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# USGS Workshop on Scientific Aspects of a Long-Term Experimental Plan for Glen Canyon Dam, April 10–11, 2007, Flagstaff, Arizona


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U.S. Department of the Interior
U.S. Geological Survey

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A report of the USGS Grand Canyon Monitoring and Research Center

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**U.S. Department of the Interior**
**U.S. Geological Survey**

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Cover: Humpback chub (photo courtesy of Arizona Game and Fish Department); sand grains on the surface of a Colorado River eddy sandbar (USGS photo by David Rubin); sign at entrance of Grand Canyon National Park (USGS photo by Don Becker); and Secretary of the Interior Kempthorne opening the jet tubes at Glen Canyon Dam (USGS photo by Anne Phillips).

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# USGS Workshop on Scientific Aspects of a Long-Term Experimental Plan for Glen Canyon Dam, April 10–11, 2007, Flagstaff, Arizona

## Executive Summary

Glen Canyon Dam is located in the lower reaches of Glen Canyon National Recreation Area on the Colorado River, approximately 15 miles upriver from Grand Canyon National Park (fig. 1). In 1992, Congress passed and the President signed into law the Grand Canyon Protection Act (GCPA; title XVIII, sec. 1801–1809, of Public Law 102-575), which seeks "to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established." The Glen Canyon Dam Adaptive Management Program (GCDAMP) was implemented as a result of the 1996 Record of Decision on the Operation of Glen Canyon Dam Final Environmental Impact Statement to ensure that the primary mandate of the GCPA is met through advances in information and resources management (U.S. Department of the Interior, 1995).

On November 3, 2006, the Bureau of Reclamation (Reclamation) announced it would develop a long-term experimental plan environmental impact statement (LTEP EIS) for operational activities at Glen Canyon Dam and other management actions on the Colorado River. The purpose of the long-term experimental plan is twofold: (1) to increase the scientific understanding of the ecosystem and (2) to improve and protect important downstream resources. The proposed plan would implement a structured, long-term program of experimentation to include dam operations, potential modifications to Glen Canyon Dam intake structures, and other management actions such as removal of nonnative fish species. The development of the long-term experimental plan continues efforts begun by the GCDAMP to protect resources downstream of Glen Canyon Dam, including Grand Canyon, through adaptive management and scientific experimentation.

The LTEP EIS will rely on the extensive scientific studies that have been undertaken as part of the adaptive management program by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC), one of the four research stations within the USGS Southwest Biological Science Center. On April 10 and 11, 2007, at the behest of Reclamation, the GCMRC convened a workshop with scientific experts to identify one or more scientifically credible, long-term experimental options for Reclamation to consider for the LTEP EIS that would be consistent with the purpose and need for the plan. Workshop participants included government, academic, and private scientists with broad experience in the Colorado River in Grand Canyon and regulated rivers around the world. Resource managers and GCDAMP participants were also present on the second day of the workshop.

In advance of the workshop, Reclamation and LTEP EIS cooperating agencies identified 14 core scientific questions. Workshop participants were asked to consider how proposed options would address these questions, which fall primarily into four areas: (1) conservation of endangered humpback chub (*Gila cypha*) and other high-priority biological resources, (2) conservation of sediment resources, (3) enhancement of recreational resources, and (4) preservation of cultural resources.

A secondary objective of the workshop was the evaluation of four long-term experimental options developed by the GCDAMP Science Planning Group (SPG) (appendix B). The flow and nonflow treatments called for in the four experimental options were an important starting point for workshop discussions.

At the beginning of the workshop, participants were provided with the final LTEP EIS scoping report prepared by Reclamation. Participants were also advised that Reclamation had committed to "make every effort…to ensure that a new population of humpback chub is established in the mainstem or one or more of the tributaries within Grand Canyon" in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (U.S. Department of the Interior, 1995). This decision was consistent with the U.S. Fish and Wildlife Service's 1995 biological opinion for Glen Canyon Dam operations that describes the establishment of a "second spawning aggregation" of endangered humpback chub as a reasonable and prudent alternative.

Before beginning their discussions, workshop participants were also briefed by GCMRC scientists on the current status and trends of downstream resources, particularly native and nonnative fish and sediment resources. The following findings were presented to the participants and provided the basis for workshop discussions:

- Nonnative fish removal efforts from 2003–06, including the removal of more than 19,000 rainbow trout (*Oncorhynchus mykiss*), seem to have accelerated the decline of rainbow trout in the vicinity of the confluence of the Little Colorado River, a tributary of the Colorado River in Grand Canyon. Possibly in response to the reduction of competitive and predatory nonnative species, native fish represented 60 percent of the fish community captured near the confluence of the Little Colorado River in 2006, which was up from 10 percent in 2003 (U.S. Geological Survey, unpub. data, 2007); however, natural warming caused by warmer than average releases from Glen Canyon Dam (2004–06) is a confounding factor in determining the impact of mechanical removal on native fish.

- Between 2001 and 2005, the number of adult humpback chub (age-4+) appears to have stabilized at approximately 5,000 (Melis and others, 2006). A summary of the analysis of the Grand Canyon humpback chub published after the workshop concludes that the adult population in 2006 was approximately 6,000 (Coggins, 2007). The number of humpback chub younger than 4 years of age appears to have reached a modern low in 1991, but in 2001, the most recent year for which data are available, population numbers have increased to the levels found during the late 1980s. There is also some indication that a few young humpback chub survived in the mainstem nearshore habitats near river mile 30, which is above the Little Colorado River, during the winter of 2005–06 (U.S. Geological Survey, unpub. data, 2007).

- Bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*Catostomus latipinnis*) catch rates increased fivefold between 2003 and 2006 (Arizona Game and

Fish Department, unpub. data, 2007; U.S. Geological Survey, unpub. data, 2007). The presence of multiple size classes of flannelmouth sucker indicate that this species has successfully recruited during this period.

- Substantial increases in total eddy-sandbar area and volume are only possible during high-flow releases following large tributary floods, which enrich sand supplies in the main channel of the Colorado River (Rubin and others, 2002; Topping and others, 2006).
- Sandbars created by the 2004 beach/habitat-building flows (BHBF) test increased the windborne transport of sand toward some of the archaeological sites in Grand Canyon (Draut and Rubin, 2006). Increased sand carried by the wind from restored sandbars may reduce erosion and increase the preservation potential at some sites.

Participants discussed the pros and cons of the possible flow and nonflow experimental treatments identified by the SPG. Flow treatments considered by participants included steady, fluctuating, and beach/habitat-building flows. Nonflow treatments included the installation of a temperature control device (TCD), also called a selective withdrawal structure; nonnative fish control; humpback chub translocation; and increased mainstem water temperatures. The discussions relied on the available scientific literature and professional opinion. Workshop participants reached the following conclusions:

- The single most important condition that would benefit the endangered humpback chub in the near term is warming mainstem nearshore habitats, although control of nonnative species is also very important. Given existing volumetric constraints and the current state of knowledge, the most readily available tool to stabilize the presence and persistence of nearshore habitats and, thus, enhanced warming in those environments during the summer months, is steady flows from Glen Canyon Dam.
- Additional BHBF tests should occur following tributary sand enrichment and be evaluated to determine whether this treatment is capable of rebuilding and maintaining sandbars in a sustainable manner or if augmentation of the downstream sand supply is needed to achieve sediment conservation goals.
- A TCD should be built only if it is designed to release the warmest water possible. Additionally, the TCD must have the ability to release cool water under all conditions, including when reservoir conditions are relatively low. The ability to also release cool water was thought to be necessary to control the expansion of warmwater nonnative aquatic species.
- Managers should continue their efforts to control nonnative fish numbers, including both warmwater and coldwater species, especially in the vicinity of the Little Colorado River, where more than 90 percent of the Grand Canyon population of humpback chub spend most of their lives.
- Monitoring efforts should be increased for warmwater nonnative fish because they pose a significant risk to the humpback chub population and their numbers may increase if warmer water temperatures continue. Early, consistent monitoring of warmwater species is critical to successful control. It is highly unlikely that these species can be controlled as readily as rainbow trout.

- The risk of catastrophic loss of Grand Canyon humpback chub would be reduced if one or more populations were reproducing and growing in the mainstem Colorado River or in another Grand Canyon tributary. The best possible alternative for a spawning location is the main channel of the Colorado River.
- Translocation of young humpback chub from the Little Colorado River to one or more of the tributaries the Colorado River could be beneficial for the Grand Canyon humpback chub population, providing a refuge and perhaps expanding the population. It was considered unlikely that such translocations would confound humpback chub monitoring or population modeling.

Following discussions of possible treatments, the participants developed an experimental research design that was consistent with the stated purpose and need of the LTEP EIS. The experimental design, called the environmental triggers approach, uses environmental cues to trigger new experimental treatments or management actions. The best defined of these environmental triggers is the delivery of additional sediment from tributary streams to trigger BHBF tests.

An important element of the environmental triggers approach requires the specification of desired future conditions, or measurable targets, for humpback chub, sediment conservation, archaeological sites, camping beaches, and other resources of interest to managers. Explicit desired future conditions will provide reference points for evaluating treatment effectiveness and the need to implement additional treatments or management actions. Workshop participants also recommended a comprehensive monitoring program for native and nonnative fishes. The results of monitoring would be used to trigger changes in dam operation and nonnative fish control.

From 2009 through 2012, before a TCD could be built, the participants recommended testing summer and fall steady dam releases. The environmental triggers approach includes the construction and testing of a TCD.

Because it takes at least 4 years for humpback chub to reach maturity (reviewed in U.S. Fish and Wildlife Service, 2002), treatments should be applied for 4 consecutive years to measure biological response, especially in the humpback chub population. However, shorter, isolated flow treatments, such as beach/habitat-building flows, would be likely to provide new information about sediment conservation strategies and possible benefits to other resources.

## Introduction and Background

Glen Canyon Dam, one of the last major dams built on the Colorado River, is located in the lower reaches of Glen Canyon National Recreation Area, approximately 15 miles upriver from Grand Canyon National Park (fig. 1). The international prominence of Grand Canyon and public concern about the impacts of the dam resulted in Federal efforts to protect downstream resources. In 1992, Congress passed and the President signed into law the Grand Canyon Protection Act (GCPA; title XVIII, sec. 1801–1809, of Public Law 102-575), which seeks “to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established.” The Glen Canyon Dam Adaptive Management Program (GCDAMP) was implemented as a result of the 1996 Record of Decision on the Operation of Glen Canyon Dam Final Environmental Impact Statement to ensure that the primary mandate of the GCPA is met through advances in information and resources management (U.S. Department of the Interior, 1995).

On November 3, 2006, the Bureau of Reclamation (Reclamation) announced it would develop a long-term experimental plan environmental impact statement (LTEP EIS) for operational activities at Glen Canyon Dam and other management actions on the Colorado River. The stated time period for the LTEP EIS is 2009–19, and the downstream environment it considers, known as the Colorado River ecosystem (CRE), encompasses the Colorado River corridor from the forebay of Glen Canyon Dam to the western border of Grand Canyon National Park (fig. 1). The proposed plan would implement a structured, long-term program of experimentation including dam operations, potential modifications to Glen Canyon Dam intake structures, and other management actions such as removal of nonnative fish species. The purpose of the long-term experimental plan is twofold: (1) to increase the scientific understanding of the ecosystem and (2) to improve and protect important downstream resources. This LTEP EIS process is consistent with and implements the provisions of the settlement agreement recently executed between the United States and the Center for Biological Diversity and other environmental groups in the Center for Biodiversity v. Kempthorne litigation regarding the operation of Glen Canyon Dam.

The development of the long-term experimental plan continues efforts begun by the GCDAMP to protect resources downstream of Glen Canyon Dam, including Grand Canyon, through adaptive management and scientific experimentation. As a result, the LTEP EIS will rely on the extensive scientific studies that have been undertaken as part of the adaptive management program by the U.S. Geological Survey’s (USGS) Grand Canyon Monitoring and Research Center (GCMRC), one of the four research stations within the USGS Southwest Biological Science Center. The GCMRC conducts scientific monitoring and research for the Glen Canyon Dam Adaptive Management Program.

On April 10 and 11, 2007, at the behest of Reclamation, the GCMRC convened a workshop with scientific experts to discuss options for a long-term experimental plan to be considered by the LTEP EIS. The workshop involved scientists with broad experience in the Colorado River in Grand Canyon and regulated rivers around the world. Resource managers and GCDAMP participants were also present on the second day of the workshop.

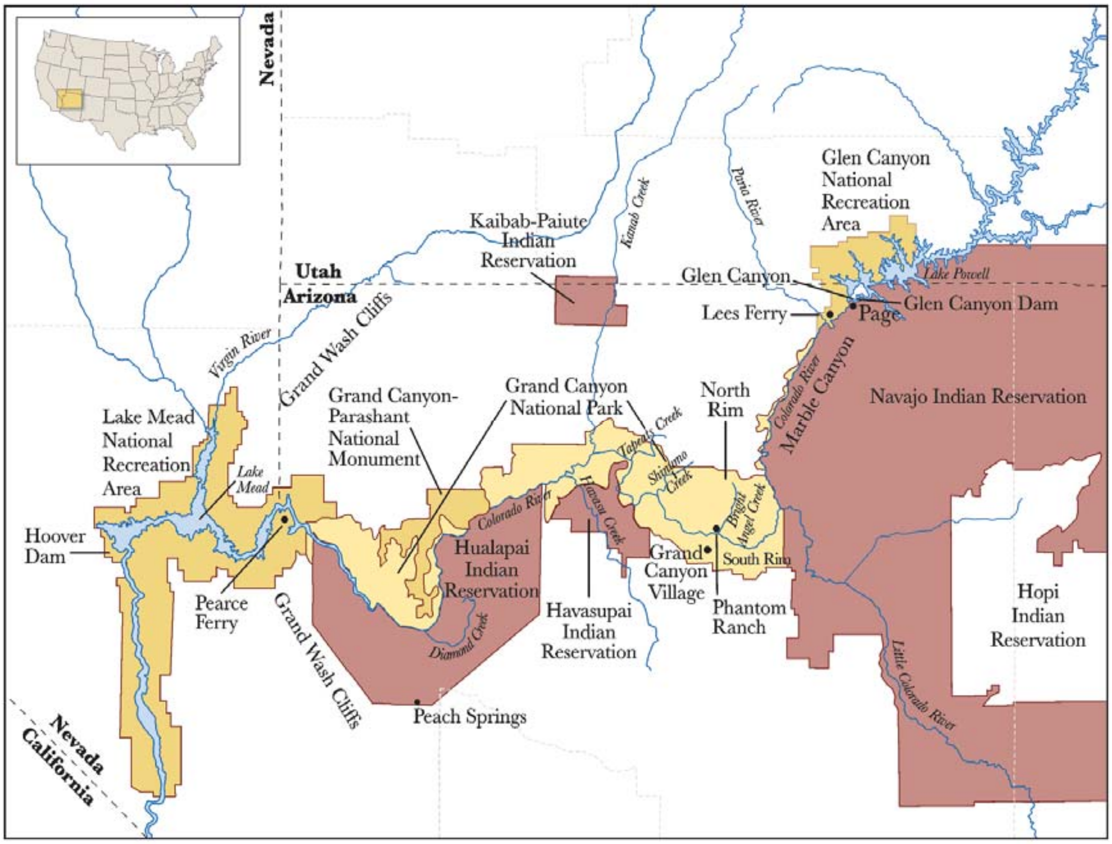


**Figure 1**. Map of the Colorado River ecosystem, showing the Colorado River corridor that extends from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park.

## Role of Science

Experimental research plays an important role in providing information to land and resource managers and stakeholders participating in the Glen Canyon Dam Adaptive Management Program. The GCDAMP has been identified as a model for adaptive ecosystem assessment and management (Walters and others, 2000). The 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (U.S. Department of the Interior, 1995) was developed using experimental studies conducted between 1990 and 1995. Over the past decade, monitoring and research data for CRE resources have been collected, evaluated, and reviewed for GCDAMP by the Grand Canyon Monitoring and Research Center. As early as 1998, sediment scientists published findings suggesting that the strategy for rebuilding and maintaining eroded sandbar habitats proposed in the 1995 environmental impact statement needed to be reevaluated (Rubin and others, 1998). By 2002, sediment researchers had identified alternative experimental flow strategies for conserving the limited sand supplies below the dam and recommended to managers specific tests tied to such strategies (Rubin and others, 2002). Gloss and others (2005) reported that many of the anticipated resource responses for sediment, endangered humpback chub (*Gila cypha*), cultural sites, and other resources identified in the 1995 environmental impact statement had not been realized.

In response to the scientists' earlier reports to stakeholders in 2002, and on the basis of recommendations from the GCDAMP later that year, the U.S. Department of the Interior approved new experimental flow and nonflow research for 2003 and 2004. This research was intended to promote learning about how CRE resources could be better managed to meet management objectives. The experimental research was approved for another 2 years (2005–06); however, the extension recognized the need for a longer term experimental plan for the program beyond 2006. GCDAMP participants and others called for a different approach than the one originally proposed in the 1995 environmental impact statement (U.S. Department of the Interior, 1995). In response, Reclamation proposed the preparation of an LTEP EIS.

## Workshop Purpose and Scope

On April 10 and 11, 2007, the Grand Canyon Monitoring and Research Center, at the request of Reclamation, convened a workshop with scientific experts to discuss experimental options and treatments that could be considered during the development of the LTEP EIS for operational activities at Glen Canyon Dam and other management actions. The workshop took place in Flagstaff, Ariz. Reclamation has the lead responsibility for identifying alternatives consistent with various Federal and State laws, including, but not limited to, the Grand Canyon Protection Act, the Endangered Species Act, various laws and Supreme Court decrees known as the Law of the River, the Interim Shortage Criteria Environmental Impact Statement, and the Annual Operating Plan for the Colorado River.

The workshop convened scientists with broad experience in the Colorado River in Grand Canyon and regulated rivers around the world. Participants came from the United States and Canada. The experience of the participants was diverse, with competence in fluvial geomorphology, river hydrology, and fish biology, especially in the regulated rivers of western North America. The participants are listed in appendix A and their abbreviated curricula vitae are presented in appendix D.

The specific purpose of the eventual long-term experimental plan as stated in the Federal Register (December 12, 2006) is to:

> increase understanding of the ecosystem downstream from Glen Canyon Dam and to improve and protect important downstream resources. The NEPA [National Environmental Policy Act] process would evaluate the implications and impacts of each of the alternatives on all of the purposes and benefits of Glen Canyon Dam as well as on downstream resources. The proposed plan would implement a structured, long-term program of experimentation (including dam operations, modifications to Glen Canyon Dam intake structures, and other non-flow management actions, such as removal of non-native fish species) and monitoring in the Colorado River below Glen Canyon Dam.
>
> The proposed Long-Term Experimental Plan is intended to ensure a continued, structured application of adaptive management in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon

National Park and Glen Canyon National Recreation Area were established, including, but not limited to natural and cultural resources and visitor use, consistent with applicable Federal law.

The goal of the workshop was the identification of one or more scientifically credible, long-term experimental options consistent with the purpose and need for the long-term experimental plan. A research and monitoring program would be developed by the GCMRC following completion of the LTEP EIS. In addition to improving and protecting downstream resources, the purpose of the long-term experimental plan would be to increase scientific understanding of the ecosystem. Workshop participants were asked to consider how the proposed options would address 14 core scientific questions (table 1) identified by Reclamation and LTEP EIS cooperating agencies.[1] The core scientific issues to be addressed by the plan fall primarily into four areas: (1) conservation of endangered humpback chub and other high-priority biological resources, (2) conservation of sediment resources, (3) enhancement of recreational resources, and (4) preservation of cultural resources. Following the workshop, GCMRC scientists developed answers to the first 10 core scientific questions based on the information presented and discussions undertaken during the workshop (see appendix E).

A secondary objective of the workshop was the evaluation of four long-term experimental options developed by the GCDAMP Science Planning Group (SPG) (appendix B). The flow and nonflow experimental treatments called for in the four options were an important starting point for workshop discussions. Because the workshop was limited to 2 days, activities focused primarily on the two resources identified by Reclamation as priorities of the LTEP EIS: humpback chub and sediment. There was inadequate time to address the full range of resources or science questions of interest to resource managers.

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[1] State of Arizona—Arizona Department of Water Resources, Arizona Game and Fish Department, Bureau of Indian Affairs, State of Colorado—Colorado Water Conservation Board, Hualapai Tribe, Kaibab Band of Paiute Indians, National Park Service, State of New Mexico—New Mexico Interstate Stream Commission, Pueblo of Zuni, The Hopi Tribe, Upper Colorado River Commission, U.S. Fish and Wildlife Service, U.S. Geological Survey, Utah Associated Municipal Power Systems, State of Utah—Utah Department of Natural Resources, and Western Area Power Administration.

**Table 1.** Core scientific questions identified by the Bureau of Reclamation and cooperating agencies to be considered in the environmental impact statement for a long-term experimental plan for operation of Glen Canyon Dam.

| |
|---|
| 1. What are the factors limiting humpback chub reproduction and rearing in the main channel of the Colorado River below Glen Canyon Dam? |
| 2. Have humpback chub population estimates stabilized or increased recently, and if so, why (warmer water temperatures, nonnative control, other factors)? |
| 3. Will warming dam releases positively affect listed or special status species in the Colorado River ecosystem (including humpback chub and effects of nonnative species)? |
| 4. Can the decline in sediment resources since 1990 be reversed using "flow" options with remaining downstream sand supplies from tributaries (Paria and Little Colorado Rivers and lesser tributaries)? |
| 5. Will high-flow experiments promote conservation of high priority Adaptive Management Program biological resources (for example, native fishes, native riparian vegetation, aquatic food base, rainbow trout)? |
| 6. What effect do powerplant releases (ramp rates, fluctuating and steady) have on listed or special status species (including humpback chub) in the Colorado River ecosystem? |
| 7. Can the decline of humpback chub be reversed by expanding the current range of humpback chub into suitable unused historical habitat within Grand Canyon National Park and Glen Canyon National Recreation Area (tributaries/mainstem)? |
| 8. If the answer to core question 4 is yes, will enhanced sediment conservation promote in situ preservation of archaeological sites? |
| 9. How can invasive or nonnative species be eliminated, reduced, or controlled in the Colorado River ecosystem? |
| 10. If the answer to core question 4 is yes, will enhanced sediment conservation promote conservation of recreation beaches and campable area? |
| 11. How can the Lees Ferry trout fishery be improved? |
| 12. Will dam operations, including temperature changes, diel fluctuations, and high experimental flows, affect razorback sucker in Lake Mead and Grand Canyon? |
| 13. Will high-flow experiments affect the water quality released from Glen Canyon Dam? |
| 14. Can visitor experience (boating, camping, sightseeing, safety) be enhanced through alteration of the modified low fluctuating flow regime? |

# Context for Workshop Discussions

Before the workshop, participants were provided with the final public scoping report prepared by Reclamation, which also contained the purpose and need statement excerpted from the Federal Register notice of intent to prepare an environmental impact statement. Descriptions of the flow and nonflow treatments contained in the four experimental options developed by the Science Planning Group were provided to the participants in advance of the workshop and were an important starting point for the workshop deliberations (see appendix B for a summary of the treatments). Flow treatments included reduced or increased fluctuating flow releases, beach/habitat-building flows (BHBF) tests, and steady flow tests. Nonflow treatments included installation and operation of a temperature control device (TCD), or selective withdrawal structure, on Glen Canyon Dam and removal of nonnative fishes. The four SPG options were described by their proponents to the participants during a telephone conference call on April 5, 2007.

At the beginning of the workshop, a Reclamation representative reviewed the purpose and need of the LTEP EIS for the participants. Participants were advised that the U.S. Fish and Wildlife Service's (USFWS) 1995 final biological opinion on the operation of Glen Canyon Dam included a reasonable and prudent alternative calling for the establishment of a "second spawning aggregation" of humpback chub downstream of Glen Canyon Dam (U.S. Fish and Wildlife Service, 1995). Consistent with this alternative, Reclamation made an environmental commitment in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement to "make every effort…to ensure that a new population of humpback chub is established in the mainstem [Colorado River] or one or more of the tributaries within Grand Canyon" (U.S. Department of the Interior, 1995). How a "second spawning aggregation" and a "new population" may be similar or different has not been formally determined.

Workshop scientists were briefed about the current status and trends of native and nonnative fishes, sediment resources, and water release temperatures from the dam. GCMRC staff provided updates on preliminary and published results from past experimental research on both sediment and fish between 1996 and 2006. The briefings included information about two BHBF tests conducted in 1996 and 2004, the low summer steady flow (LSSF) of 2000, the 4-year-long experimental nonnative fish removal in specific reaches below the dam, and an overview of GCMRC fisheries research, including estimates of the Grand Canyon adult humpback chub population.

## Management Objectives

The 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (U.S. Department of the Interior, 1995) identified resources that the preferred alternative (the alternative selected and described in the final EIS, along with the basis for selection) and other management actions might improve or affect. The natural and cultural resource categories identified included (1) sediment and aquatics, (2) vegetation, (3) wildlife, (4) endangered and other special-status species, (5) cultural resources, (6) air quality, (7) recreation, and (8) power. Because the humpback chub is a federally listed endangered species, conserving the Grand Canyon population has long been a focus of management activities. Sediment conservation has also driven management efforts because of its relationship to other resources, including habitat, recreation, and cultural sites.

Improvements projected in the 1995 environmental impact statement for a number of downstream resources, including both humpback chub and sediment, had not been met by 2004 (Lovich and Melis, 2005). As a result, humpback chub and sediment have been identified by Reclamation as the primary focus of the LTEP EIS. Workshop discussions were guided by the need to reach management objectives for these resources. In most cases, measurable targets have not yet been defined.

## 1995 Biological Opinion Reasonable and Prudent Alternative

The U.S. Fish and Wildlife Service prepared a biological opinion in 1995 on Glen Canyon Dam relating to operation and other criteria of the preferred treatment alternative for the 1995 environmental impact statement. The USFWS recognized that there were risks inherent to the entire Grand Canyon humpback chub population being dependent on a single tributary for spawning and rearing habitat, namely, the Little Colorado River, a tributary of the Colorado River in Grand Canyon (fig. 1). To help reduce this risk, the biological opinion required the establishment of a second spawning aggregation of humpback chub in Grand Canyon (U.S. Fish and Wildlife Service, 1995).

The current Grand Canyon humpback chub population is heavily dependent on the Little Colorado River. More than 90 percent of the fish spend most of their lives in the lowest 11 miles of the Little Colorado River and in the reach of the Colorado River immediately upstream and downstream from the Little Colorado River (Paukert and others, 2006). This geographic constriction has some advantage for genetic homogenization (Douglas and Douglas, 2007) because the majority of the adult population remains in proximity to other adults, increasing the likelihood of complete mixing of genetic material during spawning, especially over a period of years. However, the geographic constriction also means that the population is susceptible to catastrophic loss. There is general agreement among scientists working with the Grand Canyon humpback chub population that the greatest risk from catastrophic loss would be an accidental spill of hazardous liquids (for example, petroleum products) where U.S. Highway 89 crosses the river drainage near Cameron, Ariz. (U.S. Fish and Wildlife Service, 2002). Just such an accident occurred in summer 2005 when a tanker truck carrying gasoline ran off the highway and overturned in Moenkopi Wash, a tributary of the Little Colorado River. Fortunately for the aquatic resources downstream, this accident occurred during a dry period when the wash did not contain running water. If water had been present, as regularly occurs during rainstorms, gasoline could have been transported to the Little Colorado River. Although other risks threaten the Grand Canyon humpback chub, the risk of an accidental spill may be the most critical, because if it occurs a large proportion of the population could be lost quickly along with the attendant genetic diversity (Douglas and Douglas, 2007). The risk of catastrophic loss would be reduced if one or more humpback chub populations were reproducing and growing in the mainstem Colorado River or in another Grand Canyon tributary stream.

## Sediment Conservation

A recent synthesis of geomorphic data on sandbars below Glen Canyon Dam reported a 25 percent reduction in the sandbar area within the 87-mile reach from Lees Ferry to Bright Angel Creek between 1984 and 2000 (Schmidt and others, 2004). It is clear that managers are interested in mitigating further losses of these sediment resources, but there is little detail about the future desired conditions that managers are seeking to achieve. The focus of sandbar habitats is on terrestrial deposits, which supply recreational camping areas and terrestrial substrates for riparian plant communities. As an aquatic habitat resource, sandbars are known to support low-flow-velocity zones within recirculating eddies, known commonly as backwaters (Goeking and others, 2003). Because of warm temperatures and low velocities found in backwaters, such habitats are thought to benefit early life stages of native fish (Goeking and others, 2003), but little conclusive data exists to support this hypothesis in Grand Canyon. Further research will be required to determine the extent to which sandbars and related habitats play a role, if any, in the life history and management of humpback chub.

### Increase Camping Beaches

According to recent data compiled by USGS and cooperating scientists, open sand area preferred by recreational campers has decreased by 55 percent since 1998, with an average rate of decline of about 15 percent per year (Kaplinski and others, 2005). The only deviation from the overall decline in available campable area has occurred in conjunction with BHBF tests in 1996 and 2004. In both cases, the increases in campable area were relatively short lived and did not reverse the overall downward trend in available campsite area. Reduction in sediment supply related to dam operations, plus the lack of periodic sediment-rich flood flows to replenish sediment above the zone of daily fluctuating flows, have contributed to the loss of camping area. Additionally, colonization of sandbars by native and nonnative vegetation, which is no longer periodically reduced or removed by floods, has also contributed to the loss of campable area over time (Kearsley and others, 1994; Kaplinski and others, 2005).

The diminishing availability of campable area, particularly in some of the narrower reaches of the river corridor, is an important issue for national park managers and recreational river runners. The loss of campable area could increase campsite crowding and competition for campsites, which impacts the quality of the recreational experience for park visitors (U.S. Department of the Interior, 1995). The primary recreation-related management goal of the GCDAMP is to “maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem,” and a closely related secondary objective is to “increase the size, quality, and distribution of camping beaches” (Glen Canyon Dam Adaptive Management Program, 2003). Measurable targets tied to these objectives have not yet been defined.

### Cultural Resource Protection

The preservation of cultural resources, specifically archaeological sites, is closely linked to sediment conservation because the majority of sites near the Colorado River below Glen Canyon Dam are either situated in or buried by sediment derived from the predam river (Fairley and others, 1994; Hereford and others, 1996; Draut and others, 2005). As the ecosystem has adjusted to postdam hydrologic parameters, there has been an overall reduction in sediment being supplied to lower elevation sandbars and a lack of periodic high flows to replenish sand deposits at higher elevations above the current daily fluctuating flows zone. Meanwhile, uncontrollable natural processes such as precipitation and wind remove fine sediment from higher elevation zones. These interrelated factors of reduced sediment supply, insufficient sediment availability, and the postdam hydrologic regime, coupled with precipitation, wind deflation, and visitor impacts, all contribute to the degradation of archaeological sites within the river corridor (Fairley, 2005). The general management objective is to mitigate the surface sediment loss and gully erosion now occurring at the many archaeological sites in the river corridor.

## Resources, Conditions, and Trends

The following summarizes the published literature and other current information that was discussed by the participants. Some information was so current that it is still being prepared for publication.

### Rainbow Trout

Nonnative fishes have been present in Colorado River for more than 100 years (Mueller and Marsh, 2002). The community species composition likely changed through time (for example, Woodbury and others, 1959), and it can be anticipated that it will continue to change in response to climate, water temperatures, and other factors. Native fishes persisted in the presence of nonnative species, but absolute community species ratios are unknown because rigorous sampling and estimating for them was not conducted. With the closure of Glen Canyon Dam in 1963, the hydrology of the river changed dramatically, with more daily flow fluctuations but reduced annual variability (Topping and others, 2003). The temperature of the river continues to exhibit an annual cycle as it did historically, but, like the flow pattern, the temperature pattern now exhibits much less seasonal and annual variability, with a lower average annual temperature (Voichick and Wright, 2007). Because of the presence of Glen Canyon Dam, the annual peak release temperatures occur in the late fall or winter instead of the summer as they did before the dam (Vernieu and others, 2005). These conditions, along with the reduced sediment loads, have allowed expansion of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) populations.

The rainbow trout population introduced below the dam is currently concentrated between the dam and Lees Ferry, although rainbow trout can also be found further downstream in Grand Canyon. Using data collected in cooperation with the Arizona Game and Fish Department, population trends and condition factors (a measure of relative body proportions that indicates individual health) can be correlated with releases from Glen Canyon Dam. In 2006, the rainbow trout catch rate was relatively low, but the condition of individuals was moderate to high, on average. Catch rates of rainbow trout below Glen Canyon Dam have been shown to be correlated with population size (Makinster and others, 2007). Between 1997 and 2001, the catch rate for rainbow trout was usually inversely proportional to condition. In other words, when catch rates were high, individual condition was low, and vice versa. Catch rates were proportional to annual flow volume; higher flows were generally coincident with higher catch rates. In turn, annual flow volume was generally proportional to basin hydrology (L.G. Coggins, oral commun., 2007).

At least two size classes of rainbow trout (50–200 mm and >200 mm) can be identified in the reach of the Colorado River between Glen Canyon Dam and Lees Ferry. Numbers of rainbow trout diminish with distance downstream, and smaller size classes are generally not represented downstream to the mouth of the Little Colorado River; larger, presumably older rainbow trout are usually found near the Little Colorado River confluence (Gorman and others, 2005; Korman and others, 2005).

The GCDAMP engaged in experimental removal of rainbow trout and other nonnative fish in the vicinity of the Little Colorado River confluence from 2003 through 2006. This effort removed more than 19,000 rainbow trout. In 2003, rainbow trout represented more than 90 percent of the fish captured using electrofishing at night, consistent with the findings of Gorman and others (2005). However, the proportion of the fish had dropped to less than 10 percent by 2006 (U.S. Geological Survey, unpub. data, 2007). By contrast, native fish, including humpback chub, were only 10 percent of the fish captured in 2003; in 2006, native fish represented more than 60 percent of the fish community captured in the Little Colorado River experimental reach (U.S. Geological Survey, unpub. data, 2007). While GCMRC and Arizona Game and Fish Department scientists have found that rainbow trout declined throughout Marble Canyon (upstream of the mechanical removal reach) during this period, the removal of more than 19,000 rainbow trout seems to have accelerated the population decrease of this species also in the vicinity of the Little Colorado River confluence. Other factors that may have caused a decrease in population numbers of rainbow trout include increased intraspecific competition and warmer mainstem water temperatures.

## Other Nonnative Fishes

It is likely that current coldwater conditions are generally hindering the proliferation of warmwater nonnative fish in the CRE (Moyle and Light, 1996). It is known that a suite of warmwater nonnative fishes continues to inhabit the Lower Colorado River and tributaries in Grand Canyon (Gloss and Coggins, 2005, table 1; Mueller and Marsh, 2002, table 6; Stone and others, 2007). Additional species are possible in the future. Warmwater nonnative fishes prey on and compete with native Colorado River fish (Minckley and Meffe, 1987; Minckley and Deacon, 1991; Lynch and others, 1996; Tyus and Saunders, 2000).

GCMRC scientists presented a comprehensive overview of current data and findings regarding other nonnative Grand Canyon fishes. The 2003–06 experimental removal project discussed above contributed to changes in the composition of the fish community in the treatment reach, which was located immediately upstream and downstream of the mouth of the Little Colorado River. With removal of large numbers of rainbow trout, the proportions of other native and nonnative fishes increased during the sampling period (L.G. Coggins, oral commun., 2007).

Below the Little Colorado River, catch rates for striped bass (*Morone saxatilis*) and channel catfish (*Ictalurus punctatus*) increased with distance below the Little Colorado River. The frequency of both of these species in the catch below Diamond Creek (river mile 225) increased above the rates within Grand Canyon (Ackerman and others, 2006).

### Humpback Chub

The participants were informed that the current population of adult humpback chub (age-4+) is less than 50 percent of what it was as late as 1990, according to the most recent capture and modeling information that was available (Coggins and others, 2006). This conclusion assumes that the initial 1989 population estimate was accurate. Colder water temperatures and predation by and competition with nonnative fishes are likely causative factors for the decline. Since 2000, however, the number of adult fish stabilized at a new, lower level, which is estimated at 5,000 (Melis and others, 2006). Results of even more current data, published after the workshop, indicate that the adult humpback chub population is closer to 6,000 (Coggins, 2007). The recent stabilization of the adult population could reflect the loss of humpback chub that resided primarily in the mainstem since the late 1980s and the inability of mainstem habitat to support successful recruitment. The current population of approximately 6,000 adults may represent the capacity of the Little Colorado River. These population changes may or may not reflect a response of the population to changes in river conditions or actions taken under the auspices of the GCDAMP.

The participants also reviewed information regarding the recruitment abundance of humpback chub younger than 4 years old. This segment of the population seems to have reached a modern low in 1991. However, numbers of young humpback chub increased steadily during the 1990s, returning to approximately late 1980s levels by 2001, the most recent year for which these data are available (Coggins, 2007).

Humpback chub are adapted to warmer water conditions than are currently available in the mainstem Colorado River in Grand Canyon (Hamman, 1982; Kaeding and Zimmerman, 1983; Clarkson and Childs, 2000). Summer and fall temperatures are still colder than historical levels during the same seasons (Voichick and Wright, 2007). This remains true in spite of slight increases in the temperature of water releases from the dam during the summer and fall of recent years, especially in 2005 when the released water temperature was warmer than 16°C in October. Humpback chub appear able to survive the current temperatures, at least during adult life stages. Colder summer mainstem temperatures may be limiting to the survival of smaller, younger native fishes. Adult mainstem survival has been documented by the repeated captures of adult humpback chub in the mainstem (for example, Valdez and Ryel, 1995).

Summer mainstem water temperatures, however, are so low that growth is reduced and spawning is almost exclusively limited to the Little Colorado River (Stone and Gorman, 2006). Nearly all humpback chub are hatched in and return to this tributary for spawning. Following spawning here, most humpback chub spend their life either in the tributary or the mainstem immediately upstream and downstream from the tributary (Paukert and others, 2006).

Aggregations of humpback chub elsewhere in Grand Canyon have been documented (Valdez and Ryel, 1995; Valdez and Masslich, 1999; Paukert and others, 2006). The numbers of individuals in these aggregations are much smaller than the number of fish associated with the Little Colorado River, making accurate abundance estimates more difficult. The strong site fidelity of the humpback chub captured in these aggregations suggests that adult fish, once established, tend to remain at or return to these locations (Paukert and others, 2006). The source of young fish for the aggregations found downstream of the Little Colorado River is not known—whether active spawning occurs at the aggregation locations, or humpback chub spawned in the Little Colorado River are dispersed downstream to aggregations, or both.

The aggregation of humpback chub at river mile 30, which is upstream of the confluence with the Little Colorado River, occurs in the vicinity of warmer perennial springs that emerge from the riverbed (Valdez and Masslich, 1999). Catches of humpback chub less than 1 year old increased between 2003 and 2005 (Melis and others, 2006). Using a bioenergetics model for humpback chub (Petersen and Paukert, 2005), scientists estimate that some of the young humpback chub captured in nearshore habitats in the vicinity of river mile 30 in 2006 were hatched in 2005 and survived the winter of 2005–06 in this habitat (Ackerman, 2008). This estimate is being reviewed, but it suggests that habitat conditions in this mainstem reach may allow for some spawning and larval survival of humpback chub. Winter temperatures are elevated in the reach relative to historical predam water temperatures, and the summer and fall mainstem temperatures between 2003 and 2006 were elevated over the 12-year running average (Voichick and Wright, 2007). In addition to having warmer water temperatures, the river mile 30 reach is approximately 20 river miles upstream from the start of the area from which nonnative fishes, especially rainbow trout, were removed during 2003–06. The lower rainbow trout population in Marble Canyon, which was reduced because of intraspecific competition, warmer water temperatures, mechanical removal, or some combination of these, could have resulted in reduced predation of and competition with humpback chub; these factors may have contributed to the increased captures of young humpback chub in river mile 30 reach. Natural warming is a confounding factor in determining the impact of mechanical removal on native fish.

## Other Native Fishes

Scientists with GCMRC, Arizona Game and Fish Department, and U.S. Fish and Wildlife Service have noted increases in catch rates of not only humpback chub in 2005 and 2006, but also bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*Catostomus latipinnis*). Catch rates for these two native sucker species increased fivefold, especially below the confluence of the Colorado and Little Colorado Rivers (fig. 1). Examination of length frequency distributions for native fish caught in the Little Colorado River removal reach suggests that most of this abundance increase is because of increased numbers of juvenile fish. These observations of shifts in native fish length frequency distributions support the increases in abundance indicated by the catch-rate data and suggest multiple successful recruitment events, particularly for flannelmouth sucker.

Bluehead sucker were so abundant in the Little Colorado River during 2006 that they filled hoop nets before they could be pulled and enumerated (Van Haverbeke and Stone, 2007). This species has demonstrated elevated catch rates throughout Grand Canyon from 2002–06 (R.S. Rogers, Arizona Game and Fish Department, unpub. data, 2006). The high catch rates for flannelmouth sucker in 2006 remained elevated throughout Grand Canyon, and the size structure of the population indicated recent successful reproduction (R.S. Rogers, Arizona Game and Fish Department, unpub. data, 2007).

## Sediment

Participants were briefed by GCMRC staff and other cooperating sediment scientists about the results of sediment studies conducted during the past decade; much of this information is summarized by Wright and others (2005). As a means of providing the participants with additional information about the recent status of sediment resources and BHBF research, GCMRC staff also reviewed information contained in a recently published U.S. Geological Survey fact sheet (Melis and others, 2007).

Studies have demonstrated that sandbars can be rebuilt relatively quickly when high flows such as BHBF tests are released from the dam, but that new tributary sand inputs do not accumulate in the river channel under typical modified low fluctuating flow (MLFF) dam operations as predicted in the 1995 environmental impact statement (U.S. Department of Interior, 1995).

### Summary of the 2004 Beach/Habitat-Building Flows Results

In September 2002, the U.S. Department of the Interior approved implementation of new BHBF testing on the basis of a triggering threshold linked to sand inputs from the Paria River. The new experimental paradigm focused on evaluating how effectively high-flow releases could be used to move new sand up onto shorelines before it was flushed downstream. The sand input trigger was to be a high volume of sand deposition from the Paria River, which occurs every other year on average. The only BHBF test conducted as a result of the Paria sediment trigger occurred in 2004; significant sand inputs to Marble Canyon occurred during September–November 2004 and exceeded the sediment trigger. A supplemental environmental assessment was prepared and approved in order to permit the BHBF test that began on November 21, 2004 (U.S. Department of the Interior, 2002).

During the 2004 experiment, a net transfer of channel sand into eddies resulted in an increase in sandbar total area and volume in the upper half of Marble Canyon, approximately river mile 1 through river mile 40 (Topping and others, 2006). Further downstream, where sand was less abundant, the experiment resulted in the net transfer of sand out of eddies (Topping and others, 2006).

Results of the 2004 BHBF test confirmed that high flows released under sand-enriched conditions can increase the nearshore source areas for windborne sand, leading to increases in the rate of sand transported toward some locations in Grand Canyon that contain cultural resources (Draut and Rubin, 2006). Increased sand transport by wind and backfilling of gullies and deflated areas with aeolian sand can potentially reduce the rate of erosion and increase the preservation potential of these sites. Draut and Rubin (2006) have shown that a measurable increase in sediment transport to some archaeological sites is possible when sandbars are created at higher elevations during a BHBF and when the sandbars have time to dry out and are retained long enough to be available for reworking by wind during the spring windy season. These findings suggest that if more high-elevation sandbars could be created and retained for sufficient time periods, it would be possible to mitigate some of the surface sediment loss and gully erosion now occurring at some archaeological sites in the river corridor that are subject to aeolian processes.

Scientists also confirmed that substantial increases in total eddy-sandbar area and volume are only possible during high-flow releases conducted under the sand-enriched conditions that follow large tributary floods (Rubin and others, 2002; Topping and others, 2006). In the future, more sand than the 800,000 to 1,000,000 metric tons of sand available during the 2004 experiment will be required to achieve increases in total eddy-sandbar area and volume throughout all of Marble and Grand Canyons (Topping and others, 2006).

Because tributary inputs of sand larger than those that preceded the 2004 BHBF test are relatively rare, it is not considered feasible to achieve significant systemwide rebuilding of sandbars with a single BHBF test. Rather, the most promising method of rebuilding sandbars over the long term is by following each average to above-average tributary input of sand with a short-duration BHBF test (Topping and others, 2006). Under this scenario, each subsequent BHBF test could presumably build upon the depositional results of the previous one, potentially resulting in cumulative increases in systemwide sandbar area and volume over decadal time scales. However, this strategy is only feasible if the intervening powerplant releases do not completely erode the sand deposited in sandbars by BHBF tests. Since theory and monitoring data in this system have shown that fluctuating flows transport more sand than equivalent-volume steady flows, intervening releases with the least amount of fluctuation will have the highest probability of maintaining the sandbar building achieved during BHBF tests. Hence, there is a long-term need for monitoring sandbar changes over a period of repeated BHBF tests under multiple sand enrichment scenarios (perhaps at least over a decade) to answer the core science question for sediment (table 1, no. 4). The establishment of specific goals for this resource and associated monitoring will be necessary to determine whether sandbars are created and maintained where they are most desired by managers.

### Sand Triggering and other Considerations for Future BHBF Tests

Following the 2004 BHBF, the sand input trigger used for that experiment was reevaluated by the GCMRC and the Science Planning Group and revised to include sand inputs from the Little Colorado River and other lesser tributaries in addition to the Paria River. The revised sediment trigger proposed for future BHBF tests would occur when 0.5 million metric tons of sand are introduced by the Paria River and retained above river mile 30, and an additional "weighted" 0.5 million metric tons of sand are delivered by the Paria River, Little Colorado River, or sources that enter the ecosystem annually (late summer and fall through early winter) in between these two primary tributaries and retained upstream of Diamond Creek (fig. 1). To calculate the weighted input, sand from the Paria River is given full value and sand from the Little Colorado River and other sources is valued at 50 percent of the actual input. Thus, a BHBF test could be triggered with an input of 1.0 to 1.5 million metric tons of sand, depending on how much of the sand is derived from the Paria River. The rationale for revising the sand input trigger is that it allows experimentation under enriched sand conditions that could occur below Marble Canyon from the Little Colorado River during periods when the Paria River inputs alone may not equal the earlier trigger, but weights the Paria River inputs over downstream inputs to prevent BHBF tests from occurring at times when Marble Canyon has not had any annual sand inputs. Under the revised triggering criteria, repeated experiments could occur more frequently and would facilitate a more rapid evaluation of whether or not cumulative sandbar deposition occurs on a systemwide basis through time.

In general, the optimal timing for a BHBF test is when the most new tributary-derived sand is available in the system. The rationale for conducting experiments under sediment-enriched conditions has been documented in several peer-reviewed outlets, including Webb and others (1999), Topping and others (2000), Rubin and Topping (2001), Rubin and others (2002), Schmidt and others (2004), Wright and others (2005), Hazel and others (2006), Topping and others (2006), and Melis and others (2007). Historically, the largest Paria River inputs have occurred during the late-summer and fall thunderstorm season. For the Little Colorado River, large inputs may occur during the late summer and fall as well as during spring floods.

The rate at which the tributary-derived sand is exported downstream to Lake Mead is dependent on the availability of new sand and releases from the dam. Under moderate and higher dam releases, the export rate can be quite high, which may constrain the time available for the new sand to be used for BHBF tests (Rubin and others, 2002). Most sand in a moderate input is predicted to be lost within days (at discharges >35,000 cfs), weeks (at discharges of about 25,000 cfs), or months (at discharges of about 15,000 cfs); however, at discharge rates of 10,000 cfs and less, sand is retained for periods of months to years.

The new sand will only be available for a BHBF if the test is implemented promptly following sediment inputs or if dam releases are constrained; however, basin hydrology may prohibit low releases. Because of this interaction between the timing of tributary inputs and basin hydrology, the optimal timing of BHBF tests will vary from year to year. For example, during periods of wet hydrology and high dam releases, when export rates are expected to be high, the optimal time to conduct BHBF tests would likely be within days or weeks of large tributary inputs, such as during late fall for typical Paria inputs. Conversely, during periods of dry hydrology and low-volume dam releases, when export rates are expected to be lower, it may be optimal to wait until late in the spring so as to accumulate Paria and Little Colorado River sand throughout the input seasons. Finally, export rates are dependent on the amount of fluctuation as well as the total volume; thus, the amount of fluctuation will affect the amount of sand available and the optimal timing of BHBF tests (that is, less fluctuation leads to more retention and thus more flexibility in timing BHBF tests). Clearly, the optimal timing for a BHBF in one year may not be the same as in another year, but ideally a BHBF test would avoid the summer and early fall when the probability of high numbers of juvenile humpback chub entering the mainstem is highest.

Consistent with the 1995 environmental impact statement (U.S. Department of the Interior, 1995), as well as BHBF tests undertaken in 1996 and 2004, future tests should be conducted in the range of 41,500 to 45,000 cfs, or possibly higher if Lake Powell storage is high enough to reach the spillway gate elevations, to promote the most robust conservation of sand at higher elevations along river banks. Replication of the 2004 peak magnitude of 41,500 cfs during future BHBF tests is most likely to support comparative analyses to determine whether sandbar habitats can be effectively rebuilt and maintained by sand-enriched high flows.

The concept of replicating the 2004 hydrograph (rising limb, peak, and descending limb) was discussed extensively among cooperating sediment scientists at the 2005 knowledge assessment workshop convened by the GCMRC with stakeholders. The 2004 test hydrograph was designed on the basis of sandbar simulations for a subset of eddies under a scenario of 45,000-cfs peak magnitude and sand concentrations that were measured in the postdam era. These outcomes of the simulations and data collected from the 1996 BHBF test influenced the choice of 60 hours as the reduced duration for peak flow, down from the 168-hour test that occurred in 1996. The 2004 peak magnitude was limited to 41,500 cfs because one of the eight units at Glen Canyon Dam was undergoing maintenance. Replication of the 2004 hydrograph in a future test is aimed at determining whether or not the sandbar-building responses that occurred under the 2004 BHBF test in upper Marble Canyon will occur consistently each time a BHBF test is released under locally sand-enriched conditions. Replication of the 2004 test hydrograph would also allow scientists to evaluate whether there are incremental cumulative benefits to sandbar conservation in lower Marble Canyon and Grand Canyon reaches each time sand-enriched BHBF tests occur.

The GCMRC and its science cooperators recently evaluated the limitations and benefits of a shorter duration peak at 41,500 cfs, such as one that would last for only 30 hours. Exact predictions about the outcome of a BHBF test with a shorter duration are not possible at this time without field experimentation. Predictability is limited because current sediment models have limited success in making such robust predictions; there are many factors to consider related to peak-flow duration and peak magnitudes for high-flow experiments. While the main recommendation from scientists at present is to use the same hydrograph for the next test as was used in 2004, they acknowledge that a peak-flow duration of not less than 30 hours would also provide sufficient data collection to advance learning about these high releases and sediment dynamics.

By conservation of mass, flood waves in a wet channel travel downstream at a higher velocity than the water (Lighthill and Whitman, 1955). Additionally, the water travels much faster than the sand in suspension. Thus, depending on the longitudinal distribution of sand in the river, substantial lags may develop between an experimental BHBF flood wave and the sand in transport, with the flood wave greatly leading the suspended sand. During the 2004 BHBF test, this disparity in travel time between the flood wave and the water and new sand input from the Paria River was as much as 27 hours by the time the flow peak reached Diamond Creek, more that 250 river miles below Glen Canyon Dam. During evaluation of the flow and sediment data from the 2004 test, it became apparent that once the peak of the test release had moved ahead of the new sand supply in upper Marble Canyon, it became another test of the 1996 BHBF, except with even less sand available in the downstream reaches owing to continued sand export between 1996 and 2004.

Although the fall 2004 dam releases (5,000- to 10,000-cfs daily range) were very effective in limiting downstream sand transport between September and late November 2004, having the new sand mostly stockpiled in the upper section of Marble Canyon meant that the flood wave's higher velocity took it downstream of the new sand supply by the time the flood reached lower Marble Canyon and beyond. As a result, scientists now hypothesize that some redistribution of new sand inputs should occur before conducting future BHBF tests. The hypothesis to test here is that a more uniformly distributed new sand supply will be more evenly transferred to eddy sandbars throughout this critical upper Marble Canyon reach as the fast-moving flood wave propagates downstream. It is unknown whether such preconditioning of new sand supplies can be effectively achieved or not. The 2004 BHBF test followed several months of downstream transport under 1996 Record of Decision operations. Some uniform distribution of sandbars was observed. If the results from replicating the 2004 experimental BHBF hydrograph under more sand-enriched conditions in the spring result in even more uniformly distributed sandbars, or deposition progresses farther downriver with successive floods as upriver eddies become filled, then this approach may be interpreted as being a sustainable strategy for longer term habitat rebuilding and maintenance.

# Discussions

To clarify the range of proposed management options that could be evaluated experimentally, the workshop facilitator described a variety of flow and nonflow experimental treatments that had been previously identified by the Science Planning Group (appendix B). Examples of flow treatments include steady, fluctuating, and beach/habitat-building flows. Consideration was given to how flow treatments affect sediment conservation and native fish. Examples of nonflow treatments include construction and operation of a temperature control device and continued efforts to mechanically remove and control the abundance of nonnative fish.

## Flow Treatments

### Steady Releases

The participants discussed whether there was any value in recommending steady releases from Glen Canyon Dam. Steady releases appear to allow shallow nearshore habitats to warm more than the mainstem when exposed to the higher solar radiation values available from June to September. They agreed the evidence indicated that the most important treatment managers could implement to benefit humpback chub was the warming of mainstem nearshore habitats; however, they emphasized the need to control predation and competition by nonnative fishes, since warming the water might promote the expansion of warmwater nonnative fishes as well.

Nearshore habitats are usually located between the margin of the mainstem current and the shoreline and are typically characterized by low water velocities (compared to the mainstem) and reduced turbulent mixing. Nearshore habitats generally include low-angle sandy shorelines, talus slopes, tributary mouths, and backwaters (usually associated with eddies).

The physical mechanisms controlling the development of nearshore habitats are relatively well known. For example, backwater environments are typically formed in eddy return-current channels and are partially isolated from mainstem flows by reattachment bars. Sediment mass balance and transport data suggest that stabilized dam releases may inhibit the daily fluctuation of these types of nearshore environments, resulting in increased potential for warming because of the lack of turbulent mixing with cold mainstem water.

While numerous empirical datasets indicate that some nearshore environments, especially backwaters, have the potential for warmer water temperatures than the mainstem (for example, Arizona Game and Fish Department, 1996; Korman and others, 2006; Kaplinski, 2006; W.S. Vernieu, U.S. Geological Survey, unpub. data, 2001), there are relatively few published studies that definitively link elevated nearshore water temperatures to steady flows. The Arizona Game and Fish Department (1996) showed that daily mean, minimum, maximum, and diel temperature ranges were significantly warmer under steady versus fluctuating flows at four backwater sites near the confluence of the Little Colorado River for a 7-day period in the summer of 1994. Korman and others (2006) showed similar warming patterns for three nearshore habitat sites during a 2-month period in fall 2004. Both of these studies, however, cautioned that the effects of steady versus fluctuating flows on nearshore water temperatures are highly variable and dependent upon several complex, interacting factors, such as the timing of maximum and minimum flows, backwater morphology, and ambient meteorological conditions. Additionally, recent thermal modeling studies by the GCMRC suggest that release volumes may play a more substantial role in mainstem warming than daily flow regimes (Anderson and Wright, in press).

To maximize benefit to native fishes, low-volume releases during the summer months would provide the highest available mainstem temperatures (Anderson and Wright, in press). In turn, low-volume, steady releases would hypothetically yield warmer nearshore water temperatures. Given the volumetric constraints imposed by water law and the current state of knowledge on nearshore habitat morphology and resultant thermal dynamics, the most readily available tool to stabilize the presence and persistence of nearshore habitats and, thus, enhance warming in those environments during the summer months is the release of steady flows from Glen Canyon Dam.

The timing of desired temperature increases was discussed extensively. If the primary goal is to promote humpback chub spawning in the mainstem and increased larval survival in the mainstem, then efforts to increase mainstem temperatures should be initiated in June. If the goal is limited to promoting survival and growth of fish produced in the Little Colorado River that are transported into the mainstem of the Colorado River by late summer monsoon rain events, then efforts to increase mainstem temperatures should be initiated in August. Downstream and nearshore warming also requires elevated air temperatures, so reduced flows in late fall (that is, past about mid-October) would not be expected to increase water temperature. Workshop participants emphasized the need for an aggressive monitoring and control program for nonnative fishes that could benefit from warmer water, a point also made by previous review panels (Mueller and others, 1999; Garrett and others, 2003).

## Fluctuating Releases

There was little discussion of the effect of increased, load-following flow fluctuations during nonsummer months on native fish. Participants recognized that there are few, if any, data that suggest that existing fluctuations during nonsummer months were adversely impacting native fish. At the same time, they believed that greater fluctuations were also unlikely to provide any benefit for native fish. These conversations took place in the context of seeking to balance biological and financial considerations, because fluctuating releases are used to generate hydropower. However, there are scant data available for a definitive conclusion that nonsummer fluctuating flows have no ill effects on native fishes in Grand Canyon, and so additional investigation would be needed before it could be accepted as true. Although the youngest humpback chub are 6 months old or older in the winter, and so have some swimming ability, winter can be a sensitive season for organisms as they attempt to survive adverse conditions and limited food resources. Overwinter survival is a primary factor determining year-class strength for most temperate fishes (Garvey and others, 1998). Small changes in growth or mortality have been shown to have important impacts on population recruitment in fishes (Houde, 1987). Haines and others (1998) showed that Colorado pikeminnow (*Ptychocheilus lucius*) survival was much reduced in a year with high, fluctuating winter releases from Flaming Gorge Dam on the Green River, compared to more stable years. Therefore, in the absence of more data, it would be premature to conclude that high, fluctuating releases from Glen Canyon Dam during the winter months would have minimal impact on humpback chub and other native fishes.

## Beach/Habitat-Building Flows

BHBF tests, common to all of the SPG options, were also considered by workshop participants for rebuilding sandbars and related habitats throughout the river ecosystem. Given the information presented by sediment experts participating in the workshop and owing to the fact that testing of this flow treatment started early in the program in 1996, the participants acknowledged that the strategy for future BHBF testing and evaluation has evolved further than other experimental treatments such as steady flows or operation of a temperature control device. The sediment transport processes associated with using short-duration high flows to conserve sand, though complex, are easier to study and evaluate over short time periods, compared with treatments aimed at the conservation of humpback chub.

Participants found no evidence that two previous BHBF tests negatively impacted native fishes below the dam. They concluded that additional BHBF tests should occur following tributary sand enrichment, assuming they can be timed to minimize negative effects on native fishes. The tests should be further evaluated to determine whether or not they achieve sandbar rebuilding and maintenance in a sustainable manner. Participants debated the presumed critical role for rearing of juvenile humpback of backwaters formed by sandbars along shorelines. The possible, though unproven, importance of shoreline habitats was acknowledged. Clearly, further research will be required to determine the extent to which sandbars and related habitats play a role in management of humpback chub.

BHBF tests may be of benefit to native fishes because high flows may displace or disrupt reproduction of nonnative fish species (Valdez and others, 2001). Springtime BHBF tests seem to hold promise for contributing to small-bodied nonnative fish control, and would not conflict with summer and fall flow optimization to benefit native fishes. Further experimentation would be needed to evaluate the efficacy of this potential management tool.

Use of steady flow tests combined with sand-enriched BHBF tests was also thought to support the most favorable flow, temperature, and habitat objectives for humpback chub. The participants acknowledged that although this experimental sediment strategy was likely to benefit downstream sediment resources and promote rapid learning (both objectives of the LTEP EIS), it could also impose significant operating constraints for generating hydropower at the dam.

## Nonflow Treatments

### Temperature Control Device

Another approach that Reclamation is considering to improve river conditions for native fishes is the implementation of a temperature control device for Glen Canyon Dam. At least two previous scientific review panels have evaluated the potential benefits and risks of the temperature control device (Mueller and others, 1999; Garrett and others, 2003). Current designs call for modification of at least two intake structures on Glen Canyon Dam that would allow for the withdrawal of water from the reservoir at higher elevations than those currently available, especially during years in which the reservoir is relatively high. Water near the surface of the reservoir is exposed to increased solar radiation, especially during spring through fall, leading to increased warming of the releases (Vernieu and others, 2005). Current modeling results produced by the GCMRC indicate that water released through a temperature control device on Glen Canyon Dam could be expected to increase release temperatures about 5°C during the summer and fall months (Garrett and others, 2003; U.S. Geological Survey, 2006).

The participants supported construction and testing of a temperature control device with the following caveats: the TCD (1) should be designed to maximize warmwater releases and (2) must have the ability to release cool water, even in years when the reservoir elevation is relatively low. Maximizing release temperatures is important because the temperature targets in the Little Colorado River confluence are relatively cool and suboptimal for humpback chub reproduction and growth (Hamman, 1982; Clarkson and Childs, 2000), especially compared to the warmwater temperatures that humpback chub populations in the upper Colorado River Basin are exposed to during the brief summer season. The participants suggested that the proposed TCD must also have the flexibility to release cool water because reducing mainstem water temperatures could help to control the abundance of warmwater nonnative fishes.

The previous reviews of Mueller and others (1999) and Garrett and others (2003) emphasized that a TCD could increase existing risks to native fishes. Both reviews noted that warmer water was likely to favor not only nonnative fishes, but also invertebrate species, including introduced New Zealand mudsnail (*Potamopyrgus antipodarum*) and a range of fish parasites, including anchorworm (*Lernaea cyprinacea*) and Asian fish tapeworm (*Bothriocephalus acheilognathi*). The review by Mueller and others (1999) also anticipated the introduction of whirling disease (*Myxosoma cerebralis*) below Glen Canyon Dam. Whirling disease is caused by an organism that infects young rainbow trout and would benefit from warmer water temperatures. Arizona Game and Fish Department unpublished data indicate that whirling disease has now been found in very low concentrations below the Dam. Workshop participants recommended BHBF tests and releases of cool water as tools that might control infestation rates from these organisms as well as nonnative fish populations.

## Sediment Augmentation

Recent studies by Randle and others (2007) determined that importing fine sediment into the CRE from source areas upstream of Glen Canyon Dam is technically feasible using existing technologies. However, the practicality of sediment augmentation remains uncertain owing to factors such as environmental concerns and costs for the construction and operation of a sediment delivery system. Given time limitations, there were no substantive discussions about how a sediment delivery system could be included in future experimental programs. Sediment scientists at the workshop recommended determining whether the BHBF (flow-only) strategy was viable before developing experimental designs involving sediment augmentation. The biological implications associated with importation of silt and clay to manage elevated turbidity in the mainstem (presumably to disadvantage sight predators and thereby benefit juvenile native fishes) were not discussed during the workshop.

## Nonnative Fishes Control

All of the Science Planning Group's experimental options include nonnative fish control. The motivation for limiting the population size of nonnative fish below Lees Ferry comes from experience in other parts of the Colorado River, where native fish have suffered severe declines after the introduction and proliferation of nonnative fish species (Minckley and Deacon, 1991; Lentsch and others, 1996). The participants discussed several case studies, including the recent and dramatic shift from natives to nonnatives in the Green and Yampa Rivers (Bestgen and others, 2006; 2007), as justification for doing everything practical to control nonnative fishes in the Colorado River ecosystem.

Although nonnative fish removal between 2003 and 2006 reduced salmonid abundance, especially rainbow trout (U.S. Geological Survey, unpub. data, 2007), scientists have not determined whether this benefited native fish. However, on the basis of the participants' knowledge of other ecosystems, they suggested that managers should continue to suppress nonnative fish abundance (coldwater and warmwater species) in the future rather than allow their numbers to increase.

The participants explored the value of conducting an experiment to determine which factor—the presence of nonnatives or water temperatures—was most likely to limit native fish population expansion. For example, the active removal of nonnative fishes could be stopped, allowing nonnative fish populations to increase, while water temperatures increased because of low reservoir levels, thereby providing a contrast to the 2003–06 period of experimental mechanical removal when both warmer water and nonnative removal were the "treatments." The participants determined that allowing an increase in the population size of rainbow trout in the Little Colorado reach for the purpose of experimentation would be inconsistent with the goal of increasing the humpback chub population in Grand Canyon (that is, the LTEP EIS purpose and need that call for benefits to downstream resources). In this instance, they determined that resource conservation should take priority over scientific learning. Control of nonnatives has proven difficult in many cases (Minckley and Deacon, 1991; Bestgen and others, 2007) and given the current threats to humpback chub, the participants concluded that the best course of action was to continue to suppress rainbow trout and other nonnative fish, especially in the vicinity of the Little Colorado River. Nonnative fish control in the Little Colorado River and at its confluence at the mainstem must be considered a priority because of the critical importance of the tributary for humpback chub and because of the numbers and diversity of nonnative species present there (Stone and others, 2007).

Similarly, the participants determined that the risk to the humpback chub population posed by warmwater nonnative fishes would grow if increased water temperatures were to continue, whether as a result of below-average basin hydrology, a TCD, or both. They noted that it will be important to increase monitoring of the abundance of these species, which will also help inform scientists and managers regarding effective control measures (for example, appropriate gear, timing of monitoring and removal). Consistent with their discussions regarding rainbow trout, the participants agreed that early, consistent monitoring and control of nonnative species is critical because reactionary control efforts initiated after nonnative species have proliferated often have limited or no success (Bestgen and others, 2007).

The participants observed that control of fish adapted to cold water, such as rainbow trout, will likely be easier than controlling warmwater nonnative fish, because the latter, as a group, have greater capacity for explosive population growth when favorable conditions exist. Warmwater nonnative fishes also have higher potential for habitat overlap with warmwater native fishes, and so they pose a greater risk to natives than coldwater species. The risks from warmwater species expansions are formidable and warrant a high level of attention in order to support native fish conservation in Grand Canyon. The participants observed that nonnative fish control will have to include tributary populations if there is to be any reasonable hope of success.

## Humpback Chub Second Population and Translocation

The participants discussed possible alternatives for spawning locations, such as other Grand Canyon tributaries, and the associated impact to the entire population of transferring some individuals. They agreed that the best option to pursue was the mainstem Colorado River. While translocating young humpback chub from the Little Colorado River to other tributaries (for example, Shinumo Creek) may be successful in supporting some reproduction and growth, the size and length of these streams suggest that they could only support a population of a few hundred fish (Valdez and others, 2000). The existence of one or more of these populations certainly decreases the risk of catastrophic loss; however, multiple small populations would be required to maintain the numbers of fish needed to preserve genetic integrity (U.S. Fish and Wildlife Service, 2002). Current recovery goals for humpback chub recommend that individual populations consist of at least 2,100 individuals to maintain a minimum level of genetic diversity within each population (U.S. Fish and Wildlife Service, 2002). A review of some of the available scientific literature on the subject finds widely varying estimates of the population numbers (from dozens to thousands of individuals) necessary to maintain genetic diversity in wild vertebrate populations (Franklin and Soulé, 1981; Gilpin and Soulé, 1986; Haig and Avise, 1996; Reed and others, 2003).

Grand Canyon National Park is proposing to move approximately 300 young-of-year humpback chub from the Little Colorado River to Shinumo Creek (fig. 1; M. Hahn, Grand Canyon National Park, oral commun., 2007). The workshop participants generally agreed that such translocations were unlikely to cause any important confounding of humpback chub monitoring or population modeling. Further, they concluded that such translocations could support expansion of the humpback chub population, and that the best available review of this topic is the work of Valdez and others (2000), which serves as an informed starting point for managers who may wish to conduct translocations as a conservation action.

### Humpback Chub Refuge

The establishment of one or more offsite refuges for humpback chub was not discussed by the participants owing to time constraints. However, the participants did discuss the value of laboratory studies for contributing to our understanding of the effects of various physical parameters, especially temperature, on humpback chub. The establishment of a refuge population of humpback chub that was able to successfully spawn could supply the fish needed to support such laboratory experiments.

### Increased Mainstem Water Temperatures

The participants determined that warmer mainstem water temperatures could encourage (1) growth of humpback chub hatched and reared in the Little Colorado River and (2) increased humpback chub spawning and rearing in the mainstem. These two different life-history stages are temporally distinct, and therefore the timing of warmer water releases would affect whether one or both of the two life-history stages are supported by warmer dam releases.

Humpback chub hatched and reared in the Little Colorado River spend from 1 to 16 months residing in this tributary before they are washed by high flows into the mainstem Colorado River (Valdez and Ryel, 1995). The high flows that transport these young fish out of the tributary occur between July and September in most years (Robinson and others, 1998). The participants agreed that the thermal shock of being washed from the relatively warm Little Colorado River into the colder Colorado River may reduce humpback chub survival in the mainstem (Clarkson and Childs, 2000). Therefore, survival of these young fish produced in the Little Colorado River may be enhanced by warming mainstem water temperatures between July and September.

The participants noted that the goal of increased spawning of humpback chub in the mainstem Colorado River is consistent with the 1995 biological opinion on the operation of Glen Canyon Dam (U.S. Fish and Wildlife Service, 1995) and the 1995 environmental impact statement (U.S. Department of the Interior, 1995). Participants agreed that temperature was the most important physical parameter to be addressed to increase mainstem spawning. Warmer mainstem temperatures greater than 18°C (Hamman, 1982) as early as May or June would likely promote mainstem spawning. However, it is unlikely that humpback chub would engage in large-scale mainstem spawning with a single year of warmer temperatures. It is more likely that they would gradually increase spawning as increasing numbers survived to maturity and were able to locate suitable habitats. Mainstem temperatures would need to be warm enough to allow feeding to support growth and maintenance of body size as well as warm enough to stimulate the maturation of gonads, a necessary precursor to successful spawning.

As discussed above, warmer temperatures would also favor expansion of nonnative fish species (Moyle and Light, 1996). A TCD at Glen Canyon Dam that allows for the release of cooler water may inhibit the proliferation of warmwater nonnative fish. Effective nonnative fish monitoring to detect changes in distribution or abundance and a control program for nonnative fishes are essential. These measures were all recommended by workshop participants.

# Workshop Outcomes

## Environmental Triggers Approach

The experimental research design developed to be consistent with the stated purpose and need of the LTEP EIS included the use of environmental cues, or triggers, to determine management actions. Specifically, workshop participants recommended the continued evaluation of the current flow regimes and associated resource responses in water years 2007 and 2008. By 2009, additional data would be available on the effects on humpback chub and sand resources of flow and nonflow treatments implemented between 2003 and 2008. The flow and nonflow treatments implemented during this period included (1) mechanical removal of nonnative trout within treatment and control reaches, which resulted in a 90 percent decrease of trout in the treatment reach, (2) at least five consecutive summers (2003–07) of dam releases that were warmer than average releases from 1988 through 2002, (3) testing during three consecutive years of larger winter fluctuating flows, (4) consistent release of modified low fluctuating flows (Record of Decision operations) under minimum hydrologic conditions during spring through fall, and (5) a fall 2004 test of the beach/habitat-building flows under moderately enriched sand supply conditions.

The environmental triggers approach also included a recommendation for the construction and testing of a temperature control device at Glen Canyon Dam not only to benefit humpback chub (warm releases), but also to suppress expansion of warmwater nonnative fishes (cool releases) during periods of drought when warm releases would otherwise be unavoidable. The participants suggested that by 2013 the TCD could either be operated to continue warmer releases (in the event that the reservoir has refilled) or provide cooler releases.

From 2009 through 2012, the participants recommended testing summer and fall steady releases from the dam for anticipated benefits to native fish. Steady flows might warm nearshore habitats, which are hypothesized to be beneficial for survival of young humpback chub in the mainstem. Steady flows were also identified as a potential means of mitigating the effects of cooler releases in the absence of the TCD. Blocks of treatments lasting four or more consecutive years were recommended to test responses in all resources, especially in humpback chub, because this species matures on average at 4 years of age. Implementing treatments in 4-year blocks also provides researchers with opportunities to evaluate reproduction and age-1 year-class strength for several years. The environmental triggers approach is summarized in table 2 and figure 2, which illustrate one example of the timeline and decision points that would be used under the environmental trigger approach.

An important element of the environmental triggers approach requires the specification of desired future conditions, or measurable targets, for humpback chub, sediment, archaeological sites, camping beaches, and other resources of interest to managers. Explicit targets will provide the needed reference points for evaluating the effectiveness of treatments and the need to implement additional treatments. Accurate monitoring data to assess the status of native and nonnative fish, sediment, and other important resources were also critical elements of this strategy.

The participants discussed the ability of the environmental triggers approach to definitely answer the core science questions that were developed and prioritized by the managers (table 1). The consensus of the participants was that to fully answer the questions, particularly biological questions, would be complicated and could be impossible in the 10-year timeframe of the LTEP EIS. Participants reached this conclusion because of factors that may confound the interpretation of experimental studies, including large hydrologic variability of the upper Colorado River Basin, continued introductions of nonnative species, and climate change. Despite such problems, the scientists encouraged managers to develop the desired future conditions and pursue an adaptive management strategy as the most viable approach for providing resource benefits and learning.

The participants discussed the environmental triggers approach with managers after the workshop during a teleconference meeting on April 26, 2007, and through e-mail correspondence. The teleconference discussion between workshop participants and managers is summarized in appendix C.

**Table 2.** Timeline with contingencies for environmental triggers and experimental approach.

| **Interim Phase, 2007–08: Continued evaluation of resource responses to modified low fluctuating flow (MLFF)** |
|---|
| Continue modified low fluctuating flow operations: Monitor native and nonnative fish, sediment, and other relevant resource data, and compare changes relative to baseline data from Record of Decision operations collected from 1991 through 2002. Compare the resource status with desired future conditions (DFCs) to determine Phase I treatments. |
| **Phase I, 2009–12: Evaluate steady versus fluctuating flows** |
| 1a. Continue MLFF operations: If target resources (humpback chub, sediment, etc.) are meeting DFCs, continue MLFF operations. Maintain monitoring and control for nonnative fishes. Discontinue MLFF operations if declines in target resources are identified. |
| 1b. Test summer steady flows: If DFCs for sediment and humpback chub resources are not met, implement steady flows in summer months (June–August), to test anticipated benefits of warming, especially in nearshore habitats, and sediment retention. |
| **Phase II, 2013–16: Temperature control device (TCD) operational** |
| 2a. Test warm TCD releases: Use a TCD to warm release temperatures if humpback chub are in decline. Emphasize warm, steady releases in June–August to encourage mainstem spawning, growth, and recruitment. TCD operation will be especially important in the event that basin hydrology returns to higher, colder dam releases. If warmwater nonnative species increase significantly above previously determined trigger levels, then implement cool releases. Cooling could be accomplished with a TCD that extracts water from the lower depths of the reservoir. If DFCs for humpback chub are not met, continue to operate TCD to warm mainstem water temperatures. Maintain monitoring and control for nonnative fishes. If DFCs are not met, consider implementation of additional flow and nonflow treatments to benefit humpback chub. |
| 2b. Test cool TCD releases: If by 2016 the humpback chub population is meeting DFCs, which are assumed to include mainstem reproduction, or if populations of nonnative fishes significantly increase in the mainstem, discontinue use of TCD and lower release temperatures to limit expansion of nonnative fishes, ideally increasing likelihood of new humpback chub cohort(s) recruiting to adult population. Implement nonnative fish control. |
| 2c. Relax flow restrictions and warm releases with TCD: If the humpback chub population begins to reproduce in the mainstem and nonnative fish populations are not considered a threat, relax flow restrictions somewhat to allow for hydropower load-following operations. Reinstate flow restrictions if mainstem humpback chub population begins to decline or undesirable decreases in other resources are detected as by ongoing monitoring activities. |

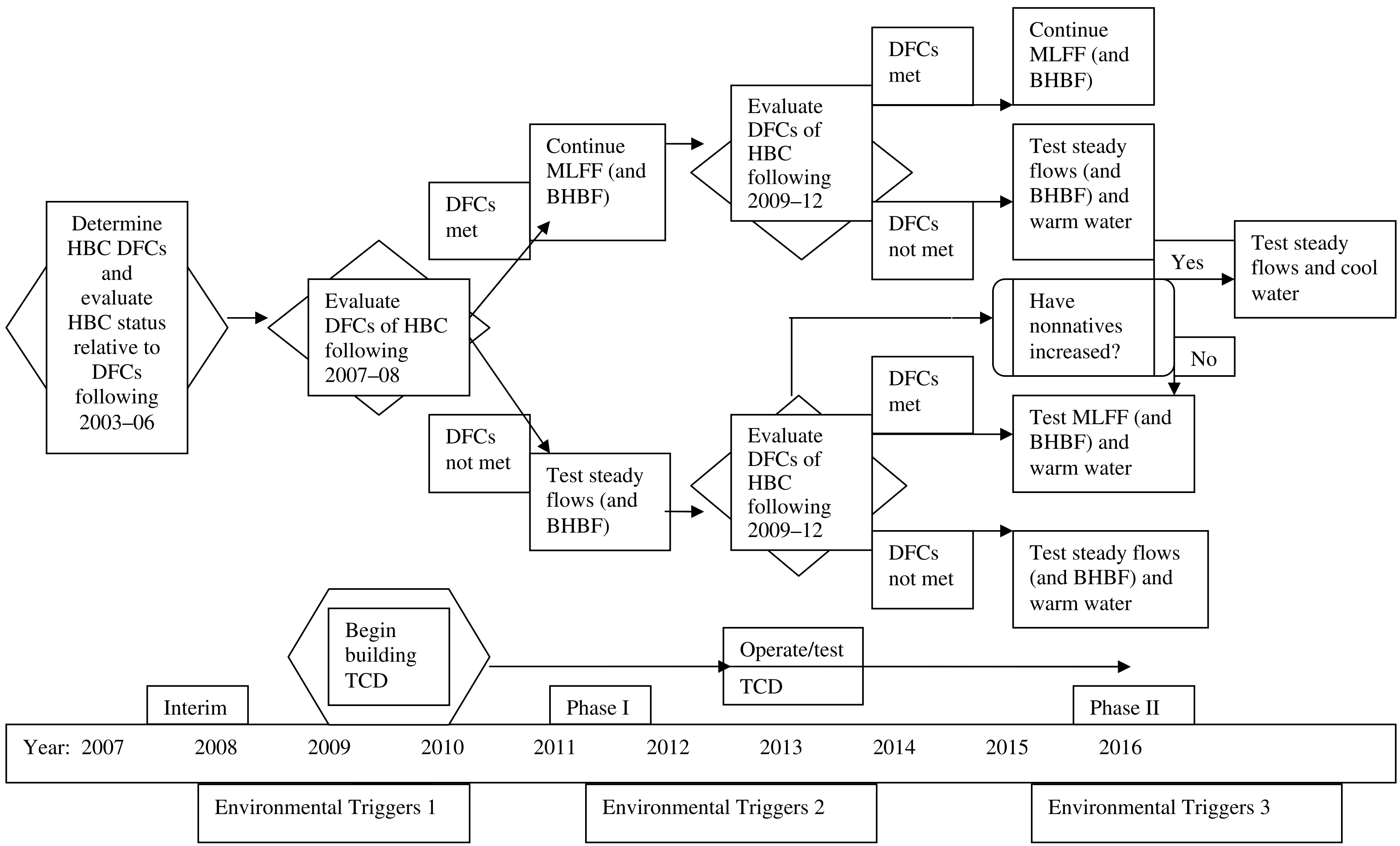


**Figure 2.** Simplified illustration of a decision tree based on humpback chub responses to treatments compared to humpback chub desired future conditions. DFCs are desired future conditions; BHBF is beach/habitat-building flows test; HBC is humpback chub; MLFF is modified low fluctuating flow; TCD is temperature control device.

## Comparison of Environmental Triggers Approach to Science Planning Group Options

The participants had insufficient time to fully evaluate all of the specific elements of the four experimental approaches (SPG options A, A′, B, and C, see below) that were developed by the GCDAMP Science Planning Group in 2005–06. However, participants suggested that managers consider further evaluation of the SPG options by comparing each of them to the environmental triggers approach developed during the workshop. Such comparisons may be useful for determining where overlap exists between the various options. One commonality among all four SPG options is that they depend on assessments of environmental criteria, much like the environmental triggers approach.

### SPG Option A and A′

The participants agreed that there were no specific data suggesting that increased fluctuations in winter and spring would be detrimental to humpback chub, although, as noted above (p. 23), overwinter habitat conditions are critical for many fishes. However, increased fluctuations at these times would promote more sediment transport and erosion of sandbars (Rubin and others, 2002; Wright and others, 2005). Because increased fluctuations in summer and fall are potentially a limiting influence on both nearshore warming and edge habitat stability, these fluctuations were hypothesized to be counter to the needs of humpback chub reproduction and rearing in the main channel. Steady flows were not identified as part of SPG option A and A', representing a major point of contrast with the environmental triggers approach, which provided for steady flows testing to benefit humpback chub and sediment conservation.

### SPG Option B

The participants partially concurred with the implementation of steady flows during the summer and fall seasons that were advocated in this option. The participants and reviewers of this document identified limited scientific justification for implementing and testing steady flows in winter and spring to promote the early life-history needs of native fish, but there are very limited data on this subject in Grand Canyon. Sediment would be conserved during extended periods of steady flows, compared with other SPG options or the environmental triggers approach. The sediment experts in the workshop stated that steady flows throughout the year would produce the most learning and benefit for sediment resources and would likely be achieved in the shortest amount of time.

### SPG Option C

The participants determined that the timing of steady flows proposed in this option—during September and October—would provide stable habitat and possible warming only for a short portion of the early life history of juvenile humpback chub. There was wide agreement that SPG option C would provide greater benefit to humpback chub if it included steady flow tests earlier in the summer, such as in June or perhaps mid-July through October. A possible environmental trigger for steady flows during the month of August is included in this alternative, but the criteria for such an operational decision had not yet been identified by managers.

### Treatment Elements Common to the Environmental Triggers and SPG Options

All of the SPG experimental options included the testing of a temperature control device, which would presumably entail retrofitting of at least two of the eight Glen Canyon Dam units. However, details about how the TCD would be designed and tested were not clearly articulated in the SPG options. Owing to time limitations, workshop participants were not able to identify a detailed approach for long-term testing and evaluation of a TCD.

Mechanical removal of nonnative fish is a common element included in all the options, including the environmental triggers approach. The workshop participants concluded that some advantage would be gained through continued mechanical control of nonnative fishes; although, they noted that the control of warmwater species is likely to be much more difficult than the relatively successful mechanical removal of salmonids.

Continued BHBF testing was common to all the options, including the environmental triggers approach, as a means of rebuilding sandbars and related habitats throughout the river ecosystem. Because BHBF tests have been conducted since 1996, the strategy for future BHBF testing and evaluation is further evolved than other experimental treatments such as steady flows or operation of a temperature control device.

## Conclusions

The purpose of the LTEP EIS is to increase scientific understanding and protect important resources in the Colorado River ecosystem downstream of Glen Canyon Dam. Workshop participants identified a variety of treatments and an experimental approach that meets the purpose and need of the LTEP EIS. Their conclusions are supported by the best available science and years of professional experience studying the Colorado River and other regulated North American rivers. Many of their conclusions were consistent with two previous scientific reviews of a proposed temperature control device. Elements of the recommended approach, many of which were identified in one or more of the four options developed by the GCDAMP Science Planning Group, include

1. releasing steady flows from Glen Canyon Dam, which is the most readily available tool to enhance warming in nearshore environments during the summer months;
2. implementing periodic beach/habitat-building flows during sand-enriched conditions following tributary flooding;
3. building and testing a temperature control device that can both increase and decrease water temperatures according to need as indicated by monitoring of aquatic organisms (Warmer water is likely to benefit humpback chub spawning and recruitment in the mainstem and cooler water could be used to disadvantage nonnative fish, nonnative invertebrates, and fish parasites.);

4. continuing mechanical removal of both coldwater and warmwater nonnative fish near the confluence of the Little Colorado and Colorado Rivers; and
5. translocating humpback chub from the Little Colorado River to other Grand Canyon tributaries with suitable habitat.

The participants recognized that the Colorado River ecosystem below Glen Canyon Dam is a large, complex environment that is difficult to study and understand. However, they believe a great deal of information is available to inform future management decisions related to the operation of Glen Canyon Dam. Existing knowledge—particularly with regard to humpback chub and sediment transport—is sufficient to propose an approach supporting the purpose and need of the LTEP EIS, that is, the environmental triggers approach.

The environmental triggers approach relies on measurable resource goals as the basis for determining the experimental treatments that should be implemented. Currently, measurable resource goals and clear criteria for meeting goals are not available for CRE resources. However, participants asserted that such measurable goals are needed for managers to determine whether or when to test summer steady flows, for example. The use of environmental triggers to initiate management treatments is common to all SPG experimental options. Similar criteria would presumably need to be determined in advance of any of the other SPG options that promote either steady flow or TCD tests. The participants agreed that they may be able to assist managers with an evaluation of the status of various resources, but insisted that it was not appropriate for scientists to define triggering criteria that would be fundamentally tied to nonscientific values and resource management objectives for the ecosystem. Ultimately, the specific environmental triggering criteria will be up to managers to determine, presumably on the basis of desired future conditions for downstream resources.

The environmental triggers approach calls for the continued evaluation of flow regimes for water years 2007 and 2008. Continuing treatments would provide data on the effects on humpback chub of flow and nonflow treatments implemented between 2003 and 2008. Following assessment of ongoing treatments, the environmental triggers approach proposes 4 years (2009–12) of summer–fall steady flows testing, if resource goals for humpback chub and sediment have not been reached as the result of current operations. From 2013–16, the approach recommends testing of a temperature control device capable of releasing both warm and cool water. The participants were very concerned about the potential for the expansion of species adapted to warm water and strongly recommended increasing monitoring efforts for these species, echoing the concerns of previous scientific review panels (Mueller and others, 1999; Garrett and others, 2003). Participants agreed that early, consistent monitoring and control of nonnative species is critical to successful nonnative fish management. If humpback chub begin to reproduce in the mainstem and nonnative fishes are not considered a threat, the approach calls for some relaxation of flow restrictions to allow for hydropower load-following operations. However, the impact of winter fluctuations on native fishes is little studied in Grand Canyon, and managers should not assume that they would have no impact on native fishes.

Two days of deliberations were insufficient for all resources to be fully considered, so the workshop participants focused, at Reclamation's request, on humpback chub and sediment. Flow recommendations for Glen Canyon Dam must take into account a complex suite of natural, social, economic, and political factors. Compounding this complexity is the likelihood that the Colorado River Basin will be experiencing higher than historical temperatures and lower than historical runoff in the years and decades to come (Seager and others, 2007), which would affect its capacity to serve all needs and values. Any long-term planning should take the warmer, drier forecast into account. The participants focused on natural concerns; full consideration of societal values was beyond the scope of the workshop. Further consideration should be given to how the approach could be modified to consider other resources, including hydropower production. The participants expressed the hope that the insights resulting from the workshop will inform future experimentation in the Glen Canyon Dam Adaptive Management Program.

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# Appendix A. Workshop Participants and Attendees

## Workshop Participants

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**Mike Bradford, Ph.D.**, Research Scientist, Freshwater Ecosystems Section, Fisheries and Oceans Canada, Cooperative Resource Management Institute based at Simon Fraser University, Canada

**Lewis G. Coggins, Jr.**, Fishery Biologist, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

**David L. Garrett, Ph.D.**, Executive Director of Glen Canyon Dam Adaptive Management Program Science Advisors, M3 Research

**Theodore A. Kennedy, Ph.D.**, Aquatic Ecologist, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

**Theodore S. Melis, Ph.D.**, Physical Scientist, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

**Randall Peterson**, Environmental Resources Division Manager, Upper Colorado Region, Bureau of Reclamation

**William E. Pine III, Ph.D.**, Assistant Professor, Department of Fisheries and Aquatic Sciences, University of Florida

**Roger Pulwarty, Ph.D.,** Director, National Integrated Drought Information System Physical Scientist (Climatologist), National Oceanic and Atmospheric Administration, Physical Sciences Division

**Dale M. Robertson, Ph.D.**, Research Hydrologist, Wisconsin Water Science Center; Glen Canyon Dam Adaptive Management Program Science Advisor

**David J. Topping, Ph.D.**, Research Hydrologist, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

**Harold M. Tyus, Ph.D.,** Senior Research Associate, Center for Limnology, Cooperative Institute for Research in Environmental Studies, University of Colorado; Glen Canyon Dam Adaptive Management Program Science Advisor

**Richard A. Valdez, Ph.D.**, Senior Aquatic Biologist, SWCA Environmental Consultants

**Carl Walters, Ph.D.**, Professor, Fisheries Centre, University of British Columbia

**Scott A. Wright, Ph.D.**, Research Hydrologist, U.S. Geological Survey, California Water Science Center

## GCMRC Scientists and Cooperating Scientists in Attendance

Matthew E. Andersen, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

Craig Anderson, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

Glenn Bennett, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

Amy Draut, Ph.D., U.S. Geological Survey, Marine Geology Team.

Helen C. Fairley, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

A. Elizabeth Fuller, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

Dan Gwinn, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

John F. Hamill, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

Josh Korman (Workshop Facilitator), Ecometric Research, Inc., Vancouver, British Columbia, Canada.

David Rubin, Ph.D., U.S. Geological Survey, Marine Geology Team.

William S. Vernieu, U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

## LTEP EIS Cooperators and other Interested Parties in Attendance

Jan Balsom, Grand Canyon National Park.

Charley Bulletts, Southern Piaute Consortium.

Kelly Burke, Grand Canyon Wildlands Council.

Wayne Cook, Western Area Power Administration.

Cole Crocker-Bedford, Grand Canyon National Park.

Norman Henderson, National Park Service.

Leslie James, Colorado River Energy Distributors Association.

Rick Johnson, Grand Canyon Trust.

Glen Knowles, U.S. Fish and Wildlife Service.

Dennis Kubly, Bureau of Reclamation.

Andrew Markinster, Arizona Game and Fish Department.

Steve Martin, Grand Canyon National Park.

Ken McMullen, Grand Canyon National Park.

Don Ostler, Upper Colorado River Commission.

Clayton Palmer, Western Area Power Administration.

Heather Patno, Bureau of Reclamation.

R. Scott Rogers, Arizona Game and Fish Department.

Tom Ryan, Bureau of Reclamation.

Sam Spiller, U.S. Fish and Wildlife Service.

Mark Steffen, Federation of Flyfishers.

Bill Werner, Arizona Department of Water Resources.

Mike Yeatts, Hopi Tribe.

# Appendix B. Flow and Nonflow Treatments Associated with Various Experimental Science Planning Group Options and Environmental Triggers Approach.

Summary matrix of flow and nonflow treatments that scientists and managers have identified as possible elements of Glen Canyon long-term experimental strategies

| Flow or nonflow treatment | Treatment description | Potential range of variable | Workshop environmental triggers strategy[1] | Science Planning Group option A | Science Planning Group option A variation | Science Planning Group option B | Science Planning Group option C |
|---|---|---|---|---|---|---|---|
| Flow | Increased daily flow fluctuations | No flow fluctuations to 20,000 cfs/day | No | Yes (increased by 50 to 66% in winter months and by 25% in summer months) | Yes (increased by 25 to 66% in all months except April and May) | No | Yes (increased by 50 to 66% in winter months) |
| Flow | Stable flows | Stable flows from 0 to 12 months/year | Yes, either (a) Jun. 1, or (b) Jul. 15 through mid-Oct. (2009–12)[2] | No | No | Yes, (tests of 4, 8, and 12 months) | Yes (Sept. through Oct.) |
| Flow | Beach/habit at-building flows | BHBF frequency between 1-time test and every year | Yes, winter/spring under sand triggering[3] | Yes, as tests under sand triggering | Yes, as tests under sediment input triggering | Yes, as tests under sand triggering | Yes, as tests under sand triggering |
| Flow | Alternative ramping rates | Ramping rates from 0 cfs/hr (steady flow) to 5,000 cfs/hr | No[4] | Yes (hourly downramping rate increased 100% in all months) | Yes (hourly downramping rate increased 100% in Apr.–Oct. and 167% in Nov.–Mar.) | No | Yes (hourly downramping rate increased by 100% in Nov–Jul only) |
| Nonflow | Temperature control device | TCD construction, with releases from 9–22 °C | Yes[5] | Yes | Yes | Yes | Yes, two units assumed |

| **Flow or nonflow treatment** | **Treatment description** | **Potential range of variable** | **Workshop environmental triggers strategy**[1] | **Science Planning Group option A** | **Science Planning Group option A variation** | **Science Planning Group option B** | **Science Planning Group option C** |
|---|---|---|---|---|---|---|---|
| Nonflow | Control of nonnative coldwater fish | Reduction of nonnative coldwater fish from 0 to ~ 95% | Yes, ongoing and within control reach | Yes, as needed | Yes, as needed | Yes, as needed | Yes |
| Nonflow | Control of nonnative warmwater fish | Control of nonnative warmwater fish from 0 to unknown level of reduction | Yes, with enhanced monitoring and to the degree determined possible[6] | Yes, as needed, with R&D starting in 2007 | Yes, as needed, with R&D starting in 2007 | Yes, as needed, with R&D starting in 2007 | Yes, with R&D starting in 2007 |
| Nonflow | Humpback chub disease/parasite research | Unknown | Yes | Yes | Yes | Yes | Yes, with R&D starting 2008 |
| Nonflow | Humpback chub translocation | Translocation from 0 to 5 tributaries | Yes[7] | Yes | Yes | No | Yes[8] |
| Nonflow | Humpback chub refuge(s) | Use of 0 to 2 refuges | N/A | Yes | Yes | Possibly | Yes[8] |
| Nonflow | Humpback chub population augmentation planning | Unknown | N/A[9] | Yes, planning efforts toward implementation, as needed | Yes, planning efforts and implementation | No | Yes, planning phase[8] |

| Flow or nonflow treatment | Treatment description | Potential range of variable | Workshop environmental triggers strategy[1] | Science Planning Group option A | Science Planning Group option A variation | Science Planning Group option B | Science Planning Group option C |
|---|---|---|---|---|---|---|---|
| Flow and nonflow | Mini-field experiments[10] | Unknown | No[11] | Yes | Possibly | Yes | Yes[8] |
| Experimental design | Factorial, reverse or forward titration | | Forward titration with min. 4-yr treatments | Reverse titration | Reverse titration | Factorial | Forward titration |

[1]Environmental triggers approach. This option was described as the best combination of learning and resource protection by the scientists participating in the April 2007 workshop. The participants noted a recent increase in chub recruitment that is coincident with warmer water temperatures resulting from lower Lake Powell elevations, and the mechanical predator removal program. The goal of this option is to continue some of the conditions thought to have lead to resource improvement while maintaining flexibility for uncertain future events. Some additional alternatives were discussed, but this summary represents what participants believe is the best alternative. The name is taken from the fact that the participants described an approach that is responsive to environmental changes. For example, if basin hydrology increased, increasing the level of Lake Powell and thereby lowering the release temperatures, the participants would favor responding to that variable by offering more steady flows beginning about the time of the summer solstice to favor humpback chub and other native fishes. Another example is that if multiple years of warmwater releases were observed to be favoring increases in warm water-adapted nonnative fishes, then the participants would recommend releasing cooler water. This is also the primary reason that they counseled that part of the TCD design effort include development of an engineering option that allows for releasing cooler water. In the latter case, one ecological trigger indicating this action would be an increase in warmwater nonnative fishes.

[2]The participants recommended that warmer temperature water be released to encourage survival, growth, and spawning of humpback chub. The timing of the warmer water was dependent on the resource response desired. If managers wish to encourage survival and growth of humpback chub hatched in the LCR, mainstem temperatures should be increased beginning about July 15, at the time that these fish are washed from the LCR into the mainstem during flooding events. If managers want to encourage mainstem spawning of humpback chub, mainstem warming would need to occur earlier, or about June 1. In the absence of a temperature control device, the primary means for warming the mainstem, at least in shallow nearshore habitats, is reducing flow fluctuations, so this treatment is recommended.

[3]The participants favored the use of beach/habitat-building flows as a tool both for conserving sediment and cultural resources, and also for creating shallower nearshore and backwater environments in the mainstem. The warmer water found in such habitats, especially after the summer solstice, was thought to be very beneficial to humpback chub, based on laboratory and field observations of this species. The overall significance of these habitats to humpback chub recruitment is currently unknown—especially in the case of LCR recruitment.

[4]The participants did not identify any ecological or scientific benefit, whether for learning or resource protection, associated with implementation of larger flow fluctuations relative to the core science questions provided by the managers.

[5]The participants thought that increased release temperatures provided by a TCD could be of great benefit to humpback chub. They also identified the importance of having a cool temperature release device as a component of the TCD. This importance is associated with the increased risk posed by

warmwater fishes as predators on and competitors with native fishes. If cool releases were available as a management tool, they could be valuable in the control of nonnative fishes.

[6]The participants found that the efforts to control rainbow trout and associated nonnatives (2003–06) had been relatively successful. They noted that continued suppression of nonnatives was warranted because this is a less expensive or risky alternative to letting this populations recover, as may be proposed for a full experimental option with block treatments. They were concerned, however, that control of warmwater nonnative fishes would be more difficult than control of coldwater nonnative fishes. To address this risk, the participants recommended increased efforts to monitor these species and to develop effective control methods, both of which will require appropriate gear types and protocols.

[7]In their discussions, the participants assumed that the National Park Service would proceed with translocation of humpback chub from the Little Colorado River to other tributaries in Grand Canyon National Park. The participants thought that this was a potentially useful effort for expanding the humpback chub distribution in Grand Canyon, thereby decreasing the risk from a catastrophic loss. The participants thought that humpback chub in one or more tributaries would support the Grand Canyon population by reducing the risk of catastrophic loss, but did not expect that a second spawning aggregation, as called for in the 1995 Biological Opinion, could be successfully established in a tributary alone. They thought that mainstem habitats would be necessary to expansion/establishment of a second Grand Canyon humpback chub spawning aggregation. Participants also expressed their belief that a TCD would likely be necessary to ensure long-term sustainability of a second spawning aggregation in the mainstem.

[8]For option C: Ancillary projects not considered part of the main experiment; implementation decision includes consideration of confounding the main experiment.

[9]The workshop participants did not specifically address the need for offchannel rearing and augmentation of humpback chub. They agreed with the current analysis that the Grand Canyon humpback chub population is generally stable at this time.

[10]Mini experiments are short-term field experiments that do not confound main experimental treatment effects. For option C: These experiments are considered undefined concepts and would be incorporated if defined and not in conflict with the main experiment.

[11]The workshop participants were wary of the results of tests conducted in the field for short periods of time (termed “mini field experiments”). They observed that antecedent conditions will be very important to organisms, so tests must be temporally separated to allow for comparable starting conditions. They also observed that humpback chub do not reproduce until approximately their fourth year of life and that the first 2 years of life may be particularly sensitive to environmental conditions, so it is important that experimental conditions thought to favor humpback chub be provided for four years or more to identify impacts to more than one year class of humpback chub. Alternatively, the invited science workshop participants spoke very favorably of the value of laboratory experiments as one tool to help resolve questions about the response of aquatic organisms to environmental conditions, including water temperature and habitat stability.

# Appendix C. Summary of Post-Workshop Telephone Conference Call (April 26, 2007)

It was clear at the end of the workshop that managers involved with developing the environmental impact statement for a long-term experimental plan of operation for Glen Canyon Dam would require more clarification from the participants about how the environmental triggers approach they proposed could be implemented. During a post-workshop teleconference between managers and scientists that took place on April 26, 2007, participants attempted to clarify their proposal by answering three questions about the triggers.

## Managers' triggering question 1—If (Lake Powell) reservoir releases continued to be warm after 2009, would participants still recommend steady flow tests during the summers of 2009–12 (presumably on the basis that such steady flows were designed to warm habitats)?

The participants recommended the continued evaluation in 2008 and 2009 of the biological responses of humpback chub to experimental treatments implemented in 2003–06, including mechanical removal of nonnative fishes and warming dam releases. The workshop participants and the USGS Grand Canyon Monitoring and Research Center are operating under the assumption that no flow-regimen changes can be implemented until 2009, given the constraints of the Annual Operating Plan, and environmental compliance activities (that is, compliance with the National Environmental Policy Act) that would have to accompany any changes. If this is correct, the first summer in which steady flows could be implemented is 2009. It was anticipated that the modified low fluctuating flow (MLFF) would be the continuing flow regime in the summers of 2007 and 2008. This was why the participants recommended initiation of a multiyear treatment of steady flow testing beginning in summer 2009. Steady flows were deemed to be a means of continuing downstream warming in nearshore habitats, if dam releases turned colder again without a temperature control device in place. However, steady flows under continued warm releases could be expected to provide further benefit for native fishes, while also providing a learning opportunity. For example, scientists could learn how much of a limiting factor the MLFF alternative had been (if at all) on humpback chub reproduction and rearing in the mainstem during the previous several years (2003–08), given the recent naturally warmer dam releases.

The summer releases of 2003–06 provided testing of the effects of warm releases with fluctuations (the MLFF release schedule), and, based on the constraints noted above, MLFF releases will likely continue in 2007 and 2008. The apparent resource responses to those conditions have been, and will continue to be, documented and evaluated annually by scientists. Managers will presumably assess these annual resource updates and compare responses to management objectives in making a recommendation by spring 2009 whether or not to implement a multiyear treatment of steady flow testing. There has been minimal testing of warm, steady flows, especially during the summer months, with the exception of the summer of 2000. The workshop participants observed that summer steady flow testing was likely to benefit both native fish and sediment conservation between at least July and October (and perhaps even more so starting in June). Steady flows that began in June could be expected to not only increase survival of humpback chub produced in the Little Colorado River, but also may encourage additional mainstem spawning and rearing. In short, a multiyear treatment of steady, warm summer flows has not been tested; these flows can be expected to provide resource benefits and learning opportunities, and the participants suggest that such flows be tested for a minimum of four consecutive years at the first available opportunity. This suggestion seems to be in line with the stated purpose and need of the long-term experimental plan (LTEP) environmental impact statement (EIS).

A return to fluctuating flows could also be warranted if nonnative fish monitoring indicates that warmwater nonnatives are increasing and likely to explode in abundance. Participants acknowledged that managers may be justified if they decided to forego steady flow testing in 2009 altogether under continued natural warmer releases—particularly if priority resources had responded in ways that had met their objectives between 2003 and 2008. Hence, a "stay the course" policy beyond 2008 may be appropriate on the basis of the adaptive management response to updated resource conditions, as determined through monitoring and modeling. The same approach could be used for sediment resources and steady flows. This approach is advocated by workshop participants as in keeping with the spirit of adaptive ecosystem assessment and management.

Obviously, value-based issues related to both resource benefit and learning must be considered in deciding to implement future steady flow tests over multiyear periods, and the participants did not believe they could provide further input on this topic without clearer articulation of resource objectives (desired future conditions) from the managers.

## Managers' triggering question 2—If the TCDs were not built and [Lake Powell] reservoir releases returned to colder temperatures in 2013, would the participants recommend continuing steady flows to warm humpback chub habitats or allow cool releases and MLFF as a contrasting treatment?

Cold dam releases with MLFF fluctuations were applied to the Colorado River ecosystem almost continuously between 1991 and 2002, with the exception of 2000, when the low summer steady flow test was implemented. Resource responses (especially relating to humpback chub and other native fish) were observed, recorded, evaluated, and published. If managers believed that replication of such operations carried out during this time (a period coincident with declining humpback chub population) would be of value—perhaps to document that such conditions do not favor humpback chub—then additional replicate testing of cold releases and MLFF may be warranted. The participants did not believe that managers would support such replication, believing instead that learning opportunities with this treatment appear limited. They spoke favorably of learning opportunities, but not to the detriment of resources, so participants generally agreed with a strategy for releasing steady summer and fall flows (to promote warmer nearshore habitats) to benefit humpback chub until warmer releases could be achieved through use of a TCD (a device that they strongly recommended be built and tested, but with the ability to release cooler water if naturally warm releases persisted under protracted drought).

The participants could not identify known detrimental effects to humpback chub from continued release of MLFF in late fall through early spring months, but saw no evidence that such diurnal fluctuations provided benefit to native fishes or other downstream resources, either. They did acknowledge that fluctuating flows are known to increase sediment losses from the ecosystem and may limit the effectiveness of future BHBF tests to rebuild and maintain sandbar habitats by depleting the system of sediment. The workshop participants emphasized the importance to native fishes, especially humpback chub, of warm water and so identified that steady summer to fall releases known to warm downstream, nearshore habitats would be particularly important to implement over multiple years as a test if the TCD were not built. They expressed little belief or hope that a second humpback chub spawning aggregation in the mainstem could be established or maintained without a TCD.

### Managers' triggering question 3—If humpback chub responses were positive during any of these block-type treatments, then would participants recommend continuing the treatment or changing the treatment as planned in the scientists' proposed schedule?

The workshop participants favored taking advantage of learning opportunities whenever possible, but not to the detriment of resources, especially the endangered humpback chub. They felt strongly that enough aspects of the fish's life history in Grand Canyon are known that some recommendations can be made. This seems to be an especially important consideration to observe until such time that humpback chub status meets or exceeds management objectives, which is yet to be fully documented. The participants noted that, in the presence of warmer water and control of nonnative fishes, the response of humpback chub was encouraging, although an increase of the population had not yet occurred, and the second spawning aggregation called for in the 1995 Biological Opinion had not yet been established. The workshop participants recognized the need for more specific management goals to direct scientific recommendations. As applied to this question, this means that a "positive" response is not quantified, and so a quantified response to the question is difficult to provide. However, if the block treatment approach can be implemented without negative impacts to the resources, then the learning that can be achieved is desirable. Participants also acknowledged that the much hoped for "cause-effect" answers that may be of critical interest to some managers may not be possible to produce in the complicated, noncontrolled experimental setting found in the Colorado River ecosystem.

A major recommendation from the workshop participants to managers was to do as much as possible in the near term to clearly identify (prior to experimentation) (1) desired future conditions (with an objective method for evaluating alternative management treatments), (2) models that will be used to evaluate ecosystem resource responses as new data become available (such as continued use of age structure mark-recapture estimates, but also other shorter term methods), and (3) a clear suite of proposed treatments along with definite limits on how they could be implemented and a rigorous monitoring program for providing managers with frequent resource updates (particularly for use in evaluating possible responses of warmwater nonnative fish under warmer and more stable habitat conditions, if tested). The participants also favored micro- and mesoscale experiments that would shed additional light on predator-prey interactions, and temperature, flow, and sediment effects on both native and nonnative species. Many of the inferences about the effects of the dam on humpback chub and other native species are from lab studies, and this mode of learning could be highlighted more strongly as an alternative if the goal of humpback chub conservation is to take precedence over ecosystem manipulation.

# Appendix D. Participants Abbreviated Curricula Vitae or Biographies

## Kevin Bestgen, Ph.D.

Director
Larval Fish Laboratory
Department of Fishery and Wildlife Biology
Colorado State University

### Education

Ph.D., 1997, Fishery and Wildlife Biology, Colorado State University
M.S., 1985, Fishery and Wildlife Biology, Colorado State University
B.A., 1981, Biology, Saint Cloud State University, Minnesota

### Current Research

Current research includes investigations of dispersal, survival, population abundance, and recruitment patterns of endangered cypriniform fishes in the Colorado River system. Other interests include effects of river regulation on aquatic biota, fish screening and passage evaluations, longitudinal gradient analysis of stream biota, stream fish community ecology, taxonomy and biology of larval fish, and long-term monitoring of stream fish communities. Most of my work is at the interface of ecology and management, particularly related to endangered fishes.

### Recent Publications

Bestgen, K.R., Zelasko, K. A., Compton, R. I., and Chart T., in press, Survival, condition, habitat use, and predation on stocked bonytail in the Green River, Colorado and Utah: Southwestern Naturalist.

Johnson, B.M., Martinez, P.J., Hawkins, J.A., and Bestgen, K.R., in press, Ranking relative predatory threats by nonnative fishes in the Yampa River, Colorado via bioenergetics modeling: North American Journal Fisheries Management.

Walford, C.D., and Bestgen K.R., in press, Establishment of Iowa darter Etheostoma exile in the Yampa River, Colorado: Southwestern Naturalist.

Olden, J.D., Poff, N.L., and Bestgen, K.R., 2008, Trait synergisms and the rarity, extirpation, and extinction risk of native fishes in the Lower Colorado River Basin: Ecology, v. 89, no. 3, p. 847–856.

Bestgen. K.R., 2008, Effects of water temperature on growth of razorback sucker larvae: Western North American Naturalist, v. 68, no. 1, p. 15–20.

**Michael James Bradford, Ph.D.**
Research Scientist
Freshwater Ecosystems Section, Fisheries and Oceans Canada
Cooperative Resource Management Institute, Simon Fraser University

## Education

Ph.D., 1991, McGill University, Montreal, QC
M.S., 1984, Biology, Simon Fraser University, Vancouver, B.C.
B.S., 1980, Biology, Simon Fraser University, Vancouver, B.C.

## Current Research

Current research activities include risk assessment and risk management frameworks for fish habitat management, effects of flow regulation on stream ecosystems and salmonid fishes, conservation of threatened salmon populations, and ecology of juvenile chinook salmon in the Fraser and Yukon Rivers.

## Recent Publications

Cleary, J.S., M.J. Bradford and D. Janz, in preparation, Seasonal and spatial variation in lipid and triacylglycerol levels in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from the Bridge River, British Columbia, Can. J . Fish. Aquat. Sci.

Bradford, M.J., von Finster, A., and Milligan, P., 2008, Life history, habitat, and the production of chinook salmon from the upper Yukon Basin, *in* C. Kruger and C Zimmerman, eds., Sustainability of the Arctic-Yukon-Kuskokwim salmon fisheries: Amer. Fish. Soc.

Bradford, M.J., and Heinonen, J.S., 2008, Low flows, instream flow needs and fish ecology: Canadian Water Resources Journal.

Decker, A.S., Bradford, M.J., and Higgins, P.S., 2008, Rate of biotic colonization following flow restoration below a diversion dam in the Bridge River, British Columbia. Rivers: Research and Management.

Bradford, M.J., Duncan, J., and Jang, J.W., 2008, Downstream migrations of juvenile salmon and other fishes in the upper Yukon River: Arctic.

## Lewis G. Coggins, Jr., Ph.D.

Fishery Biologist
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

### Education

Ph.D., 2008, Fisheries and Aquatic Science, University of Florida
M.S., 1997, Fisheries, University of Alaska, Fairbanks
B.S., 1990, Ecology and Evolutionary Biology, University of Arizona

### Current Research

Current research activities include design of experimental management policies and monitoring protocols that yield information on system behavior useful to inform successful management of fisheries, with particular interest in developing novel quantitative approaches to both predict and observe resource response to management actions.

### Recent Publications

Coggins, L.G., Jr., Catalano, M.J., Allen, M.S., Pine, W.E., III, and Walters, C.J., 2007, Effects of cryptic mortality and the hidden costs of using length limits in fishery management: Fish and Fisheries, v. 8, p. 196–210.

Coggins, L.G., Jr., Pine, W.E., III, Walters, C.J., and Martell, S.J.D., 2006, Age structured mark recapture analysis (ASMR): a VPA based model for analyzing age structured capture-recapture Data: North American Journal of Fisheries Management, v. 26, p. 201–205.

Coggins, L.G., Jr., Pine, W.E., III, Walters, C.J., Van Haverbeke, D.R., Ward, D., and Johnstone, H.C., 2006, Abundance trends and status of the Little Colorado River population of Humpback Chub: North American Journal of Fisheries Management, v. 26, p. 233–245.

Paukert, C.P., Coggins, L.G., Jr, and Flaccus, C.E., 2006, Distribution and movement of humpback chub in the Colorado River, Grand Canyon, based on recaptures: Transactions of the American Fisheries Society, v. 135, p. 539–544.

Yard, M.D., Bennett, G.E., Mietz, S.N., Coggins, L.G., Jr., Stevens, L.E., Hueftle, S., Blinn, D.W., 2005, Influence of topographic complexity on solar insolation estimates for the Colorado River, Grand Canyon, AZ: Ecological Modelling, v. 183, p. 157–172.

## David L. Garrett, Ph.D.

Executive Director, Glen Canyon Dam Adaptive Management Program Science Advisors
Principal, M3 Research

### Biography

Dr. Garrett's academic training is in biology, forestry, economics, and systems science. He has conducted and managed natural resource science programs in every major ecological region of the United States. As a U.S. Department of Agriculture scientist and science center leader, he began applying systems and management science approaches to forest restoration and wood energy programs in the Southeast, North Central, and New England regions.

During the last 25 years, he has focused on ecosystem approaches to forest resource management, forest restoration science, and riverine ecosystem restoration science and monitoring in the Rocky Mountain, Southwest, Pacific Northwest and Alaska regions. These efforts have included landscape-level terrestrial and riverine restoration assessments, improved restoration treatment methods and prescriptions, system models to evaluate restoration research and monitoring, restoration management applications for watersheds 5,000 to 30,000 acres in size, and applied science and management programs for terrestrial landscapes 100,000 to 200,000 acre in size and a variety riparian and riverine systems.

Dr. Garrett has focused on Southwest forest and riverine ecosystem restoration during the past 10 years. In 1996, he was requested by the Secretary of the Interior to work collaboratively with stakeholders and scientists to develop a management and science program that would advance understanding of downstream resource impacts stemming from the operation of Glen Canyon Dam. This effort resulted in the Glen Canyon Dam Adaptive Management Program.

As a dean at Northern Arizona University, Dr. Garrett developed the university's College of Ecosystem Science, where he worked with the faculty to create a wide range of programs to advance ecosystem approaches to forest and watershed riparian science and management. Programs in terrestrial and riparian restoration science and teaching continue to provide national leadership today.

During the last 5 years, as principal of M3 Research, a restoration science consulting firm, Dr. Garrett has focused on both forest and river restoration programs. He directs the Science Advisory Board that advises the Glen Canyon Dam Adaptive Management Program on science and management restoration programs in the Colorado River. Through M3 Research, Dr. Garrett works with county, State, and Federal leaders in New Mexico, Arizona and, Colorado on issues of forest and riparian-area restoration. Most recently, Dr. Garrett has completed forest restoration assessments on the Kiabab and Apache Sitgreaves National Forests, Ariz., and Lincoln National Forest, N. Mex.

Dr. Garrett has authored more than 100 science papers, reports, and models. As a consultant, he conducts research, workshops, lectures; he also contributes papers and reports on both terrestrial and riverine restoration programs and projects. He is actively involved at the State, regional, and national level on restoration programs.

**Theodore A. Kennedy, Ph.D.**
Aquatic Ecologist
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

## Education

Ph.D., 2002, Ecology, University of Minnesota
B.S., 1994 Ecology, California Polytechnic State University at San Luis Obispo

## Current Research

Current research involves the development of a research program on the aquatic food base that will clarify the role that food plays in determining the distribution, growth, and condition of fish in the Colorado River.

## Recent Publications

Kennedy, T.A., Finlay, J.C., and Hobbie, S.E., 2005, Eradication of invasive saltcedar (*Tamarix ramosissima*) along a desert springbrook increases native fish density: Ecological Applications, v.15, p. 2072–2083.

Kennedy, T.A., and Hobbie, S.E., 2004, Salt cedar invasion (*Tamarix ramosissima*) alters organic matter dynamics in a desert stream: Freshwater Biology, v. 49, p. 65–76.

Kennedy, T.A., Naeem, S., Howe, K.M., Knops, J.M.H., Tilman, D., Reich, P., 2002, Biodiversity as a barrier to ecological invasion: Nature, v. 417, p. 636–638.

Levine, J., Kennedy, T.A., and Naeem, S., 2002, Neighbourhood-scale effects of species diversity on biological invasions and their relation to community patterns, *in* Naeem, S., Loreau, M., and Inchausti, P., eds., Biodiversity and ecosystem functioning: syntheses and perspectives: Oxford University Press, p. 114–124.

Raffaelli, D., van der Putten, W.H., Persson, L., Wardle, D.A., Petchey, O.L., Koricheva, J., van der Heijden, M., Mikola, J., and Kennedy, T., 2002, Multi-trophic dynamics and ecosystem processes, *in* Naeem, S., Loreau, M., and Inchausti, P., eds., Biodiversity and ecosystem functioning: syntheses and perspectives: Oxford University Press, p. 147–154.

## Josh Korman—Workshop Facilitator

Systems Ecologist
Ecometric Research Inc.

### Education

Ph.D, in progress, Zoology, University of British Columbia, Vancouver, B.C.
M.S., 1989, Biological Oceanography, University of British Columbia, Vancouver, B.C.
B.S., 1984, Biology, McGill University, Montreal, Quebec

### Current Research

Current research activities include statistical analysis of environmental and fisheries data, development of computer simulation models for resource management, experimental design for environmental monitoring, fisheries stock assessment (analysis and field work), and development of decision support system software.

### Recent Publications

Korman, J., Melville, C.C., and Higgins, P.S., 2007, Integrating multiple sources of data on migratory timing and catchability to estimate escapement for steelhead trout (*Oncorhynchus mykiss*): Can. J. Fish. Aquat. Sci., v. 64, p. 1101–1115.

Korman, J., Wiele, S.M., and Torizzo, M., 2003, Modelling effects of discharge on habitat quality and dispersal of juvenile humpback chub (*Gila Cypha*) in the Colorado River, Grand Canyon: Riv. Res. Applic., v.12, p. 1–23.

Korman, J., Ahrens, R.N.M., Higgins, P.S., and Walters, C.J., 2002, Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (O*ncorhynchus mykiss*) derived from repeat mark-recapture experiments: Can. J. Fish. Aquat. Sci., v. 59, p. 1116–1131.

Korman, J., and Higgins, P.S., 1997, Utility of escapement time series data for monitoring the response of salmon populations to habitat alteration: Can. J. Fish. Aquat. Sci., v. 54, p. 2058–2097.

Korman, J., Peterman, R.M., and Walters, C.J., 1995, Empirical and theoretical analyses of time-series bias in stock-recruitment relationships of Sockeye salmon (*Oncorynchus nerka*): Can. J. Fish. Aquat. Sci., v. 52, p. 2174–2189.

## Theodore S. Melis, Ph.D.

Physical Scientist
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

### Education

Ph.D., 1997, Geosciences, University of Arizona
B.S. and M.S., 1990, Geology, Northern Arizona University

### Current Research

Current interests involve the design and implementation of scientific investigations associated with biology, physical, and cultural resource monitoring and research in support of the Glen Canyon Dam Adaptive Management Program.

### Recent Publications

Wright, S.A., Schmidt, J.C., Melis, T.S., Topping, D.J. and Rubin, D.M., in press, Is there enough sand? Evaluating the fate of Grand Canyon sandbars, GSA Today, Geological Society of America.

Melis, T.S., Topping, D.J., Rubin, D.M. and Wright, S.A., 2007, Research furthers conservation of Grand Canyon sandbars, U.S. Geological Survey Fact Sheet 2007-3020, 4p.

Rubin, D.M., Chezar, H., Harney, J.N., Topping, D.J., Melis, T.S., and Sherwood, C.R., 2006, Underwater microscope for measuring spatial and temporal changes in bed-sediment grain size: U.S. Geological Survey Open-File Report 2006–1360, http://pubs.usgs.gov/of/2006/1360/

Rubin, D.M., Chezar, H., Topping, D.J., Melis, T.S., and Harney, J., 2007, Two new approaches for measuring spatial and temporal changes in bed-sediment grain size: Sedimentary Geology, 7 p., doi: 10.1016/j.sedgeo.2007.03.020.

Rubin, D.M., Chezar, H., Harney, J.N., Topping, D.J., Melis, T.S., Sherwood, C.R., 2007, Underwater microscope for measuring spatial and temporal changes in bed-sediment grain size, Sedimentary Geology, doi: 10.1016/j.sedgeo.2007.03.020

## Randall Peterson

Environmental Resources Division Manager, Upper Colorado Region
Bureau of Reclamation

### Biography

Mr. Peterson graduated from the University of Utah in 1978 with a bachelor's degree in Civil Engineering. He has worked in the Department of the Interior with the Bureau of Reclamation for the past 30 years, working extensively on hydrologic estimations and risk-based decision making. For 15 years he led Reclamation's operation of the mainstem Upper Colorado River Basin reservoirs, including Glen Canyon Dam. He was instrumental in modifying the operation of Glen Canyon Dam following the flood years of the 1980s to reduce the frequency of uncontrolled flooding, and in the mid-1990s led the negotiation of an agreement between the Department of the Interior and the Colorado Basin States allowing the 1996 test of the Beach/Habitat Building Flow, the widely publicized spike flow from Glen Canyon Dam. He has co-chaired the Colorado River Management Work Group, a public involvement group which is involved in the operation of the entire Colorado River reservoir system, and served as program manager of the Glen Canyon Dam Adaptive Management Work Group, a science-based collaborative effort which seeks to protect the resources of the Grand Canyon while meeting the project purposes of the dam. He is currently the Upper Colorado regional office environmental resources division manager.

## William E. Pine III, Ph.D.

Assistant Professor
Department of Fisheries and Aquatic Sciences
University of Florida

### Education

Ph.D., 2003, Zoology, North Carolina State University, Raleigh, North Carolina
M.S., 1999, Fisheries Science, University of Florida, Gainesville, Florida
B.S., 1997, Fisheries Management, Auburn University, Auburn, Alabama

### Current Research

Primary research responsibilities are related to evaluating how riverine fish populations respond to modified flow regimes related to minimum flow and level regulations or to hydroelectric dam operations. Additional areas of research include developing new estimation techniques for evaluating trends in animal populations and estimating population vital rates.

### Recent Publications

Pine, W.E., III, Martell, S.J.D., Jensen, O.P., Walters, C.J., and Kitchell, J.F., submitted, Effects of post-release mortality of the efficacy of length limits and catch-and-release policies: a case study of blue, white, and striped marlin, Canadian Journal of Fisheries and Aquatic Sciences.

Pine, W.E., III, Martell, S.J.D., Walters, C.J., and Kitchell, J.F., submitted, Counterintuitive responses of fish populations to management: some common causes and implications for predictions based on ecosystem modeling, Fisheries.

Martell, S.J.D., Pine, W.E., III, and Walters, C.J., in press, Parameterizing age-structured models from a fisheries management perspective, Canadian Journal of Fisheries and Aquatic Sciences.

Coggins, L.G., Jr., Catalano, M.J., Allen, M.S., Pine, W.E., III, and Walters, C.J., 2007, Effects of cryptic mortality and the hidden costs of using length limits in fishery management, Fish and Fisheries, v. 9, p. 196–210.

Pollock, K.H., and Pine, W.E., III, 2007, The design of field studies to estimate catch and release mortality, Fisheries Ecology and Management, v.14, p.1–8.

## Roger Pulwarty, Ph.D.

Director, National Integrated Drought Information System
Physical Scientist (Climatologist), National Oceanic and Atmospheric Administration, Physical Sciences Division

### Education

Ph.D., 1994, Climate, University of Colorado, Boulder
BS, 1986, Atmospheric Sciences, York University

### Current Research

Climate impacts assessment, climate analysis, and applications research for adaptation and climate services development.

### Recent Publications

Pulwarty, R., and S. Cohen, 2007, Communicating scientific information: Moving within and beyond climate impact assessments: Global Environmental Change.

Pulwarty, R., Simpson, C., and Nierenberg, C., 2007, The Regional Integrated Sciences and Assessments Program: Crafting regional assessments for the long haul, *in* Knight, C., and Jager, J., eds., Integrated regional assessments: Cambridge Press.

Pulwarty, R., Trotz, N., and Nurse, L., 2007, Risk and Criticality: Caribbean Islands in a Changing Climate: *in* Bataglia A., and Hare, W., eds., Key vulnerable regions and climate change: Potsdam Institute Potsdam.

Pulwarty, R., Wilhite, D., Diodato, D., and Nelson, D., 2007, Drought in changing environments—Creating a Roadmap: Vehicles and Drivers Natural Hazards Observer.

Pulwarty, R., Olanrewaju, S., and Zorba, P., 2007, Communicating agro-climatological information, including forecasts, for agricultural decisions, *in* Stigter K., ed, Guide to agro-meteorological practices: WMO Commission for Agricultural and Meteorological Practices and the International Society for Agricultural Meteorology Geneva, 40 p., http://www.wmo.ch/web/wcp/agm/RevGAMP/chap18-draft.pdf.

### Dale M. Robertson, Ph.D.

Research Hydrologist
U.S. Geological Survey
Wisconsin Water Science Center
Glen Canyon Dam Adaptive Management Program Science Advisor

#### Education

Ph.D., 1989, Oceanography and Limnology, University of Wisconsin, Madison
M.S., 1984, Oceanography and Limnology, University of Wisconsin, Madison
B.S., 1981, Biology, Chemistry, and Mathematics; St. Norbert College, DePere, Wisconsin

#### Current Research

Research deals with understanding the influence of environmental factors, watershed management strategies, and in-lake management alternatives on the water quality of lakes, reservoirs, and rivers; modeling water quality and the effects of artificial destratification; modeling regional loading; and examining ice cover as a climatic indicator.

#### Recent Publications

Robertson, D.M., and Schladow, S.G., 2008, Response in the water quality in the Salton Sea to changes in phosphorus loading: An empirical modeling approach: Hydrobiologia, v. 604, p. 5–19.

Robertson, D.M., Schladow, S.G., and Holdren, G.C., 2008, Long-term changes in the phosphorus loading to and trophic state of the Salton Sea: Hydrobiologia, v. 604, p. 21–36.

Robertson, D.M., Garn, H.S., and Rose, W.J., 2007, Response of calcareous Nagawicka Lake, Wisconsin, to changes in phosphorus loading: Lake and Reservoir Management, v. 23, p. 298–312.

Robertson, D.M., Graczyk, D.J., Garrison, P.J., Wang, L., LaLiberte, G., and Bannerman, R., 2006, Nutrient concentrations and their relations to the biotic integrity of wadeable streams in Wisconsin: U.S. Geological Survey Professional Paper 1722, 139 p.

Robertson, D.M., Saad, D.A., and Heisey, D.M., 2006, A regional classification scheme for estimating reference water quality in streams using land-use-adjusted spatial regression-tree analysis: Environmental Management, v. 37, no. 2, p. 209–229.

## David J. Topping, Ph.D.

Research Hydrologist
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

### Education

Ph.D., 1997, Geological Sciences, University of Washington, Seattle, Washington
M.S., 1991, Geological Sciences, University of Washington, Seattle, Washington
B.S., 1988, Earth, Atmospheric, and Planetary Sciences; Massachusetts Institute of Technology, Cambridge, Massachusetts

### Current Research

Research focuses on the physical interactions between the flow, upstream sediment supply, channel geometry, and bed-sediment grain size. Centerpiece of research has been the investigation of sediment transport in rivers with intermittent, limited supplies of sediment. Key scientific impact from this work has been to show that in many settings changes in bed grain size can play important roles in regulating sand transport. In certain settings, such as the regulated Colorado River in Grand Canyon, grain-size changes may be as or more important than flow changes in regulating sand transport. These findings contradict conventional sediment-transport paradigms, in which water discharge is typically considered the de facto dominant regulator of sand transport.

### Recent Publications

Topping, D.J., Rubin, D.M., Schmidt, J.C., Hazel, J.E., Jr., Melis, T.S., Wright, S.A., Kaplinski, M., Draut, A.E., and Breedlove, M.J., 2006, Comparison of sediment-transport and bar-response results from the 1996 and 2004 controlled-flood experiments on the Colorado River in Grand Canyon: CD-ROM Proceedings of the 8th Federal Inter-Agency Sedimentation Conference, Reno, Nevada, April 2–6, 2006, ISBN 0-9779007-1-1.

Topping, D.J., Rubin, D.M., and Melis, T.S., 2007, Coupled changes in sand grain size and sand transport driven by changes in the upstream supply of sand in the Colorado River: Relative importance of changes in bed-sand grain size and bed-sand area: Sedimentary Geology, 24 p., doi: 10.1016/j.sedgeo.2007.03.016.

Topping, D.J., Wright, S.A., Melis, T.S., and Rubin, D.M., 2007, High-resolution measurements of suspended-sediment concentration and grain size in the Colorado River in Grand Canyon using a multi-frequency acoustic system: Proceedings of the Tenth International Symposium on River Sedimentation, August 1–4, 2007, Moscow, Russia, v. 3, p. 330–339.

Melis, T.S., Topping, D.J., Rubin, D.M., Wright, S.A., 2007, Research furthers conservation of Grand Canyon sandbars: U.S. Geological Survey Fact Sheet 2007-3020, 4 p.

Wright, S.A., Schmidt, J.C., Melis, T.S., Topping, D.J., and Rubin, D.M., in press, Is there enough sand? Evaluating the fate of Grand Canyon sandbars: GSA Today.

## Harold M. Tyus, Ph.D.

Senior Research Associate
Center for Limnology
Cooperative Institute for Research in Environmental Studies
University of Colorado
Glen Canyon Dam Adaptive Management Program Science Advisor

### Education

Ph.D., 1971, Zoology, N.C. State University
M.S., 1969, Zoology, N.C. State University
B.S., 1964, Chemistry and Biology, Florida Southern College

### Current Research

Biology and ecology of freshwater fishes. Conservation and management of native and endangered fishes. Colorado River fishes.

### Recent Publications

Portz, D.E., and Tyus, H.M., 2004, Fish humps in two Colorado River fishes: An induced morphological response to cyprinid predation?: Environmental Biology of Fishes, v. 71, p. 233–245.

Tyus, H.M. and Saunders, J.F., III, 2000, Nonnative fish control and endangered fish recovery: lessons from the Colorado River: Fisheries, v. 25, no. 9, p. 17–22.

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### Education

Post-Doctorate, 1997, Aquatic Stream Ecology, Utah State University, Logan
Ph.D., 1975, Fisheries Ecology, Utah State University, Logan
M.S., 1971, Fisheries, Utah State University, Logan
B.S., 1968, Wildlife Management, New Mexico State University, Las Cruces

### Current Research

Research efforts focus on fisheries biology in aquatic ecosystems of western North America, including fish population dynamics, abundance estimators, recruitment models, stock assessment, population viability analysis, design and implementation of monitoring programs.

### Recent Publications

Price-Stubbs Fish Passage—Technical assistance to U.S. Fish and Wildlife Service (USFWS) on design and implementation of fish passage on the Price-Stubbs Dam of the Upper Colorado River near Grand Junction, CO (2007–present).

Green River Study Plan—Chairman of Committee to develop a long-term study plan for the Green River as part of the Flaming Gorge Dam EIS for USFWS (2006–07).

Nonnative Fish Workshop—Facilitator for three annual Nonnative Fish Workshops for the Upper Colorado River Basin at request of USFWS (2005–07).

Yampa River Nonnative Fish Strategy—Author and coordinator for developing strategy at request of Implementation Committee for Upper Colorado River Recovery Program (2007–present).

Glen Canyon Dam Environmental Impact Statement (EIS)—Member of Science Panel and writing team for Long-Term Experimental Plan EIS for Bureau of Reclamation (2006–present).

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### Education

Ph.D., 1969, Colorado State University, Fort Collins, Colorado
M.S., 1967, Colorado State University, Fort Collins, Colorado
B.S., 1965, Humboldt State College, Arcata, California

### Current Research

Current research is on the theory of harvesting in natural resource management; the development of rapid techniques for teaching systems analysis and mathematical modelling to biologists and resource managers, using problem-oriented workshops and seminars; and active field research program on the responses of aquatic communities to disturbances such as removal of selective species by introduced fish populations and enhancement of productivity through fertilization.

### Recent Publications

Allen, M.S., Walters, C.J., and Myers, R., 2008, Temporal trends in voluntary release of largemouth bass, with fishery implications: North American Journal of Fisheries Management, v. 28, p. 418–427.

Walters, C., Martell, S.J.D., and Christensen, V., 2007, An Ecosim model for exploring ecosystem management options for the Gulf of Mexico: implications of including multistanza life history models for policy predictions: Bull. Mar. Sci.

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## Scott A. Wright, Ph.D.

Research Hydrologist
U.S. Geological Survey
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### Education

Ph.D., 2003, Civil Engineering, University of Minnesota
M.S., 1997, Civil Engineering, University of Iowa
B.S., 1994, Civil Engineering, University of Iowa

### Current Research

Surface water, sediment transport, and water-quality monitoring, modeling, and research related to the effects of Glen Canyon Dam on the Colorado River ecosystem in Marble and Grand Canyons.

### Recent Publications

Anderson, C.R., and Wright, S.A., in press. Development and application of a water temperature model for the Colorado River ecosystem below Glen Canyon Dam, Arizona, Proceedings of the American Institute of Hydrology Annual Meeting and International Conference, April 22–25, Reno, NV.

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# Appendix E. Responses to EIS Cooperator Questions

Representatives from some of the agencies cooperating with Reclamation in the development of the long-term experimental plan (LTEP) environmental impact statement (EIS) had questions during the first few months of 2007 regarding resources affected by Glen Canyon Dam operations. The questions are presented below, ranked in order of importance in relation to future experimental designs.

Following the workshop, GCMRC scientists developed concise answers to these questions based on the discussions and results of the workshop. Questions 11 through 14 were not addressed at the workshop.

## 1. What are the factors limiting humpback chub reproduction and rearing in the main channel of the Colorado River below Glen Canyon Dam?

Current mainstem Colorado River water temperatures are too low in the summer and fall to support large-scale expansion of the Grand Canyon humpback chub population (Valdez and Masslich, 1999; Clarkson and Childs, 2000); warmer summer and fall water temperatures are needed. This finding is supported by numerous investigations on the deleterious effects of suboptimal water temperature on swimming performance, predator avoidance (Ward and others, 2002; Ward and Bonar, 2003), growth (Robinson and Childs, 2001), and reproduction (Kaeding and Zimmerman, 1983) of native fish species. As a result, water temperature is potentially the most important factor limiting expansion of the Grand Canyon humpback chub population (Clarkson and Childs, 2000; Kaeding and Zimmerman, 1983). The recent stabilization of the population appears to be consistent with the observation that warmer water benefits native fishes, although some increase in humpback chub recruitment likely began before the onset of the warmest recent mainstem water temperatures (Melis and others, 2006).

## 2. Have humpback chub population estimates stabilized or increased recently, and if so, why (warm water, nonnative control, other factors)?

Current abundance estimates for the Little Colorado River population of humpback chub suggest that the adult population size may have stabilized at a new, lower level beginning in 2000 (Melis and others, 2006). As described by Coggins and others (2006a), these estimates are generated using the age-structured mark-recapture (ASMR) model, which is an open-population framework that updates all current and past population estimates as new information is incorporated. As a result, estimates of past abundance may change with incorporation of new data. For instance, the adult population estimate was 4,356 adult fish in 2001, which was produced using the ASMR3 model with the data available through 2002 and with constant adult mortality (Coggins and others, 2006b). The 2001 adult abundance estimate using the same model but considering data through 2005 was 4,474 fish (Melis and others, 2006). The difference in point estimates is predominantly a result of updating estimates of mortality rate and can lead to differences in absolute estimates, particularly in the most recent years of the assessment. As noted by Melis and others (2006), much of this discrepancy is the result of uncertainty in mortality rate estimation, resulting from large decreases in sampling intensity during the mid to late 1990s. As more years of consistent sampling accrue since this lapse, uncertainty in mortality rate should decrease. However, it is important to note that point estimate updating, particularly for the most recent years, will always occur as more information on individual cohorts becomes available.

The participants agreed that the Grand Canyon humpback chub population possibly benefited from both warmer mainstem water temperatures and the removal of nonnative fishes, especially rainbow trout, near the mouth of the Little Colorado River (Melis and others, 2006). Although this conclusion is based predominantly on general ecological principles and knowledge of Colorado River native fish life history, benefits to native fauna have been documented as a result of nonnative control efforts elsewhere (Ruzycki and others, 2003; Vredenburg, 2004). Resolution as to which of these factors is more important to humpback chub conservation is intellectually appealing, but would require greater experimentation than the participants recommend. For example, one approach to determining the relative importance of nonnative fish removal to the conservation of humpback chub would be to discontinue nonnative control efforts and allow the nonnative populations to increase without bound. If the current stabilization of the humpback chub population (Melis and others, 2006) continued while release water temperatures remained elevated, it would suggest that temperature was a more important factor than nonnative removal. However, the participants cautioned against employing such an approach, with its emphasis on learning about resource protection. A number of the participants have firsthand experience with the deleterious effects of nonnative fish populations on native species (Bestgen and others, 2006; Pine and others, 2007; Olden and others, 2006; Tyus and Saunders, 2000), experiences that suggest that it is important to keep these species under control while they are still relatively small proportions of the total fish population (Bestgen and others, 2007). When nonnative populations expand quickly, it may be impossible to reduce or contain them. Therefore, the participants agreed that as the GCDAMP moves into the future, there may be cases where resource protection and reducing risk (Francis and others, 2007) will have to be emphasized at the expense of determining specific cause-and-effect relationships. The participants did not eschew learning altogether, strongly advocating for it whenever possible, but not at the expense of rare resource protection, particularly in the case of the humpback chub.

## 3. Will warming dam releases positively affect listed or special status species in the Colorado River ecosystem (including humpback chub and effects of nonnative species)?

Future releases of warm water could occur naturally (Seager and others, 2007) as the result of prolonged drought conditions and reduced flows from Glen Canyon Dam, or with the operation of a temperature control device, or both. It is widely believed that warmwater conditions may benefit Colorado River native fish, but it is also likely that some nonnative fish may benefit from a changed thermal regime (Moyle and Light, 1996). Warmwater nonnative fishes are widely regarded as a major threat to humpback chub and other native fishes in the Colorado River Basin in general, and Grand Canyon in particular (Tyus and Saunders, 2000).

Because the expansion or invasion of warmwater species is potentially more detrimental than the current salmonid-dominated nonnative community (Minckley and

Deacon, 1991; Lentsch and others, 1996; Bestgen and others, 2006; Bestgen and others, 2007), the participants recognized that an option to cool the dam release temperatures may be critical to help control warmwater nonnative fish. The participants called for an expanded, aggressive program to better understand the composition of the Grand Canyon fish community, including impacts from the natural warming of 2002–06. They underscored the need to detect any changes in nonnative abundance so as to address negative impacts with additional actions, as needed.

## 4. Can the decline in sediment resources since 1990 be reversed using “flow” options with remaining downstream sand supplies from tributaries (Paria and Little Colorado Rivers and lesser tributaries)?

On the basis of previous studies, sandbars and associated habitats have apparently decreased since closure of Glen Canyon Dam, owing primarily to the fact that 84–94 percent of the natural sand supply is now trapped within the reservoir behind the dam (Wright and others, 2005). It is also known that 1996 Record of Decision releases from the dam are capable of transporting new sediment supplies entering the ecosystem from downstream tributaries in relatively short periods—days to months—under dam releases associated with average to wetter hydrology of the upper Colorado River Basin (Rubin and others, 2002). Such dam operations also export remnant sandbars that remain from the period before dam closure. Schmidt and others (2004) report that about 25 percent of the sandbar area between river miles 0 and 87 was lost to ongoing erosion between 1983 and 2000.

In response to this information, sediment scientists have suggested an experimental option for managers to consider that could reverse sandbar erosion. The proposed experimental approach depends upon the ability of managers to release short-duration spike flows of 42,000 to 45,000 cfs within weeks to a few months of tributary floods that add new sand to the Colorado River ecosystem (Rubin and others, 2002; Wright and others, 2005; Topping and others, 2006). To determine whether declines in sediment resources can be reversed with flows, such future tests presumably need to occur, at least initially, at the same frequency that significant new tributary sand supplies are added to the river. The participants accepted that future sediment testing would likely be part of any proposed long-term experimental design and saw no reason why such tests could not be conducted as part of the environmental triggers strategy.

## 5. Will high flow experiments promote conservation of high priority AMP biological resources (for example, native fishes, native riparian vegetation, aquatic food base, rainbow trout)?

## 6. What effect do powerplant releases (ramp rates, fluctuating and steady) have on listed or special status species (including humpback chub) in the Colorado River ecosystem?

In the opinion of the participants, high and/or fluctuating releases from Glen Canyon Dam would not result in ecological benefits. There was no resource benefit identified from such flows for native fish, sediment conservation, or other natural resources (Gloss and others, 2005). The participants did note that there is evidence humpback chub may be able to tolerate some flow fluctuations, particularly if fluctuations occurred in winter months; however, winter fluctuations may not be consistent with sediment conservation, and the winter life-history stages of Grand Canyon humpback chub have received little study. Indeed, the recently observed population stabilization of adult humpback chub has occurred in the presence of the modified low fluctuating flow regime. The assertion that fluctuating flows could provide additional food to rainbow trout and humpback chub assumes that these species are dependent on drifting aquatic vegetation and invertebrates produced below Glen Canyon Dam. The assumption that these fish are limited by available food resources is currently being investigated. Limited fluctuations, such as beach/habitat-building flows, may, at least temporarily, disadvantage nonnative fish, especially small-bodied species (Minckley and Meffe, 1987; Valdez and others, 2001); this hypothesis needs further testing. In conclusion, fluctuations did not appear to be of any benefit to native fishes (other than their potential to disadvantage nonnative fishes if necessary) and have been shown to accelerate the export of sediment out of Grand Canyon (Rubin and others, 2002; Wright and others, 2005).

## 7. Can the decline of humpback chub be reversed by expanding the current range of humpback chub into suitable unused historical habitat within GRCA/GLCA (tributaries/mainstem)?

The participants concluded translocations could support expansion of humpback chub in Grand Canyon. In the opinion of the participating experts, the tributary stream with the best likelihood of success for such a project is Bright Angel Creek; however, they thought that other tributaries could also be successful in establishing humpback chub (Valdez and others, 2000). Translocating some humpback chub to Bright Angel Creek would likely require complete removal of all nonnative fishes first with chemical treatment, which may be difficult or impossible in a national park. There was general agreement among the participants that groups of humpback chub in small tributary streams would be unlikely to be considered additional populations because of the limited numbers of individuals that could be maintained in waterways of that size (Valdez and others, 2000). The participants concluded that if a second population were to be established in Grand Canyon, success was much more likely in the mainstem (somewhat independent of the Little Colorado River-based population) than in any one tributary stream. The participants generally agreed that such translocations were unlikely to cause any important confounding of humpback chub monitoring or population modeling.

## 8. If the answer to core question 4 is yes, then will such enhanced sediment conservation promote in situ preservation of archaeological sites?

(NOTE: Core question 4. Can the decline in sediment resources since 1990 be reversed using “flow” options with remaining downstream sand supplies from tributaries [Paria and Little Colorado Rivers and lesser tributaries]?)

Participants did not specifically discuss the issue of promoting in site preservation of archaeological sites other than to note that sediment supplies above the zone of inundation need to be maintained to provide any benefits to these higher elevation, sediment-dependent resources. The main mechanism for achieving these objectives would appear to be periodic beach/habitat-building flows conducted during sediment-enriched conditions.

### 9. How can invasive or nonnative species be eliminated, reduced, or controlled in the Colorado River ecosystem?

The participants noted that the first step in addressing this question would be a better understanding of which nonnative fish species threaten the native fishes in Grand Canyon and where they occur. This understanding can only be developed with a more robust sampling program for nonnative species; the participants recommended that the existing program be expanded as soon as possible.

The participants also strongly recommended the inclusion of a temperature control device design that allows for the release of cool water in addition to warm water. The most important reason for including this design option was to allow for the release of cool water to limit the expansion and success of warmwater nonnative fish, in case their numbers increase to levels that threaten native fishes.

### 10. If the answer to core question 4 is yes, then will such enhanced sediment conservation promote conservation of recreation beaches and campable area?

(NOTE: Core question 4. Can the decline in sediment resources since 1990 be reversed using “flow” options with remaining downstream sand supplies from tributaries [Paria and Little Colorado Rivers and lesser tributaries]?)

Participants did not specifically discuss the question of using “flow” options with downstream sand supplies other than to note that sediment supplies above the zone of inundation need to be maintained to provide any benefits to these higher elevation, sediment-dependent resource categories. The main mechanism for achieving these objectives would appear to be periodic beach/habitat-building flows conducted during sediment-enriched conditions.

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