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Subject: Executive Summary: BHBF Science Plan

We just received the "Executive Summary: Science Plan for Potential 2008 Beach/Habitat-Building Flows Test at Glen Canyon Dam" and were asked by GCMRC to distribute this to all AMWG/TWG members and alternates.

cc: Amy Heuslein / Garry Cantley (via fax @ 602-379-3833)

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Attachment

Executive Summary: Science Plan for Potential 2008 Beach/Habitat-Building Flows Test at Glen Canyon Dam

Introduction

This science plan describes proposed monitoring and research activities to be conducted by the U.S. Geological Survey's Grand Canyon Monitoring and Research Center (GCMRC) should the Secretary of the Interior approve a beach/habitat-building flows (BHBF) test at Glen Canyon Dam in 2008. The study area is the Colorado River ecosystem (CRE), the river corridor that extends from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (fig. 1). This plan is designed to build upon existing scientific knowledge to inform managers about the efficacy of using BHBF testing to rebuild not only sandbars but also to benefit various downstream resources, particularly the endangered humpback chub (*Gila cypha*).

The GCMRC has responsibility for monitoring and research activities for the Glen Canyon Dam Adaptive Management Program (GCDAMP), a Federal initiative to protect and improve resources downstream of Glen Canyon Dam. Because of the lengthy lead time required to plan and execute a BHBF test, the Adaptive Management Work Group (AMWG)—the Federal Advisory Committee within the GCDAMP that provides recommendations to the Secretary of the Interior on the operation of the dam—recommended that the GCMRC prepare this plan in anticipation of a future test. Following this recommendation, the Department of the Interior directed GCMRC to develop an "off-the-shelf" science plan to take advantage of potential BHBF research opportunities in the future.

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 24 km (15 mi) upriver from Grand Canyon National Park. Before the dam, the Colorado River swelled with spring snowmelt from the Rocky Mountains in most years, producing flood events and transporting large quantities of sediment that created and maintained sandbars in Grand Canyon. The native fish community found in Grand Canyon, including species found nowhere else on Earth, evolved in the large, turbid, and seasonally variable predam Colorado River. Most noticeably, several of the native species share unusual body shapes, including a large adult body size, small depressed skulls, large predorsal humps, and small eyes, which presumably developed to adapt to life in the Colorado River. Today, three of the eight native fish species have been eliminated from the Colorado River in the study area and two are federally listed as endangered, razorback sucker (*Xyrauchen texanus*) and humpback chub, under the Endangered Species Act of 1973. The razorback sucker is widely thought to no longer be found in Grand Canyon.

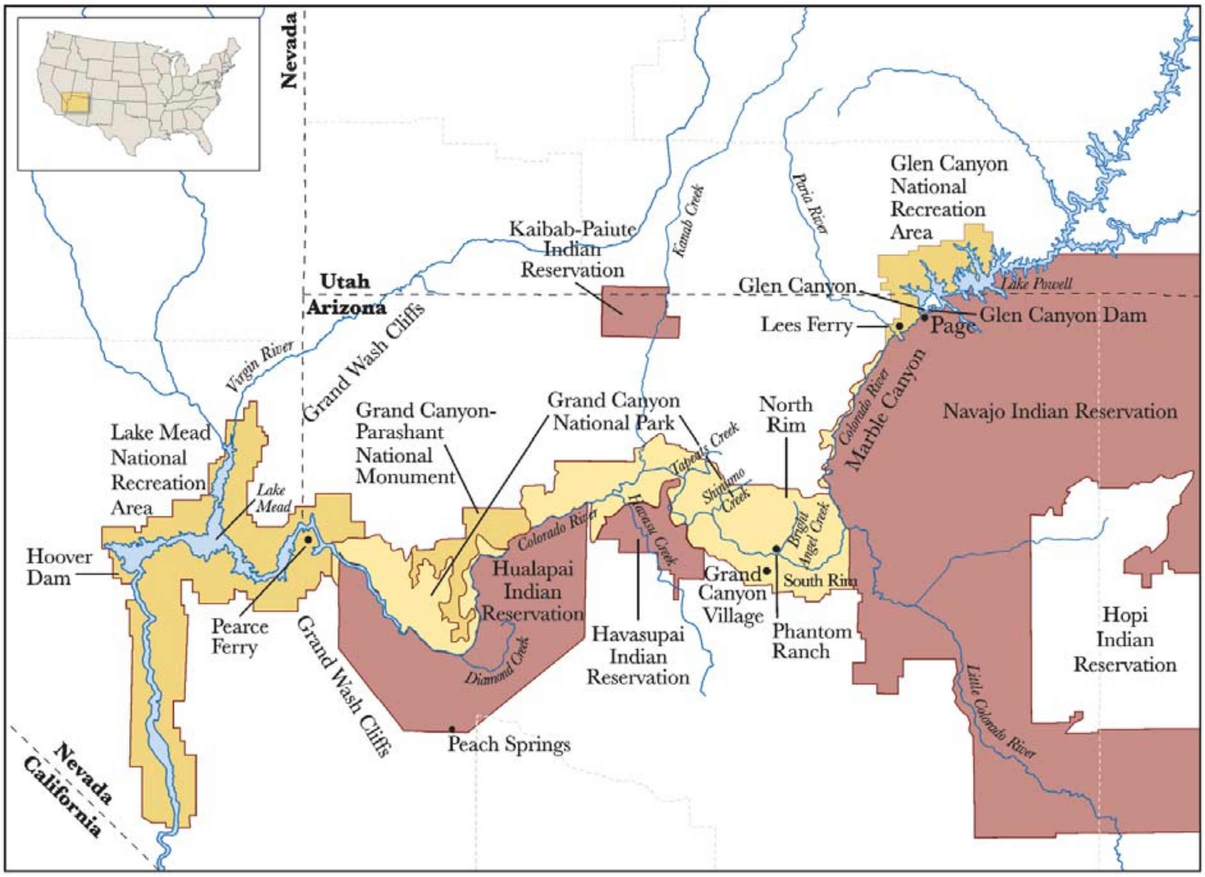

Figure 1. Map of the Colorado River ecosystem, the Colorado River corridor that extends from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park.

In Grand Canyon, sandbars supply camping beaches for river runners and hikers, provide sediment needed to protect archaeological resources from weathering and erosion, and are thought to create habitats for native fish and other wildlife. For example, sandbars create backwaters—areas of stagnant or low-velocity flow—that may be used as rearing habitat by humpback chub and other native fishes. Today, the river usually runs clear below Glen Canyon Dam, because Lake Powell traps all of the sediment upstream from the dam (Wright and others, 2005). As a result, Grand Canyon receives 6%–16% of its predam sand supply, which comes primarily from the Paria and Little Colorado Rivers when they enter the mainstem below the dam (Wright and others, 2005).

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, the Grand Canyon Protection Act (GCPA) was enacted "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 GCDAMP was established by the 1996 Record of Decision on the Operation of Glen Canyon Dam Environmental Impact Statement (EIS) to ensure that the primary mandate of the GCPA is met (U.S. Department of the Interior, 1995). An adaptive management process is being used to evaluate the effects of dam operations on the ecosystem below Glen Canyon Dam and to identify future modifications of dam operations to enhance resource conditions. Adaptive management is a systematic process that uses experimentation and monitoring to continually improve management practices.

Beach/Habitat-Building Flows

One of the experiments identified by the EIS was the use of BHBF tests to rebuild high-elevation sandbars, deposit nutrients, and restore backwater channels. Replenishing sandbars requires both a sufficiently large upstream sand supply and higher than normal flows to deposit sand at higher elevations. In the EIS, a BHBF test is defined as a release of water from Glen Canyon that is at least 10,000 cubic feet per second (cfs) greater than the allowable peak discharge (30,000 cfs) but not greater than 45,000 cfs. The EIS specified the testing of BHBFs prior to their implementation as a long-term management action.

Importantly, the design of the 2008 BHBF test and the accompanying experimental studies proposed in this plan build on learning that occurred as the result of BHBF tests conducted in 1996 and 2004. For example, as the result of the 1996 BHBF test, scientists learned that tributary-supplied sand does not accumulate on the riverbed over multiyear periods under typical dam operations, as had been hypothesized. Additionally, the 1996 BHBF test was conducted when the Colorado River was relatively sand depleted, especially in Marble Canyon, and, as a result, the primary sources of sand for building high-elevation sandbars were the low-elevation parts of the upstream sandbars and not the channel bed (Andrews and others, 1999; Schmidt, 1999; Hazel and others, 2006). During the 1996 BHBF, the erosion of low-elevation sandbars actually resulted in a net reduction in overall sandbar size. Sandbars eroded during the 1996 BHBF test did not recover their former sand volume during the late 1990s in spite of above-average sand supplies and the implementation of Record of Decision operations.

These results indicated that high-flow releases conducted under sand-depleted conditions, such as those that existed in 1996, will not successfully sustain sandbar area and volume. Scientists and managers used this information to focus their efforts on the need to strategically time BHBF testing to take advantage of episodic tributary floods that supply new sand to the Colorado River downstream of Glen Canyon Dam.

The Importance of Tributary Floods

In September 2002, the U.S. Department of the Interior approved the implementation of new BHBF testing tied to triggering thresholds linked to sand inputs from the Paria River (U.S. Department of the Interior, 2002). Significant sand inputs to Marble Canyon occurred during September through November 2004 and exceeded the sediment trigger established in 2002. Approval of a supplemental environmental assessment (U.S. Department of the Interior, 2004) allowed scientists to test the value of conducting a BHBF test under sand-enriched conditions. In November 2004, scientists evaluated the efficacy of conducting a BHBF test following tributary floods for the first time. Scientists reached the following conclusions as the result of the BHBF test that was conducted in November 2004:

- The 2004 experiment resulted in an increase of total sandbar area and volume in the upper half of Marble Canyon, but further downstream, where sand was less abundant, a net transfer of sand out of eddies occurred that was similar to that observed during the 1996 experiment (Topping and others, 2006).

- Substantial increases in total eddy-sandbar area are only possible when BHBF tests are conducted under the sand-enriched conditions that occur following large tributary floods that enrich sand supplies in the main channel of the Colorado River (Rubin and others, 2002: Topping and others, 2006).
- More sand will be required than was available during the 2004 BHBF test (800,000 to 1,000,000 metric tons) to achieve increases in total sandbar area and volume throughout all of Marble and Grand Canyons in the future (Topping and others, 2006).
- Sandbars created by the 2004 BHBF test increased the windborne transport of sand toward some archaeological sites in Grand Canyon (Draut and others, 2005; Draut and Rubin, 2006). Increased sand carried by the wind from restored sandbars may reduce erosion and increase preservation potential at some archaeological sites.

Humpback Chub Response

The last high spring flow that occurred in Grand Canyon was the 1996 BHBF test (March 22 to April 8, 1996). The fish community response to these flows was studied and a peer-reviewed report documenting the response was prepared by Valdez and others (2001). These authors found that the native fish community, including humpback chub, did not experience decreased distribution or abundance as a result of the BHBF test; however, there was temporary displacement of nonnative fish species. During the 2004 BHBF test, which occurred in November, fisheries scientists attempted to sample the fish community before and after the test to further document the response of humpback chub and other fishes to high flows. Unfortunately, the sampling following the event was confounded by a natural flood event in the Little Colorado River, which greatly increased turbidity in the main channel, possibly lowering the efficiency of the sampling gear. Because of the timing and magnitude of the spate from the Little Colorado River, it cannot be determined whether the observed decline in catch rate following the 2004 BHBF test was a result of a decline in fish density or a decline in sampling gear efficiency.

In terms of humpback chub, the 2008 BHBF test has been proposed primarily to help determine whether BHBF tests can be used to successfully restore sand-dependent habitats in Grand Canyon. This GCMRC science plan includes an experimental study (1D) to help document the habitat response and to determine the use of backwater habitats by small-bodied fishes, both native and nonnative. In addition to this BHBF-specific study, the GCMRC will continue a variety of ongoing projects that monitor the status and trends of the humpback chub population in Grand Canyon (see appendix B of the full plan).

Much of the humpback chub mark recapture data are used to support stock assessment of the Little Colorado River population of humpback chub using a tool known as the age-structured mark recapture model (ASMR; Coggins and others 2006). The ASMR results for the years 1989–2006 indicate that the population of adult (age 4+) humpback chub in Grand Canyon declined to a modern low in 2001 but has been increasing since that time (fig. 2). This period of increasing population includes the November 2004 BHBF test.

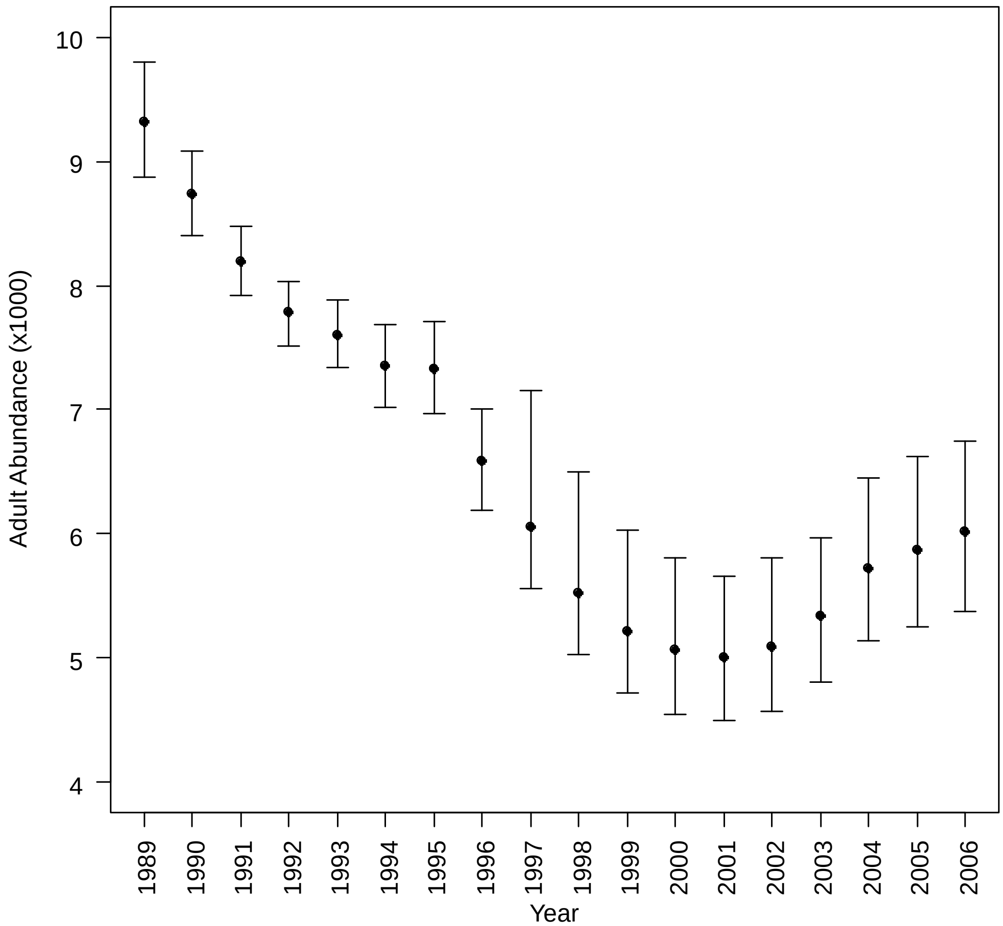

Figure 2. Trend of adult (age 4+) humpback chub population in Grand Canyon modeled by the age-structured mark recapture model of Coggins and others, 2006 (U.S. Geological Survey, unpub. data, 2007). Error bars represent 95% profile confidence intervals.

It is important to note that several factors may have contributed to the increasing adult humpback chub population between 2001 and 2006, including warmer releases from Glen Canyon Dam and the mechanical removal of rainbow trout (*Oncorhynchus mykiss*) from the mainstem Colorado in the reach above and below the mouth of the Little Colorado River. Though the exact cause of the increased population cannot be determined with certainty, the November 2004 BHBF test does not appear to have been detrimental to the adult population of humpback chub. While the spring 1996 BHBF test occurred during a period of decline for adult humpback chub, the decline occurred for a limited time and the population responded with an increase in ensuing years.

The ASMR model also allows for an estimate of the abundance of recruitment of humpback chub (fig. 3), that is, how many young fish were produced in particular years. The currently available data allow for an estimate of recruitment strength for 1988–2002. Overall, recruitment has been increasing from 1994 through 2002, a period that included the 1996 BHBF test, though the uncertainty in these estimates is large. Considered together, these data suggest that BHBF tests have not been detrimental to humpback chub. It is also possible that BHBF tests offer advantages to humpback chub, including the temporary displacement of nonnative fishes (Valdez and others, 2001) and the maintenance and construction of backwater habitats, which may offer growth advantages to humpback chub and other native fishes (Arizona Game and Fish Department, 1996).

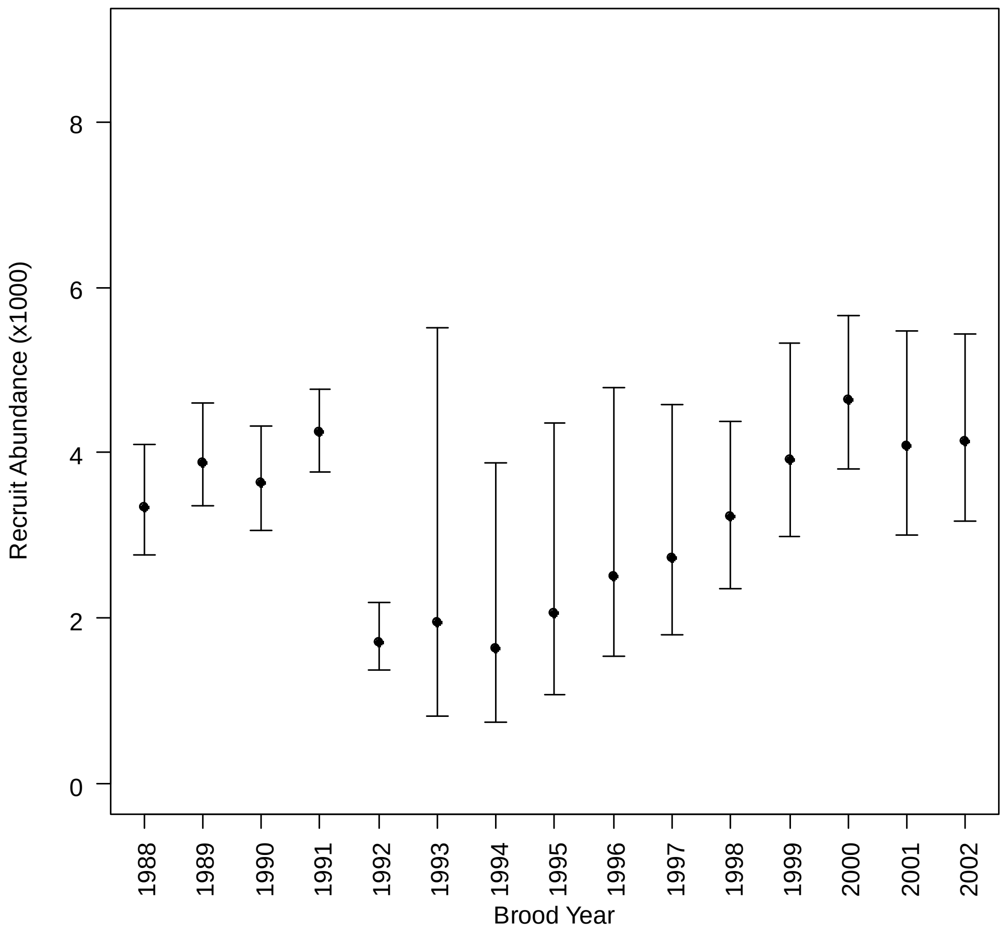

Figure 3. Estimated recruitment to the Little Colorado River humpback chub population from brood years 1988–2002 (U.S. Geological Survey, unpub. data, 2007). Error bars represent 95% profile confidence intervals.

2008 Potential Beach/Habitat-Building Flows Test

BHBF Timing

The GCMRC believes that the best time to conduct a BHBF test in 2008 would be early to mid-March 2008 for the following reasons:

- The system is currently enriched with sediment as a result of several tributary floods from the Paria River in October 2006 and August–September 2007 that delivered 2,500,000 metric tons

(±500,000 metric tons) of sand into the Colorado River ecosystem below Glen Canyon Dam. As a result, sand supplies in the upper reaches of Grand Canyon National Park now contain approximately two to three times the minimum sand volume that was needed to trigger the 2004 BHBF test. Sand production by the Paria River in Water Year 2007 has been twice the long-term average and the current level of sand enrichment is greater than it has been since at least 1998.

- A March BHBF test could support increases in the numbers of native fishes if it creates additional habitats where young native fish can find refuge from predation and benefit from warmer water temperatures that encourage growth.
- A March BHBF test is expected to have moderate to low impact on the production of algae and diatoms between the dam and Lees Ferry and, as a result, should not limit the availability of these food sources for nonnative and native fishes. Rather, a March BHBF test has the potential to crop off senescent or dead algae and to encourage fresh, new growth as increased solar radiation is available from March through October as compared to the remainder of the year.
- March is before the flowering of the nonnative tamarisk (*Tamarix ramosissima*), and so would reduce the potential for increasing its distribution.
- A March test will maximize the potential for newly created sandbars to contribute additional sand to nearby archaeological sites, because a March BHBF test would create sandbars just before the onset of the spring windy season (April–June).
- For 2007–8, the earliest practical time for a BHBF test would be early March 2008, given the logistical, administrative, and compliance activities associated with conducting the research outlined in this plan.

Peak Flow Magnitude and Duration

The GCMRC proposes replication of the 2004 BHBF hydrograph in a BHBF test in 2008 to allow scientists to determine if the locally robust and consistent sandbar-building responses that occurred in upper Marble Canyon in 2004 can be repeated and possibly enhanced. By reproducing the 2004 test hydrograph scientists will also be able to evaluate if there are cumulative benefits to sandbar conservation in lower Marble and Grand Canyons each time a sand-enriched BHBF test occurs. Consistent with the 1995 EIS (U.S. Department of the Interior, 1995), as well as previous BHBF tests in 1996 and 2004, a potential 2008 test should be conducted in the range of 41,500 to 45,000 cfs. To replicate the 2004 BHBF hydrograph, scientists recommend a peak flow duration of 60 hours, the same duration used for the 2004 BHBF and 108 hours shorter than the 1996 test.

Flows immediately preceding and following a March 2008 BHBF test are anticipated to be similar to normal modified low fluctuating flow (MLFF) patterns typically released in the transition month of March during 8.23 million acre-feet (maf) release years. The daily range of flows would likely be 6,000 cfs with diurnal peaks flows of 12,000–13,000 cfs. These operations would probably be very similar to the December 2004 MLFF patterns that followed the November 2004 test and preceded the experimental fluctuating flows of January through March 2005.

2008 Test Includes Important Differences

A test conducted in 2008 would be different from BHBF tests conducted previously in several important ways. As noted above, the 1996 BHBF was conducted when sand supplies in the

Colorado River were relatively depleted. The 2004 test occurred shortly after Paria River flooding had enriched the sand supply in Marble Canyon; however, the amount of sand present in 2004 was insufficient to achieve increases in total sandbar area and volume throughout both Marble and Grand Canyons. In November 2007, sand supplies in the main channel of the Colorado River are two to three times larger and more evenly distributed longitudinally than in 2004. Conducting a BHBF test under current sediment conditions would allow scientists to evaluate the effectiveness of conducting a test under much enriched conditions.

A second important difference is that a 2008 BHBF test would be followed by normal Record of Decision operations unlike previous tests, which were followed by higher fluctuating flows than would have otherwise occurred. The 2008 test would allow a unique comparison of the relative stability of sandbars and backwaters under the relatively low fluctuating flows associated with spring versus higher summer monthly operations during a minimum release year (8.23 maf).

Experimental Studies to Address a Variety of Scientific Questions

Previous BHBF science plans concerned themselves primarily with sediment conservation, including the size, volume, and distribution of sandbars. In December 2005, the AMWG identified concerns and questions about the effects of BHBF testing on a variety of CRE resources. These concerns and questions are reflected in a series of science questions developed by the GCMRC that form the basis for this science plan (appendix A, table 1). As a result, this plan proposes to determine how BHBF tests affect not only sediment resources and sandbars, but also backwater habitats used by the endangered humpback chub and other native fishes, aquatic food base, rainbow trout recruitment and emigration, riparian vegetation, and archaeological resources in close proximity to the Colorado River. For example, experimental study 1 (parts A–D) addresses questions related to sediment and seeks to determine not only if BHBF tests are an effective tool that will rebuild and maintain sandbars over time, but also if BHBF tests have the ability to create additional backwater habitats for native fish and how new sand deposits affect archaeological sites. Experimental studies 2–5 address the impacts of BHBFs on riparian vegetation, food base, rainbow trout, and Lake Powell water quality, respectively.

One of the concerns managers have with BHBF tests is their potential to affect aquatic food resources at lower trophic levels, thereby indirectly affecting native and nonnative fishes. However, the exact effect of these events has not been well studied, so conclusions about their effects remain speculative. The study of the aquatic food base anticipates monitoring the effects of a BHBF test on the primary and secondary producers below Glen Canyon Dam. Monitoring before and after a BHBF test would be an important link in the ongoing research and data collection that is being conducted throughout the river corridor to help determine what changes, if any, are a result of the BHBF test.

Other biological activities also build on ongoing scientific research to address key strategic science questions. For example, experimental study 1D is being used not only to help develop methods for mapping backwater habitats to better understand their creation and persistence in the months following a BHBF test, but also is intended to build on the existing efforts by expanding the fall sampling of backwater habitat for small-bodied fish to include sampling during the spring. Spring sampling for small-bodied fishes will complement the fall sampling that currently occurs and will provide additional insights into the persistence of backwaters and use of backwater habitats by native and nonnative fishes. The GCDAMP undertakes a diverse program of monitoring for native and nonnative fishes that will be in place to help evaluate potential longer term effects of a BHBF test.

Besides answering pressing scientific questions, a BHBF test is needed to provide information to inform the continued development of a sediment model that will help determine the optimum frequency, timing, duration, and magnitude of future BHBF tests under varying sediment enrichment conditions. Study 1B is specifically designed to gather information that will be critical to developing the sediment model. A well-calibrated, robust predictive sediment model could be used to help minimize the impacts of BHBF tests on Glen Canyon Dam hydropower production. Model construction has not been possible with the currently available information.

Cost of 2008 BHBF Test

As shown in table 1, the cost of the research activities associated with the next BHBF test is approximately $1,600,000 to $2,100,000 depending on the scope of studies that are implemented. In 2003, the GCDAMP established an experimental fund to pay for experimental research projects, such as BHBF tests, so they can be conducted without financially impacting other ongoing aspects of the science program. The balance of the experimental fund in FY 2008 is approximately $1,450,000. In FY 2009, an additional $500,000 is planned to be deposited into the experimental fund. Thus, based on current and anticipated deposits into the experimental fund, most of the funds needed to implement the studies included in this BHBF science plan are available.

In addition to the cost of studies, some portion of the flows needed for a BHBF test will bypass the powerplant at Glen Canyon Dam. The Western Area Power Administration has estimated that approximately $1–2 million of replacement power costs will be incurred as a result of a BHBF test. The extent of these costs will depend on the magnitude, duration, and timing of a BHBF test. It has also been suggested that a BHBF test could have a negative impact on the Marble Canyon economy that is dependent on the Lees Ferry trout fishery. However, these economic impacts and the economic benefits associated with potential improvements to resources and recreation in the Colorado River ecosystem have not been quantified. All of the associated economic impacts of dam operations, including a BHBF test, are outside the scope of this document, but should be addressed by future National Environmental Policy Act analysis.

Table 1. Description of experimental studies proposed by this science plan, including cost estimates for fiscal yeas 2008–9.

Experimental study	Description	FY2008 cost estimate	FY2009 cost estimate
	Sediment, archaeological sites, and backwaters		
1A. Sand budgeting	Data will be collected to determine the amount of sediment available in the system and its availability for restoring sandbars and camping beaches, patterns of erosion and deposition, and changes in sediment grain size	$310,806	$91,707
1B. Eddy-sandbar studies	Data will be collected on the evolution of specific eddy sandbars before, during, and after a BHBF test. These data may be used to improve the predictive capabilities of the existing sediment model and determine the optimal peak flows of future BHBF tests.	$99,634	$82,057
1C. Response of sandbars and select cultural site	Data will be gathered to determine (1) if sandbars throughout the Colorado River ecosystem gain or lose sand as the result of a sand-enriched BHBF test, (2) if new sand can offset gully erosion, and (3) if enlarged sandbars provide source material for the windborne transport of sand upslope into archaeological sites.	$566,760	$136,730
1D. Biological and physical aspects of backwater habitats	Study will measure backwater habitats and sample these habitats for fish in spring and fall to evaluate how (a) backwaters formed by a BHBF test change over time and (b) fish, particularly humpback chub, use available backwaters.	$113,986	$127,774
	Riparian vegetation		
2. Riparian vegetation studies	Study will document changes in riparian vegetation (native versus nonnative) following a BHBF test to determine if disturbances influence the success rate of nonnative species.	$41,859	$30,889
	Aquatic food base		
3. Effects of on food available for invertebrates	Data will be collected to determine how BHBF tests affect the quantity and quality of food available to invertebrates and, ultimately, fish.	$164,644	$6,050
	Rainbow trout		
4A. Redds study	Data will be collected to determine how BHBF tests affect spawning and survival of early-life stages of rainbow trout in Lees Ferry	$120,472	$10,609
4B. Movement study	Study will collect data to determine if BHBF tests displace rainbow trout from Lees Ferry and if displacement varies by fish length.	$91,069	$8,590
	Lake Powell		
5. Lake Powell	Data will be collected to determine if a BHBF test results in higher nutrient releases and changes in the hypolimnion.	$16,925	$7,484
	Logistical support		
Logistical support	(Logistical support costs presented here reflect expenses not associated with specific research activities and not included in individual experimental study budgets.)	$77,415	$0
	Conservation measures		
Kanab ambersnail	To minimize impacts to an endangered species, move Kanab ambersnail habitat at Vaseys Paradise.	$32,886	$0
6. Synthesis of knowledge resulting from studies 1–5	Synthesize data and knowledge gained as the result of the BHBF test in an attempt to address strategic science questions		To be determined
Totals		**$1,636,456**	**$504,889**

Long-term Strategy for Future BHBF Experimentation and Frequency

The data gathered as the result of the experimental studies proposed in this science plan will feed into the GCDAMP adaptive management process, so that new information will be available to resource managers and stakeholders. Figure 4 depicts how information derived from a 2008 BHBF test will be used by the GCDAMP to improve decision making and refine predictive models.

Based on the two tests conducted to date, scientists cannot say at this time whether BHBF tests are an effective strategy for stopping the ongoing erosion of sand and sandbars in the Colorado River ecosystem. A long-term research strategy involving further BHBF testing and model development will be necessary to assess whether BHBF tests can effectively conserve sediment and help achieve other related resource benefits (increased humpback chub recruitment, enhanced camping beaches, protection of cultural resource, minimized hydropower impacts, etc). It is very likely that at least several more BHBF tests will be needed to address the major uncertainties associated with the use of BHBF as an effective long-term management tool. This is partly because BHBFs are believed to build sandbars with less efficiency than historical floods owing to the shorter duration and smaller volume of BHBFs compared to predam floods, and the loss of the upstream sand supply in the postdam era. Additionally, intervening flows will export sand from the system. The rate of those exports depends on the volume of flow and the magnitude of daily fluctuations from Glen Canyon Dam. The frequency of BHBF tests needs to be high enough so that more sand can accumulate than is being eroded by intervening flows. In addition, sand supplies are greatly reduced over what was available historically, and sand is replenished only from tributary floods that occur on irregular intervals. Replication is needed to provide sufficient observations of BHBF test effects under the range of natural conditions that are most likely to occur in the future. It may be possible to reduce the number of tests by developing models that will interpolate between observed effects and help rule out scenarios that are unlikely to yield positive, sustainable results. Some of the data needed to develop a model could be obtained through laboratory studies or field studies conducted during normal flow conditions. This may reduce the overall research costs and help minimize impacts to hydropower.

It is also expected that a second generation of BHBF tests will be required to further define environmental conditions that affect and contribute to maintenance of humpback chub habitat or other important ecosystem components that may be affected, or provided for, by releases of BHBF tests, especially beaches, backwaters, and other nearshore habitats.

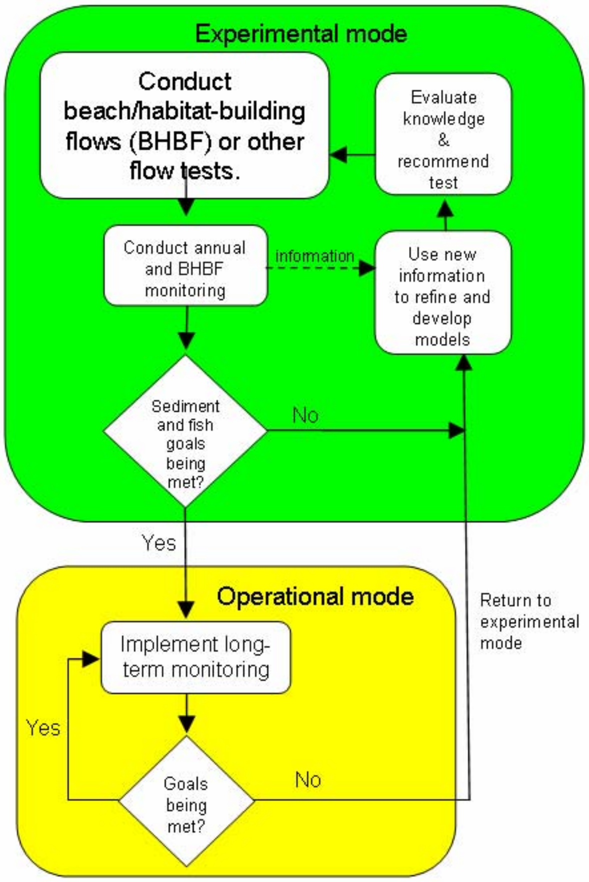

Figure 4. Flow chart showing how field data and modeling information are fed into the adaptive management process and used to improve management of resources downstream from Glen Canyon dam in compliance with the Grand Canyon Protection Act of 1992 and the Endangered Species Act of 1973. Experimental operations must be evaluated over a timeframe sufficient to take into account of natural variability (e.g., decadal scale).

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Appendix A

Table 1. Strategic science questions related to AMWG information needs, BHBF science questions, and the experimental studies that will address in part or in whole individual questions.

Question	Experimental studies
Sediment and related resources	
Strategic science question: Is there a “flow-only” operation that will rebuild and maintain sandbar habitats over decadal timescales?	
BHBF science question: How do conditions of suspended sediment concentration and grain size evolve and vary through time and by reach below Glen Canyon Dam during replication of the 2004 BHBF test hydrograph under more highly enriched sand supply conditions; and how do these data compare with similar data collected at similar locations during the 1996 and 2004 BHBF tests? Is the net mass balance of sand following the BHBF test net positive, negative, or neutral?	1A
Approach: *Continuous measurements of suspended sediment concentration and grain size shall be collected before, during, and after the BHBF test at seven fixed measurement sites throughout the Colorado River ecosystem. Simultaneously, two river trips shall collect the same type of data between fixed measurement points from boats whose downstream movement will be timed such that two separate packets of river water and suspended sediment will be repeatedly monitored for changes in suspended sand concentration and grain size. Fixed location and moving location data shall then be compared to sandbar data from 1.C (changes in channel storage of sand and eddy sandbars).*	
BHBF science question: What is the minimum duration for BHBF tests needed to build and maintain sandbars under sand-enriched conditions?	1B
Approach: *High-resolution measurements of eddy sandbar depositional rates shall be made within a subset of six to eight study sites throughout Marble Canyon and the eddy bar responses shall be evaluated over the 60-hour duration of the BHBF test hydrograph. The variability in depositional rates between sites shall be evaluated and a the total sandbar responses will be compared to the duration of the test to determine whether or not the duration of the flow test was appropriate relative to sandbar deposition and evolution. These measurements, along with those made as within projects 1A, 1C, and 1D, may also be used to support ongoing sediment model research; particularly SORT and LES (eddy simulations) development and verification.*	1B
BHBF science question: Can the next BHBF test increase campable areas at sandbars on a sustainable basis?	1C
Approach: *High-elevation sandbar study sites shall be re-measured at 45 long-term study sites and assessed with respect to net camping area changes before and after the BHBF test. Geomorphic synthesis studies have shown that these long-term sites to be representative of system-wide trends in high-elevation sand storage (at least throughout Marble and eastern Grand Canyons).*	
BHBF science question: How do post-BHBF Record of Decision (ROD) operations under 8.23 million acre feet annual release volumes affect the persistence of sandbars and related backwaters compared to non-ROD operations that followed the 2004 BHBF test?	1D

Approach: *A backwater/fish monitoring project will be initiated that evaluates the size and distribution of backwater habitats and use of those habitats by native and nonnative fishes. Fall backwater monitoring is already part of the annual work plan; a spring monitoring trip will be initiated approximately two months after the BHBF test. Detailed physical measures of backwaters will be made in both fall and spring, and use of backwater by native and nonnative fishes will be documented. Additional physical habitat measurements will be added to fall monitoring. Spring and fall surveys will be conducted each year to allow for comparison of backwaters characteristics and fish use in years with and without a BHBF.* 1D

Humpback chub

Strategic science question: How important are backwaters and vegetated shoreline habitats to the overall growth and survival of young-of-year and juvenile native fish? Does the long-term benefit outweigh short-term potential costs?

BHBF science question: Do BHBF tests result in creation of backwater habitats that may offer physical benefits to humpback chub and other native fishes? To what extent are backwater habitats created by a BHBF used by humpback chub and other native fishes? 1D

Approach: *This project initiates a repeated spring sampling trip that evaluates the use of backwater habitats by small-bodied fishes. By conducting this work in the spring and the fall of each year, the presence or absence of small-bodied native and nonnative fishes in these habitats is documented in years with and without a BHBF to allow insights into how these species do or do not make use of backwaters. This project collects data in support of the ongoing fish monitoring projects.*

Cultural resources

Strategic science question: How effective are various treatments in slowing rates of erosion at archaeological sites over the long term?

BHBF science question: Do sandbars deposited by BHBF tests contribute to preservation of archaeological sites in the river corridor? 1C

Approach: *This question will be addressed by tracking the size, shape, and persistence of sandbars formed near select archaeological sites using repeat total station surveys immediately following the BHBF and 1 year later. Stationary cameras will be used to track the effects of intervening flows on bar size and morphology. Simultaneously, the study will monitor the contribution of aeolian sand derived from these sandbars to the sediment covering a sample of archaeological sites using weather monitoring equipment with sand traps to quantify sediment transport rates. This information, in conjunction with previous data collected from 2003–5 and data currently being collected for the cultural monitoring research and development effort, will allow for the evaluation of the relative contribution from newly created sandbars and determine whether bars formed under sediment-enriched conditions do or do not affect the amount of sediment transported to archaeological sites.*

BHBF science question: Do BHBF tests contribute to added stability or erosion of archaeological sites located in close proximity to the river? 1C

Approach: *This question will be addressed by measuring changes in the depth and configuration of gully systems at a sample of archaeological sites immediately after the BHBF test, 6 months, and 1 year later. Some sites that are the focus of the gully measurement work were previously surveyed in conjunction with the 1996 and 2004 BHBF tests, therefore, comparisons of this next BHBF with previous results can be made to determine whether gully backfilling and site stability were enhanced by conducting a BHBF test under sediment-enriched conditions.*

Other priority resource issues

Strategic science question(s): What Glen Canyon Dam operations maximize trout fishing opportunities and catchability? Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages?

BHBF science question: How will a BHBF test affect spawning, survival of early life history stages of rainbow trout (BBT) in the Lees Ferry reach? Will a BHBF test stimulate downstream migration of age-1 RBT? 4A, 4B

Approach: *Two studies are described, 4A and 4B. Study 4A evaluates the fate of rainbow trout redds and larvae in the reach immediately below the dam to evaluate effects on these resources in response to a BHBF test. Study 4B proposes to tag small rainbow trout to evaluate how they move in response to a BHBF test. These data support the ongoing monitoring of the Lees Ferry rainbow trout population.*

Strategic science questions: How is invertebrate flux affected by water quality and dam operations?

BHBF science question: How will a future BHBF test affect food production and availability for rainbow trout in the Lees Ferry reach? What are the effects of BHBF tests on aquatic food production? How do these effects impact native fishes? 3

Approach: *This study will sample the aquatic food base (algae, invertebrates) before and after the BHBF test to assess immediate changes that may occur. It will provide additional information to compare to the status of these resources in the context of the ongoing aquatic food base monitoring project.*

Strategic science questions: How is invertebrate flux affected by water quality and dam operations?

BHBF science question: Will the next BHBF test result in higher nutrient releases and shrinking of the hypolimnion? Will the operation of the river outlet works and the penstocks at capacity measurably alter Lake Powell hydrodynamics or stratification, or alter release water quality? 5

Approach: *This study will monitor water-quality parameters above and below the dam to assess any changes in these parameters that may occur because of the BHBF test. It will provide additional information to compare to the status of these parameters in the context of the ongoing Lake Powell water-quality monitoring project.*

Strategic science questions: Do dam controlled flows affect rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?

BHBF science question: Are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation following a disturbance? 2

Approach: *This study will monitor the fate of currently vegetated and open soil riparian areas in response to the BHBF test. It provides additional data to support the ongoing vegetation monitoring project.*