and compliance with the law of the river.
- **3.0 Benefits and Risks of the Experimental Flows –** describes benefits and risks of the three hydrographic periods for abiotic and biotic resources.
- **4.0 Evaluation and Monitoring –** presents and describes an experimental study design, primary hypotheses to be tested, sample frequency and analysis, role of monitoring, non-native fish control strategy, and safeguard measures and criteria for either short-term termination of a treatment or long-term discontinuation of the experiment.
- **5.0 Implementation and Estimated Costs –** outlines implementation steps, contingency actions, costs, and logistics.

1.1 JUSTIFICATION AND NEED FOR A PROGRAM OF EXPERIMENTAL FLOWS

The Adaptive Management Work Group (AMWG) of the Glen Canyon Adaptive Management Program has directed the development of a program of experimental flows, which is to be implemented and evaluated by the Grand Canyon Monitoring and Research Center (GCMRC) and/or contractors. The program is described in element 1A of the reasonable and prudent alternative (RPA) of the 1994 Final Biological Opinion (Opinion; U.S. Fish and Wildlife Service [FWS] 1994) for the Final Environmental Impact Statement on the Operation of Glen Canyon Dam (GCDEIS; Reclamation1995). The Opinion, which was issued by the FWS on behalf of the Secretary of the Interior (Secretary), determined that the modified low fluctuating flow (MLFF), the preferred alternative of the GCDEIS, ". . . is likely to jeopardize the continued existence of the humpback chub [*Gila cypha*] and razorback sucker [*Xyrauchen texanus*] and is likely to destroy or adversely modify designated critical habitat" (FWS 1994). The Opinion requires Reclamation to execute the elements of the RPA to eventually remove the likelihood of further jeopardizing the two endangered fishes.

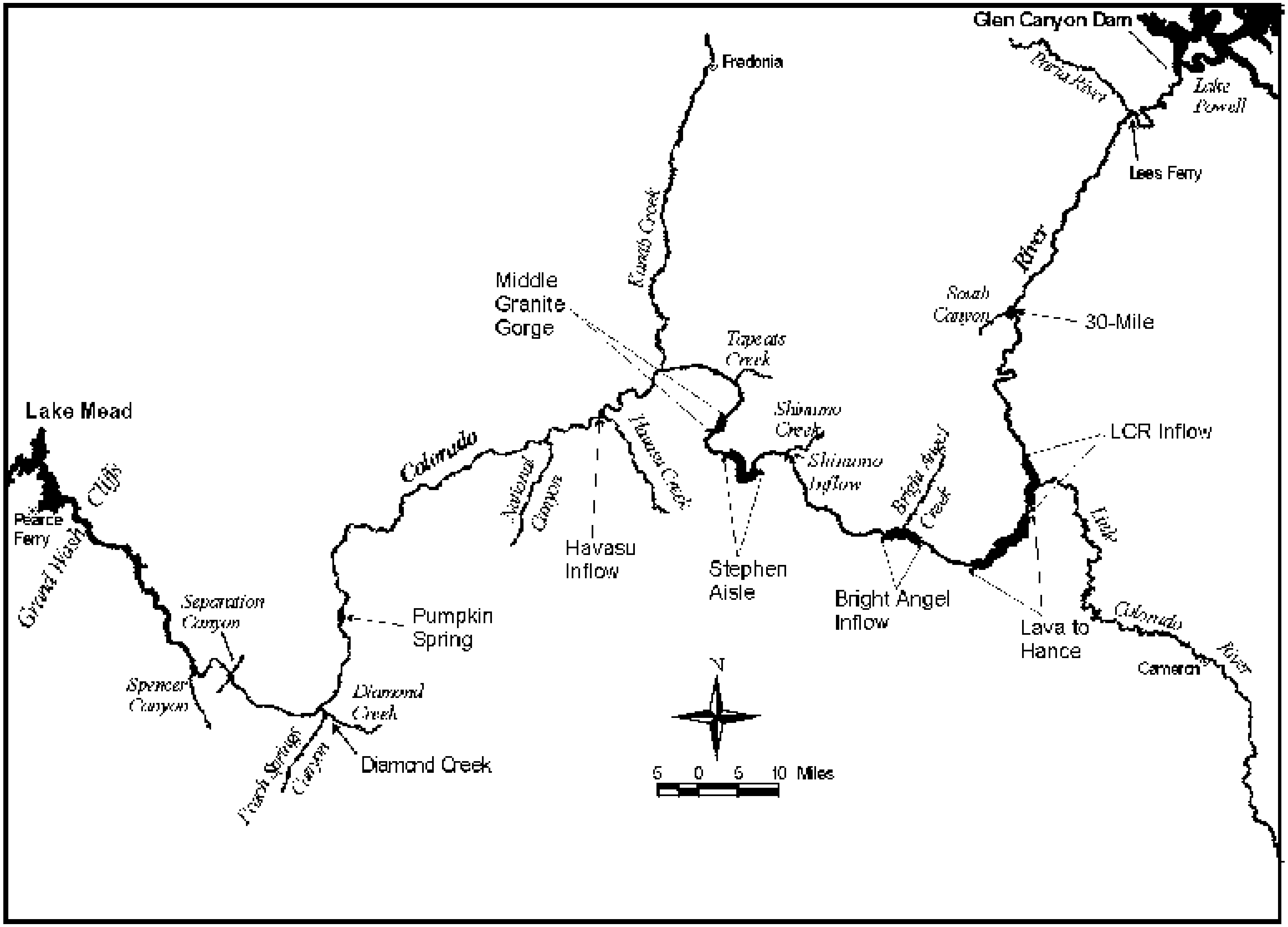

Figure 1. Locations of nine aggregations of humpback chub in the Colorado River though Glen and Grand Canyons. (From Valdez and Ryel 1995)

The concept of experimental flows was first identified as element 1a of the RPA of the Draft Opinion of 19 May 1993 (FWS 1993), which stated that ". . . Reclamation shall pattern water releases comparable with the natural hydrograph . . . during low release years (8.23 maf) . . . ." The purpose of the release pattern was ". . . to facilitate natural ecosystem processes which include accommodat-ing the needs of endangered and other native fishes." The Final Opinion of 21 December 1994 (FWS 1994) retained the concept of a natural hydrograph and identified a program of experimental flows as one of four elements of an RPA:

> *A program of experimental flows will be carried out to include high steady flows in the spring and low steady flows in summer and fall during low water years (releases of approximately 8.23 maf) to verify an effective flow regime and to quantify, to the extent possible, effects on endangered and native fish. Studies of high steady flows in the spring may include studies of habitat building and habitat maintenance flows. Research design and hypotheses to be tested will be based on a flow pattern that resembles the natural hydrograph, as described for those seasons in the SASF.*

The proposed program of experimental flows rests on the premise that steady flows are more likely to benefit the endangered and other native fishes than the MLFF. As identified in the Opinion, the program would be based on release patterns described for the seasonally adjusted steady flow (SASF) alternative of the GCDEIS, which consists of high steady releases from Glen Canyon Dam in spring and early summer, low steady releases in late summer and autumn, and moderate steady releases through winter (Table 1). Clarkson et al. (1994) discussed the rationale for the SASF alternative, which was intended to approximate the hydrologic pattern under which the native Colorado River fishes evolved.

The RPA was developed with the stated objective of attaining ". . . riverine conditions that support all life stages of endangered and native fishes . . ." (FWS 1994). Although the Opinion expressed concern for all native fishes, elements of the RPA focused on the humpback chub. According to the RPA, the 470-km reach of the Colorado River downstream of Glen Canyon Dam does not appear to provide suitable conditions for all life stages of this species. In particular, this reach does not provide an environment for successful spawning and recruitment. The Opinion also noted that only marginal habitat for adult razorback suckers had been identified in the mainstem downstream of Glen Canyon Dam. The Opinion recognized that the razorback sucker is rare in Grand Canyon, and that riverine conditions that support recruiting populations of the species have not been found. Nevertheless, the FWS maintained that the stretch of the Colorado River through Grand Canyon provides one of the few remaining opportunities for recovering the razorback sucker because of its ". . . length, management direction, and limited number of non-native fish species . . ." and its "connection to Lake Mead" (FWS 1994).

Table 1. Release characteristics of the GCDEIS No Action, MLFF, and SASF alternatives,[1] compared to the Experimental Flow (EF). Discharge is given in cubic feet per second (cfs).

Alternative	Minimum Release (cfs)	Maximum Release (cfs)	Daily Fluctuations (cfs/24 hrs)	Ramp Rate
No Action	1,000 Labor Day-Easter 3,000 Easter-Labor Day	31,5000	30,500 Labor Day-Easter 28,500 Easter-Labor Day	Unrestricted
Modified Low Fluctuating Flow (MLFF; Preferred Alternative)	8,000 7 a.m.-7 p.m. 5,000 7 p.m.-7 a.m.	25,000	5,000; 6,000; or 8,000 depending on monthly release volume	4,000 cfs/hr up 1,500 cfs/hr down
Seasonally Adjusted Steady Flow (SASF)	8,000 Oct–Nov 8,500 Dec 11,000 Jan-Mar 12,500 Apr 18,000 May–Jun 12,500 Jul 9,000 Aug–Sep	18,000	± 1,000	2,000 cfs/day when releases are changed between steady flow periods
Experimental Flow (EF): High Steady Spring, Low Steady Summer	21,400 15 Mar-18 May 8,000 Jun-Feb	33,000 spike for 4 days last week Apr 33,000 spike for 4 days last week Sep	±1,000	1,000 cfs/day (8,000 to 21,400 cfs, 1-14 March) 1,000 cfs/day (21,400-8,000, 18-31 May) 4,000 cfs/hr up, 1,500 cfs/hr down for spikes

[1] Source: U.S. Bureau of Reclamation (1995)

Benefits of steady flows on the aquatic ecosystem were further identified in the Opinion (FWS 1994):

> *Fluctuating flows limit solar warming of backwaters, flush organisms and nutrients important as food resources, and force earlier life stages of endangered and other native fishes out of quiet protected waters into unfavorable mainstem conditions. These conditions might include increased exposure to predation and debilitating effects of cold water and increased velocities.*

The program of experimental flows was designed to begin as soon as possible with scheduling dependent on annual river volume (FWS 1994):

> *Design of the experimental flows and associated studies will begin as soon as possible and be targeted for completion by October 1996. Unless the Service determines information provided seriously questions the validity of experimental designs developed or contribution of the resulting data to remove jeopardy to the federally-listed aquatic fauna of the Grand Canyon, experimental flows will be initiated in April 1997. If sufficient progress and good faith effort is occurring towards initiating experimental flows, implementation of experimental flows may occur later in 1997. If the Service believes there is not sufficient progress, Glen Canyon Dam would be operated as SASF flows during spring through fall (April to October) beginning in 1998. If the Service determines a study design can not be developed that is expected to provided* [sic] *information to support removal of jeopardy to the razorback sucker and humpback chub populations in the Grand Canyon and associated tributaries, such will be considered new information and may be grounds for reinitiating formal consultation.*

The flows would be implemented only in low-water years, or years with releases of approximately 8.23 million acre feet (maf), and begin before or coincident with issuance of the Record of Decision (ROD) for the GCDEIS (9 October 1996; Reclamation 1996). Experimental flows were not implemented in spring 1997, 1998, or 1999 because these years were forecast as moderate water years (>8.23 maf). According to the RPA, low-water years (≤8.23 maf) have occurred about 50% of the time since the dam became operational in 1963 (FWS 1994). Thus, the experimental flows would be expected only about 50% of the time over the long term, with no control over the sequence of years in which the experiment could be conducted. The RPA described the duration (number of years) of the experiment as "... a sufficient period of time to allow for experimental design, biological processes to function and for variability inherent in riverine ecosystems to be expressed. The number of years is, therefore, indeterminate" (FWS 1994).

1.2 PURPOSE AND OBJECTIVES

The purpose of the program of experimental flows, as presented in this document, is to test the overriding hypothesis that high spring releases and low steady summer/fall flows in low water years will benefit the endangered and other native fish species of the Colorado River through Grand Canyon. The design of this program emphasizes an ecosystem perspective that benefits native fishes while controlling populations of non-native fishes that compete with and prey on the native species. The objectives of this program of experimental flows are to:

- enhance survival and growth of young native fishes by providing stable, warm, productive shoreline nursery habitats;
- increase recruitment of native fishes;
- minimize adverse effects of non-native fishes; and
- contribute toward recovery of endangered humpback chub.

1.3 PARADIGM FOR EXPERIMENTAL FLOWS

Restoring elements of the natural hydrograph has been identified as a cornerstone in restoration of riverine ecosystems and recovery of native biota, including threatened and endangered species (Bain et al. 1988, Minckley and Meffe 1987, Tyus 1992, Stanford 1994, Poff et al. 1997, Schmidt et al. 1998). Natural hydrograph restoration of western rivers has two basic cause and effect elements. The first is restoring natural physical processes and habitat, including reestablishing sediment transport patterns and channel geomorphology and floodplains that characterized the river before human-caused modifications (Webb et al. 1989, Schmidt and Rubin 1995, Van Steeter and Pitlick 1998). The second element is restoring biota, including, but not limited to, benefitting primary and secondary production by increasing nutrient loads and benefitting fish populations by providing spawning cues (John 1963; Nesler et al. 1988; Stevens et al. 1995, 1997; Webb et al. 1999). Floods may also benefit native species by suppressing non-native species. Minckley and Meffe (1987) found that fish communities in canyon-bound reaches of unregulated southwestern streams invariably shifted from a mixture of native and non-native species to predominantly, and in some cases, exclusively native forms after floods approaching or exceeding two orders of magnitude greater than mean discharge.[1]

Limited testing of natural hydrographic elements has taken place in recent years, but experiments of the magnitude and duration described in this plan have not been conducted in other major mainstem dams in the United States. Flow recommendations for reoperation of both Flaming Gorge Dam on the Green River, Utah (Muth et al. 2000), and Navajo Dam on the San Juan River, New Mexico (Holden 1999), identify a return to high spring flows and low summer flows. The duration of the high

[1] Minckley and Meffe studied seven unregulated reaches of southwestern streams whose mean discharges ranged from 17.7 cfs (Bonita Creek) to 872.3 cfs (Salt River above Roosevelt Dam).

releases varies from 5-21 days at Navajo Dam to 3-8 weeks at Flaming Gorge Dam, depending on the volume of water available for the year. In the case of Navajo Dam, the objective is to "mimic the natural hydrograph" with a recommended 5-day peak release of 10,000 cfs or 83% of historic average peak flow of about 12,000 cfs. At Flaming Gorge Dam, the recommended 3-8 week release of 10,500 cfs is 59% of historic average peak flow of about 17,650 cfs. These flows have not been fully implemented and evaluated. A 7-day controlled flood of 45,000 cfs from Glen Canyon Dam in March-April 1996 was short-term and focused on a high release designed to redistribute and store sand and sediments (Andrews et al. 1999), recycle organic elements and nutrients (Parnell et al. 1999), reset primary and secondary production (Blinn et al. 1999), and temporarily reduce numbers of non-native fishes (Hoffnagle et al. 1999). The experiment was considered a moderate success relative to ecosystem benefits, but was highly valuable for better understanding resource response (Valdez et al. 1999a, Webb et al. 1999).

The concept of a low steady summer flow to maximize backwater formation was introduced in the upper Colorado River basin in about 1990, when the FWS (Tyus and Karp 1991) recommended summer and autumn flows of 1,800 cfs (25% fluctuation below target on a weekly or greater basis) for the primary nursery reaches of Colorado pikeminnow (*Ptychocheilus lucius*) in the Green River. The recommendation was based on aerial photography and mapping of backwater habitats at different flows (Pucherelli and Clark 1989). Colorado pikeminnow hatch during late June through July and require stable, sheltered, warm, and productive backwater habitats during their first 8-10 months of life (Tyus 1991). Preliminary results from the Interagency Standardized Monitoring Program (McAda 1999) show a steady increase in catch rate of age-0 Colorado pikeminnow, as well as population estimates of adults indicating that the management action may have increased survival of the young in nursery backwaters and hence, recruitment to the adult life stage.

1.4 THE FISHES

The present assemblage of fishes in the Colorado River through Grand Canyon (between Lees Ferry and Diamond Creek) consists of approximately 18 species, including 5 native and at least 13 non-native species (Valdez and Ryel 1997, Hoffnagle et al. 1999). The native species are the endangered humpback chub and razorback sucker, as well as the flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), and speckled dace (*Rhinichthys osculus*). A description of the status and life history of these species in Grand Canyon is presented by Valdez and Carothers (1998). Three additional species that are native to the Colorado River—bonytail (*G. elegans*), roundtail chub (*G. robusta*), and Colorado pikeminnow—have been extirpated from Grand Canyon (Minckley and Deacon 1991). Primary limiting factors have been identified as cold dam releases that preclude mainstem spawning, blocked passage by the dam, fragmented habitat, non-native fishes, and possibly fluctuating flows from hydropower releases (Minckley 1991, Valdez and Ryel 1997).

The humpback chub, which is endemic to the Colorado River Basin, was listed as endangered on 11 March 1967 (32 FR 4001) because of fragmented and degraded habitat, degraded water quality, and non-native fish predators and competitors (FWS 1990). This species remains as only six populations in the states of Colorado, Utah, and Arizona (Valdez and Clemmer 1982). Five of these populations are found in the upper Colorado River basin and one occupies Grand Canyon in the lower basin. In Grand Canyon, the species occurs as eight non-spawning aggregations in the mainstem Colorado River, and one spawning aggregation that inhabits the Little Colorado River (LCR) and the mainstem near the inflow of the LCR (Figure 1; Douglas and Marsh 1996, Valdez and Ryel 1997). The razorback sucker was listed as endangered on 23 October 1991 (56 FR 54957). The species was probably never abundant in Grand Canyon, possibly occurring only as a transient (Douglas and Marsh 1998), and is extremely rare today with fewer than 10 confirmed specimens captured in the last 55 years (Valdez 1996). The species may now be extirpated from Grand Canyon. Critical habitat was designated for the humpback chub, razorback sucker, bonytail, and Colorado pikeminnow on 21 March 1994 (50 FR 13374). In Grand Canyon, humpback chub critical habitat includes the Colorado River from Nautiloid Canyon (RM 34.0, 80 km downstream from Glen Canyon Dam) to Granite Park (360 km downstream from the dam), as well as the lower 12.9 km of the LCR. Razorback sucker critical habitat in Grand Canyon includes the Colorado River from the Paria River to Hoover Dam.

Twenty-four non-native fish species have been reported from the Grand Canyon region since 1956, including 17 warm-water, 1 cool-water, and 6 cold-water forms (Valdez and Ryel 1997). Recent surveys revealed 13 non-native species (Arizona Game and Fish Department 1996, Valdez and Ryel 1997). Of the 24 species, 17 (71%) were reported before Glen Canyon Dam was completed in 1963. The first non-native fishes in Grand Canyon were common carp (*Cyprinus carpio*) and channel catfish (*Ictalurus punctatus*), which were introduced into the lower Colorado River basin in about 1890 (FWS 1980, Miller and Alcorn 1943). By the end of the 19th century, these species were widespread throughout the Colorado River Basin (Carothers and Brown 1991). Shortly after establishment of Grand Canyon National Park in 1919, brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*) were introduced into Bright Angel Creek, Tapeats Creek, and Shinumo Creek in 1920, 1923, and 1926, respectively. Black bullheads (*Ameiurus melas*) were reported in the region in 1904 (U.S. Fish and Wildlife Service 1980); mosquitofish (*Gambusia affinis*) were common by about 1920 (Miller and Lowe 1967); and plains killifish (*Fundulus zebrinus*) were reported in about 1938 (Miller and Lowe 1967), but their origins are unknown. By the 1940s catfish dominated the catches of fishermen in the Colorado River in both Glen and Grand canyons (Webb and Melis 1994), and scientists began to express concerns about the decline of the native fishes (Miller 1961).

With completion of Hoover Dam in 1935 and formation of Lake Mead, many game fishes were introduced into the region, including largemouth bass (*Micropterus salmoides*), black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), and green sunfish (*Lepomis cyanellus*) (Wallis 1951, McDonald and Dotson 1960, McCall 1979). Fathead minnows (*Pimephales promelas*) and red shiners (*Cyprinella lutrensis*) were sold locally in bait shops (Hubbs 1954). Threadfin shad (*Dorosoma petenense*) were introduced into Lakes Mead and Powell in 1954 and 1968, respectively, primarily as forage for striped bass (*Morone saxatilis*), which were introduced into these reservoirs in 1969 and 1974, respectively (McCall 1979; Gustaveson et al. 1985, 1990). Yellow perch (*Perca flavescens*) and walleye (*Stizostedion vitreum*) were released into the lower Colorado River in the early 1960s (Minckley 1973; Gustaveson et al. 1985, 1990), and kokanee salmon (*O. nerka kennerlyi*), coho salmon (*O. kisutch*), and cutthroat trout (*O. clarki*) were released near Lees Ferry in

1967, 1970-71, and 1978, respectively (Stone and Rathbun 1968, McCall 1979, Haden 1992). Utah chub (*Gila atraria*) and golden shiner (*Notemigonus crysoleucas*) were probably imported into the region by bait anglers (McDonald and Dotson 1960, Suttkus et al. 1976).

1.5 OPERATION OF GLEN CANYON DAM

Flow of the Colorado River through Grand Canyon has been regulated by Glen Canyon Dam since the dam was completed in 1963 (Figure 2). That regulation has altered the annual hydrograph by decreasing spring peak flows and increasing summer, fall, and winter base flows. Regulation has also increased the frequency of daily flow fluctuations as a result of hydropower generation. Sediment load has been greatly reduced and river temperature has changed from seasonally variable (0-25°C) to a nearly constant regime of 8-11°C, reflective of hypolimnetic withdrawals from deep in the reservoir (Valdez and Carothers 1998). Present operations are described as the MLFF, which was the preferred alternative of the GCDEIS (Table 1). The MLFF was chosen by 11 of the 12 cooperating agencies as the draft GCDEIS preferred alternative (unpublished minutes, GCDEIS Cooperating Agencies meeting 27-29 January 1993, Reclamation, Colorado River Studies Office, Salt Lake City, Utah). This alternative was thought by its supporters to be the most balanced approach, benefitting the widest range of resources (including the aquatic food base and fish) when compared to historic dam operations. While the MLFF would result in a significant loss of hydropower benefits, compared to historic dam operations, those losses would be less than incurred under the SASF. The dissenting vote was cast by the FWS, which felt that the MLFF would not provide sufficient benefit to humpback chub to remove jeopardy (Reclamation 1994).

2.0 THE EXPERIMENTAL FLOWS

2.1 PROCESS FOR DEVELOPMENT

The following is a program of experimental flows that was developed during two 2-day workshops by a team of scientists (the authors of this document) consisting of biologists, population ecologists, and bio-statisticians. The hydrograph was designed and developed to match various flow periods with the life history needs of the endangered and native fishes of Grand Canyon. Life history phenologies were first developed for each of the four native fishes, including humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace (Figures 3a-3d), based on data and information collected for the species from Grand Canyon (Kaeding and Zimmerman 1983; Marsh and Douglas 1997; Valdez and Ryel 1997; Valdez and Carothers 1998; Douglas and Marsh 1996, 1998; Gorman and Stone 1999). A phenology was not developed for the razorback sucker because of its rarity and the lack of life history information from Grand Canyon.

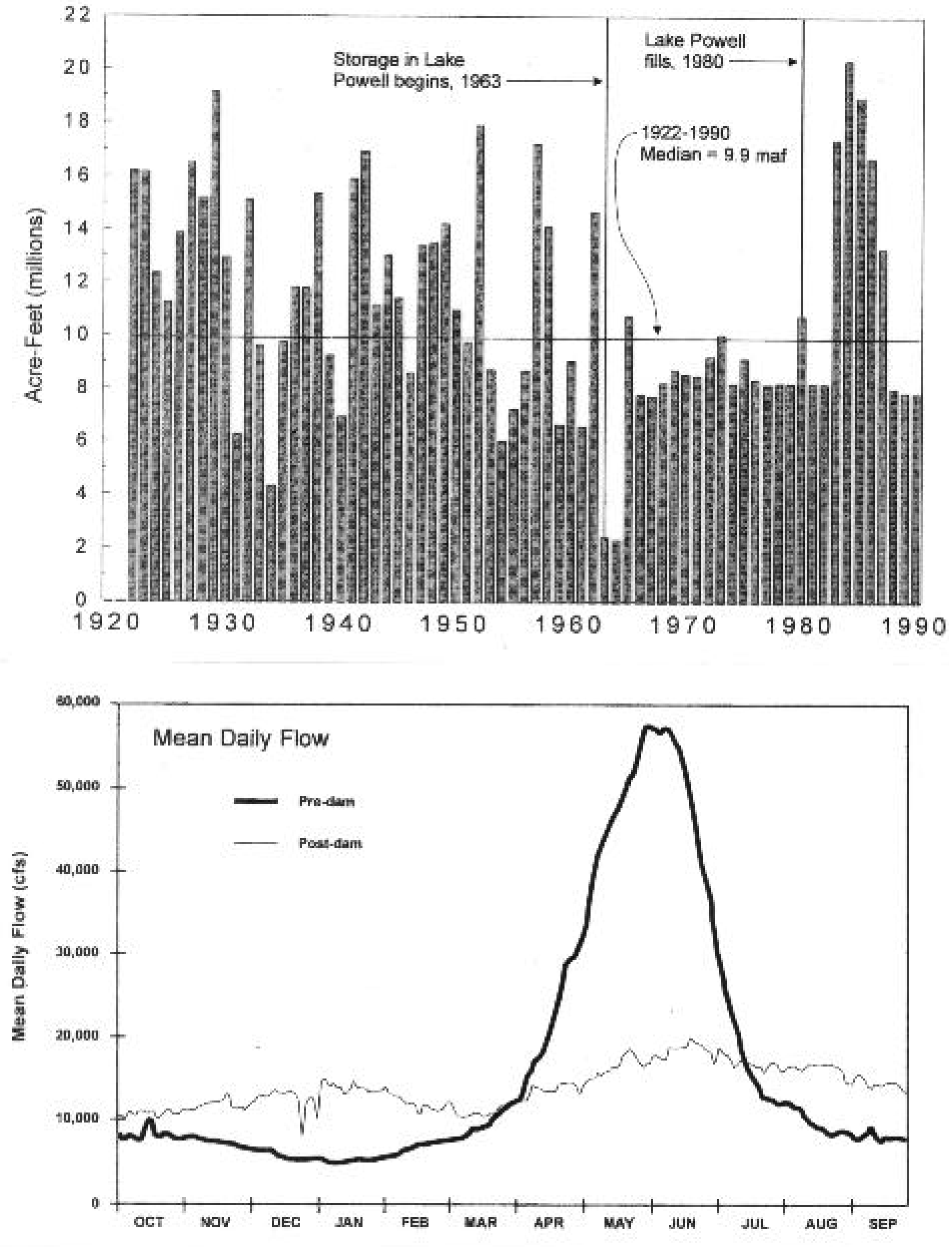

Figure 2. Annual discharge (water years 1922-98) and mean daily pre-dam (water years 1922-62) and post-dam (water years 1965-92) flow of the Colorado River at Lees Ferry, AZ (U.S. Geological Survey stream flow data)

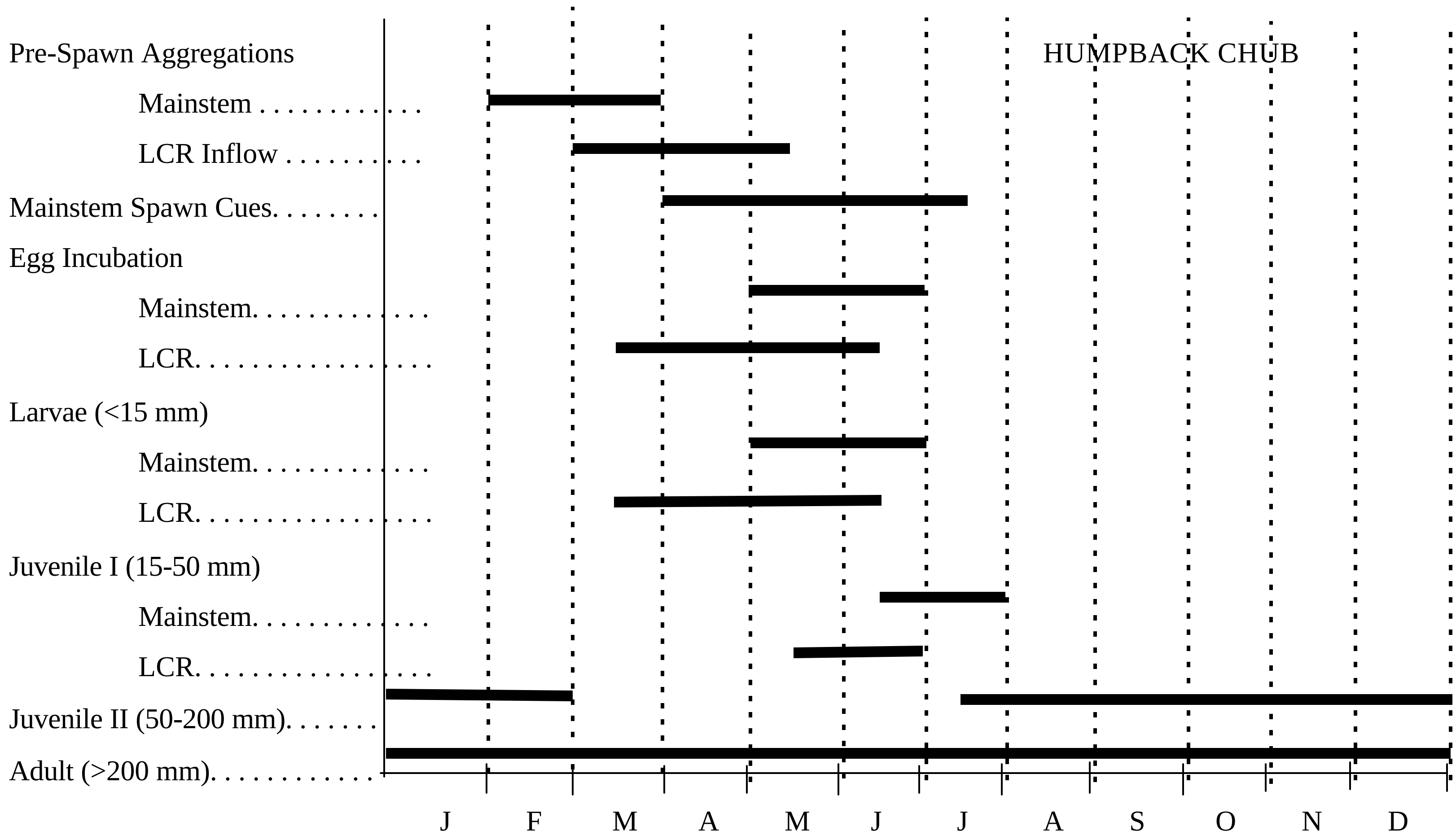

Figure 3a. Life history phenologies for the native fishes in the mainstem Colorado River and the Little Colorado River (LCR) in Grand Canyon.

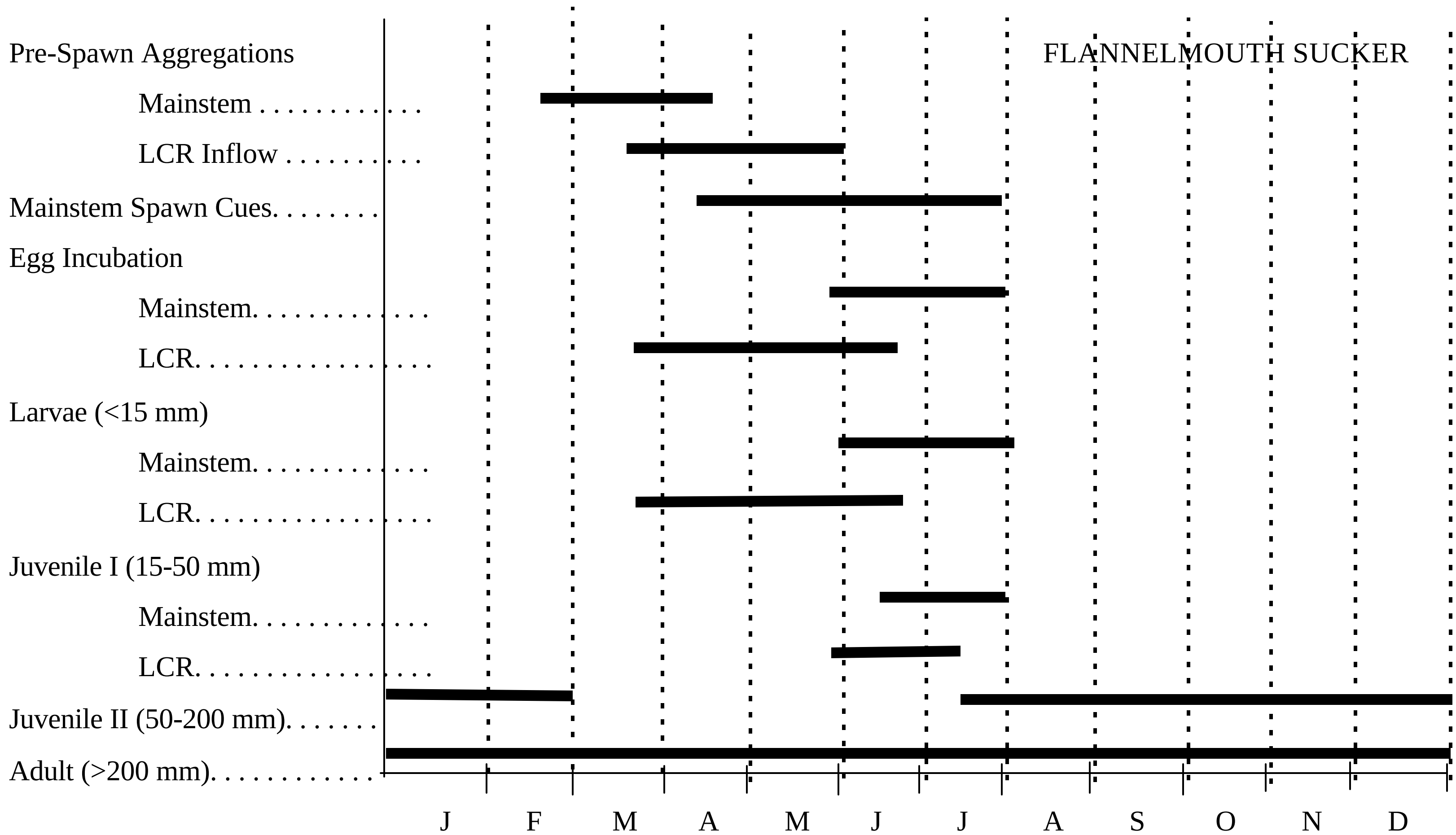

Figure 3b. Life history phenologies for the native fishes in the mainstem Colorado River and the Little Colorado River (LCR) in Grand Canyon.

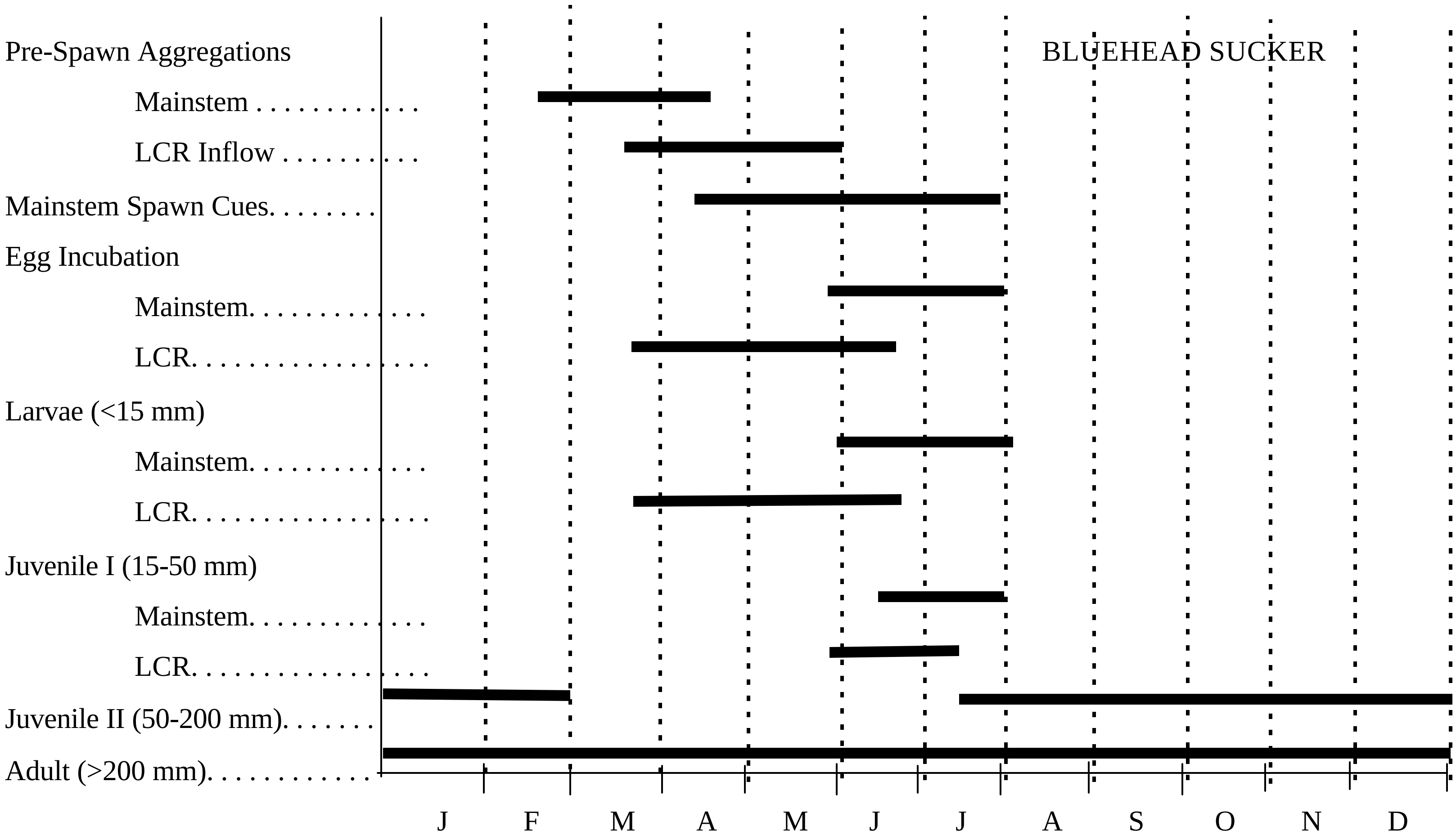

Figure 3c. Life history phenologies for the native fishes in the mainstem Colorado River and the Little Colorado River (LCR) in Grand Canyon.

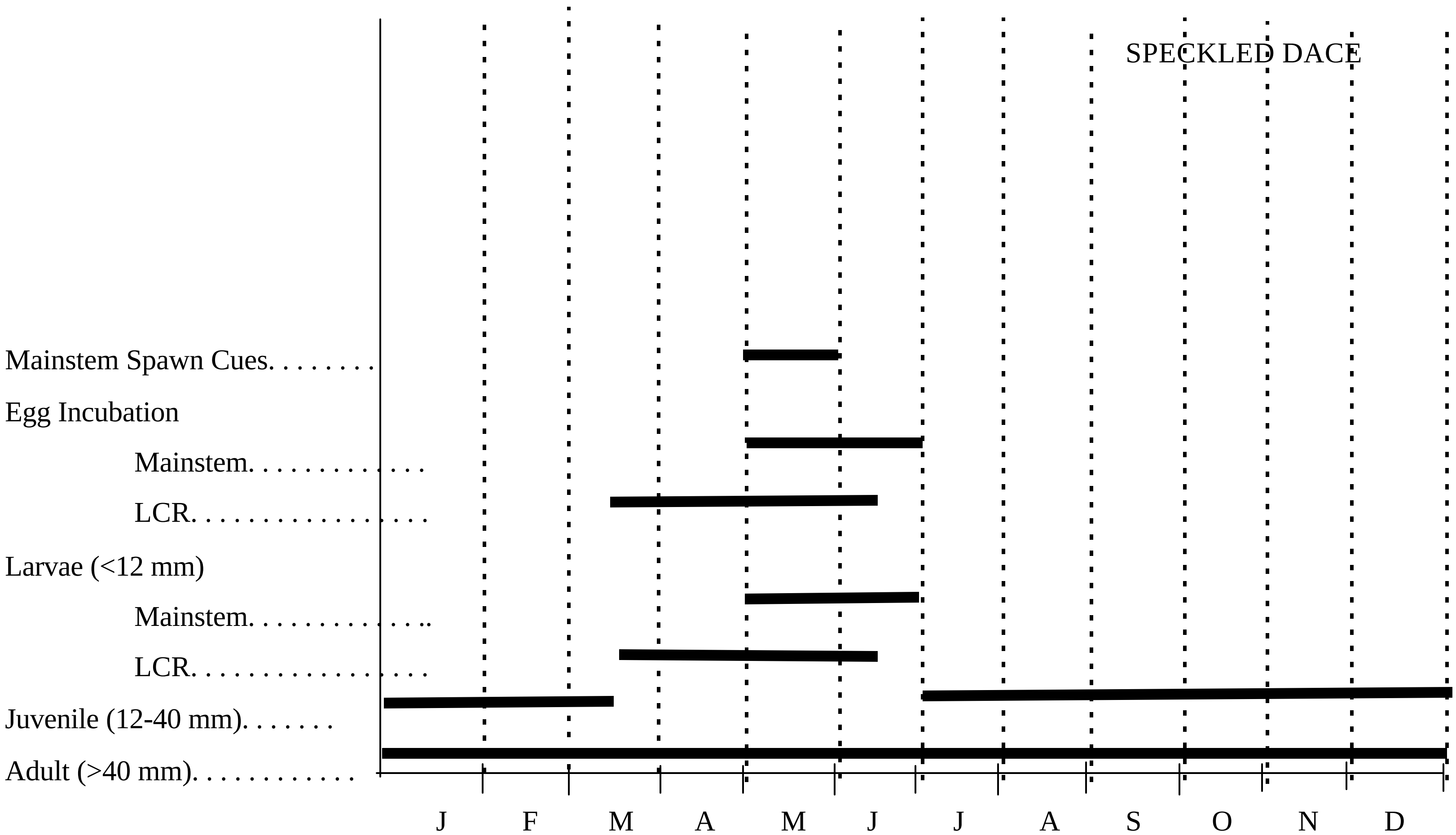

Figure 3d. Life history phenologies for the native fishes in the mainstem Colorado River and the Little Colorado River (LCR) in Grand Canyon.

A comparison was made of optimal temperature ranges for spawning/hatching and rearing of native fishes and warm-water non-native fishes (i.e., fathead minnow, red shiner, common carp, plains killifish, channel catfish, black bullhead) with temperatures of the Colorado River at Glen Canyon Dam, the Little Colorado River inflow, and Diamond Creek, under MLFF and EF (Figure 4). Maximum midsummer temperatures are expected to reach nearly 20°C at Diamond Creek with EF and benefit newly hatched native fishes. However, the occurrence of these warm temperatures is likely to coincide with spawning, hatching, and rearing of warm-water non-native fishes, possibly resulting in increases and expansions of these competitors and predators of the native fishes.

Life stages were identified as pre-spawning aggregations, spawning cues, spawning and egg incubation, larvae, juvenile, and adult. Juvenile life stages of humpback chub, flannelmouth sucker, and bluehead sucker were divided into two phases (I and II) to reflect distinctly different habitat uses, where juvenile I fish use shallow, nearshore habitats, and juvenile II fish use deeper, offshore habitats (Arizona Game and Fish Department 1996, Valdez and Ryel 1995, Converse et al. 1998). Life history phenologies were identified for both the mainstem Colorado River and the LCR since all four native fishes rely on seasonally warmed tributaries. Life histories for these species are 1-2 months earlier in the LCR than in the historic mainstem because of earlier seasonal warming in the LCR (Kaeding and Zimmerman 1983; Douglas and Marsh 1996, 1998; Valdez and Ryel 1997). These phenologies reflect periods of time when the majority of fish of that species are in a given life stage. For example, spawning by humpback chub in the LCR is identified as mid-March to mid-June, although some spawning activity occurs throughout summer (Kaeding and Zimmerman 1983, Gorman and Stone 1999).

As a result of these life history phenologies, the hydrograph was divided into three periods: March-May, June-September, and October-February. For each hydrographic period, the most critical life history needs of the native fishes were identified (Table 2). For example, larval humpback chub are expected to drift down the LCR and into the mainstem Colorado River during March-May, and juveniles phase I occupy shorelines and backwaters during June-September, while juveniles phase II occur along deeper shorelines during October-February. Since the life history phenologies for the four native fish species are similar, division of the annual hydrograph approximately corresponds to the various life stages of the four native fish species.

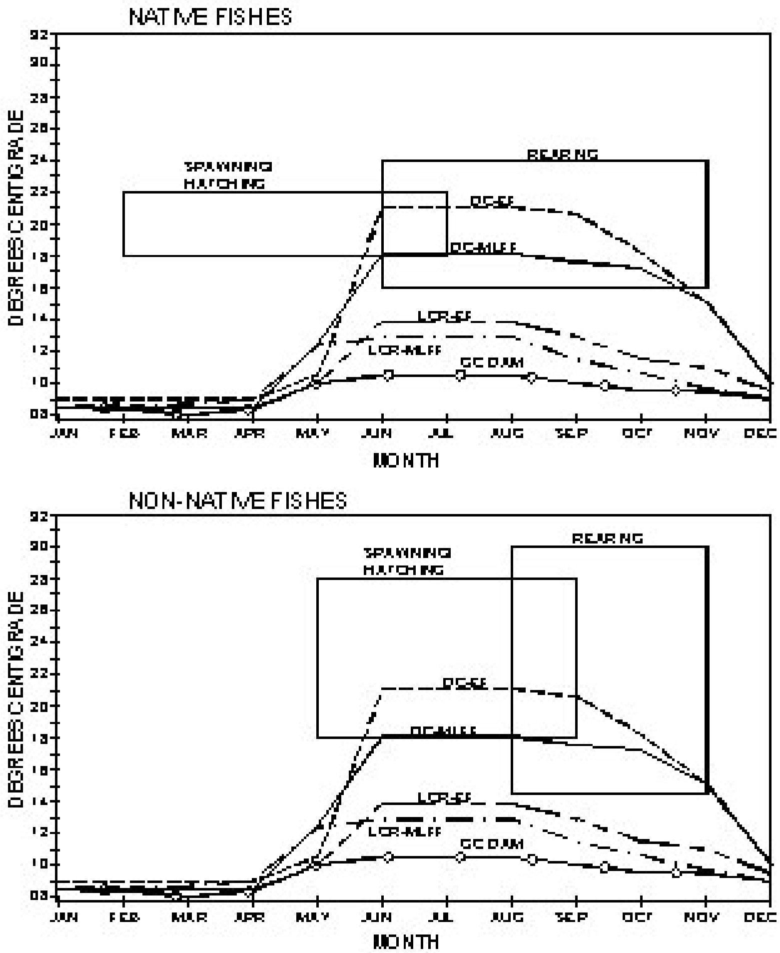

Figure 4. Optimum temperature ranges for spawning/hatching and rearing of native and warm-water non-native fishes compared to temperatures at Glen Canyon Dam, the Little Colorado River inflow, and Diamond Creek under modified low fluctuating flows (MLFF) and experimental flows (EF)

Table 2. Important life stages of the four native fishes by hydrographic period.

Fish Species	Period I: March-May	Period II: June-September	Period III: October-February
Humpback Chub	–pre-spawning aggregations at mouth of LCR in March-April –adults ascend LCR for spawning –spawning in LCR and drift of larvae to mainstem –larvae and early juveniles rearing along shallow shorelines and backwaters, mainly in LCR	–larvae and juvenile I swept into mainstem during summer spates –juvenile I rearing along shallow shorelines and backwaters in LCR and mainstem –adults in mainstem eddies	–adults need food resources for maximum accumulation of fats leading to spawning –adults in pre-spawning aggregations in mainstem eddies in February –juvenile II rearing along deep shorelines and backwaters
Flannelmouth Sucker	–adults in pre-spawning aggregations at tributary inflows –adults ascend tributaries for spawning –larvae drift into mainstem –larvae and early juveniles rearing along shallow shorelines and backwaters	–juvenile I rearing along shallow shorelines and backwaters –adults dispersed through mainstem	–adults need food resources for maximum accumulation of fats leading to spawning –juvenile II rearing along deep shorelines and backwaters
Bluehead Sucker	–adults in loose pre-spawning aggregations at tributary inflows in April –adults ascend tributaries for spawning –larvae drift into mainstem –larvae and early juveniles rearing along shallow shorelines and backwaters	–juvenile I rearing along shallow shorelines and backwaters –adults dispersed through mainstem, mainly near tributary inflows	–adults need food resources for maximum accumulation of fats leading to spawning –juvenile II rearing along deep shorelines and backwaters
Speckled Dace	–adults in loose pre-spawning aggregations at tributary inflows and mainstem in April-May –adults use tributary inflows and mainstem shorelines for spawning –larvae drift in mainstem –larvae and early juveniles rearing along shallow shorelines and backwaters	–juveniles rearing along shallow shorelines and backwaters –adults dispersed along shoreline debris fans, cobble riffles, and in tributary inflows	–adults need food resources for maximum accumulation of fats leading to spawning –adults dispersed along shorelines and in tributary inflows

2.2 THE HYDROGRAPH

The EF hydrograph extends for 1 year, from 1 March through 28 February (Table 1, Figure 5). The hydrograph consists of a relatively high steady spring release of 21,400 cfs during March-May, interrupted by a spike release of 33,000 cfs for 4 days during the last week of April. The high steady release is followed by a low steady summer/fall release of 8,000 cfs during June-September with a spike release of 33,000 cfs for 4 days during the last week of September. The period October-February consists of a low steady winter release of 8,000 cfs. The minimum release of 8,000 cfs and ramping rates for spike releases of 4,000 cfs/hr up and 1,500 cfs/hr down are consistent with requirements of Glen Canyon Dam operations as established by the GCDEIS (Reclamation 1995) and implemented through the ROD (Reclamation 1996). The spike releases are equivalent to habitat maintenance flows in the GCDEIS and do not exceed the power plant capacity of 33,000 cfs. The volume of this experimental flow is approximately 8.5 maf, as identified in the Opinion. This includes about 4,260,960 af for 269 days at 8,000 cfs; 3,722,528 af for 88 days of 21,400 cfs; and 516,512 af for 8 days at 33,000 cfs.

The EF hydrograph has elements characteristic of a natural hydrograph, with some important exceptions. From 1921 to 1961 (pre-dam), there were 10 years in which flow volume of the Colorado River at Lees Ferry was less than 8.5 maf (i.e., approximately 8.23 maf; U.S. Geological Survey [USGS] stream gage data, Lees Ferry, Arizona). For these dry years, the average spring peak of 40,290 cfs (range, 25,300-50,400 cfs) typically occurred on 5 June and flows were typically above 20,000 cfs for 1-2 months during May and June. The high steady release of the EF during March-May and the spike release in late April are about 1 month earlier than historic high flows to correspond with spawning and downstream movement of young native fishes from seasonally warmed tributaries, such as the LCR (see section 2.3.1). The 33,000 cfs spring spike of the EF is about 82% of the average historic peak magnitude during dry years.

Historic flows (i.e., 1921-1961) also reveal one to three late summer spikes in 9 of the 10 dry years (one year had no spikes). The average peak of 18 late summer spikes during this period was 14,494 cfs (range, 4,390-24,700 cfs), and the average day of occurrence was 15 September for an average duration of 2.1 days (maintained within 10% of peak). Hence, the 33,000 cfs of the EF is about 228% of average historic late summer spike magnitude. The late summer spike of the EF was set as high as possible to have the maximum adverse effect on non-native fishes (see section 2.3.1).

2.3 COORDINATION WITH RELATED ACTIONS

2.3.1 Beach/Habitat-Building Flows

The concept of beach/habitat-building flows (BHBF), a common element of alternatives in the GCDEIS, involves a release greater than powerplant capacity. Originally, it was to be considered in low reservoir storage years to rejuvenate beaches and backwater fish habitats. In the ROD on the GCDEIS, however, the Secretary determined that the objectives of a BHBF were to be accomplished instead in high reservoir storage years using releases greater than powerplant capacity required for

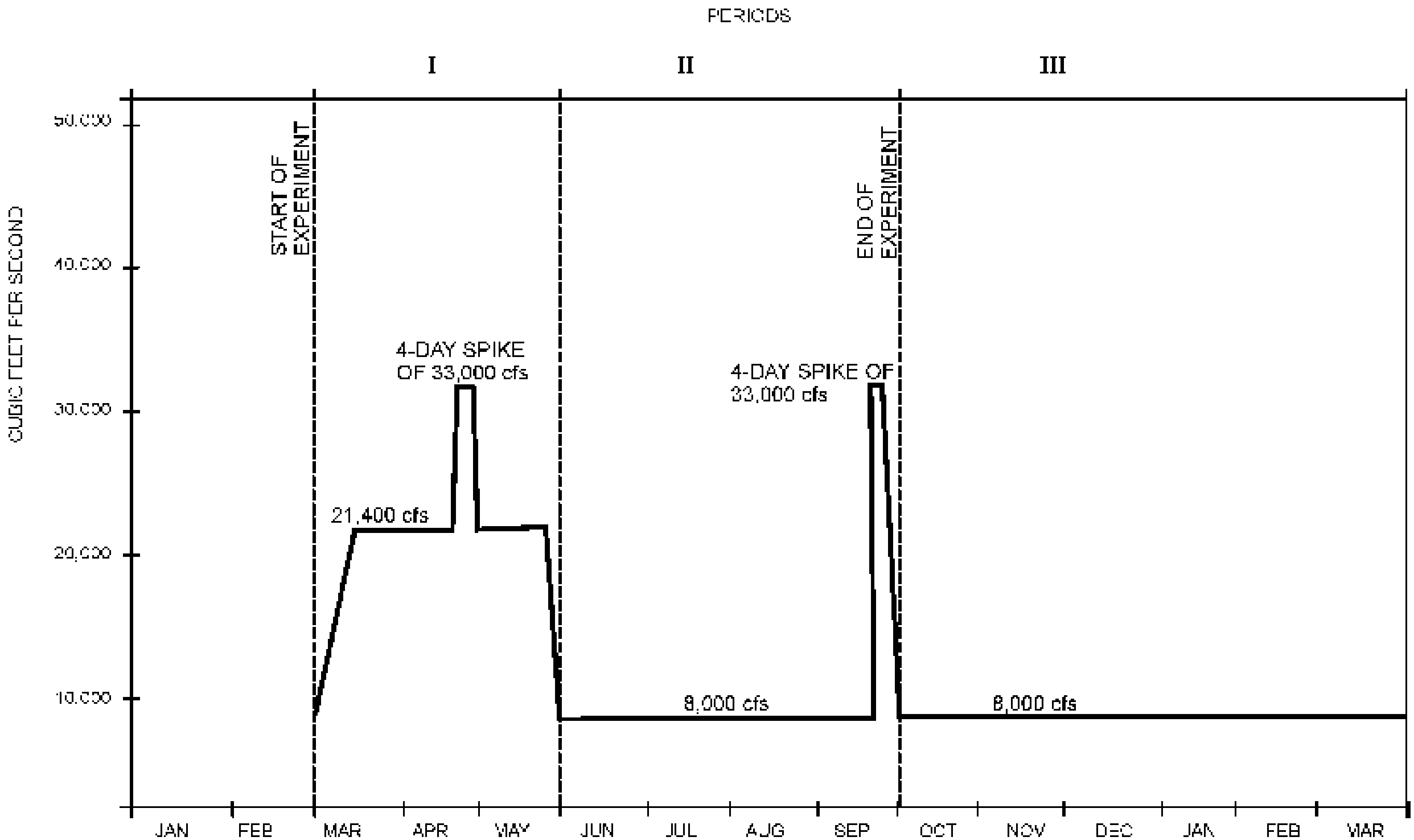

Figure 5. Hydrograph of experimental flows designed to release a volume of approximately 8.23 maf.

dam safety purposes (Reclamation 1996). A Spike Flow Subgroup was established by the TWG to evaluate alternative spill avoidance operations and risk thresholds in order to recommend specific triggering criteria when a BHBF can be prescribed (Pers. Comm., Bill Persons, Chair, Spike Flow Subgroup, GCMRC 1998). Since a BHBF is to be prescribed only during high reservoir storage years, it is unlikely that an EF hydrograph, which requires low steady summer releases, would be implemented in the same year. Hence, a BHBF and an EF hydrograph should not conflict. Coordination will be required by the Spike Flow Subgroup to ensure that a conflict does not occur.

2.3.2. Long-Term Monitoring Program

A formal long-term monitoring program for fish is needed in Grand Canyon. Past investigations under the Glen Canyon Environmental Studies (GCES) were primarily research efforts, and monitoring of fish populations has tended to be fragmented (Valdez and Ryel 1995; Arizona Game and Fish Department 1996; Douglas and Marsh 1996, 1998; Gorman and Bramblett 1999). An ongoing, long-term monitoring program with formal protocols is vital to understanding the status and trends of fish populations and to establishing a baseline of information that will help to evaluate long-term biological responses to a program of experimental flows. Evaluation of an EF hydrograph would have to be done as a hypothesis-driven research element, specifically designed to evaluate resource responses, and incorporated as a component of a long-term monitoring program.

2.3.3 Dam Modifications to Control Downstream Temperatures

In January of 1999, Reclamation issued a Plan and Draft Environmental Assessment for Glen Canyon Dam Modifications to Control Downstream Temperatures (Reclamation 1999). This proposal is discussed in this program of experimental flows because implementation of this temperature control device could enhance the beneficial effects of a low steady release by ensuring warm temperatures in mainstem reaches occupied by humpback chub aggregations. Under MLFF, longitudinal warming (1°C/51 km; Valdez and Ryel 1995) provides maximum summer temperatures of about 16°C at 30-Mile, 17.5°C at the LCR confluence, and 19.4°C in Middle Granite Gorge (Table 3), which are suitable temperatures for spawning, egg incubation, hatching, and growth of humpback chub and the three other species of native fishes in Grand Canyon. The combination of a low steady release of 8,000 cfs and a temperature control device is expected to provide maximum summer temperatures of about 17.0°C at 30-Mile, 18.2°C at the LCR confluence, and 21.0°C in Middle Granite Gorge.

Table 3. Predicted maximum water temperatures at locations of mainstem aggregations of humpback chub in the Colorado River downstream of Glen Canyon Dam under present operation of modified low fluctuating flow (MLFF), experimental flow (EF), the proposed temperature modification (TM) on Glen Canyon Dam, and TM with EF.

Aggregation	Distance From Dam (km)	MLFF (10°C at dam)[1]	EF (10°C at dam)[2]	MLFF with TM (15°C at dam)[1]	EF with TM (15°C at dam)[2]
30-Mile	75	11.5	12.0	16.5	17.0
LCR Inflow	124	12.5	13.2	17.5	18.2
Lava To Hance	131	12.6	13.4	17.6	18.4
Bright Angel Inflow	167	13.3	14.3	18.3	19.3
Shinumo Inflow	200	14.0	15.2	19.0	20.2
Stephen Aisle	214	14.2	15.6	19.3	20.6
Middle Granite Gorge	230	14.6	16.0	19.6	21.0
Havasu Inflow	278	15.6	17.2	20.6	22.2
Pumpkin Spring	368	17.4	19.6	22.4	24.6

1 Longitudinal warming rate of 1°C/50 km

2 Longitudinal warming rate of 1.3°C/50 km

The plan to control downstream temperatures was prompted by element 1B of the RPA, which identified the need for Reclamation to implement a "selective withdrawal program for Lake Powell waters" to warm dam releases for the benefit of native and endangered fishes. The plan identifies an alternative that would cost an estimated $15 million to modify all eight water intakes and allow for testing of the thermal modification (Reclamation 1999). If the modification proves to be beneficial to the fishes, a more flexible but expensive alternative would be considered, such as that constructed and implemented on Flaming Gorge Dam on 30 June 1978.

One plan under consideration involves removing the top of the trashrack structure and installing a gate at each penstock intake to allow withdrawal of warmer waters closer to the lake's surface. This modification could increase summer and fall release temperatures from about 8-11°C to about 18°C when warm water is available from about mid-May to November (Pers. Comm., Susan Hueftle, GCMRC 1999). Although warmer water is available during this period, the maximum water temperature of releases is proposed at 15°C, as the optimal temperature for growth of trout in the tailwater fishery. This temperature would benefit the tailwater trout fishery, and longitudinal warming would provide suitable temperatures for native fish populations further downstream.

2.4 COMPLIANCE WITH THE LAW OF THE RIVER

The proposed EF hydrograph must and does comply with the Law of the River, that body of law comprising statutes, regulations, court rulings, international treaties, and interstate compacts that govern use of the Colorado River. Most important, the hydrograph complies with the minimum annual delivery of 8.23 maf of water from the upper Colorado River basin to the lower Colorado River basin, as described in the Annual Operating Plan for Colorado River Reservoirs (U.S. Department of the Interior 1998) and mandated by the tenets of the Colorado River Compact of 1922 and the 1944 Water Treaty with Mexico (Ingram et al. 1991). Restricting the EF to low-water years ensures that Reclamation will not compromise reservoir operations designed to guarantee dam safety and the need to make downstream deliveries.

3.0 BENEFITS AND RISKS OF THE EXPERIMENTAL FLOWS

The three periods of the EF hydrograph have anticipated benefits and risks to abiotic and biotic resources, based on available data (Table 4). These are evaluated and described in the following sections.

Table 4. Anticipated benefits and risks for abiotic and biotic resources by hydrographic period.

Fish Species	Period I: March-May	Period II: June-September	Period III: October-February
Benefits to Abiotic Resources	–possibly scour backwaters –mobilize and store sands and sediments	–low steady flows may store sand and sediment in river channel –spike flow may resuspend and store sand and sediment from tributary monsoonal floods	–low steady flows may store sand and sediment in river channel
Risks to Abiotic Resources	–transport sediments from system	–spike flow may transport sand and sediment from system instead of storing it	–No significant risks
Benefits to Biotic Resources	–ponded tributary inflows as thermal refuges for drifting larvae and young fish –ponded tributary inflows ease access for spawning runs of native fish –destabilized habitats to disadvantage non-native fishes –redistributed nutrients –reset community production –cue mainstem spawning –spike flows flush non-native fish from backwaters and shorelines	–increased growth and survival of young native fishes –increased autotrophic algal and macroinvertebrate production –possible mainstem egg incubation and hatching success –spike flows flush non-native fish from backwaters and shorelines	–increased survival of young native fishes –maintain stable winter conditions to minimize energy expenditure –maintain overwinter autotrophic production in mainstem, shorelines, backwaters
Risks to Biotic Resources	–warm ponded tributary inflows attract non-native fish predators/competitors	–mainstem reproduction by non-native fishes –increased growth and survival of non-native fishes –increased infestation of parasites and diseases –decreased drift of food for fish –minimize thermal plume at 30-mile may reduce survival of young humpback chub –increased water clarity may lead to increased predation of native fish by sight feeders	–possible overwinter survival and expansion of non-native fishes –possible greater spawning success of downstream populations of trout –increased predation by sight feeders –decreased drift of food for fish

3.1 PERIOD I: HIGH STEADY SPRING RELEASE WITH SPIKE (MARCH-MAY)

3.1.1 Benefits to Abiotic Resources

- Scour and maintain backwaters – The April spike release of 33,000 cfs may deepen some backwater habitats by increasing velocities in return current channels (backwaters) that form in association with large recirculating eddies (Rubin et al. 1990); however, areas of smaller recirculation zones may actually fill more than scour (Hazel et al. 1999). Overall, the effects of a 33,000 cfs release on sediment resources for the proposed duration (i.e., 4 days) are presently unknown.

- Mobilize and store sands and sediments – Depending on the availability of sand and sediment in the river channel, the spike may resuspend and store some sand and sediments in eddy complexes and along channel margins (Wiele 1998, Wiele et al. 1996).

3.1.2 Risks to Abiotic Resources

- Transport sediments from the system – The high steady flow and spike may serve to transport sediment from the system instead of storing it, further depleting this resource in Grand Canyon (Wiele et al. 1996). High flows will generate high velocities that suspend sediment and may transport this material downstream if eddy complexes become flow-through systems and lose their storage capabilities.

3.1.3 Benefits to Biotic Resources

- Ponded tributary inflows as thermal refuges for young fish – The primary benefit of a high steady spring release of 21,400 cfs is ponding of tributary inflows to provide thermal refuges for recently hatched native fishes that might otherwise descend from warm tributaries into the cold mainstem (Clarkson et al. 1994, McIvor and Thieme 1999). The release of 21,400 cfs extends from mid-March to the end of May during the period of highest larval transport from tributaries such as the LCR (Robinson et al. 1998). Valdez and Ryel (1995) surmised from examination of scales that most humpback chub less than about 52 mm TL were not surviving the transition from the LCR to the colder mainstem. Measured water temperatures in the lower LCR over this period were 14-21°C (Gorman 1994) compared with mainstem temperatures of about 10°C. Flows greater than 17,000 cfs effectively ponded the LCR, when at base flow of 230 cfs (Wegner and Protiva 1994). During the 1996 experimental flood of 45,000 cfs, the LCR was ponded for nearly 1 km, and large numbers of humpback chub staged in the slackwater (Valdez and Hoffnagle 1999). The flood of late March lasted only 7 days and occurred before larval transport. The 1996 flood also increased the area of the Paria River mouth by 8-fold and formed a slackwater pool 0.76 km long, which was used extensively by adult flannelmouth suckers staging to ascend and spawn in this tributary (McIvor and Thieme 1999).

- Destabilized habitats to disadvantage non-native fishes – The late April spike of 33,000 cfs is intended to flood and destabilize shorelines and backwaters, and reduce numbers of non-native fishes. Significantly lower densities of non-native fishes were observed in backwaters and along shorelines following the 45,000 cfs controlled flood of 1996, but these returned to former densities 2-5 months after the flood (Hoffnagle et al. 1999). This short-term reduction in non-native fishes may provide a window of opportunity during which early life stages of native fishes can escape predation and competition.

- Redistributed nutrients – The April spike is expected to resuspend organic material stored along the shoreline and redistribute it into the mainstem. This material will provide nutrients to the aquatic system through a cascade effect (Parnell et al. 1999).

- Reset community production – The spike flow is expected to scour benthic periphyton and possibly reset community production. The 1996 experimental flood in Grand Canyon scoured large amounts of benthic periphyton (Marzolf et al. 1999, Brock et al. 1999), resulting in high primary and secondary production following the flood (Blinn et al. 1999).

- Cue mainstem spawning – The only evidence of mainstem spawning by native fishes is for humpback chub at 30-Mile (Valdez and Masslich 1999) and flannelmouth suckers in the Lees Ferry reach (Weiss, S.J., 1993; McKinney et al. 1998). Also, twenty-three small humpback chub, including one only 23 mm long, were captured between RM 168 and 208, suggesting spawning well downstream of the LCR, possibly in the mainstem (Arizona Game and Fish Department 1996). The April spike may provide a cue for mainstem spawning (although cold mainstem temperatures are limiting) or for fish staging to spawn in tributaries. Evidence of spawning cues from flow and temperature has been found for other Colorado River fishes, including Colorado pikeminnow (Nesler et al. 1988) and razorback sucker (Minckley et al. 1991). Evidence of spawning cues for humpback chub is not clear, but photoperiod, flow, and temperature may affect gonadal maturation and timing of spawning individually or synergistically (Valdez and Clemmer 1982, Kaeding et al. 1990, Valdez and Ryel 1995, Gorman and Stone 1999).

3.1.4 Risks to Biotic Resources

- Warm ponded tributary inflows attract non-native fish predators – The primary risk of ponding tributary inflows is that these sheltered habitats also attract non-native fishes, some of which are predators of young native fishes. Non-native fishes, such as common carp, channel catfish, fathead minnows, and rainbow trout were numerous to abundant in the ponded LCR inflow during the 1996 experimental flood (Hoffnagle et al. 1999).

3.2 PERIOD II: LOW STEADY SUMMER/FALL RELEASE WITH SPIKE (JUNE-SEPTEMBER)

3.2.1 Benefits to Abiotic Resources

- Sediment storage – The low steady summer/fall flow of 8,000 cfs is expected to transport less sand and sediment than the current operation, resulting in increased storage of this resource in the river channel (Wiele et al. 1996). This is beneficial to the system because the stored sediment can be resuspended and deposited in eddy complexes and shoreline margins with appropriate high flows.

- Spike may resuspend and store sand and sediment – The short-term spike of 33,000 cfs, scheduled for the last week of September, could resuspend and store sand and sediment from recent tributary monsoonal floods, which can deliver large volumes of sediment and sand to the mainstem (Wiele et al. 1996). This material is quickly eroded by the mainstem (Wiele 1998, Wiele et al. 1996) unless it is stored in high elevation eddy complexes and shoreline margins. The long-term benefit of this spike would be to store sand and sediment above the water line for MLFF for resuspension and long-term storage with a subsequent BHBF. These fines contain valuable organic matter for primary and secondary producers in the aquatic ecosystem.

3.2.2 Risks to Abiotic Resources

- Loss of sand and sediment – The September spike could transport sand and sediment from the system instead of storing it in eddy complexes and along shorelines. Flow magnitude and duration at which sediment transport and storage occurs is not well understood.

3.2.3 Benefits to Biotic Resources

- Increased growth and survival of young native fishes – The primary benefit expected from the low steady summer/fall release of 8,000 cfs is increased growth and survival of young native fishes as a result of the combination of stable nearshore and backwater habitats (Converse et al. 1998) and longitudinal river warming. Valdez and Ryel (1995) and Converse et al. (1998) hypothesized that changes in river stage from daily hydropower generation and differences in monthly release volumes created unstable shoreline habitats for young humpback chub, leading to increased energy expenditure and predation by brown trout, channel catfish, and rainbow trout. Similarly, Arizona Game and Fish Department (1996) reported extensive use of eddy return channels (backwaters) by native fishes, but flow fluctuations and high releases made these habitats available irregularly. Maximum backwater habitat in studies during 1985 to 1996 (Anderson et al. 1986; Weiss, J., 1993; McGuinn-Robbins 1995; Brouder et al. 1999) occurred at flows lower than 10,000 cfs, with flows of 5,000-8,000 cfs resulting in the greatest numbers of backwaters. During summer, water in these backwaters can be much warmer than the mainstem, offering attractive thermal refuges for young fish. Use of backwaters by larval and juvenile humpback chub, flannelmouth suckers, bluehead suckers, and speckled dace in Grand Canyon is documented (Arizona Game and Fish Department 1996), but talus, debris fans, and vegetated shorelines are also used extensively (Valdez and Ryel 1997, Converse et al. 1998). In contrast, young humpback chub in the upper basin do not use backwaters as extensively, since the young hatch during and after spring runoff (Valdez and Clemmer 1982, Kaeding et al. 1990, Valdez 1990, Valdez et al. 1990) when river flows are usually too high for formation of low-elevation backwaters (Harvey et al. 1993, Andrews 1986). Juvenile humpback chub use backwaters in the upper basin transiently (Valdez et al. 1990).

The low steady release is expected to increase longitudinal warming of the Colorado River during summer months. Releases from Glen Canyon Dam during summer/fall are usually 8-11°C, depending on reservoir elevation. Existing temperature models show maximum longitudinal warming during summer ranges from 1°C/51 km under interim flows (Valdez and Ryel 1995) to 1°C/48 km (Korn and Vernieu no date) and 1°C/46 km (Arizona Game and Fish Department 1996) under MLFF. Low steady releases of 8,000 cfs could warm the river longitudinally by an additional 1°C/80 km or about 0.625°C/50 km (Valdez and Ryel 1995). Assuming a release temperature of 10°C, maximum mainstem temperatures at the LCR and Middle Granite Gorge are expected to be 13°C and 16°C, respectively. Low steady flows are expected to result in warm, more persistent backwaters during summer. Under the MLFF, backwaters were significantly warmer than the mainstem (Arizona Game and Fish Department 1996). Maximum backwater temperature was 28°C in May and September, and the highest average of 16.75°C occurred in August.

- <u>Increased autotrophic algal and macroinvertebrate production</u> – Autotrophic algal and macroinvertebrate production in the mainstem, shorelines, and backwaters is likely to increase if water clarity and temperatures increase (Stevens et al. 1995, Benenati et al. 1998, Blinn et al. 1998). Valdez and Ryel (1995) measured a significant increase in water clarity when flows changed from fluctuating releases of 7,000-25,000 cfs to a steady 3-day release of 5,000 cfs. Water clarity increased dramatically within 24 hours from about 1.0 m to 5.5 m Secchi depth. Water clarity decreased to about 2.0 m Secchi depth with a steady release of 15,000 cfs.

While warmer water temperatures are expected to enhance shoreline and backwater primary and secondary production, a possible offsetting effect of warmer temperatures could be a change in composition of the diatom epiphyte community from more upright taxa available to grazing invertebrates, to more closely attached, unavailable taxa (Blinn et al. 1998).

- <u>Mainstem egg incubation and hatching success</u> – In the lower reaches of the canyon, longitudinal warming is likely to produce suitable temperatures (16-22°C) for successful mainstem egg incubation and hatching of native fishes. This temperature range is also considered optimum for survival and growth of humpback chub (Hamman 1982, Marsh 1985). Stable flows will decrease susceptibility of eggs to exposure and desiccation.
- <u>Spike flow flushes non-native fishes from backwaters and shorelines</u> – The main purpose for the 4-day spike release of 33,000 cfs in late September is to displace and disadvantage small forms, especially early life stages of non-native fishes, by flooding and destabilizing shorelines

and backwaters. This flooding is expected to transport non-native fishes downstream and into high velocity environments, where their survival is expected to be low; many non-native species in Grand Canyon are primarily slow-water inhabitants and are ill-adapted to swift currents. The spike is similar to natural late-summer rainstorm events and is not expected to adversely affect yoy native fishes (Hoffnagle et al. 1999). The majority of these fish should be at a juvenile II stage, which have less dependence on shallow protected shorelines (Converse et al. 1998). The spike may also resuspend, transport, and store sand and sediment from recent tributary monsoonal floods. These floods can deliver large volumes of sediment and sand to the mainstem (Wiele et al. 1996, Wiele 1998). The long-term benefit of this spike is temporarily to store sand and sediment for resuspension and more long-term storage with a subsequent higher release. This sand helps to form eddy return-current channels, which function as backwater fish habitats. A spike release shortly after a monsoonal flood will serve to resuspend and store fine sediments and organic matter that are usually transported from Grand Canyon within weeks (Wiele et al. 1999).

3.2.4 Risks to Biotic Resources

- Mainstem reproduction by non-native fishes – Of the 13 non-native fish species presently found in Grand Canyon, 11 are warm-water forms with similar temperature requirements to the four native species. Low steady releases are likely to increase reproduction of warm-water fishes, especially along shorelines and in backwaters Increased abundance and distribution of non-native species could result in increased competition and predation on native forms (Minckley 1991).

- Increased growth and survival of non-native fishes – The primary risk of a low steady release is increased numbers and distribution of warm-water, non-native fishes, which are competitors and predators of native fishes (Minckley 1991). Of the 13 non-native species recently found in Grand Canyon, 11 are warm-water forms with similar temperature requirements to the four native species. Low steady releases are likely to allow for reproductive success and increase growth and survival of non-native fishes in the mainstem. The low steady release may result in increased water clarity of the mainstem Colorado River, in the absence of tributary sediment-laden floods, and possibly increase the risk of predation by sight feeders (Valdez and Ryel 1995, 1997). It is understood that, while a decrease in turbidity is expected, it may not be biologically significant (Hoffnagle 1996).

- Increased infestation of parasites and diseases – Warmer water is also likely to increase the incidence of parasites and diseases among fishes and increase stress and possibly mortality. The Asian tapeworm (*Bothriocephalus acheilognathi*) requires 25°C for maturation and reproduction (Grannath and Esch 1983), while the parasitic copepod (*Lernaea cyprinacea*) requires at least 25°C for parasitizing of fish (Marcogliese 1991). Both parasites are prominent in fishes of Grand Canyon (Brouder and Hoffnagle 1997, Clarkson et al. 1997, Valdez and Ryel 1995), and could reduce survival of fish through increased stress. Facultative fungal and bacterial infections are also more likely to occur at warmer temperatures (Stoskopf 1993). The protozoan parasite *Myxobolus cerebralis*, known as whirling disease, is widespread and is also temperature dependent (Hoffman 1990); spores form and fish show symptoms in 52 days at 17°C, 3 months at 12°C, and 4 months at 7°C (Halliday 1973). This parasite is known primarily from salmonids, which occur in the dam tailwaters, an area not likely to be significantly affected by longitudinal warming, and further downstream near tributary mouths. Whirling disease has not been reported in any fish species from Grand Canyon (Pers. Comm., Bill Persons, Arizona Game and Fish Department).

- Decreased drift of food for fish – Low steady releases are likely to decrease drift of macroinvertebrates and detritus as food for fish. Valdez and Ryel (1997) reported that the higher macroinvertebrate drift rates during fluctuating flows than during steady flows was reflected in diets of humpback chub.

- Minimized thermal plume at 30-Mile – Post-larval humpback chub were reported from a riverside warm spring at 30-Mile (i.e., 72 km downstream from Glen Canyon Dam) indicating successful spawning in this warm spring (Valdez and Masslich 1999). The thermal plume from this spring becomes entrained in a recirculating eddy at mainstem flows of 15,000-18,000 cfs, providing a thermal refuge and a benefit to recently hatched humpback chub. Releases lower than 15,000 cfs stop the recirculating eddy effect and wash the spring plume downstream, quickly diluting the thermal effect. Humpback chub at the 30-Mile aggregation are all adults, indicating little or no recruitment, and suggesting that these fish were hatched before 1970 when mainstem temperatures were sufficiently warm (Valdez and Ryel 1995).

- Predation due to increased water clarity – A low steady release of 8,000 cfs may result in increased water clarity of the mainstem Colorado River, in the absence of tributary sediment-laden floods (Valdez and Ryel 1995). While increased water clarity is likely to increase autotrophic production, it also increases the risk of predation by sight feeders, such as brown trout and rainbow trout, on native fishes.

3.3 PERIOD III: LOW STEADY WINTER RELEASE (OCTOBER-FEBRUARY)

3.3.1 Benefits to Abiotic Resources

- Sediment storage – The low steady winter release of 8,000 cfs is expected to transport less sand and sediment than the current operation, resulting in increased storage of this resource (Wiele et al. 1996).

3.3.2 Risks to Abiotic Resources

- No significant risks are expected for abiotic resources.

3.3.3 Benefits to Biotic Resources

- <u>Increased survival of young native fishes</u> – Survival of young-of-the-year humpback chub in the first year of life is estimated at 0.10 (Valdez and Ryel 1997). It is hypothesized that more stable shorelines and backwaters will increase overwinter survival of native fishes.

- <u>Maintain stable winter conditions</u> – Winter is one of the most stable periods for fish. Flows are typically low and stable, and cold water temperatures reduce community and fish metabolism (Schmidt et al. 1987). Low steady winter flows will simulate natural flows.

- <u>Maintain overwinter autotrophic production</u> – Compared to MLFF, low steady flows are likely to produce greater overwinter autotrophic production of algae and macroinvertebrates in the main channel, shorelines, and backwaters.

3.3.4 Risks to Biotic Resources

- <u>Overwinter survival and expansion of non-native fish</u> – Expansion of non-native fishes during low winter releases of 8,000 cfs may occur. The late September 4-day spike of 33,000 cfs is designed to disadvantage non-native fishes before winter.

- <u>Greater spawning success of downstream populations of trout</u> – The primary risk of a low steady winter release is increased mainstem and tributary inflow spawning by populations of rainbow trout and brown trout downstream of Lees Ferry (Arizona Game and Fish Department 1994). Local populations of rainbow trout at Vasey's Paradise, and inflows of Nankoweap Creek, Bright Angel Creek, Deer Creek, and other tributaries are likely to have higher reproductive success as a result of the steady flows, resulting in increased numbers of trout. Rainbow and brown trout from these downstream populations are thought to be the principal predators of young humpback chub (Valdez and Ryel 1997, Marsh and Douglas 1997). Mark-recapture studies show no significant downstream movement of tailwater trout to areas inhabited by humpback chub (Valdez and Ryel 1995).

- <u>Increased predation by sight feeders</u> – If water clarity increases, predation of native fish by sight feeders such as rainbow and brown trout, known predators of native fishes, may increase as well (Valdez and Ryel 1995, Marsh and Douglas 1997). Rainbow trout are known to significantly decrease reactive distance to prey items at turbidity levels of >30 NTU, or about <0.5 m Secchi depth (Barrett et al. 1992).

- Expansion of non-native fish – Rainbow trout and brown trout and other non-native fishes may disperse during low winter releases. Significant downstream displacement of rainbow trout was recorded as a result of the 1996 experimental flood (Hoffnagle et al. 1999).
- Decreased drift of food for fish – Decreased drift is likely to occur, but is not expected to result in a significant loss of food for fish. October through February is an important period for humpback chub to improve their fat level and body condition before spawning (Kaeding and Zimmerman 1983, Meretsky et al. 1999).

4.0 EVALUATION AND MONITORING

We recommend a program of experimental flows that will be evaluated by establishing a 1-year baseline, supported by data of past studies, against which at least two 1-year treatments will be independently compared. Lack of ongoing, long-term monitoring data and the low likelihood of consecutive low waters years preclude time series analysis. Hypotheses should be tested to determine the responses by fish to these treatments and compared with the baseline. We understand that one of the primary limiting factors for the successful evaluation of the effects of a steady flow experiment will be climatic vagaries that render prediction of inflow into Lake Powell difficult over any substantial length of time. Low predictability makes it difficult to plan and implement dam release regimes and scientific evaluation of those regimes over multiple seasons and consecutive years. Still, we must propose an experiment that includes as much scientific rigor as possible under the circumstances.

Since the purpose of the EF is to alter conditions such that native fishes will benefit more than non-native fishes, the goal of the experimental design is to evaluate relevant life history parameters to determine whether native and endangered fishes respond favorably as shown by significant changes in these parameters. While the experimental study design evaluates short-term responses, an ongoing program of monitoring is imperative for thorough evaluation of long-term responses of EF. This research plan is broad in scope and intended to provide the framework for a final detailed study design, including the formulation of specific research hypotheses, that must be refined by the researchers who will be collecting and analyzing the field data.

4.1 THE EXPERIMENTAL STUDY DESIGN

Each 1-year experimental flow of approximately 8.23 maf ($EF_{8.23}$) is considered an independent treatment against which a 1-year baseline of MLFF with approximately 8.23 maf ($MLFF_{8.23}$) is compared (Figure 6). The treatments are compared against a baseline of similar flow volume to minimize the confounding effects of water volume. The year of $MLFF_{8.23}$ must precede the $EF_{8.23}$ to avoid a shift in ecological equilibrium and confounding of conditions created by the $EF_{8.23}$; i.e., effects of a treatment could alter baseline conditions. Hence, the first year with an expected release volume of approximately 8.23 maf would be operated under current operations of MLFF to establish a baseline of information. Baseline data will be supplemented with information gathered in past investigations (Kaeding and Zimmerman 1983; Maddux et al. 1987; Valdez and Ryel 1995, 1997; Arizona Game and Fish Department 1996; Douglas and Marsh 1996, 1998; Gorman and Bramblett 1999).

Dam modifications to control downstream temperatures could have a significant effect on this experimental study design if not implemented equally for the baseline $MLFF_{8.23}$ and at least 2 years of the $EF_{8.23}$ treatments. If dam modifications are not completed in time for the baseline $MLFF_{8.23}$, then at least 2 years of $EF_{8.23}$ must be conducted before implementation of temperature controls. Since temperature and flow are the primary variables of this experiment, as much control as possible should be maintained over these variables.

Since low-volume years of approximately 8.23 maf may not occur consecutively, each $EF_{8.23}$ is considered an individual treatment. A low-volume dam release of approximately 8.23 maf ($\leq$8.5 maf) has occurred in 16 of 35 water years (46%) for the post-dam period, 1964-99 (USGS stream gage data, Lees Ferry, Arizona). During that time, two or more consecutive releases of approximately 8.23 maf occurred five times with a 26% probability of a future occurrence. The last consecutive occurrence of 8.23 maf releases was in water years 1988, 1989, and 1990, and the greatest number of consecutive years of approximately 8.23 maf releases was in 1976, 1977, 1978, and 1979. Since each $EF_{8.23}$ is considered an independent treatment, lack of consecutive order between the baseline and treatment will not affect the experimental study design. Dam releases during 1988-1990 were under high fluctuating releases and research flows (Valdez and Ryel 1997); therefore, some data collected during 1989-1990 (no data were collected in 1988) under GCES Phase II (Valdez and Ryel 1995, Arizona Game and Fish Department 1996) may be useable as baseline information.

Although the program of experimental flows consists of a 1-year baseline of $MLFF_{8.23}$ and at least two treatment years of $EF_{8.23}$, life history parameters will be evaluated in time series within each treatment and at the end of each treatment year. Significant negative responses (e.g., large numbers of non-native fishes and low numbers of native fishes) will be evaluated and the experiment either terminated or re-evaluated and modified (see section 3.8). Monitoring is a critical part of evaluating this program of experimental flows since treatment evaluation is for a short-term response that may have long-term biological consequences.

This experimental study design imposes no restrictions on dam operations during years with releases greater than approximately 8.23 maf. Nevertheless, it is important to understand that special releases, such as a BHBF in an intervening year between the baseline and a treatment, or between treatments, could alter prior conditions and confound the experiment, possibly leading to faulty conclusions about accepting or rejecting hypotheses. This situation points out the need for a monitoring program to evaluate ongoing dam operations.

4.2 PRIMARY HYPOTHESES TO BE TESTED

The two primary hypotheses to be tested are:

Ho I: No significant changes will occur in life history parameters of native fishes.

Ho II: No significant changes will occur in life history parameters of non-native fishes.

The life history parameters to be tested under each of these hypotheses include growth, survival, condition, recruitment, density, and distribution. Additional hypotheses should be developed for each life history parameter for sub-adults and adults of each species of native and non-native fish in Grand Canyon. The list of specific hypotheses is long and redundant, and only the hypothesis for growth of pre-adult humpback chub is presented below as an example. A list of potential detailed hypotheses developed by GCMRC is provided as Appendix A.

Ho1: Growth of pre-adult humpback chub during experimental flows (i.e., $EF_{8.23}$) will not differ significantly from growth under modified fluctuating flows (i.e., $MLFF_{8.23}$).

Growth is defined as the increase in length of sub-adult or adult fish during the 1-year baseline or during each 1-year treatment, and is measured directly from calculated mean lengths at the beginning and end of each 1-year period. Survival is the number of fish of each cohort remaining at the end of the baseline or each treatment, and can be assessed directly from decreased abundance or calculated from survival models based on mark-recapture data (Brownie et al. 1985). Condition of adults can be computed as relative condition factor from accurate field weights and lengths of individual fish (Meretsky et al. 1999), while condition of sub-adults and small-bodied fishes can be better determined by relative weight (i.e., weight of samples of fish; Murphy et al. 1991). Recruitment is defined as fish surviving between subsequent age groups and can be based on relative density and/or population estimates, or survival and recruitment models (Ricker 1975). Long-term recruitment of young fish through more than one age group to adulthood must be evaluated through a long-term monitoring program. Abundance will be determined as population estimators (from multiple mark-recapture) and catch rate indices (catch-per-unit-effort; CPE). Where possible, mark-recapture techniques will be used to derive population estimates, since gear types vary in efficiency they may not be consistently based on spatial or temporal sample efforts. Population estimators (Chao 1987, 1989) similar to those used by Douglas and Marsh (1996, 1998) and by Valdez and Ryel (1997) should be used. Distribution will be determined as occurrence of fish longitudinally as well as by habitat type.

Although in this document we focus on attempting to quantify fish responses to the EF, to identify specific cause and effect relationships between dam releases and fish responses we fully expect investigators to test hypotheses associated with responses in physical habitat parameters as well, particularly effects of the EF on nearshore water temperature and velocity.

4.3 SAMPLE FREQUENCY

Field sampling to evaluate life history parameters of native and non-native fishes will be conducted in late-June, early October, and February of the baseline $MLFF_{8.23}$ and each treatment $EF_{8.23}$ (Figure 6). All sample periods occur during 8,000 cfs to reduce the effect of flow on sampling efficiency and variability. The late-June sample follows the high steady release period and provides a baseline measure of cohort abundance, distribution, and size for all native species in the system and most non-natives. June is a time when sampling variability in Grand Canyon is less likely to be exacerbated by variable river flows and turbidity brought on by monsoonal storm events, which usually occur mid-July to mid-September. The second sample period in early October is designed to provide an interim measure of life history parameters and evaluate effects of the late September spike. October is also a time when sampling variability in Grand Canyon is less likely to be exacerbated by flows and turbidity. The third sample period in February provides data collection at the end of each treatment and is designed to provide data for estimates of fish numbers, growth, survival, condition, and recruitment. Since October occurs within the non-motorized season (15 September - 15 December), a waiver for motorized support and sampling boats will be necessary to carry out the fish sampling.

4.4 ANALYSES

Evaluation of the EF will be based on comparing data gathered on life history parameters (growth, survival, conditions, recruitment, density and distribution) during treatments ($EF_{8.23}$) with baseline data ($MLFF_{8.23}$ and recent studies). Hypothesis testing will determine if a significant response has occurred, based on alpha level of 0.05. Statistical analyses to be performed will depend on the characteristics of data distributions. Data will be evaluated for normality and kurtosis (Sokal and Rohlf 1987) to determine the most appropriate averaging statistic for mean comparisons. McAda (1989) investigated several methods of data analysis for the upper Colorado River basin monitoring program and determined that for CPE, geometric-mean was more appropriate than standard arithmetic mean because of the high occurrence of zero catches and non-normal distributions.

Causal relationships may not be as evident as biological responses. A "weight-of-evidence" (Beyers 1998) approach recognizes the shortcomings of traditional statistical analyses with large field experiments, such as this one, that lack randomization, replication, and controls. Statistical analyses provide evidence of a change in resource parameters and are critical for any objective understanding of system response, but without replication, causal relationships can be difficult to establish. The "weight-of-evidence" approach bases causal inference on a series of logical arguments based on criteria established *a priori* and concordant with laboratory and field results. Causal inference with the use of logical argument, supported by available data and analyses, is consistent with the rigors of the scientific method. With the ecosystem perspective in mind, evaluation of the experiment would be done by determining if the treatment caused a shift in the fish community/assemblage toward a better situation for native fishes.

4.5 ROLE OF MONITORING

An ongoing fish monitoring program in Grand Canyon is vital to successful and complete evaluation of a program of experimental flows. Although the experimental study design described in this program provides short-term evaluation of treatments, monitoring is important to evaluate responses to treatments that may have long-term biological consequences. Long-term biological responses require ongoing monitoring to better understand population cycles and linkages to physical, chemical, and other environmental factors. Based on the longevity and generation time of the Colorado River native fishes, and inherent variability in populations, it is estimated that at least 10 years of monitoring would be required to accurately evaluate long-term biological responses to EF. This period may be much longer, considering climatic variations and the frequency of occurrence of low-water years.

Ongoing, annual monitoring will also contribute substantially to baseline data and information. Monitoring data should be compared on an ongoing basis to past data and to the 1-year $MLFF_{8.23}$ baseline for integration and congruence of data that represent the life history parameters of the fish species in Grand Canyon. These integrated baseline data will provide valuable information for comparison of treatments under the program of experimental flows.

Stock-recruitment models have recently been recommended as a vehicle for assimilation and synthesis of fishery data from Grand Canyon (Pers. Comm., Carl Walters, University of British Columbia, 2000). Mark-recapture data can be used in these models to assess cohort strength and recruitment that result from a variety of demographic and environmental conditions, such as reproductive success, and growth, survival, and predation rates. During the years 2000 and 2001, stock recruitment models will be developed for each of the native fish species as well as the more significant non-native fish species. Data collected from past investigations will be used in these models, and future data collection needs will be identified.

4.6 ROLE OF GRAND CANYON CONCEPTUAL MODEL

Development of the conceptual model for the Colorado River ecosystem in Grand Canyon (Walters and Korman 1998, 1999) revealed major uncertainties about the aquatic ecosystem from a lack of linked quantitative data. Estimates of fish life history parameters are scant and lack synthesis and integration with other canyon resources. This program of experimental flows will help to fill those data gaps, and the model will help to provide a better understanding of flow-related causal relationships and linkages to other resources. The model can also be used to synthesize and integrate information and provide insights into competition, predator-prey relationships, and responses to EF. Time-series analyses can be used to test long-term resource responses and better understand resource linkages. The proposed EF hydrograph will be evaluated with the conceptual model before implementation.

The successful evaluation of a program of experimental flows will be measured by the information gathered and the knowledge gained about the ecosystem. The results of this EF program will provide valuable information for the conceptual model and increase the accuracy and precision of predicting aquatic resource response for given dam management scenarios.

4.7 A NON-NATIVE FISH CONTROL STRATEGY

Non-native fishes are identified as a major limiting factor for native fishes in the Colorado River in Grand Canyon (Minckley 1991, Walters and Korman 1999). A significant concern with this program of experimental flows is a positive response by non-native fishes and a subsequent negative effect on native species from increased predation and competition. Since many non-native fishes are warm-water species with similar life history requirements to the native forms, the conditions of stable shoreline habitats, warm backwaters, and enhanced production are likely also to benefit non-native species. A non-native fish control strategy is imperative before starting the EF (Valdez and Carothers 1998). That strategy must incorporate institutional, operational, and ecological considerations relative to controlling non-native fish. It must include efforts to determine the likelihood of response by each of the non-native fish species in Grand Canyon, and methods and strategies for controlling these species in case densities and distributions increase significantly because of the EF (Valdez et al. 1999b). A non-native fish control strategy, developed for the upper Colorado River basin (Tyus and Saunders 1996), may serve as a model for a program in Grand Canyon.

4.8 ROLE OF ADAPTIVE MANAGEMENT

In the RPA, the FWS couches the experimental flows within the framework of the Adaptive Management Program, a common element of all GCDEIS alternatives. The RPA (FWS 1994) embraces the adaptive management approach as follows:

> *We recognize that the aquatic and terrestrial ecosystems below Glen Canyon Dam are still adjusting to impacts from dam operations that will continue into the future. Thus, the need for adaptive management. Actions taken through this approach must be based on an integrated resource approach, and, as discussed by Hilborn (1992), an active rather than a passive learning system that includes deliberate experimental design.*

Adaptive management uses scientific methods and information to help formulate, adjust, and improve management strategies (Holling 1978, Lee and Lawrence 1986, Walters 1986, Hilborn 1992). In Grand Canyon, adaptive management:

> *. . .encompasses dam-operation experiments (such as controlled floods and daily flow regimes) hypothesized to achieve downstream ecosystem benefits; monitoring effects of those experiments; research to explain those effects; design of new experiments to more fully achieve ecosystem benefits; and stakeholder-guided policy experiments to weigh monitoring and research results when recommending dam-operation experiments and adjustments to the Secretary of the Interior* (National Research Council 1999).

Adaptive management plays an important role in implementation and evaluation of the steady flow experiment. Through adaptive management, information gathered from this experiment can be used to determine if low steady summer flows, or some other component of the experiment, are beneficial to the native fishes and should be incorporated into the annual operation plan for Glen Canyon Dam.

This experiment will also provide insights into responses by other resources in Grand Canyon to the experimental flows, and the information gathered can be used to better manage the entire ecosystem.

4.9 SAFEGUARDS AND CRITERIA FOR TERMINATING OR DISCONTINUING EXPERIMENTAL FLOWS

The following is a recommended safeguard protocol for either terminating a treatment or discontinuing the experiment. It may be necessary to terminate a treatment if an undesirable response is observed or measured that is considered to be a risk to human safety, or irreversible and ecologically damaging, such as a large invasion of non-native predatory fishes from Lake Mead or a sudden outbreak of disease or parasites. It may also be necessary to discontinue the program of experimental flows if negative responses outweigh positive responses or if no significant responses occur over a reasonable period of time. The decision to either terminate a treatment or discontinue the program should be made as part of the adaptive management process, with the understanding that this program is an experiment in which achieving a balance between successful testing of flows and averting ecological disaster has to be an ongoing process.

4.9.1 Immediate Termination of a Treatment

A safeguard method is recommended for implementation to avert possible deleterious long-term effects from EF on the aquatic ecosystem. Using empirical data as definitive evidence of an adverse or undesirable effect to justify terminating a treatment is tenuous, at best. Inherent natural and sampling variability, as well as time required for analyses, preclude an immediate response and decision for termination. Criteria that may constitute termination of a treatment are:

1. Unacceptable risks to human safety from rafting incidents because of low flows.

2. Unacceptable river water quality leading to human health risks.

3. Large numbers of large predatory species (e.g., striped bass, walleye, channel catfish) moving from Lake Powell or Lake Mead into the region of the LCR.

4. Large outbreaks of fish diseases or parasites with substantial deaths of individuals.

5. Significant loss of the food base.

We recommend that the evaluation of termination criteria be the responsibility of GCMRC in consultation with an Experimental Flows Committee formed before EF implementation. Members of this committee would be appointed by the TWG and consist of the following seven individuals:

1. A representative of GCMRC, who would serve as Chairperson of this committee;
2. The Chairperson of the Technical Work Group;
3. A representative of the FWS;

4. A representative of Reclamation;
5. A representative of the Arizona Game and Fish Department;
6. A representative of Grand Canyon National Park; and
7. The Principal Investigator for fisheries investigations.

We recommend the following procedure (Figure 7): the Principal Investigator should notify GCMRC of significant deleterious threats to humans or to the aquatic ecosystem within 10 days after a field sampling trip. The GCMRC chairperson should then call an emergency meeting of the Experimental Flows Committee (Committee) within 1 week of the notification. Because of the short notice, the Chairperson may have to conduct the meeting via a conference call. After the issues of concern are discussed, GCMRC would decide whether to terminate a treatment based on a recommendation from the Committee. The decision should be rendered within 1 week of the filing of concern. This committee would also make recommendations to GCMRC for coordinating EF with other flow requirements of Glen Canyon Dam (i.e., habitat/beach building flows, habitat maintenance flows).

4.9.2 Discontinuation of the Experiment

In addition to emergency termination of a treatment, procedures should be in place to discontinue the program of experimental flows if it fails to meet program objectives. We recommend that AMWG have the responsibility to discontinue the program based on a recommendation from the Experimental Flows Committee and consultation with the TWG and GMCRC, as appropriate. That decision may be made if the following criteria are met:

1. The majority of primary hypotheses do not result in desirable resource responses, or

2. Possible irreversible deleterious effects or damage to the aquatic ecosystem outweigh the benefits or positive effects.

The decision to discontinue the program of experimental flows should be based on the results of the evaluation studies. No significant improvement in target resources (e.g., growth and survival of humpback chub), and deleterious measurable effects (e.g., significant increases in density and distribution of non-native fishes) are grounds for ending the program of experimental flows.

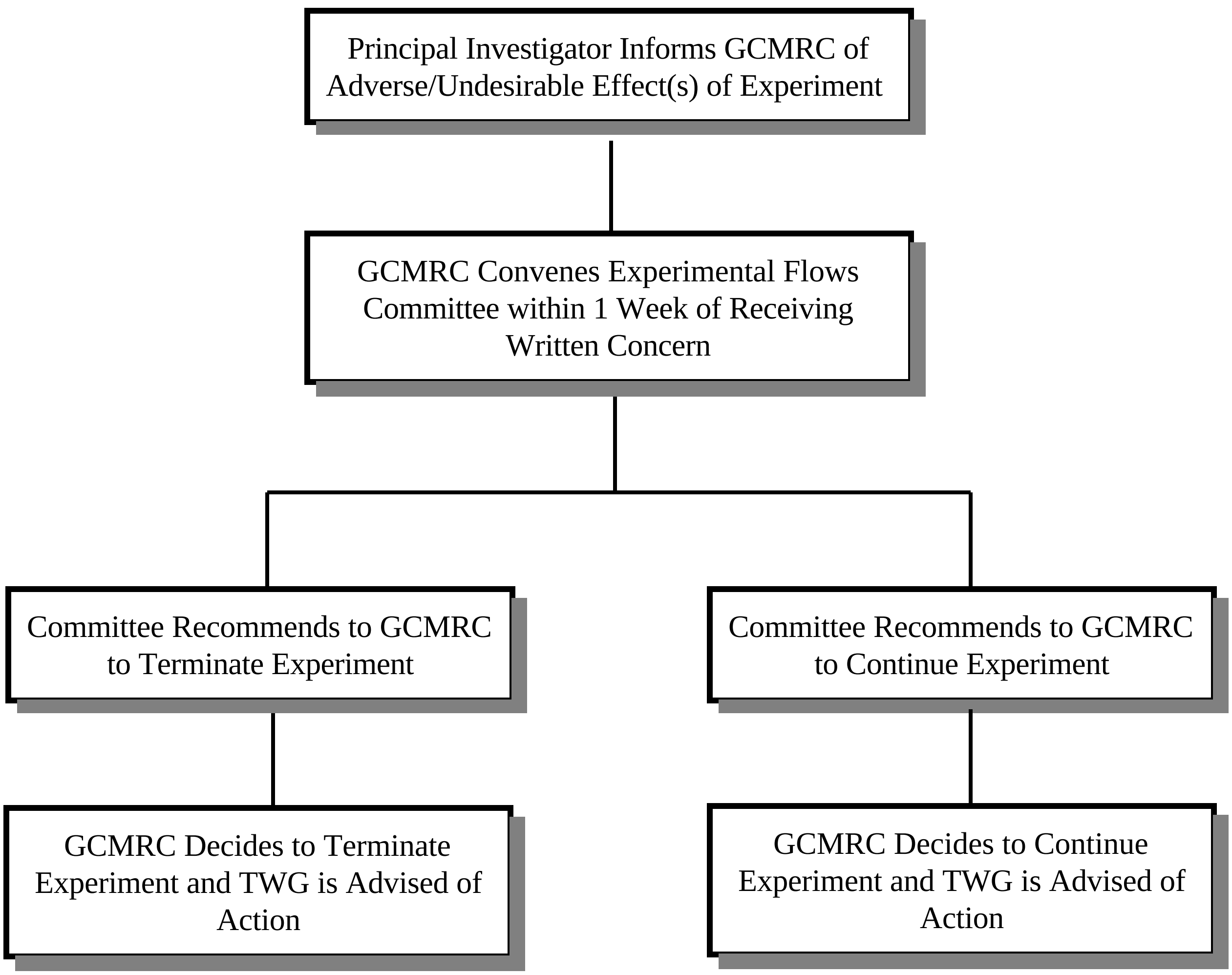

Figure 7. Decision chart for immediate termination of a treatment.

5.0 IMPLEMENTATION AND ESTIMATED COSTS

5.1 STEPS FOR IMPLEMENTATION

Implementing a program of experimental flows at Glen Canyon Dam requires concurrent action in four general areas: technical, administrative, political, and legal. Management of the Grand Canyon has its own unique set of circumstances and requirements that are identified in each of the following general areas:

5.1.1 Technical Steps – These steps describe a suggested approach to implementing the program of experimental flows as described in this document.

1. Identification and prioritization of studies to evaluate EF
2. Final Scopes of Work to the TWG
3. Development of Requests for Proposals (RFPs)
4. Review of proposals and cost estimates
5. Issuance of contracts and coordination meeting of researchers
6. Coordination and arrangement of logistical support
7. Implementation and coordination of field work
8. Receipt of progress, annual, and final reports into an integrated monitoring program
9. Progress Reports to the TWG

5.1.2 Administrative Steps – These steps, which would be conducted concurrently, address permitting and agency compliance and coordination.

1. National Environmental Policy Act
   a. Determine level of significant effects
   b. Develop Environmental Assessment (EA) on the specific federal action
   c. Integrate into Programmatic EA
   d. Coordinate with State and Federal entities
2. Coordinate with Fish and Wildlife Service
   a. Ensure that program is consistent with Biological Opinion
   b. Continue informal consultation through program evaluation
3. Coordinate with Reclamation
   a. Ensure that the EF hydrograph is part of Annual Operating Plan
   b. Coordinate releases to correspond with the EF hydrograph
4. Coordinate with Arizona Game and Fish Department
   a. Obtain scientific collecting permits
   b. Conduct ongoing liaison and coordination
5. Approval from Grand Canyon National Park
   a. EA approval
   b. Research permits for each study and trip permits for field work
6. Approval from Glen Canyon National Recreation Area

  a. EA approval
  b. Research permits for appropriate studies and trip permits for field work
7. Cultural Resource considerations
  a. Grand Canyon National Park
  b. Glen Canyon National Recreation Area
  c. Tribal groups
  d. Coordinate with State Historic Preservation Officer
8. Funding approval from Reclamation, Western Area Power Administration, and power user associations
9. Develop contracts and agreements for funding specific studies
10. Follow-up on funding with Reclamation and others
11. Coordinate field schedule with Grand Canyon National Park to acquire all river permits and obtain approval before issuing Work Orders to contractors. Make sure all parties have river permits and scientific collecting permits in hand before they get to Lees Ferry

5.1.3 Political Steps – The following are recommended political steps. Specific actions at the time of the EF program would depend on current political circumstances.

1. Flow Releases outside of normal operations at Glen Canyon Dam
  a. Secretary of the Interior sign-off
  b. Coordinate with the seven Colorado River basin states
2. Native American considerations
  a. Coordinate with the tribes on potentially impacted areas and resources - personal meetings
3. Respond to conservation community and recreation group considerations
4. Contact and advise appropriate State and Federal offices of research flows. Work with the public relations staff in each office. Provide new releases for use in interviews.

5.1.4 Legal Steps – These steps are best taken as an ongoing process. Legal issues can be minimized or avoided with appropriate communications in advance of an EF program.

1. Respond as necessary to potential lawsuits (environmental groups, special interests, private citizens)
2. Ensure all NEPA documentation are signed and filed
3. Ensure all ESA documents are signed and filed
4. Ensure all cultural compliance documents are signed and filed
5. Ensure all Grand Canyon National Park research permits are signed and filed
6. Ensure each biological researchers have appropriate collection permits in hand before they launch
7. Ensure that all river permits are signed and filed with Grand Canyon National Park before launch

5.2 CONTINGENCY ACTIONS

It is impossible to predict all situations and scenarios associated with developing and implementing a program of experimental flows. The most effective contingency is to develop a network of contacts that could be engaged as specific problems arise. These contacts include:

1. Grand Canyon National Park
   – Chief Scientist
   – River Subdistrict Office/Rangers
2. U.S. Bureau of Reclamation
   – Dam Operations Office
   – Regional Director
   – Logistics Support (e.g., helicopter pilot)
3. U.S. Fish and Wildlife Service
   – Endangered Species Coordinator
   – Grand Canyon Coordinator
4. Arizona Game and Fish Department
   – Grand Canyon Coordinator
   – Permits Office
5. Native American Groups
   – Tribal Contacts
   – Tribal Chairs and Councils

5.3 COSTS AND LOGISTICS

Estimated costs for implementing the EF program described in this document are $400,000-$450,000. These costs include three field sample trips per year, data entry and analysis, and reports. Each sample trip is estimated to be 20 days long and will require guides, support boats, food packs, and logistical support. Costs are based on six biologists per trip together with two motorized sampling boats (1 electrofishing, 1 netting) and sample gear. The program of experimental flows consists of a minimum of 1 year of baseline and 2 years of treatments. Although baseline and treatments are not likely to occur in consecutive years, evaluation studies should be conducted by the same group to provide continuity and reduce sampling variability. Changes in power revenues resulting from program implementation are not factored into these estimated costs, nor are costs to evaluate resources other than fish assemblages.

5.4. RECOMMENDATIONS FOR IMPLEMENTATION

Implementing a program of experimental flows is a substantial commitment in time and money for the Grand Canyon Adaptive Management Program. Because of a low probability (26%) of consecutive years with forecast releases of approximately 8.23 maf from Glen Canyon Dam, the program could potentially span 10 years or more for completion of the 1-year baseline and the two subsequent treatments. The high probability of discontinuity between the baseline and the treatments dictates implementation of a treatment study design over a more powerful time series analyses. This leads to a greater risk of faulty conclusions, particularly with the greater interval between the baseline and treatments or between treatments, when other experimental management actions may be implemented (e.g., BHBF, temperature control device).

We recommend identification and prioritization of experimental management actions to minimize the confounding interactive effects of multiple treatments. To truly test a given management action, it should be allowed to run to its full conclusion under a set study design, before implementing other actions that depart from the MLFF operations, as described in the GCDEIS. Because a temperature control device may be 3-5 years from environmental clearance, funding approval, design, construction, and implementation, it would be prudent to implement the program of experimental flows as soon as possible. We therefore recommend refining the requirement of a program of experimental flows from "approximately 8.23 maf" to approximately 9.0 maf. Based on the period 1964-99, dam releases of 9.0 maf or less occurred in 26 of 35 years (74%), with a 67% probability of two or more consecutive years. This places a much higher probability that the program of experimental flows could begin in the year 2000 and be conducted in consecutive years using time series analyses. A major weakness in the long-term evaluation of this program is lack of a formal fish monitoring program.

LITERATURE CITED

Anderson, L.S., L.M. Lucas, M. McGee, M. Yard, and G.A. Ruffner. 1986. Aquatic habitat analysis for low and high flows in the Colorado River in Grand Canyon. Glen Canyon Environmental Studies, Flagstaff, Arizona.

Andrews, E.D. 1986. Downstream effects of Flaming Gorge Reservoir on the Green River, Colorado and Utah. U.S. Geological Survey, Water Resources Division, Denver, Colorado.

Andrews, E.D, C.E. Johnston, J.C. Schmidt, and M. Gonzales. 1999. Topographic evolution of sand bars. Pages 117-130 *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.

Arizona Game and Fish Department. 1994. Glen Canyon Environmental Studies Phase II 1993 Annual Report. Prepared for Bureau of Reclamation, Upper Colorado Region, Glen Canyon Environmental Studies, Flagstaff, Arizona. Cooperative Agreement No. 9-FC-40-07940. Phoenix, Arizona.

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

Bain, M.B., J.T. Finn, and H.E. Booke. 1988. Streamflow regulation and fish community structure. *Ecology* 69:382-392.

Barrett, J.C., G.D. Grossman, and J. Rosenfeld. 1992. Turbidity-induced changes in reactive distance of rainbow trout. *Transactions of the American Fisheries Society* 121:437-443.

Benenati, P.L., J.P. Shannon, and D.W. Blinn. 1998. Desiccation and recolonization of phytobenthos in a regulated desert river: Colorado River at Lees Ferry, Arizona, USA. *Regulated Rivers: Research & Management* 14:519-532.

Beyers, D.W. 1998. Causal inference in environmental impact studies. *Journal of North American Benthological Society* 17(3):367-373).

Blinn, D.W., J.P. Shannon, P.L. Benenati, and K.P. Wilson. 1998. Algal ecology in tailwater stream communities: The Colorado River below Glen Canyon Dam, Arizona. *Journal of Phycology* 34:734-740.

Blinn, D.W., J.P. Shannon, K.P. Wilson, C. O'Brien, and P.L. Benenati. 1999. Response of benthos and organic drift to a controlled flood. Pages 259-272 *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.

Brock, J.T., T.V. Royer, E.B. Snyder, and S.A. Thomas. 1999. Periphyton metabolism: A chamber approach. Pages 217-224 *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.

Brouder, M.J., and T.L. Hoffnagle. 1997. Distribution and prevalence of the Asian fish tapeworm, *Bothriocephalus acheilognathi*, in the Colorado River and tributaries, Grand Canyon, Arizona, including two new host records. *Journal of Helminthological Society of Washington* 64(2):219-226.

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* 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.

Brownie, C., D.R. Anderson, K.P. Burnham, and D.S. Robson. 1985. Statistical inference from bank recovery data: A handbook. 2nd edition. Resource Publication No. 156. U.S. Fish and Wildlife Service, Washington, D.C.

Carothers, S.W., and B.T. Brown. 1991. The Colorado River through Grand Canyon, natural history and human change. University of Arizona Press, Tucson.

Chao, A. 1987. Estimating the population size for capture-recapture data with unequal catchability. *Biometrics* 43:783-791.

Chao, A. 1989. Estimating the population size for sparse data in capture-recapture experiments. *Biometrics* 45:427-438.

Clarkson, R.W., O.T. Gorman, D.M. Kubly, P.C. Marsh, and R.A. Valdez. 1994. Management of discharge, temperature, and sediment in Grand Canyon for native fishes. Issue paper. Glen Canyon Environmental Studies, Flagstaff, Arizona.

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(1):66-69.

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 for flow regulation. *Regulated Rivers: Research & Management* 14:267-284.

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(1):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(4):915-925.

Gorman, O.T. 1994. Habitat use by the humpback chub, *Gila cypha*, in the Little Colorado River and other tributaries of the Colorado River. Final report for Glen Canyon Environmental Studies Phase II. U.S. Fish and Wildlife Service, Grand Canyon Fisheries Resources Office, Flagstaff, Arizona.

Gorman, O.T., and R.G. Bramblett. 1999. Monitoring and studies of native fishes of the Colorado River ecosystem in Grand Canyon, Arizona. Interim report for Grand Canyon Monitoring and Research Center, Flagstaff, Arizona, and U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah. U.S. Fish and Wildlife Service, Grand Canyon Fisheries Resources Office, Flagstaff, Arizona.

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

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* 50:205-218.

Gustaveson, A.W., B.L. Bonebrake, S.J. Scott, and J.E. Johnson. 1985. Lake Powell fisheries investigation. Five-year completion and 1984 (Segment 13) annual performance report for Colorado River drainage and tailwaters. Utah Department of Natural Resources, Division of Wildlife Resources.

Gustaveson, A.W., H.R. Maddux, B.L. Bonebrake, and K. Christopherson. 1990. Lake Powell fisheries investigation. Annual performance report, May 1, 1989 - April 30, 1990. Utah Department of Natural Resources, Division of Wildlife Resources.

Haden, A. 1992. Nonnative fishes of the Grand Canyon. Review with regards to their effects on native fishes. Documents submitted to Glen Canyon Environmental Studies, Bureau of Reclamation, Flagstaff, Arizona.

Halliday, M.M. 1973. Studies of *Myxobolus cerebralis*: A parasite of salmonids, II. The development and pathology of *Myxobolus cerebralis* in experimentally infected rainbow trout (*Salmo gairdneri*) fry reared at different water temperatures. *Nord. Veterinaermed*. 25:349-358.

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

Harvey, M.D., R.A. Mussetter, and E.J. Wick. 1993. A physical process-biological response model for spawning habitat formation for the endangered Colorado squawfish. *Rivers* 4(2):114-131.

Hazel, Jr., J.E., M. Kaplinski, R. Parnell, M. Manone, A. Dale. 1999. Topographic and bathymetric changes at thirty-three long-term study sites. Pages 161-183 *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.

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. Arizona Game and Fish Department, Phoenix.

Hilborn, R. 1992. Can fisheries agencies learn from experience? *Fisheries* 17(4):6-14.

Hoffman, G.L. 1990. *Myxobolus cerebralis*, a worldwide cause of salmonid whirling disease. *Journal of Aquatic Animal Health* 2(1):30-37.

Hoffnagle, T.L. 1996. Changes in water quality parameters and fish useage of backwaters during fluctuating vs. short-term steady flows in the Colorado River, Grand Canyon. Final report submitted to Glen Canyon Environmental Studies, Flagstaff, Arizona. Research Branch, Arizona Geme and Fish Department, Phoenix.

Hoffnagle, T.L., R.A. Valdez, and D.W. Speas. 1999. Fish abundance, distribution, and habitat use. Pages 273-288 *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. (ed.). 1999. Flow recommendations for the San Juan River. San Juan River Basin Recovery Implementation Program. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Holling, C.S. (ed.). 1978. Adaptive environmental assessment and management. John Wiley and Sons, New York.

Ingram, H., A.D. Tarlock, and C.R. Oggins. 1991. The law and politics of the operation of Glen Canyon Dam. Pages 10-27 *in* Colorado River Ecology and Dam Management, Proceedings of a symposium, May 24-25, 1990, Santa Fe, New Mexico. National Academy Press, Washington, D.C.

John, K.R. 1963. The effect of torrential rains on the reproductive cycle of *Rhinichthys osculus* in the Chiricahua Mountains, Arizona. *Copeia* 1963:286-291.

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.

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

Korn, J., and B. Vernieu. no date. Mainstem and tributary temperature monitoring in Grand Canyon, AZ. Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Lee, K.N., and J. Lawrence. 1986. Adaptive management: Learning from the Columbia River Basin Fish and Wildlife Program. *Environmental Law* 16:431-460.

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 Canyons. Arizona Game and Fish Department, Phoenix, Arizona.

Marcogliese, D.J. 1991. Seasonal occurrence of *Lernaea cyprinacea* on fishes in Belews Lake, North Carolina. *Journal of Parasitology* 77(2):326-327.

Marsh, P.C. 1985. Effect of incubation temperature on survival of embryos of native Colorado River fishes. *Southwestern Naturalist* 30(1):129-140.

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.

Marzolf, G.R., C.J. Bowser, R. Hart, D.W. Stephens, and W.S. Vernieu. Photosynthetic and respiratory processes: An open-stream approach. 1999. Pages 205-216 *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.

McAda, C.W. 1989. Summary of the statistical power of the Interagency Standardized Monitoring Program. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

McAda, C.W. 1999. Interagency Standardized Monitoring Program: Summary of results. U.S. Fish and Wildlife Service, Grand Junction, Colorado.

McCall, T. 1979. Fishery investigation of Lake Mead, Arizona-Nevada, from Separation Rapids to Boulder Canyon, 1978-79. Final Report Contract No. 8-07-30-x0025. Arizona Game and Fish Department, Kingman, Arizona.

McDonald, D.B., and P.A. Dotson. 1960. Investigations of specific problems in Utah's fishery: Job No.V Pre-impoundment investigations of the Green River and Colorado River develop-ments. Federal Aid Project No. F-4-R-6. Utah Department of Fish and Game, Salt Lake City.

McGuinn-Robbins, D.K. 1995. Comparison of the number and area of backwaters associated with the Colorado River in Glen, Marble, and Grand Canyons, Arizona. Draft Final Report. Submitted to Glen Canyon Environmental Studies, Bureau of Reclamation, Flagstaff, Arizona.

McIvor, C.C., and M.L. Thieme. 1999. Flannelmouth suckers: Movement in the Glen Canyon reach and spawning in the Paria River. Pages 289-296 *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.

McKinney, T., W.R. Persons, and R.S. Rogers. 1998. Abundance, distribution and movement of flannelmouth sucker in the Lee's Ferry tailwater, Colorado River, Arizona. Arizona Game and Fish Department, Phoenix.

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 conservation and management. *Transactions of the American Fisheries Society*, 129:419-428.

Miller, R.R. 1961. Man and the changing fish fauna of the American Southwest. *Michigan Academy of Science, Arts and Letters*, Vol. XLVI:365-404.

Miller, R.R., and J.R. Alcorn. 1943. The introduced fishes of Nevada with a history of their introduction. *Transactions of the American Fisheries Society* 73:173-193.

Miller, R.R., and G.R. Lowe. 1967. Part 2: Fishes of Arizona. Pages 133-151 *in* C.H. Lowe (ed.). The vertebrates of Arizona. University of Arizona Press, Tucson.

Minckley, W.L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix.

Minckley, W.L. 1991. Native fishes of the Grand Canyon region: An obituary? Pages 124-177 *in* 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., and J.E. Deacon (eds.). 1991. Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson.

Minckley, W.L, and G.K. Meffe. 1987. Differential selection by flooding in stream-fish communities of the arid American Southwest. Pages 93-104 *in* W.J. Matthews and D.C. Heins (eds.). Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman.

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.

Murphy, B.R., D.W. Willis, and T.A. Springer. 1991. The relative weight index in fisheries management: Status and needs. *Fisheries* 16(2):30-38.

Muth, R.T., L.W. Crist, K.E. LaGory, J.W. Hayse, K.R. Bestgen, J.K. Lyons, T.P. Ryan, and R.A. Valdez. 2000. Flow recommendations for endangered fishes in the Green River downstream of Flaming Gorge Dam. Draft Final Report. Upper Colorado River Recovery Program Project FG-53. U.S. Fish and Wildlife Service, Denver, Colorado.

National Research Council. Committee on Grand Canyon Monitoring and Research. 1999. Downstream: Adaptive management of Glen Canyon Dam and the Colorado River ecosystem. Prepublication copy. National Academy Press, Washington, D.C.

Nesler, T.P., R.T. Muth, and A. Wasowicz. 1988. Evidence for baseline flow spikes as spawning cues for Colorado squawfish in the Yampa River, Colorado. *American Fisheries Society Symposium* 5:68-79.

Parnell, Jr., R.A., J.B. Bennett, and L.E. Stevens. 1999. Mineralization of riparian vegetation buried by the 1996 controlled flood. Pages 225-240 *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.

Poff, L.N., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: A paradigm for river conservation and restoration. *BioScience* 47(11):769-784.

Pucherelli, M.J., and R.C. Clark. 1989. Comprehensive report (1986-1988) on the effects of Green River flows on backwater habitat availability as determined by remote sensing techniques. U.S. Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191. Ottawa, Ontario, Canada.

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* 127:772-786.

Rubin, D.M., J.C. Schmidt, and J.N. Moore. 1990. Origin, structure, and evolution of a reattachment bar, Colorado River, Grand Canyon, Arizona. *Journal of Sedimentary Petrology* 60:982-991.

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* Natural and anthropogenic influences in fluvial geomorphology. Geophysical Monograph 89. The American Geophysical Union.

Schmidt, D.R., W.B. Griffiths, and L.R. Martin. 1987. Importance of anadromous fish overwintering habitat in the Sagavanirktok River delta, Alaska. *Alaska Science Conference* 38:153.

Schmidt, J.C., R.H. Webb, R.A. Valdez, G.R. Marzolf, and L.E. Stevens. 1998. Science and values in river restoration in the Grand Canyon. *BioScience* 48(9):735-747.

Sokal, R.R., and F.J. Rohlf. 1987. Introduction to biostatistics. 2nd edition. W.H. Freeman and Company, New York.

Stanford, J.A. 1994. Instream flows to assist the recovery of endangered fishes of the upper Colorado River basin. Biological Report 24. National Biological Survey, Washington, D.C.

Stevens, L.E., J.C. Schmidt, T.J. Ayers, and B.T. Brown. 1995. Flow regulation, geomorphology, and Colorado River marsh development in the Grand Canyon, Arizona. *Ecological Applications* 5(4):1025-1039.

Stevens, L.E., J.P. Shannon, and D.W. Blinn. 1997. Colorado River benthic ecology in Grand Canyon, Arizona, USA: Dam, tributary and geomorphological influences. *Regulated Rivers: Research and Management* 13:129-149.

Stone, J.L., and N.L. Rathbun. 1968. Tailwater fisheries investigations, creel census and limnological study of the Colorado River below Glen Canyon Dam. 1 July 1967 - 30 June 1968. Arizona Game and Fish Department, Phoenix.

Stoskopf, M.K. 1993. Fish medicine. W.B. Saunders Company, Philadelphia, Pennsylvania.

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

Tyus, H.M. 1991. Movement and habitat use of Colorado squawfish. Pages 379-402 *in* W.L. Minckley and J.E. Deacon (eds.). Battle against extinction: Native fish management in the American West. University of Arizona Press, Tucson.

Tyus, H.M. 1992. An instream flow philosophy for recovering endangered Colorado River fishes. *Rivers* (3):27-36.

Tyus, H.M., and C.A. Karp. 1991. Habitat use and streamflow needs of rare and endangered fishes in the Green River, Utah. Final Report. U.S. Fish and Wildlife Service, Flaming Gorge Studies, Vernal, Utah.

Tyus, H.M., and J.F. Saunders. 1996. Nonnative fishes in the upper Colorado River basin and a strategic plan for their control. Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River, U.S. Fish and Wildlife Service, Denver, Colorado.

U.S. Bureau of Reclamation (Reclamation). 1994. Comments on the October 13, 1993, Draft Biological Opinion on the Preferred Alternative for the Operation of Glen Canyon Dam, Consultation No. 2-21-93-F-167. Memorandum from Charlie A. Calhoun, Acting Regional Director, Upper Colorado Regional Office, to Regional Director, U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

U.S. Bureau of Reclamation (Reclamation). 1995. Final environmental impact statement, operation of Glen Canyon Dam. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

U.S. Bureau of Reclamation (Reclamation). 1996. Record of Decision (ROD) on the Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS). U.S. Bureau of Reclamation, Salt Lake City, Utah.

U.S. Bureau of Reclamation (Reclamation). 1999. Glen Canyon Dam modifications to control downstream temperatures. Plan and draft environmental assessment. U.S. Bureau of Reclamation, Upper Colorado Region, Salt Lake City, Utah.

U.S. Department of the Interior. 1998. Annual operating plan for Colorado River reservoirs. U.S. Department of the Interior, Washington, D.C.

U.S. Fish and Wildlife Service (FWS). 1980. Special report on distribution and abundance of fishes of the lower Colorado River. U.S. Fish and Wildlife Service, Region 2, Albuquerque, New Mexico.

U.S. Fish and Wildlife Service (FWS). 1990. Humpback chub recovery plan. U.S. Fish and Wildlife Service, Region 6, Denver, Colorado.

U.S. Fish and Wildlife Service (FWS). 1993. Draft Biological Opinion on operation of Glen Canyon Dam as the modified low fluctuating flow alternative of the Draft Environmental Impact Statement on the Operation of Glen Canyon Dam. Ecological Services, Arizona State Office, U.S. Fish and Wildlife Service, Phoenix.

U.S. Fish and Wildlife Service (FWS). 1994. Final Biological Opinion, Operation of Glen Canyon Dam as the modified low fluctuating flow alternative of the Final Environmental Impact Statement, Operation of Glen Canyon Dam (2-21-93-F-167). Ecological Services, Arizona State Office, U.S. Fish and Wildlife Service, Phoenix.

Valdez, R.A. 1990. The endangered fish of Cataract Canyon. Final report prepared for the Bureau of Reclamation, Salt Lake City, Utah, Contract No. 6-CS-40-03980, Fisheries Biology and Rafting. BIO/WEST Report No. 134-3. BIO/WEST, Inc., Logan, Utah.

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. Glen Canyon Environmental Studies, Flagstaff, Arizona.

Valdez, R.A., and S.W. Carothers. 1998. The aquatic ecosystem of the Colorado River in Grand Canyon, Grand Canyon Data Integration Project Synthesis Report. Submitted to the Bureau of Reclamation, Salt Lake City, Utah. SWCA, Inc., Environmental Consultants, Flagstaff, Arizona.

Valdez, R.A., and G.C. Clemmer. 1982. Life history and prospects for recovery of the humpback 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., 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, Washington, D.C.

Valdez, R.A., and W.J. Masslich. 1999. Evidence of humpback chub reproduction in a warm spring of the Colorado River in Grand Canyon, Arizona. *The Southwestern Naturalist*, 44(3):385-387.

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 to the Bureau of Reclamation, Salt Lake City, Utah, Contract No. 0-CS-40-09110. BIO/WEST Report No. TR-250-08. BIO/WEST, Inc., Logan, Utah.

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* Proceedings of the Third Biennial Conference on the Colorado Plateau. National Park Service, Denver, Colorado.

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., J.P. Shannon, and D.W. Blinn. 1999a. Biological implications of the 1996 controlled flood. Pages 343-350 *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.

Valdez, R.A., T.L. Hoffnagle, and W. Persons. 1999b. A non-native fish control strategy for the Colorado River and its tributaries in Grand Canyon, Arizona. Non-Native Fish Symposium Proceedings. U.S. Fish and Wildlife Service, Albuquerque, New Mexico.

Van Steeter, M.M., and J. Pitlick. 1998. Geomorphology and endangered fish habitats of the upper Colorado River: 1. Historic changes in streamflow, sediment load, and channel morphology. *Water Resources Research* 34(2):287-302.

Wallis, O.L. 1951. The status of the fish fauna of the Lake Mead National Recreation Area, Arizona-Nevada. *Transactions of the American Fisheries Society* 80(1950):84-92.

Walters, C. 1986. Adaptive management of renewable resources. Collier Macmillian Publishers, London, England.

Walters, C., and J. Korman. 1998. Grand Canyon Ecosystem Model: Preliminary development of modeling shell and straw-man sub-models. Prepared for Grand Canyon Monitoring and Research Center, Flagstaff, Arizona.

Walters, C., and J. Korman. (In Press). Ecosystem modeling for evaluation of adaptive management policies in the Grand Canyon. *Conservation Biology*.

Webb R.H., and T.S. Melis. 1994. Observations of environmental change in Grand Canyon: A report on the old timers trip. U.S. Geological Survey, Tucson, Arizona.

Webb, R.H., P.T. Pringle, and G.R. Rink. 1989. Debris flows from tributaries of the Colorado River, Grand Canyon National Park, Arizona. U.S. Geological Survey Professional Paper 1492. U.S. Government Printing Office, Washington, D.C.

Webb, R.G., J.C. Schmidt, G.R. Marzolf, and R.A. Valdez (eds.). 1999. The controlled flood in Grand Canyon. Geophysical Monograph 110. The American Geophysical Union, Washington, D.C.

Wegner, D.L., and F. Protiva. 1994. Super-hydro mapping of the inflow of the Little Colorado River in Grand Canyon, Arizona. Glen Canyon Environmental Studies, Flagstaff, Arizona.

Weiss, J. 1993. The relationship between flow and backwater fish habitat of the Colorado River in Grand Canyon. Draft Report. Glen Canyon Environmental Studies, Flagstaff, Arizona.

Weiss, S.J. 1993. Population structure and movement of flannelmouth sucker in the Paria River. M.S. Thesis, University of Arizona, Tucson.

Wiele, S.M. 1998. Modeling of flood-deposited sand distributions in a reach of the Colorado River below the Little Colorado River, Grand Canyon, Arizona. Water-Resources Investigations Report 97-4168. U.S. Geological Survey, Tucson, Arizona.

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(12):3579-3596.

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* 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.

Wilson, K.P., J.P. Shannon, and D.W. Blinn. 1999. Effects of suspended sediment on biomass and cell morphology of *Cladophora glomerata* (Chlorophyta) in the Colorado River, Arizona. *Journal of Phycology* 35:35-41.

Yard, M.D., G.A. Haden, and W.S. Vernieu. 1993. Photosynthetically available radiation (PAR) in the Colorado River: Glen and Grand Canyons. Glen Canyon Environmental Studies, Flagstaff, Arizona.

APPENDIX A

GRAND CANYON MONITORING AND RESEARCH CENTER
FY99 REQUEST FOR PROPOSALS

APPENDIX B
EVOLUTION OF EXPERIMENTAL FLOWS

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EVOLUTION OF EXPERIMENTAL FLOWS

B1.1 THE BIOLOGICAL OPINION

The concept of experimental flows was first identified as element 1a. of the RPA of the Draft Biological Opinion on the Operation of Glen Canyon Dam on 19 May 1993 (FWS 1993), which stated that "...Reclamation shall pattern water releases comparable with the natural hydrograph...during low release years (8.23 maf)...." The purpose of the release pattern was "...to facilitate natural ecosystem processes which include accommodating the needs of endangered and other native fishes." The Final Biological Opinion of 21 December 1994 (FWS 1994) retained the concept of a natural hydrograph and identified a program of experimental flows as part of an RPA:

> *A program of experimental flows will be carried out to include high steady flows in the spring and low steady flows in summer and fall during low water years (releases of approximately 8.23 maf) to verify an effective flow regime and to quantify, to the extent possible, effects on endangered and native fish. Studies of high steady flows in the spring may include studies of habitat building and habitat maintenance flows. Research design and hypotheses to be tested will be based on a flow pattern that resembles the natural hydrograph, as described for those seasons in the SASF.*

The RPA was developed with the stated objective of attaining "...riverine conditions that support all life stages of endangered and native fishes..." (FWS 1994). Although the Biological Opinion expressed concern for all native fishes, elements of the RPA focused on the humpback chub. According to the RPA, the 470-km reach of the Colorado River downstream of Glen Canyon Dam does not appear to provide suitable conditions for all life stages of this species. In particular, this reach does not provide an environment for successful spawning and recruitment. The Biological Opinion also noted that only marginal habitat for adult razorback suckers has been identified in the mainstem downstream of Glen Canyon Dam. The opinion recognized that the razorback sucker is rare in Grand Canyon, and that riverine conditions that support recruiting populations of the species have not been found. Nevertheless, the FWS maintained that the stretch of the Colorado River through Grand Canyon provides one of the few remaining opportunities for recovering the razorback sucker because of its "...length, management direction, and limited number of non-native fish species..." and its "connection to Lake Mead" (FWS 1994).

In the final opinion, the program of experimental flows was designed to begin as soon as possible with scheduling dependent on annual river volume (FWS 1994):

> *Design of the experimental flows and associated studies will begin as soon as possible and be targeted for completion by October 1996. Unless the Service determines information provided seriously questions the validity of experimental designs developed or contribution of the resulting data to remove jeopardy to the federally-*

> *listed aquatic fauna of the Grand Canyon, experimental flows will be initiated in April 1997. If sufficient progress and good faith effort is occurring towards initiating experimental flows, implementation of experimental flows may occur later in 1997. If the Service believes there is not sufficient progress, Glen Canyon Dam would be operated as SASF flows during spring through fall (April to October) beginning in 1998. If the Service determines a study design can not be developed that is expected to provided* [sic] *information to support removal of jeopardy to the razorback sucker and humpback chub populations in the Grand Canyon and associated tributaries, such will be considered new information and may be grounds for reinitiating formal consultation*.

The program of experimental steady flows identified in the opinion would be based on flow patterns described for the seasonally adjusted steady flow (SASF); implemented only in low-water years, or years with releases of approximately 8.23 million acre feet (maf); and begin before or coincident with issuance of the Record of Decision for the GCDEIS (9 October 1996; Reclamation 1996). Experimental flows were not implemented in Spring 1997, 1998, or 1999 primarily because these years were forecast as moderate water years (>8.23 maf), and the experiment can only be conducted in low-water years.

B1.2 THE DATA INTEGRATION REPORT

During development of the RPA, Reclamation (1994) expressed concern that "...steady flows may inadvertently benefit non-native fish species to the detriment of endangered and other native fish species...". Reclamation indicated that, as the agency ultimately responsible for impacts of dam operations on endangered fish and numerous other resources, it was not prepared to release steady flows until an assessment of potential risks to endangered and other native fishes had been prepared, research and monitoring designs had been developed, and threshold criteria had been established for adjusting or abandoning the flows if monitoring revealed that native fish were being adversely affected.

In 1997, Reclamation contracted a data integration project to evaluate the information available for assessing potential risks to endangered and native fishes from a program of experimental flows. The Grand Canyon Data Integration Report (Valdez and Carothers 1998) addressed the uncertainty behind the design and implementation of experimental flows through a comprehensive literature review and a workshop of biologists. The report concluded that a steady flow experiment would be valuable for testing response hypotheses, but that sufficient baseline data to fully evaluate the steady flow experiment, *a priori*, did not exist. The report also stated that a steady flow experiment is likely to have a positive effect on native fishes by warming and stabilizing nearshore habitats, including backwaters and tributary mouths, and enhancing reproduction, growth, and survival. However, a steady flow would simultaneously benefit warm-water non-native fishes, possibly reduce drifting food availability, and likely increase the incidence of fish parasites. The report noted that workshop biologists believe that positive effects of steady flows to non-native predators and competitors could offset many of the beneficial effects to native fishes, and recommended modifying the steady flow hydrograph to maximize benefits to native fishes, while minimizing benefits to non-native fishes. The authors of the report recommended implementation of a detailed study and evaluation design and a non-native fish control strategy prior to experimental steady flows.

B1.3 ADAPTIVE MANAGEMENT

In the RPA, the FWS couches the experimental flows within the framework of the Adaptive Management Program, a common element of all GCDEIS alternatives. The RPA (FWS 1994) embraces the adaptive management approach as follows:

> *We recognize that the aquatic and terrestrial ecosystems below Glen Canyon Dam are still adjusting to impacts from dam operations that will continue into the future. Thus, the need for adaptive management. Actions taken through this approach must be based on an integrated resource approach, and, as discussed by Hilborn (1992), an active rather than a passive learning system that includes deliberate experimental design.*

The GCDEIS and the Grand Canyon Protection Act of 1992 also included the implementation of an adaptive management program to deal with resource protection and dam operations. The Grand Canyon Adaptive Management Program was established under the Federal Advisory Committee Act (FACA) to coordinate implementation of elements of the GCDEIS.

The Adaptive Management Program for the operation of Glen Canyon Dam uses scientific methods and information to help formulate, adjust, and improve management strategies (Holling 1978; Lee and Lawrence 1986; Walters 1986). Successful applications of adaptive management must be based on sound science and a continuing process of action based on planning, monitoring, evaluation, and adjustment. If properly designed and effectively implemented, adaptive management will enable managers to determine how well their actions achieve their objectives and what steps are needed to improve the program's success. Sound scientific approaches require the use of a deliberate experimental design, suitable controls, and replication that allow sufficient statistical power needed to test hypotheses. A functional adaptive management process demands an understanding of sufficient and adequate baseline information before experimentation.