In cooperation with the Glen Canyon Dam Adaptive Management Program

Science Plan for Future Experimental Beach/Habitat Building Flows Released from Glen Canyon Dam

By Melis, T.S., Hamill, J.F., Andersen, M.E., Fairley, H.C., Topping, D.J, Draut, A.E., Rubin, D.M., Wright, S.A., Coggins, L.G., Gwinn, D.C., Ralston, B.E., Kennedy, T.A., Cross, W., Hall, R., Rosi-Marshall, E., and Vernieu W.S.

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Introduction

This science plan describes potential monitoring and research activities to be conducted by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) in the event that the Secretary of the Interior approves a high-flow experimental release, or beach/habitat-building flows (BHBF), from Glen Canyon Dam in the future. The GCMRC has responsibility for scientific monitoring and research efforts for the Glen Canyon Dam Adaptive Management Program (GCDAMP; program). The program is a federally authorized initiative to ensure that the mandates of the Grand Canyon Protection Act of 1992 are met through advances in information and resource management. Because of the lengthy lead time required to plan and execute a BHBF experiment, the Adaptive Management Work Group (AMWG)—the Federal Advisory Committee under the program that provides recommendations to the Secretary of the Interior on the operation of Glen Canyon Dam—recommended that the GCMRC develop this science plan in anticipation of future BHBF experiments. This plan is designed to build upon existing understanding to inform managers about the efficacy of using high flows to conserve not only sediment, but also related resources in Marble and Grand Canyons; it is not intended to be a complete and comprehensive long-term experimental plan (LTEP), but might be considered as one of several subcomponents of any future LTEP for evaluating the influence of BHBF tests over a decadal timeframe.

A BHBF, as defined by the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS), is a release of water from Glen Canyon Dam that is at least 10,000 cubic feet per second (cfs) greater than allowable peak discharge (30,000 cfs) but not greater than 45,000 cfs. The EIS termed these experimental releases beach/habitat-building flows because they were intended to, at least in part, mimic predam floods that previously maintained sandbars and related habitat throughout the Colorado River ecosystem (CRE)—the Colorado River corridor from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (figure 1.1). For the purpose of this science plan, these non-emergency high-flow dam releases shall be referred to as a BHBF or BHBF test. BHBF tests are considered bypasses or spills because they exceed normal powerplant capacity, and, to date, have been implemented only as tests to evaluate the degree to which beaches and sandbars can be maintained using this flow-only management strategy.

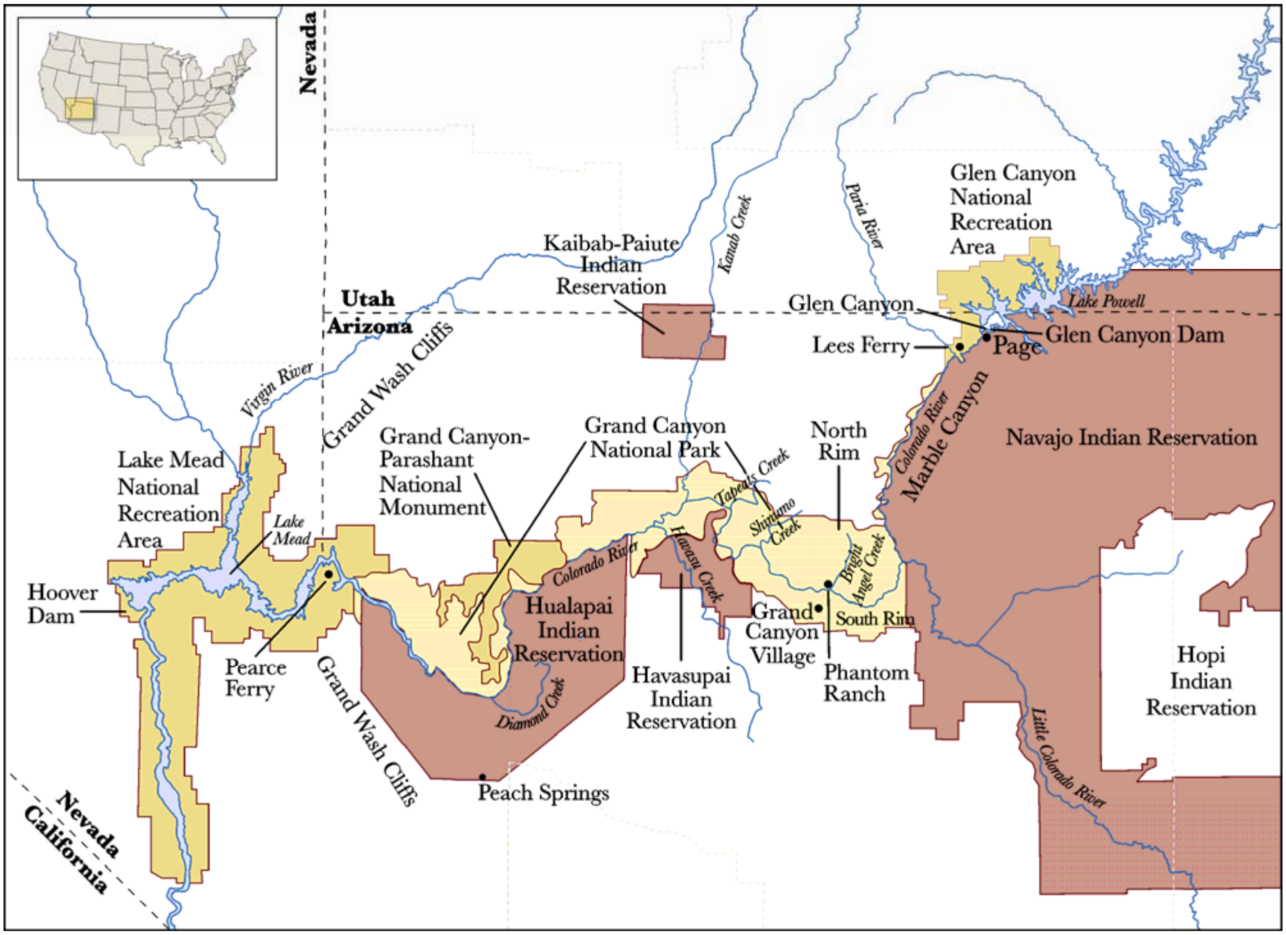

Figure 1.1. The Colorado River ecosystem encompasses the river corridor that extends from below Glen Canyon Dam to the western boundary of Grand Canyon National Park, Arizona.

Maintenance of sandbars in the CRE in the postdam era requires the periodic release of high flows from the dam to transfer sand from the channel into eddy-sandbar environments (Schmidt and others, 1999). In transferring sand to shorelines, BHBFs are known to form nearshore habitats, such as backwaters that structure the aquatic environment. BHBFs may also disadvantage nonnative fish (e.g., Minckley and Meffe, 1987), which are of concern because they are thought to compete with native species like the endangered humpback chub (*Gila cypha*) for food and prey on young native fish. Shoreline sandbar deposits that are built during BHBF tests are also sources of sand that can be transported by wind to areas upslope, which may protect archaeological resources from weathering and erosion. Conservation of sand resources, endangered humpback chub, and cultural resources found in the Colorado River ecosystem are primary goals of the Glen Canyon Dam Adaptive Management Program (U.S. Department of Interior, 1995; Patten and others, 2001).

Although this science plan primarily focuses on potential experimental studies associated with future BHBF tests, the plan also addresses concerns expressed by GCDAMP participants about issues related to future high-flow experimental research, particularly the associated costs and benefits. Appendix A presents the issues of concern, relevant information about these issues gathered during the science-planning process, and responses prepared by GCMRC scientists.

Efforts have been made to identify the pros and cons of future BHBF tests, which are also enumerated in appendix A.

Background

The most pressing question that sediment researchers have been asked to address for the program is whether it is possible to restore and maintain sandbar habitats in the Colorado River ecosystem over the long term solely through the manipulation Glen Canyon Dam releases. As articulated in GCMRC's strategic science plan (2007–11), the primary strategic science question driving sediment studies that justifies future BHBF testing is:

Is there a "flow-only" operation that will rebuild and maintain sandbar habitats over decadal timescales?

Despite continual advances in the understanding of the physical dynamics of the CRE that have accrued since the GCDAMP's inception more a decade ago, existing information and models are not yet capable of answering this question. Scientists have concluded that answering the question will require a commitment to an ongoing program of BHBFs (i.e., short duration dam releases of between 41,000 and 45,000 cfs) implemented at perhaps the same frequency as annual average to above-average new sand is provided to the system by tributaries to the mainstem Colorado River. Although sediment scientists believe that is the only potentially successful option, one to several additional BHBF tests are still required to fully evaluate the approach. 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 (2000a), 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).

The sediment-related data that researchers propose to collect for future high-flow tests will facilitate comparison with the data collected for BHBFs conducted in 1996 and 2004. Proposed experimental studies will also generate new data that can be compared to previous tests on the physical processes regulating sandbar erosion and deposition during BHBFs, sediment deposition at archaeological sites, ecosystem flux measurements related to organic tributary inputs, effects of flood disturbance on vegetation, and formation of backwater habitats used by native and nonnative fishes. These comparisons must be made to determine whether greater and more geographically extensive sandbar rebuilding is possible with future BHBFs than occurred during the 1996 and 2004 tests. The results have implications for native fish survival, cultural resource preservation, and habitat enhancement benefits for other high-priority aspects of the Colorado River ecosystem. Fully answering the strategic sediment science question posed above will obviously require additional data collection than proposed in this experimental science plan, and these additional data will likely only be collected during future monitoring activities, which could occur through 2009 and beyond.

2004 High Flow Findings

In September 2002, the U.S. Department of the Interior approved implementation of new BHBF testing on the basis of triggering thresholds linked to sand inputs from the Paria River. This new experimental strategy was adopted on the basis of new findings about CRE sediment-transport behavior following the 1995 EIS and the 1996 BHBF test that indicated the annual sand input from tributaries was not accumulating over multiyear periods under the modified low fluctuating flow

(MLFF) alternative (Wright and others, 2005). The new experimental paradigm focused on evaluating how effectively high-flow releases might be used to move new sand up onto shorelines before it was flushed downstream. The sand input trigger was specifically targeted to be a volume of sand from the Paria River that, on average, would occur about every other year. The only BHBF experiment 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. Approval of a supplemental environmental assessment paved the way for the BHBF test that began on Sunday, November 21, 2004.

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 (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). 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 BHBF test 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. Rather, the most promising method of rebuilding sandbars systemwide over the long term is by following each average to above-average tributary input of sand with a short-duration BHBF (Topping and others, 2006a). Under this scenario, each subsequent BHBF test presumably builds upon the 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 during these BHBFs. Since theory and monitoring data for 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 future 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. This science plan assumes that sufficient long-term sediment monitoring will occur during 2008 and beyond, which will supplement BHBF test evaluations, to allow scientists to investigate the effects of dam operations that occur between BHBF tests.

In terms of archaeological resources, earlier studies (e.g., Hereford and others, 1996; Draut and others, 2005) showed that many prehistoric cultural sites found in Grand Canyon are not only built on Colorado River flood deposits, but also are buried by windborne sand derived from river-deposited sediment that has helped to preserve them over time. Results following 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.

Summary of Key Findings from the 2004 BHBF Test

- Although substantially more sand was present in suspension in upper Marble Canyon during the 42,000 cfs 2004 BHBF test than during the 45,000 cfs 1996 BHBF test, there was less sand in suspension further downstream during the 2004 BHBF than during the 1996 BHBF (Topping and others, 2006).

- During the 2004 BHBF, net transfer of channel sand into eddies resulted in an increase in sandbar total area and volume in the upper half of Marble Canyon. Further downstream, where sand was less abundant, the response of eddy sandbars during the 2004 BHBF test was similar to that observed throughout Marble and Grand Canyons during the 1996 BHBF—net transfer of sand out of eddies (Topping and others, 2006).

- Substantial increases in total eddy-sandbar area and volume (such as those observed in the upper half of Marble Canyon following the 2004 BHBF) are only possible during BHBFs conducted under the sand-enriched conditions that follow large tributary floods (Rubin and others, 2002; Topping and others, 2006).

- After the 2004 BHBF, where substantial flood sediment still remained until the subsequent spring windy season, windborne sand transport was significantly greater than in the previous spring given comparable wind conditions (Draut and Rubin, 2006). Sediment-rich BHBFs can increase windborne transport of sand toward some locations in Grand Canyon that contain archaeological material, thereby reducing gully erosion and increasing the preservation potential of these sites.

Recommended Magnitude, Timing, and Duration of Future BHBF Tests

Following the 2004 BHBF test, the sand input trigger was reevaluated by the GCMRC and the Science Planning Group (SPG) and revised to include sand inputs from the Little Colorado River (LCR) 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 (RM) 30 and an additional “weighted” 0.5 million metric tons of sand are delivered by the Paria and Little Colorado Rivers, or sources that enter the ecosystem annually in between these two primary tributaries and are retained upstream of Diamond Creek (RM 226). To calculate the weighted input, sand from the Paria River is given full value and sand from the LCR and other sources is valued at 50% of the actual input. Thus, a BHBF 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 might occur below Marble Canyon from the LCR 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 BHBFs from occurring at times when the Marble Canyon has not had any annual sand inputs. Under the revised triggering criteria, repeated experiments might occur more frequently and would facilitate a more rapid evaluation of whether or not cumulative sandbar deposition occurs on a systemwide basis through time.

Seasonal Timing: Considerations about Biology and Cultural Resources

The optimal timing of future BHBF tests is dependent on the timing of tributary inputs as well as flow releases from the dam, which are in turn dependent on basin hydrology. The optimal timing for a BHBF in one year may not be the same as in another year. In general, the optimal timing is when the most new tributary-derived sand is available throughout the system.

Historically, the largest Paria River inputs have occurred during the later summer and fall thunderstorm season. For the Little Colorado River, large inputs may occur during the late summer and fall thunderstorm season as well as during springtime floods. The rate at which the tributary-derived sand is exported downstream to Lake Mead is dependent on the availability of the new sand as well as flow 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). The majority of sand in a moderate input is predicted to be lost within days (at discharges of >35,000 cfs), weeks (at discharges of ~25,000 cfs), or months (at discharges of ~15,000 cfs); however, at discharge rates of 10,000 cfs or less sand is retained for periods of months to years. As discussed previously, the new sand will only be available for BHBF tests, if the BHBF occurs shortly after new sand enters the system or if dam releases are constrained; however, as noted above, 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 later in the winter or early spring, which will allow sand from the Paria and Little Colorado Rivers to accumulate throughout the various sediment 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 (i.e., less fluctuation leads to more retention and thus more flexibility in BHBF timing).

Peak Flow Magnitude

Consistent with the 1995 EIS (U.S. Department of the Interior, 1995), as well as previous BHBFs in 1996 and 2004, future tests should be conducted in the range of 41,500 to 45,000 cfs, or possibly higher when Lake Powell storage is high enough to reach the spillway gate elevations, to promote the most robust conservation of sand at higher elevations along the river banks. Replication of the 2004 peak magnitude of 41,500 cfs during future BHBF tests has the most likelihood for supporting comparative analyses intended to determine the potential for using sand-enriched high flows to build and maintain sandbar habitats.

Peak Flow Duration and the Lag Time Phenomenon

The concept of replicating the 2004 BHBF test hydrograph 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. This, along with data collected from the 1996 BHBF test, was the basis for choosing 60 hours as the reduced duration for peak flow, which is down from 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 seeks to determine if the locally robust and consistent sandbar building responses that occurred in upper Marble Canyon as the result of the 2004 BHBF test will occur consistently. Scientists will also examine the downstream progression of sandbar building each time a BHBF is released under locally sand-enriched conditions. By reproducing the 2004 test hydrograph in future BHBF tests, scientists would also be able to evaluate if there are cumulative benefits to sandbar conservation in lower Marble Canyon and Grand Canyon each time sand-enriched BHBFs 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 lasted for only 30 hours. Exact predictions about the outcome of a BHBF with a shorter duration are not possible at this time without field experimentation. Predictability is limited because current sediment models have limited utility in making such predictions and 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 also acknowledge that future BHBF tests with durations of not less than 30 hours would also provide sufficient data collection to advance learning about BHBFs and sediment dynamics. In table A.2 of appendix A the GCMRC compares of the pros and cons associated with a 60-hour versus 30-hour peak high-flow test duration.

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 a 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 240 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 test, except with even less sand available in downstream reaches owing to continued sand export between 1996 and 2004.

Although the fall 2004 dam releases that preceded the 2004 BHBF test (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, sediment scientists now suggest the need for some period of normal dam operations following the input of new sand to allow some redistribution of new sand before to conducting future BHBF tests. Allowing the sand to be redistributed before a BHBF test might produce more optimal sandbar building than occurred during the 2004 test. 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 Canyon reach as the fast-moving flood wave propagates downstream. If the results from replicating the 2004 hydrograph under sand-enriched conditions in the spring following one to several months of downstream sand transport under Record of Decision operations are as positive as those measured in 2004, then this approach may be interpreted as being a sustainable strategy for longer term habitat rebuilding and maintenance (see figure 1.2). Positive in this case means that the BHBF test produces more uniformly distributed sandbar responses under conditions of more uniformly distributed sand supply downstream or deposition progressing farther downriver with successive floods as upriver eddies become filled.

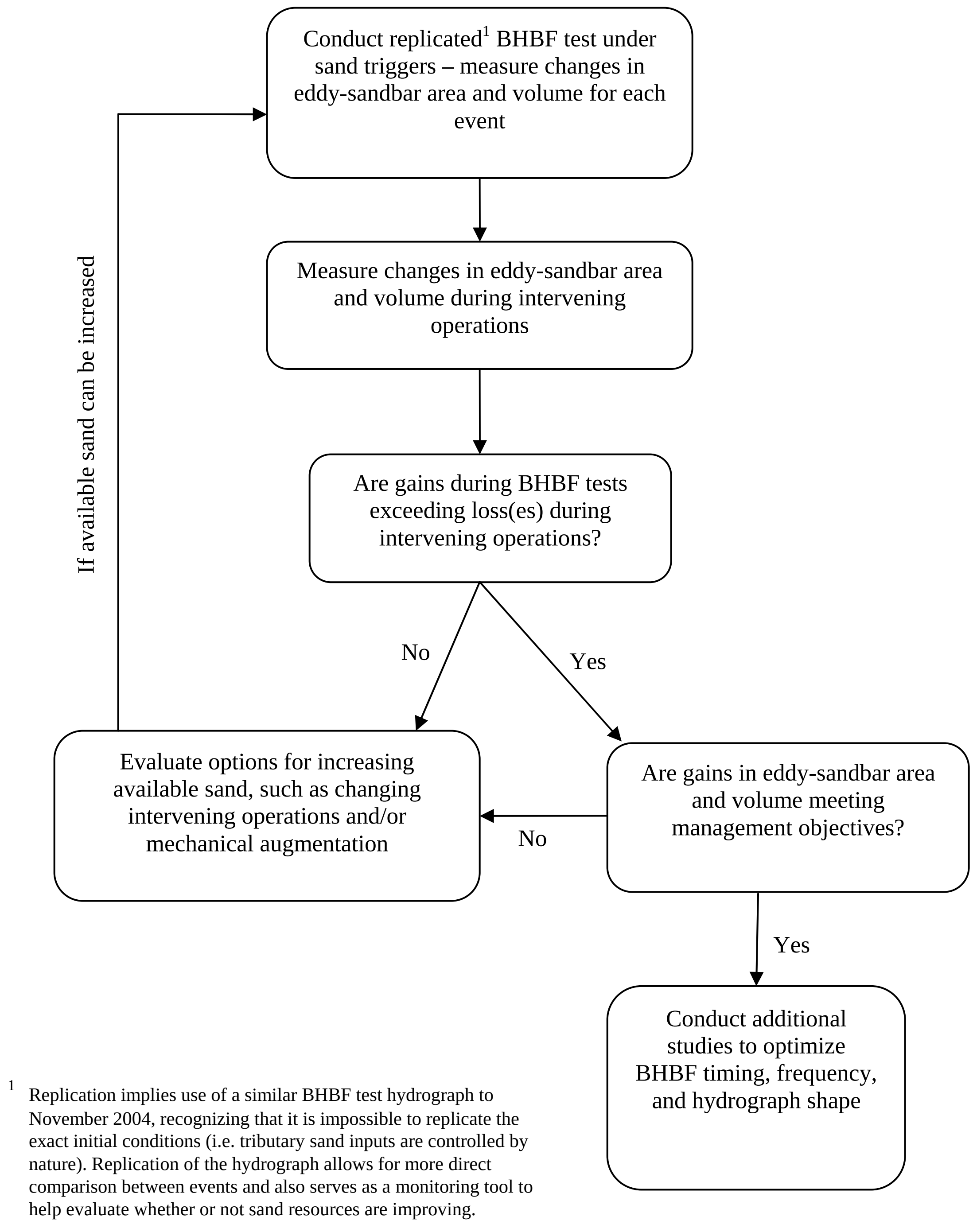

Figure 1.2. Flow chart for evaluating future BHBF test results intended to test the concept of "flow only" operational treatments combined with tributary sand supplies below Glen Canyon Dam to restore sandbar habitats and related resources.

Integrating Research and Monitoring for Future BHBF Research Studies

Previous BHBF tests in 1996 and 2004 consisted of several physical, biological, and sociocultural studies; however, these studies were not fully coordinated to achieve objectives for integrating data and interpretive results. Developing a more integrated research and monitoring program in the future is a major goal of the GCMRC during the next phase of its strategic science initiative (2007–11). Several science planning meetings between GCMRC scientists and cooperators in 2006 resulted in a more integrated study plan than those associated with previous BHBF experiments. For instance, sediment studies have been more closely integrated between suspended-sediment flux measurements, eddy sandbar and flow and sand deposition measurements, and modeling activities. Further, sociocultural elements and objectives related to the fate of new sandbars following a BHBF test, particularly with respect to secondary aeolian transport into archaeological sites (tied to better meteorological data), have been integrated into the core sediment study plan (see linked elements of experimental studies 1.A, 1.B, and 1.C).

Links between sediment and biological studies are also highlighted. For example, this science plan includes closely coordinating the study of riparian vegetation dynamics with sandbar sedimentology and fine-sediment flux data (see experimental study 2). Efforts to explore how BHBFs affect lower trophic levels (experimental study 3) has several study components, each of which is intended to interface with sediment project components. In particular, experimental study 3 is concerned with studying the fate of organics, the tributary derived debris (wood, seeds, and other organic materials) that enters the ecosystem with sediment inputs, and its movement through the river corridor. Previous studies have documented that much of this organic carbon becomes deposited within new sandbar deposits that may persist in buried beaches for extended periods, but none of the previous research has been linked to whole system carbon budgets. This information will be critical for ultimately measuring the effect of BHBF tests on inputs, retention, and export of organic matter that fuels river food webs.

In several cases, the experimental studies proposed here have also been coordinated with ongoing monitoring efforts, such as the systemwide inventory of backwaters that occurs each September to sample these habitats for fish presence and abundance (work consistently repeated each fall since 2002). Future inventories of backwaters will provide valuable distribution, size, and abundance data about fish using these habitats within several months of future BHBF tests.

The Grand Canyon fish community is actively monitored annually. This information helps evaluate the impacts of BHBF tests on this resource. Scientists at the GCMRC are actively working on additional methods to help further evaluate the fish community before and after BHBF tests (see appendix C). Experimental study 4.A is focused on nonnative rainbow trout, but the study also includes the involvement of physical scientists and flow modeling to answer questions about how high flows transport gravel in the Lees Ferry reach, a process that could have implications for redd mortality and recruitment of nonnative fishes that might influence downstream predator/prey and competition interactions between humpback chub and salmonids. Finally, experimental study 5 attempts to document changes in Lake Powell and resultant downstream quality of water; data that is intended to inform productivity studies associated with experimental study 3.

Experimental Studies

This science plan describes the suite of additional research and monitoring activities thought to be desirable, feasible, and necessary to interpret and understand the effects of conducting BHBF tests during sand-enriched conditions on key CRE resources. The experimental studies presented in this plan are designed to explore and possibly answer a number of scientific questions that are priority concerns identified by the Adaptive Management Work Group (table 1.1). In some cases, current technologies and methods were found to be inadequate for answering these priority questions, such as predicting the influence of future BHBF tests on native fish populations. Appendix B identifies ongoing monitoring and research activities associated with various resources, the challenges that confronted scientists in attempting to develop this science plan, and other considerations that influenced the selection of the experimental studies identified here.

Table 1.1 Scientific questions identified as a priority by the Adaptive Management Work Group

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SEDIMENT

- Is there a "flow-only" operation that will restore and maintain sandbar habitats over decadal timescales?
- What is the minimum duration for BHBFs needed to build and maintain sandbars under sand enrichment?
- Do sandbars deposited by BHBFs contribute to preservation of archaeological sites in the river corridor?
- How do post BHBF flows affect the persistence of sandbars and related backwater habitats?

HUMPBACK CHUB

- Do BHBFs result in creation of nearshore habitats (i.e. backwaters) that can offer physical benefits to humpback chub and other native fishes?
- Do BHBFs affect the distribution and movement of nonnative fishes?
- What are the effects of BHBFs on aquatic food production? How do these effects impact native fishes?

CULTURAL RESOURCES

- Do sandbars deposited by BHBFs contribute to preservation of archaeological sites in the river corridor?
- Do BHBFs contribute to added stability or erosion of archaeological sites located in close proximity to the river?
- How does the abundance and distribution of native and nonnative riparian species important to Native American tribes change in response to a BHBF?

RAINBOW TROUT

- Are individual rainbow trout displaced from the Lees Ferry reach as a result of a BHBF? If so, do displaced rainbow trout return to the reach, or do they establish residence elsewhere?

OTHER PRIORITY ISSUES

- **Food base:** How do BHBFs affect food production and availability for rainbow trout in the Lees Ferry reach?
- **Lake Powell:** Will BHBFs 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?
- **Riparian vegetation:** Are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation following a disturbance?
- **Kanab ambersnail:** Will BHBFs reduce habitat at Vaseys Paradise in a way that impacts the ambersnail population?
- **Camping beaches associated with sandbars:** Can BHBFs increase campable areas at sandbars on a sustainable basis?

The experimental studies presented in this science plan also recognize that resource responses are driven not only by the physical effects of the high flows but also by interrelation among resources. As a result, this plan integrates the evaluation of the high-flow effects across multiple resources.

The experimental studies identified below are in addition to or represent an expansion of ongoing research and monitoring activities typically included in the GCMRC's annual work plans. The implementation of research and monitoring activities associated with proposed experimental studies will represent a substantial undertaking by the GCMRC, cooperators, and contractors. To adjust to the increased workload that occurs in years when BHBF tests take place, the GCMRC proposes to increase the activities of existing contractors and cooperators and add additional onsite contractors to the degree feasible and affordable and to temporarily add technical staff to existing projects. When essential, new agreements and contracts would also be established for appropriate periods to accomplish the new research related to BHBF tests. Clearly the additional personnel, equipment, and supply costs associated with a BHBF test will require additional funding.

A description of each proposed experimental study follows, including the program goals and management objectives each study is designed to advance and the projected cost of each activity. Each study description includes a section that identifies links to other studies that are designed to promote integrated, cross-disciplinary science collaborations and outcomes.

These studies are briefly summarized along with estimated costs in table 1.2.

Table 1.2 Summary of proposed studies and estimated costs associated with future integrated beach/habitat-building flows (BHBF) tests.

BHBF Related Science Projects	Goal Associated with Study	Hypotheses	Estimated Cost
SEDIMENT/CULTURAL STUDIES A - Sand Budgeting	A – Sand Budgeting: (1) reach-based accounting of input vs. export during the BHBF test, (2) longitudinal patterns of erosion and deposition of sand, and (3) changes in sediment grain size related to enrichment/depletion of sand.	A - Sand Budgeting: BHBFs with sand enrichment similar to the 2004 test will result in bar building comparable to that observed during the 2004 BHBF test. If true, then sand budget will be positive between river-miles 0 and 30 for the period bracketing the tributary inputs of sand and the BHBF test. If reaches downstream from river-mile 30 are sand-enriched relative to the 2004 test, then bar building in these reaches will be greater than was observed in these reaches during the 2004 test and the sand budgets in these reaches will also be more positive than in 2004.	A&B - Sediment: ~$573,000
B - Sandbar Depositional Rates	B – Sandbar Deposition Rates: Improve understanding of time evolution of eddy sandbars and rate of deposition or erosion of eddy sandbars during BHBFs to determine optimal BHBF peak duration necessary to achieve management goals.	B - Sandbar Deposition Rates: Sand deposition rates during BHBFs are regulated by (1) interaction of the flow field with the antecedent bed topography and (2) the upstream sand supply. At a given location and for a given BHBF hydrograph, sandbars grow over time if upstream sand supply is sufficiently large; conversely, if upstream sand supply is insufficient, then sandbars will erode.	
C.1 - Sandbar Fate: Topographic and Grain-size Responses C.2 - Sandbar Fate: Effects of new Sand Deposits at Cultural Sites	C – Sandbar Fate: (1) determine if BHBFs conducted under sediment-enriched conditions can maintain/sustain eddy sandbars and	C.1 - Sandbar Fate: BHBF tests under sand enrichment like those prior to the 2004 test result in bar building and low-elevation gully infilling	C - Sediment/Cultural: ~$618,000

C.3 - Sandbar Fate: Changes in Campable Area	campsites, and (2) whether increased aeolian flux of sand from larger sandbars produced during sand-enriched BHBFs can maintain downwind (but upslope) archeological sites.	comparable to that observed during 2004 test. C.2 - If reaches downstream from river-mile 30 are more sand-enriched compared to pre-2004-test conditions, then bar building and gully infilling in these reaches will be greater than was observed in these reaches during the 2004 test. C.3 – Larger, dry sandbars will result in increased aeolian flux of sand to downwind archaeological sites, thereby increasing their preservation potential.	
AQUATICS - FISH AND FOOD STUDIES Fish – A - Lees Ferry Reach Rainbow Trout Redds Studies B – Rainbow Trout Movement Studies in Glen and Marble Canyons Food Production - - BHBF effects on lower trophic	Fish A - Determine how high flows affect spawning survival of early life history stages of rainbow trout in the Lees Ferry reach. B - Determine if a BHBF causes displacement of rainbow trout from the Lees Ferry trout fishery into Marble Canyon and Grand Canyon B - Determine if such displacement is experienced differentially among different length fish B - Provide a platform for Grand Canyon scientists to develop skills with acoustic technologies that can be applied to answering questions about native and nonnative fish movement, distribution, and sampling efficiencies. Food Production To determine whether a BHBF has a	Fish A - High flows will scour redds but the effect on the juvenile rainbow trout population will be limited because of compensatory survival responses. A - High flows will alter the distribution of age-1 fish in the Lees Ferry reach resulting in either higher mortality or migration out of the reach. B - BHBF will result in displacement of trout from the Lees Ferry reach into Marble Canyon and Grand Canyon. B - The redistribution of trout will be inversely related to size Food Production A short duration BHBF in spring	Fish: ~$150,000 Food Production: ~$155,000

levels (i.e., algae and invertebrates) in the Colorado River ecosystem	neutral, negative, or positive effect on the quantity and quality of food available for invertebrates, and ultimately fishes.	initially scours the river bottom causing reductions in algal biomass, but the new algal community is of higher quality, more productive, and is assimilated more efficiently by invertebrate consumers, leading to an increase in annual invertebrate production.	
OTHER STUDIES Native/nonnative diversity and richness - Lake Powell: Influence of BHBF on Lake Powell QW	Native/nonnative diversity and richness – Compare native/nonnative diversity in established and reworked depositional environments along a hydrological gradient following a high-flow test. Lake Powell – Determine how BHBF will alter QW in tailwaters of GCD and Lake Powell fore bay	Native/nonnative diversity and richness – Native/nonnative species richness ratios are the same across all habitats and surface elevations. A: The ratio between native/nonnative richness and cover at established sites will not change following disturbance Bare areas will have similar ratios Surface elevation will not have an affect on native/nonnative richness and cover values. B: The ratio between native/nonnative richness and cover at sites with established vegetative communities will shift toward an increase in nonnatives due to the increased nutrient availability associated with the disturbance. Native/nonnative richness and cover ratios will change by surface elevation with nonnative species decreasing with increasing surface elevations in relation to available soil nutrients. Bare areas will favor nonnative species across all surface elevations. Lake Powell – BHBF will result in higher nutrient releases and shrinking of the hypolimnion	Seed Dispersal: ~$50,000 Lake Powell: ~$3,000

CONSERVATION MEASURES			
- Kanab Ambersnail Habitat	KAS – habitat at Vaseys Paradise	N/A	KAS: ~$8,000
- Archeological Sites	Arch Site Mitigation – Glen Canyon site	N/A	Cultural Sites: ~$75,000
Public Outreach Activities		N/A	Public Outreach: ~$15,000
			TOTAL = $1,647,000

Part 2: Experimental Study Descriptions

Experimental Study 1.A: Reach-scale changes in the fine-sediment mass balance and grain size during BHBF Tests

Duration

20 months

Principal Investigator(s)

David Topping, USGS WRD-National Research Program, and David M. Rubin, USGS GD-Western Coastal and Marine Geology

Geographic Scope

River miles 0 through 226

Project Goal(s)

This project documents the following: (1) reach-based sediment budgeting during future BHBF tests, (2) longitudinal patterns of net erosion and deposition of sand, and (3) temporal and spatial changes in sediment grain size related to enrichment/depletion of sediment during future BHBF tests.

Need for Project

Detailed measurements of sediment flux and grain size are required to evaluate whether one or more future BHBF tests conducted under sand-enriched conditions can be used to maintain/sustain eddy sandbars in the Colorado River ecosystem. These data are also required for continued development/verification of predictive physically based sediment-transport models.

Strategic Science Question(s)

> **4.1** Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?

Working Hypotheses

Future BHBF tests conducted under magnitudes and longitudinal distributions of sand enrichment similar to those that existed before the 2004 BHBF test will result in sandbar building comparable to that observed during the 2004 BHBF test. If this is the case, the sand budget computed under this project will be positive between river miles 0 and 30 for the period bracketing the tributary inputs of sand and future BHBF tests. If reaches downstream from river mile 30 are sand enriched relative to their condition before the 2004 BHBF test, then sandbar building in these downstream reaches will be greater than was observed in these reaches during the 2004 BHBF test.

Methods

Hydrodynamic, sediment transport, grain size, temperature, conductivity, and turbidity data are to be collected at five locations (Lees Ferry gaging station, river mile 30, river mile 61, Grand Canyon gaging station, and above Diamond Creek gaging station) and on two Lagrangian river trips (tracking the water between river miles 0 and 226). Suspended-sediment data are collected using both conventional and laser-acoustic methodologies. Stage, discharge, and water-quality data are to be collected using standard USGS methodologies. Similar work conducted during the 1996 and 2004 BHBF tests and 2000 low summer steady flow experiment is described in Konieczki and others (1997), Rubin and others (1998, 2002), Topping and others (1999, 2000a, 2000b, 2006a, 2006b), Rubin and Topping (2001), and Hazel and others (2006). Analyses (as described in Rubin and others, 1998, and Topping and others, 1999, 2006b) of sediment-transport and sand grain-size data, and analyses of reach-based sand budgets will be used to evaluate the results of future BHBF tests relative to the BHBF tests conducted in 1996 and 2004. If the working hypotheses are supported by these analyses, then rebuilding and maintenance of sandbars might be possible through use of repeated future BHBFs conducted under sand-enriched conditions. If the working hypotheses are rejected by these analyses, then flow and non-flow strategies in addition to or other than BHBFs may be needed to restore and maintain sandbars in the Colorado River ecosystem (further constraint of operations, sediment augmentation, or a combination of both).

Links/Relationship to Other Projects

This project builds on the large quantity of previous published work on sediment transport, erosion, and deposition in the Colorado River ecosystem downstream from Glen Canyon Dam. It is also linked to several BHBF-related physical, sociocultural, and biological projects, including experimental studies 1.B (Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during future BHBF tests), 1.C (Response of sandbars and selected cultural sites to BHBF tests conducted under sediment-enriched conditions), 2 (Evaluate effect of future BHBF tests on riparian plant community development at multiple surface elevations and depositional environments), and 3 (future BHBF test effects on lower trophic levels in the CRE). Work conducted under this project will also be used by the ongoing project of the USGS's Lew Coggins, Scott Wright, and Nick Voichick relating fish-catch rates to suspended-sediment concentration and grain size.

Information Needs Addressed

The project will directly address multiple information needs, for example, as follows:

EIN 8.1.1 How do fine sediment abundance, grain-size, and distribution in the main channel below 5,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 8.3.1 How does fine sediment abundance, grain-size, and distribution, within eddies below 5,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 8.4.1 How does fine sediment abundance, grain-size, and distribution, within eddies between 5,000 to 25,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

RIN 8.5.1 What elements of Record of Decision operations (upramp, downramp, maximum and minimum flow, MLFF, HMF, and BHBF) are most/least critical to conserving new fine-sediment inputs, and stabilizing sediment deposits above the 25,000 cfs stage?

RIN 8.5.2 What is the reach-scale variability of fine-sediment storage throughout the main channel?

RIN 8.1.3, **RIN 8.2.1, RIN 8.3.1**, **RIN 8.5.6** What fine sediment abundance and distribution, by reach, is desirable to support GCDAMP ecosystem goals? [Note: Definition of “desirable” will be derived from targets for other resources and managers goals.]

RIN 7.3.1 Develop simulation models for Lake Powell and the Colorado River to predict water quality conditions under various operating scenarios, supplant monitoring efforts, and elucidate understanding of the effects of dam operations, climate, and basin hydrology on Colorado River water quality.

Products/Reports

Several peer-reviewed journal article(s) and/or USGS report(s) will be produced based on the findings of one or more future BHBF studies within 12–18 months of the BHBF testing.

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

FUNDING HISTORY	Fiscal year					
	2006	2007	2008	2009	2010	2011
Outside GCMRC Science/Labor		$118,200	$26,000			
Logistics Field Support		$110,000	-0-			
Project Related Travel/Training		$7,000	$5,000			
Operations/Supplies		$12,000	$15,000			
GCMRC Salaries		$30,000	$30,000			
Project Subtotal		$277,200	$76,000			
GCMRC overhead		$35,300	$14,500			
Project Total		$312,500	$90,500			
% Total Outsourced		43%	34%			

Experimental Study 1.B: Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during BHBF tests

Duration

20 months

Principal Investigator(s)

Scott Wright, USGS-WRD California Water Science Center; Mark Schmeeckle, Arizona State University; and Matt Kaplinski, Northern Arizona University

Geographic Scope

Middle Marble Canyon around Eminence (river mile 45)

Project Goal(s)

The goal of this project is to improve our understanding of the time evolution of eddy sandbars during future BHBF tests. Knowledge of the rate of deposition or erosion of eddy sandbars during future BHBF tests will assist in the determination of the optimal BHBF hydrograph shape for a given sand-supply condition to achieve sandbar resource management goals, while minimizing negative impacts to other resources (e.g., hydropower).

Need for Project

The development of predictive capabilities for the evolution of eddy sandbars, a primary recommendation of the August 2006 sediment protocol evaluation panel (Wohl and others 2006), has been limited by a lack of information on hydrodynamics, sediment transport, and bathymetry during future BHBF tests. The lack of predictive capability has in turn limited our ability to provide definitive recommendations related to experimental BHBF peak discharge and duration. The existing eddy model (Wiele and others, 1996; Wiele, 1998) has been tested only with before and after bathymetry downstream from the Little Colorado River following floods in 1993. Also, initial investigations of eddy hydrodynamics and sediment transport during the November 2004 BHBF test indicate that some of the assumptions in the existing model are not supported by the data (Wright and Gartner, 2006). Thus, detailed data are needed on eddy hydrodynamics and morphology during future BHBF tests, if we are to improve our predictive capabilities and thus improve our ability to identify future BHBF characteristics that most effectively rebuild and maintain available sand resources and related habitats.

Strategic Science Question(s)

4.1-1 Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

4.1-1a What are the short-term responses of sandbars to BHBFs?

4.1-1b What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?

4.1-1c What are the effects of ramping rates on sediment transport and sandbar stability?

Working Hypotheses

Sand deposition rates in eddies during future BHBF tests are regulated by (1) the interaction of the flow field with the antecedent bed topography and (2) the upstream sand supply. At a given location for a given BHBF hydrograph, an eddy sandbar will grow over time if the upstream sand supply is sufficiently large; conversely, if the upstream sand supply is insufficient, an eddy sandbar will erode over time.

Methods

This project collects hydrodynamic, sediment transport, bathymetric, and load-cell data at several eddy sandbars in middle Marble Canyon in order to improve our understanding of eddy-sandbar hydrodynamics and evolution during future BHBF tests.

We will use two separate methods to collect information on (1) the detailed temporal evolution of eddy sandbars at a sparse spatial resolution, and (2) the detailed spatial structure of hydrodynamics, sediment transport, and bathymetry at a sparse temporal scale. Ideally, sites throughout Marble and Grand Canyons would be studied during a single BHBF, but this is not logistically feasible. As a compromise, sites in middle Marble Canyon will be studied because (1) results from the November 2004 BHBF test indicate that eddies in this reach may provide varied responses, and (2) there are several eddy sandbars close to each other that have been studied previously as part of the Northern Arizona University long-term sandbar monitoring and the Integrated Fine-Sediment Team (FIST) projects.

The detailed temporal evolution of eddy sandbars at a sparse spatial resolution will be measured by deploying an array of load sensors in three eddy sandbars in the reach around river mile 45 (Eminence). The load sensors proposed for use here were used successfully for this purpose in Grand Canyon during the 1996 BHBF test (Carpenter, 1996) and for monitoring the infilling of spawning gravels with fine sediment (see http://www.rickly.com/ss/scoursensor.htm for a product description). The study team proposes to bury 3–4 load sensors within each eddy sandbar at different elevations to capture deposition or erosion that occurs during the rising limb, peak, and falling limb of the experimental BHBF hydrograph.

The detailed spatial structure of hydrodynamics, sediment transport, and bathymetry at a sparse temporal scale will be measured with a sonar system and an acoustic doppler current profiler (ADCP) using automated shore-based boat position tracking. The study area is within a FIST project reach, so the survey control is already established. The team will map the eddy sandbars where the load sensors are deployed as frequently as possible under the logistical constraints. At minimum, we plan to obtain a map of each eddy sandbar before future BHBF tests, during the rising limb, on the peak, during the falling limb, and after future BHBF tests. The ability to get multiple maps during a given segment will depend on the timing of experimental BHBFs (i.e., mapping will only be possible during daylight hours) and the peak duration. Each survey will result in a bathymetric map of the eddy sandbar and a map of the time-averaged 3-dimensional velocity structure of the eddy. Additionally, the team will collect sediment samples and attempt to calibrate the acoustic backscatter from the ADCP to suspended-sand concentration (we have had success with this in the past; see Topping and others, 2006). If successful, we will further develop maps of time-averaged suspended-sand concentration within each eddy for each survey, which, when combined with the velocity maps, will allow us to generate maps of the time-averaged flux of suspended-sand within the eddy.

Links/Relationship to Other Projects

This project is linked closely to previous and ongoing work related to numerical modeling eddy-sandbar morphology. The data acquired through this initiative has the potential to significantly enhance ongoing and potential future developments of numerical models of eddy-sandbar responses to high-flow releases from the dam. The project is also linked to several other experimental BHBF-related physical, sociocultural, and biological projects by providing sediment transport data, eddy-sandbar bathymetry, and eddy-sandbar hydrodynamics and morphology, including experimental studies 1.A (Reach-scale changes in the fine-sediment mass balance and grain size during future BHBF tests), 1.C (Response of sandbars and selected culture sites to BHBF tests conducted under sediment-enriched conditions), 2 (Evaluate effect of future BHBF tests on riparian plant community development at multiple surface elevations and depositional environments), and 3 (BHBF testing effects on lower trophic levels in the CRE).

Information Needs Addressed

The project will directly address several experimental and research information needs, as follows:

> **EIN 8.3.1** How does fine sediment abundance, grain-size, and distribution, within eddies below 5,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 8.4.1 How does fine sediment abundance, grain-size, and distribution, within eddies between 5,000 to 25,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

RIN 8.5.1 What elements of Record of Decision operations (upramp, downramp, maximum and minimum flow, MLFF, HMF, and BHBF) are most/least critical to conserving new fine-sediment inputs, and stabilizing sediment deposits above the 25,000 cfs stage?

RIN 7.3.1 Develop simulation models for Lake Powell and the Colorado River to predict water quality conditions under various operating scenarios, supplant monitoring efforts, and elucidate understanding of the effects of dam operations, climate, and basin hydrology on Colorado River water quality.

Products/Reports

One or more peer-reviewed journal article(s) or USGS report(s) will be produced based on the findings of this study.

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

FUNDING HISTORY	FY 2007	FY 2008
Outside GCMRC Science/Labor	$52,820	$74,779
Logistics Field Support & MPS	$17,000	
Project Related Travel/Training	$1,000	$2,000
Operations/Supplies	$11,000	$2,000
GCMRC Salaries		
Project Subtotal	$81,820	$78,779
DOI Customer Burden (6–17%)	$7,183	$1,430
Project Total	$89,003	$80,209
% Total Outsourced	65%	95%

Experimental Study 1.C: Response of sandbars and selected cultural sites to Future BHBF Tests conducted under sediment-enriched conditions

Duration

20 months

Principal Investigator(s)

David Rubin and Amy Draut, USGS GD-Western Coastal and Marine Geology; Rod Parnell, Matt Kaplinski, and Joe Hazel, Northern Arizona University; David Topping, USGS WRD-National Research Program; and Jack Schmidt, Utah State University

Geographic Scope

Numerous fan-eddy complexes, with associated campsites, and select cultural sites between river miles 0 and 226

Project Goal(s)

The goals of this project are to determine: (1) whether future BHBF tests conducted under sediment-enriched conditions can be used to maintain/sustain eddy sandbars and associated campsites in the Colorado River ecosystem, and (2) whether sediment deposited in arroyo mouths and/or increased aeolian flux of sand from the larger eddy sandbars produced during sand-enriched BHBF tests can offset ongoing erosion of archeological sites, thereby contributing to their preservation potential.

Need for Project

This project is required to document whether future BHBF tests conducted under sediment-enriched conditions can be used to maintain/sustain eddy sandbars and associated campsites and archaeological sites in the Colorado River ecosystem (Topping and others, 2006). Furthermore, this project will address whether such BHBFs can be used to hinder arroyo development or expansion in areas that contain cultural resources. BHBFs can result in partial to full infilling of arroyos either directly (by deposition of sand in arroyos during BHBFs) or indirectly (by increases in sandbar area leading to increased aeolian sand transport upslope into areas containing cultural sites). In addition, previous work has shown that the grain size of eddy-sandbar surfaces is the most important regulator of sand transport in the Colorado River over multiyear timescales (Topping and others, 2005) and that the coarsening of the channel bed and sandbar surfaces reduces the subsequent export of sand from the system. Data will be collected as part of this project to further advance our understanding of these effects. The documentation of effects of flow management options on aeolian sand transport provides necessary follow-up data to the observed effects of the 2004 BHBF test (Draut and Rubin, 2006) and also complements ongoing investigations by researchers from Utah State University on processes that affect gully incision in sediment deposits in the river corridor.

Strategic Science Question(s)

4.1 Is there a "Flow-Only" operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

4.1a What are the short-term responses of sandbars to BHBFs?

4.1b What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?

2.1 Do dam controlled flows increase or decrease rates of erosion at archeological sites and TCP sites, and if so, how?

2.3 If flows contribute to archeological site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?

3.9 How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?

Working Hypotheses

Future BHBF tests conducted under magnitudes and longitudinal distributions of sand enrichment similar to those before the 2004 BHBF test will result in sandbar building and low-elevation gully infilling comparable to that observed during the 2004 BHBF test. If reaches downstream from river mile 30 are sand enriched relative to their condition before the 2004 BHBF test, then sandbar building and gully infilling in these downstream reaches will be greater than was observed in these reaches during the 2004 BHBF test.

Additional hypotheses specific to the role of experimentally BHBF-enriched sandbars in increasing aeolian flux of sand to downwind archeological sites, thereby increasing their preservation potential, include:

1. More wind-blown sand will be transported into modern fluvial sourced (MFS) aeolian deposits during the spring windy season immediately following a sandbar-building flood experiment than in the spring windy season preceding the experiment. As defined by Draut and Rubin (2007), MFS deposits are those immediately downwind of fluvial sandbars that lie below the 45,000 cfs stage. This hypothesis is based on observations at 24.5 mile following the 2004 BHBF test (Draut and Rubin, 2006).

2. If dam releases that follow a winter to early spring BHBF test are managed with subsequent dam releases such that greater dry sandbar area is available in the

spring windy season, compared to the spring 2005 windy season, then presumably aeolian sand transport rates into MFS deposits may be higher than those observed in spring 2005, given comparable wind conditions. This hypothesis is qualified by the caveat that the shape of a sandbar (not just its area) relative to the shoreline and the moisture content of a sandbar are important in determining aeolian sand transport inland.

3. Future BHBF tests on the order of 45,000 cfs will not result in significantly increased aeolian sand transport into relict fluvial sourced (RFS) aeolian deposits as defined by Draut and Rubin (2007; RFS deposits formed as the wind reworked sediment from extensive predam flood deposits essentially in place, and do not necessarily lie downwind of <45,000 cfs-stage fluvial sandbars). This hypothesis is based on measurements made within RFS dune fields at Palisades (river mile 66) and Comanche (river mile 68) following the 2004 BHBF test.

Methods

This project will collect and analyze topographic, bathymetric, sedimentologic (grain size), campable area, meteorological, geomorphic, and aeolian sand-transport data at fan-eddy complexes and selected cultural sites. Geomorphic mapping, scour chain installation, and associated interpretive work will be conducted using established methods by scientists from Utah State University (Schmidt and others, 1999). Topographic and multibeam bathymetric surveys will be collected before and after future BHBF tests using established methods by scientists from Northern Arizona University (Hazel and others, 1999; Kaplinski and others, 2005). These data will be collected at numerous fan-eddy complexes located throughout Marble and Grand Canyons and at selected cultural sites. Analog cameras will be used at 28 selected sandbars and cultural sites to document the topographic evolution (by fluvial and aeolian processes) of these sites during and after future BHBF tests. River-based arroyos associated with selected cultural sites will also be surveyed as part of this study (See table 1.C-1 for locations of various project components.)

Grain size on the riverbed and on sandbar surfaces will be studied using an underwater microscope (Chezar and Rubin, 2004; Rubin and others, 2006) and digital image processing (Rubin, 2004). Grain size in flood deposits on sandbars will be measured using by sampling vertical profiles (Rubin and others, 1998) and standard lab analyses. Sedimentary structures in flood deposits will be examined by installation and excavation of scour chains, by trenching, and by inspection of natural cut banks.

Weather instrument stations will measure wind, rainfall, and aeolian sand transport at the targeted cultural sites listed above. These instruments will be deployed during February 2007, with the exception of the Malgosa site (river mile 57.9), where equipment would be deployed before future BHBF testing occurs. This part of this project will build on the findings of Draut and Rubin’s 2003–06 study on the role of aeolian sediment in the preservation of cultural sites (Draut and others, 2005; Draut and Rubin, 2005, 2006, 2007), specifically the finding from the 2004 BHBF test that high-flow releases in the

CRE can increase wind-blown transport of sand toward some of the aeolian deposits that contain archeological material, increasing their preservation potential.

Table 1.C-1. Locations of various project components. (* Individual study sites are associated with one or more archaeological sites. All river miles are generalized to protect the confidentiality of archaeological site locations.)

Day on river trip	Sandbar topography, Campsite area, Scour chains	Bathymetry, Underwater microscope	Aeolian sand-transport work*	Arroyo surveys*	Cameras
0					-9 Mile
1	3L, 8L, 16L	3L, 16L			2.6R, 8.2R
2	22R, 24L, 29L, 30R	22R, 30R	24		16.7R,22.0L, 24.5L
3	32R, 33L, 35L	32R, 35L			30.8L
4	41R, 43L, 44L	41R, 43L, 44L			41.3L,44.5R
5	45L, 47R, 50R, 51L	45L, 47R, 51L			47.6R, 50.1L
6	55R, 56R, 62R	55R, 62R	58, 60		55.9L, ~58L
7	65R, 68R	65R, 68R	66, 69	66L,	66R
8				69R,72R	69L, 72L
9	81L, 84R, 87L, 88R				81.7R,87.6R
10	119R, 122R, 123R	122R			104.4L, 19.3L, 123.2R
11	137L, 139R, 145L	139R	135		137.7R, 145.8R
12	172L, 183R	172L			172.6R, 183.3L
13	194L, 202R	194L			194.6L, 202.3L
14	213L, 220R, 225R	225R	203, 223		213.3R, 225.5L
15	39 sandbars	22 eddies			29 camera sites

Analyses (similar to those described in Rubin and others, 1998; Hazel and others, 1999, 2006; Schmidt and others, 1999; Topping and others, 1999, 2006a; and Draut and Rubin, 2005, 2006, 2007) of sandbar topographic response, sandbar stratigraphy, sand grain-size data, aeolian sand-transport data, and aeolian topographic response at cultural sites will be used to evaluate the results of future BHBF tests relative to the BHBF tests conducted in 1996 and 2004. If the working hypotheses are supported by these analyses, then restoration and maintenance of sandbars might be possible through use of BHBFs conducted under sand-enriched conditions. Furthermore, if the working hypothesis specific to the aeolian sand-transport study are supported by these analyses, preservation of archeological sites might be increased by the greater aeolian flux of sand to these sites from the larger dry upwind sandbars produced during experimental BHBFs. If the working hypotheses are rejected by these analyses, then additional flow and non-flow treatments (such as further constraints on dam operations, sediment augmentation or a combination of both) in association with future BHBF tests may be needed to restore and maintain sandbars throughout the Colorado River ecosystem.

Links/Relationships to Other Projects

This project builds on the large quantity of previous published work on sediment erosion and deposition in the Colorado River ecosystem downstream from Glen Canyon Dam. It is also linked to several other experimental BHBF-related physical, sociocultural, and biological projects, including experimental studies1.A (Reach-scale changes in the fine-sediment mass balance and grain size during future BHBF tests), 1.B (Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during future BHBF tests), 2 (Evaluate effect of BHBF tests on riparian plant community development at multiple surface elevations and depositional environments), and 3 (future BHBF testing effects on lower trophic levels in the CRE). Bed sediment grain-size data collected as part of this task will be used to help interpret shifts through time in the sediment rating-curve data collected as part of experimental studies 1.A and 1.B and predicted by many modeling studies. Similarly, grain-size grading of flood deposits will be compared to temporal changes in suspended-sediment grain size observed during high flows (components of experimental studies 1.A and 1.B).

The subsequent evolution of the post-BHBF backwaters surveyed as part of this project will be evaluated in the subsequent fall during the backwater seining trip. Extension of the aeolian/archaeological site study supplements ongoing weather monitoring, aeolian transport, and gully-erosion monitoring work. It also extends the applications of the Draut and others (2005, 2006) study on the role of aeolian sediment in the preservation of archaeological sites that collected similar data from 2003 to 2006, and therefore will provide valuable comparison data between the 2004 and future BHBF experiments. In addition, this study complements ongoing investigations by Joel Pederson and Gary O'Brian from Utah State University on geomorphic processes that affect gully incision in Colorado River sediment deposits.

Information Needs Addressed

The project will directly address multiple effects information needs and research information needs, as follows:

> **EIN 8.3.1** How does fine sediment abundance, grain-size, and distribution, within eddies below 5,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

> **EIN 8.4.1** How does fine sediment abundance, grain-size, and distribution, within eddies between 5,000 to 25,000 cfs change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

> **RIN 8.5.4** What is the significance of aeolian processes in terrestrial sandbar reworking?

EIN 8.5.1 How does fine sediment abundance, grain-size, and distribution on shorelines between 25,000 cfs and the uppermost effects of maximum dam releases change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 9.3.1 How do the size, quality, and distribution of camping beaches change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

RIN 11.1.1a What and where are the geomorphic processes that link loss of site integrity with dam operations as opposed to dam existence or natural processes?

RIN 11.1.5 What are appropriate strategies to preserve resource integrity?

EIN 11.1.1 Determine the effects of experimental flows on historic properties.

Products/Reports

Several peer-reviewed journal article(s) and/or USGS report(s) will be produced based on the findings of this study within 12–18 months of future BHBF tests.

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

Funding history	Fiscal year					
	2006	2007	2008	2009	2010	2011
Outside GCMRC Science/Labor		$310,100	$119,900			
Logistics Field Support		$120,000	-0-			
Project Related Travel/Training		$3,000	$3,000			
Operations/Supplies		$19,500	$5,000			
GCMRC Salaries						
Project Subtotal		$452,600	$127,900			
GCMRC overhead		$40,600	$6,800			
Project Total		$493,200	$134,700			
% Total Outsourced		69%	94%			

Experimental Study 2: Evaluate effect of Future BHBF Tests on riparian plant community development at multiple surface elevations and depositional environments: Are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation following a disturbance?

Duration

18 months

Principal Investigator(s)

Barbara Ralston, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

Geographic Scope

Glen Canyon Dam to lower Marble Canyon (river mile 61)

Project Goal(s)

The project goals are to document community compositional changes (native vs. nonnative species) in established and newly bare depositional environments across multiple surface elevations following a future BHBF test. The project goal addresses a subcomponent of a larger question posed in the Knowledge Assessment (Melis and others 2006): To what extent and in what respects can BHBF tests (magnitude and frequency) achieve reduction of exotic species?

Need for Project

Riparian areas are a highly susceptible to exotic species introductions and expansion (Graf, 1978; Thébaud and Debussche, 1991; Naiman and others, 2005). Furthermore, the successful establishment of an invasive species may be affected by the degree to which a community is developed at a site. Two competing hypotheses exist regarding site susceptibility to invasive species. Darwin (1859), Elton (1958), Moulton and Pimm, (1983), Case (1990), and Case and Bolger (1991) suggest that invasion success decreases as community size and structural complexity increase. Stohlgren and others (1998, 1999) postulate the opposite hypothesis, arguing that species-rich sites, such as riparian zones, are more susceptible to exotic species introductions than upland areas that may have lower species richness. The latter argues for temporarily increased resource availability associated with disturbance, while the former argues that fewer exploitable habitats are available, thus preventing new species introductions (MacArthur and Wilson, 1967; Pimm, 1991).

In human-impacted systems, determining the relationship between native and nonnative species richness and site susceptibility is important for long-term resource management. A high-flow event provides a unique opportunity to compare riparian vegetation community composition (i.e., native/nonnative ratios) in established vegetation sites subject to disturbance with large bare sites made available from sediment reworking during a future BHBF test. By comparing established and new bare sites at multiple surface elevations, scientists should be able to identify the sites that are most susceptible to nonnative species introductions and expansion. Identification of susceptible sites provides managers the opportunity to focus resources when considering nonnative species control measures following a large disturbance event.

Strategic Science Question(s)

> **4.1.** Is there a flow-only operation (i.e., strategy for dam releases, including managing tributary inputs with BHBFs without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?

Working Hypotheses

Hypothesis 1: Native/nonnative species richness ratios are the same across all habitats and surface elevations up to 1,699 m^3/s.

Alternative hypothesis: The ratio between native/nonnative richness and cover at sites with established vegetative communities will not change following disturbance because resource availability is limited by the presence of existing species. Bare areas will have ratios of native/nonnative richness and cover values similar to those of established sites. Surface elevation will not have an affect on native/nonnative richness and cover values.

Alternative hypothesis: The ratio between native/nonnative richness and cover at sites with established vegetative communities will shift toward an increase in nonnative richness and cover because of the increased nutrient availability associated with the experimental BHBF disturbance. Native/nonnative richness and cover ratios will change by surface elevation with nonnative species decreasing with increasing surface elevations in relation to available soil nutrients. Bare areas will favor nonnative species across all surface elevations.

Methods

Plots established by Kearsley (2006) as a part of riparian vegetation monitoring will be used to assess native/nonnative foliar cover. These plots occur at specific river miles (table 2.1) and include data collected from 2001 to 2005. Reassessment of these locations provides an opportunity to examine native/nonnative cover and richness ratios across years and relative to a large scale disturbance within a year. These plots are also linked to the following surface elevations: 226, 424, 708, 991, 1,274, and 1,699 m^3/s. At each location, surveys of foliar cover of all species found with four $1m^2$ plots located at each surface elevation will be recorded. Many of these sites occur in channel margin locations and will likely experience some disturbance but would be unlikely to be completely bare following a future BHBF test.

Percent foliar cover will be determined by using 10 cm grids on 1m frames. Field readers will count the number of cross-sectional grid points that coincide with the presence of a given species. This is more accurate than field crews estimating percent cover visually. All species encountered in a plot will be recorded and those species that have <1% cover will be identified as a trace and assigned a value of 0.01. All sites will be visited before a future BHBF test as a part of monitoring. Sampling following a future BHBF test will take place in association with post-flood sandbar monitoring trips, which will occur in mid-summer at the height of plant productivity and in the fall in association with regular monitoring.

Bare ground sites: Similarly sized plots will be established in newly identified depositional environments (e.g., sandbars, return current channels). Surface elevations will be determined for these sites and data collection will follow that of the established vegetation sites.

Soil collection: To determine how soil constituents and grain size affect species composition, soil samples will be collected at each site and analyzed for available nitrogen, total carbon, and particle size. Four soil samples will be taken at each site and at each surface elevation. One sample will be taken from the mid point of each $1m^2$ plot. The sample will be external of the plots so as not to disturb the plots. Standing litter will be removed before sampling and sample depths will be at least 15 cm. A soil sampler will be used to collect the soil cores. Samples will be combined into a single soil sample for each surface elevation per site. Analysis will be conducted by an external lab to be determined. Samples will be collected before and after a future BHBF test at the established vegetation plots to determine if soil constituents and grain sized changed as a result of an experimental BHBF.

Analysis: Species cover data from each surface elevation will be pooled to determine total cover and richness, as well as richness and cover values for native and nonnative species. Native/nonnative values will be compared using analysis of variance (ANOVA). Established and bare ground sites will be compared using multiple regressions. Stepwise regression will be used with soil data to determine the effect of soil constituents and particle size on native/nonnative cover and richness values.

Table 2.1. Established vegetation by river mile (R=river right and L=river left)

Establish vegetation sites by river mile
-6.0R
-2.0L
00.2R
02.7L
007.3L
008.1L
012.3R
018.2L
020.8R
035.1L
037.7R
040.8R
041.2R
042.6L
043.9L
047.0L
053.2R
056.1R
059.6L

Links/Relationships to Other Projects

This project augments general riparian vegetation monitoring because it incorporates exiting monitoring locations into data collection efforts. By using surface elevations as site location criteria, the project also links species richness and cover to operational effects on riparian vegetation across surface elevations. In terms of integrating research across resources, this project will produce data that supports experimental study 1.C (Response of sandbars and selected culture sites to future BHBF tests conducted under sediment-enriched conditions) by sampling reworked and bare sandbars and return current channel substrates, collecting and analyzing soil samples for grain-size information, and identifying plant species components in marsh and riparian habitats. It also will helps to answer a cultural research information need 11.2.3 (Determine acceptable methods to preserve or treat traditionally important resources within the Colorado River ecosystem) by providing data relevant for improving our understanding of how BHBF testing may affect culturally important native plant species composition and distributions relative to invasive nonnative species.

Information Needs Addressed

This project directly addresses and experimental information need for M.O. 6.5 associated with riparian vegetation.

> **EIN 6.5.1** How does the abundance and distribution of nonnative species change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

Activity	FY 2007	FY 2008
Outside GCMRC Science/Labor	$15,800 (½ time NAU technician)	$16,000
Logistics Field Support and NPS	Collections combined with fish, sediment and vegetation mapping trips if possible	None in 2008
Project Related Travel/publication costs	$3,000	$3,000
Operations/Supplies	$9,100 Soil sampler $100.00 Soil analysis: 480 samples (6 samples/site X 40 sites X 2 sampling events) @~18.00/sample	$500.00
GCMRC Salaries		
Project Subtotal	$27,900	$21,700
DOI Customer Burden (6–17%)	$2,686	$2,720
Project Total	$30,586	$24,420
% Total Outsourced		

Experimental Study 3: BHBF Testing effects on lower trophic levels in the Colorado River Ecosystem

Duration

19 months

Principal Investigators

Theodore Kennedy, USGS Grand Canyon Monitoring and Research Center; Wyatt Cross and Robert Hall, University of Wyoming; and Emma Rosi-Marshall, Loyola University, Chicago

Geographic Scope

Glen Canyon, the confluence of the Little Colorado River, and Diamond Creek (river miles -15 to 226)

Project Goal(s)

To measure how future BHBF testing affects the quantity, quality, and types of food available for invertebrates, and ultimately fish.

Need for Project

Previous food base research has demonstrated that a BHBF test causes short-term reductions in primary producer and invertebrate biomass (Blinn and others, 1999; McKinney and others, 1999). Blinn and others (1999) and McKinney and others (1999) focused on static measures (i.e., algal biomass, invertebrate biomass) at a relatively coarse temporal scale (i.e., monthly measurements following the flood). Although biomass of algae and invertebrates will be temporarily reduced following a BHBF test, it is possible the post-BHBF algal assemblage will be faster growing and of higher quality, leading to higher invertebrate growth rates (Note: production=biomass*growth). Higher invertebrate growth rates post-BHBF could compensate for short-term reductions in invertebrate biomass. That is, short-term (i.e., weeks) negative effects of a future BHBF test on biomass may be offset by longer term (i.e., months-year) increases in invertebrate growth rates, which would result in more food available to higher trophic levels.

Future BHBF tests are likely to alter the systemwide carbon budget that we are currently constructing. Consequently, we will quantify fluxes of transported organic matter before, during, and after future BHBF experiments. Although these types of measurements have been taken during previous BHBF tests, none of the data have been linked to whole-system carbon budgets. This information will be critical for ultimately measuring the effect of future BHBF tests on inputs, retention, and export of organic matter that fuels river food webs.

There is evidence that disturbances, such as those that might occur during future BHBF tests, lead to an algal assemblage that is dominated by fast-growing and nutritious taxa. Brock and others (1999) measured production of algae covered rocks in Glen Canyon before and after the 1996 BHBF test. They demonstrated that, although algal biomass on rocks was lower following the BHBF test, rates of net primary production and production to respiration ratios were both higher after the BHBF test. They attributed these changes to the removal of detritus and senescent algal biomass. Because rapidly growing and young algae are more nutritious than senescent algae or detritus, the study by Brock and others (1999) suggests that the post-BHBF algal assemblage was of higher quality for invertebrates than the pre-BHBF algal community. Numerous studies in Sycamore Creek, a desert stream in southern Arizona, have demonstrated that following a scouring flood the algal assemblage shifts towards more nutritious and faster growing taxa (i.e., diatoms), invertebrates readily consume these new food resources, and that invertebrate biomass rapidly recovers to pre-flood levels (Fisher and others, 1982; Grimm and Fisher, 1989; Peterson and others, 1994).

Working Hypotheses

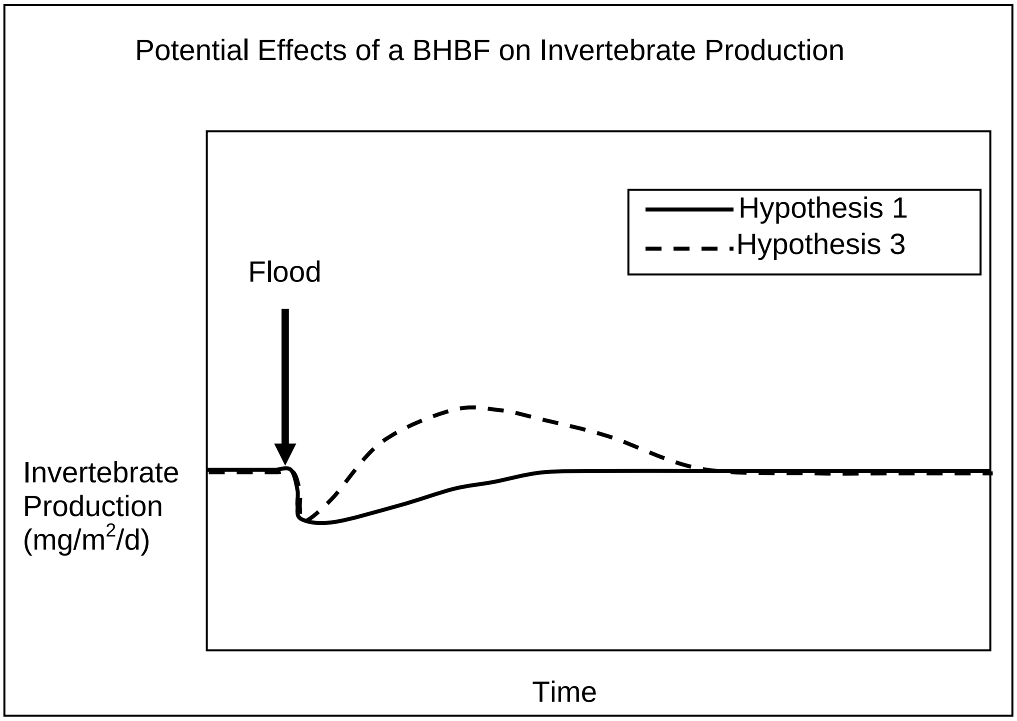
Hypothesis 1: A short-duration BHBF test in late winter scours the benthos, causing short-term reductions in algal and invertebrate biomass, and results in an overall decrease in annual invertebrate production (see figure 3.1).

Hypothesis 2: A short-duration BHBF test in late winter scours the benthos, causing reductions in algal biomass, but the new successional community of primary producers is of higher quality, more productive, and is assimilated more efficiently by invertebrates, leading to no change in annual invertebrate production.

Hypothesis 3: A short-duration BHBF test in late winter initially scours the benthos, causing reductions in algal biomass, but the new successional assemblage of primary producers is of higher quality, more productive, and is assimilated more efficiently by invertebrate consumers, thereby increasing annual invertebrate production (see figure 3.1).

Our research will test these competing hypotheses of recovery following a BHBF test. Direct measurements of invertebrate and fish growth before and after BHBF testing is intractable. However, we may be able to infer how invertebrate or fish growth rates are affected by future BHBF tests by measuring indices of growth (ribosomal RNA; Elser and others, 2003) and by quantifying invertebrate and fish diets and using literature values to determine the assimilation efficiencies of principle food resources. We will also measure whether a BHBF test changes the quality (i.e., C:N, C:P) of algal assemblages. Collectively, the proposed research will measure how a BHBF test affects the quantity and quality of food available for fishes and whether indicators of rainbow trout growth are affected by changes in food resources.

Figure 3.1. Potential effects of a BHBF test on invertebrate production



Tasks:

- Measure how a BHBF test alters the carbon budget for the CRE.
    - Measure the composition, biomass, and nutrient content of basal resources (algae, submerged aquatic vegetation, benthic organic matter)
    - Quantify whole system metabolism, a measure of primary production and resource consumption
    - Prior to BHBF, quantify standing mass of leaf litter between 20-41k cfs stage elevation
    - Measure organic drift during BHBF
- Measure how a BHBF test affects invertebrate biomass and production
    - Quantify invertebrate composition, abundance, and biomass
    - Quantify invertebrate diets and growth indicators (i.e., ribosomal RNA)
- Measure impact of a BHBF test on growth and condition indices (i.e., ribosomal RNA) for rainbow trout in Lees Ferry (in collaboration with Korman and others)

We will compare the above measures before and after a future BHBF test, and again in the following year at the same time when no BHBF test occurs. Frequent measurements before and after a BHBF test (i.e., -7d, -1d, +1d, +3d, +7d, +14d), coupled with ongoing quarterly sampling at the Little Colorado River confluence and monthly sampling at Glen Canyon and Diamond Creek, will allow us to measure the short- and long-term effects of a BHBF test on food quantity and quality.

Methods

We will measure biomass of lower trophic levels (i.e., algal and invertebrate biomass, cover and canopy height of submerged aquatic vegetation, organic drift) coupled with dynamic process oriented measures (i.e., nutrient content of basal resources, ribosomal RNA of invertebrates and fish, open-channel metabolism measurements) to test how a BHBF experimental release affects annual invertebrate production. Methods described briefly below are presented in more detail in our original food base proposal (Hall and others, 2005).

We will sample algae, submerged aquatic vegetation, and benthic organic matter with appropriate area-specific sampling devices (e.g., Ponar and Hess samplers, rock scrapes, modified suction sampler); dried to a constant mass, weighed, ashed in a muffle furnace (at 450 deg C); and reweighed to determine total dry mass and organic mass. Dried samples of these food base components will also be analyzed for carbon, nitrogen, and phosphorus content following standard methodology (CHN analyzer, acid digestion and spectrophotometry, APHA 1998). Open-channel metabolism in the Glen Canyon reach will be quantified before and after the BHBF with continuously deployed Yellow Springs Instruments (YSI) data sondes (with optical probes) using a two-station diel oxygen change method, corrected for re-aeration (e.g., Hall and Tank, 2003; see Hall and others, 2005). Downstream in Grand Canyon, we will measure metabolism using a one-station technique as part of the food base project (Hall and others, unpublished). Metabolism will be measured continuously at Diamond Creek for a period of a week before, and several months after, a BHBF test. At the Little Colorado River, metabolism will be measured continuously for one week before, and two weeks after, a future BHBF test. Coarse and fine organic drift will quantified using depth-integrated Miller net and grab samples respectively before, during, and after a future BHBF test at each site. Invertebrates will be quantified on multiple substrate types (i.e., cliff faces, talus slopes, cobble bars, depositional areas) with appropriate area-specific sampling devices (e.g., modified suction sampler, rock grabs, Hess sampler, ponar dredge). Dietary analysis will be conducted on invertebrates before and on multiple occasions after (days 1, 3, 7, 14, 30) a BHBF test using digital imaging software (Image Pro 3.0). Dominant dietary items can be easily identified with this method (e.g., diatoms, amorphous detritus, leaves, animal prey; Benke and Wallace, 1980; Hall and others, 2000). Ribosomal RNA analysis will be conducted on dominant invertebrates and fishes as a proxy for growth rate and condition (see Elser and others, 2003).

Links/Relationships to Other Projects

This project is linked to experimental Study 1.B (Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during future BHBF tests). We will share transported sediment samples and analyze them for both sediment and organic matter and determine what affect a BHBF test has on organic matter transport.

Experimental effects information needs (EIN) addressed by the proposed research include:

EIN 1.1.1 How does primary productivity for the reach between Glen Canyon Dam and the Paria River change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 1.2.1 How do benthic invertebrates in the reach between Glen Canyon Dam and the Paria River change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 1.3.1 How does primary productivity in the Colorado River ecosystem below the Paria River change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 1.4.1 How do benthic invertebrates in the Colorado River ecosystem below the Paria River change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

EIN 1.5.1 How does drift in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

FUNDING	Fiscal year	
	2007	2008
Coop Agreement—Outside GCMRC Science/Labor & Travel Principal Investigators	$21,000	
Coop Agreement—Outside GCMRC Science/Labor-Technicians	$45,000	
Logistics Field Support & NPS	$23,800	
Project related travel	$2,000	
Operations/Supplies	$13,500	
Equipment	$25,000	
Publication charges		$5,000
GCMRC Salaries& benefits		
Project Subtotal	$132,300	$5,000
DOI Customer Burden (6-17%)	$16,683	$955
Project Total	$148,983	$5,955
% Total Outsourced		

Experimental Study 4.A: Effects of Future BHBF Tests on rainbow trout early life stage survival, and the distribution, mortality, and potential downstream movement of age-1 fish in the Lees Ferry reach

Duration

10 months

Principal Investigator(s)

J. Korman, Ecometric, Inc. (GCMRC cooperator)

Geographic Scope

Glen Canyon Dam to Lees Ferry (river miles -15 to 0)

Project Goal(s)

This project seeks to determine how BHBF tests affect spawning, survival of early life history stages of rainbow trout in the Lees Ferry reach, and potential for simulating downstream migration of age-1 fish. Hypotheses that will be evaluated are: (1) a future BHBF test will scour redds (spawning nests) but the effect on the juvenile population will be limited because of compensatory survival responses, and (2) a BHBF test will alter the distribution of age-1 fish in the Lees Ferry reach resulting in either higher mortality or migration out of the reach.

Need for Project

The size of the adult population of rainbow trout in the Lees Ferry reach is very likely regulated by the survival rate and dynamics of early life stages (Houde, 1987). This experimental BHBF project would increase our understanding of these dynamics and therefore contribute to better management of the Lees Ferry trout fishery. Trout from Lees Ferry may migrate downstream and have negative effects on native fish (Korman and others, 2005; L. Coggins, unpublished data). The extent of downstream migration may be density dependent (Clone and Anderson, 1992), a normal ontogenetic habitat shift (Elliott, 1986), and/or stimulated by high flows (Heggenes and Traaen, 1988; Jensen and Johnsen, 1999; Mitro and others, 2003). A better understanding of the dynamics of the Lees Ferry population and the effects of a BHBF test therefore has implications for the control of trout densities downstream.

Strategic Science Question(s)

- To what extent could predation impacts by nonnative fish be mitigated by higher turbidities or dam controlled high-flow releases?
- To what extent is the adult population of rainbow trout controlled by survival rates during incubation and age-0/juvenile rearing stages, or by changes in growth and maturation in the adult population influencing egg deposition?
- Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages?

Working Hypotheses

To evaluate these hypotheses we will compare: (1) the number of redds before and after the high-flow event to compute the potential loss of redds because of high flows; (2) the ratio of the density of newly emerged fry to the total number of redds constructed with ratios determined in 2003, 2004, and 2006 (Korman and others, 2005); and (3) compare the abundance and distribution of age-1 fish before and after the BHBF test. We predict that: (1) redd numbers will be reduced by a future BHBF test because of scour; (2) the ratio of fry to redds will be similar to other years (2006=Record of Decision flows, 2003/4=experimental flows) because of strong compensatory mechanisms that occur shortly after emergence (Elliott, 1994); and (3) distribution of age-1 fish in Lees Ferry fish will be different after the BHBF because there will be a reduction in abundance because of mortality or downstream movement (Korman and others 2005; L. Coggins, GCMRC, unpublished data). It may be possible to determine whether mortality or movement was the cause for change in abundance, if age-1 fish are tagged as part of the proposed GCMRC sonic telemetry program.

Methods

The existing 2007 budget for the Rainbow Trout Early Life Stage Survival (RTELSS) project supports five redd surveys and one age-0 survey, a substantial reduction in effort from previous years because of funding constraints (Korman and others, 2005). The proposed BHBF test component would require: (1) five additional redd surveys to provide a more accurate and detailed estimate of redd numbers and timing of spawning; (2) three additional juvenile fish surveys to compute the age-0 to redd ratio (July sample) and to describe the change in abundance and distribution of age-1 fish (before and after BHBF sample); (3) support for physical modeling to develop a depth and velocity map for a range of discharges for the entire Lees Ferry reach. The currently supported juvenile fish survey is scheduled to occur in the late fall and provides an annual index of age-0 abundance (altering the timing of this survey disrupts the time series).

With regards to item (3) above, as fish grow they use deeper and faster habitats (Gaudin, 2001). Current age-0 surveys have been restricted to generally quite slow water (but sometimes deep) that is broadly distributed along the shoreline in the Lees Ferry reach. However, larger age-0 fish and age-1 fish appear to concentrate in the limited number of shorelines with faster water where food availability is higher (Korman and Yard, unpublished data). We need to sample these habitat types in order to provide a representative description of how high flows change abundance and distribution. The physical model would allow us to design a representative sampling regime for age-1 fish and scale-up density samples to estimate age-1 population size before and after a BHBF. Predictions of depth and velocity in Lees Ferry reach would also be useful for assessing redd scour, which we will evaluate in the field by before-after mapping of redds as part of our regular survey, and burial of existing spawning areas with sand (as apparently occurred at 6 and 8 mile sandbars as a result of the 1996 BHBF test). Data collected from past RTELSS efforts, and a complete topographical map of the Lees Ferry reach developed by the GCMRC would be integrated in an existing 2D hydrodynamic modeling framework developed by the USGS.

Links/Relationships to Other Projects

It is important to determine the how food-web dynamics influence the density and growth of rainbow trout in the Lees Ferry reach. Downstream migration of trout from the Lees Ferry reach resulting from a BHBF test will be studied by the GCMRC. Trout captured as part of the proposed study could be used as part of GCMRC's downstream movement assessment and the data would be very useful for interpreting downstream movement/mortality.

Information Needs Addressed

RIN 4.2.7 What dam release patterns most effectively maintain the Lees Ferry rainbow trout trophy fishery while limiting rainbow trout survival below the Paria River?

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

	2007
Outside GCMRC science/labor	$35,000
Logistics field support and NPS	5 redd survey trips, 3 electrofishing trips, all in Lees Ferry reach $2,000
Project related travel/publication costs	$3,000
Operations/supplies	
GCMRC salaries	
Project Subtotal	$40,000
DOI customer burden (6–17%)	$2,132
Project total	$42,132
% Total outsourced	83%

Experimental Study 4.B: Evaluate effects of a Future BHBF Test on adult trout distribution in Glen and Marble Canyons

Duration

19 months

Principal Investigator(s)

Daniel C. Gwinn, U.S. Geological Survey, Grand Canyon Monitoring and Research Center

Geographic Scope

Glen and Marble Canyons (river miles -15 to 61)

Project Goal(s)

The goals of this experimental study are: (1) to determine if a BHBF test causes displacement of rainbow trout from the Lees Ferry reach into Marble Canyon and eastern Grand Canyon; (2) to determine if such displacement is experienced differentially among different length fish; and (3) to provide a platform for Grand Canyon scientists to develop skills with acoustic technologies that can be applied to answering questions about native and nonnative fish movement and distribution and sampling efficiencies.

Need for Project

Native fishes of the Colorado River evolved in a system with an extremely flashy hydrograph with base flows as low as 5000 cfs and floods as great as 300,000 cfs. Although a BHBF of ~40,000 cfs would likely not disadvantage these native species, it is commonly observed in other systems that a naturally flashy hydrograph can disadvantage nonnative species (Meffe, 1984). It is currently unclear whether a moderate high-flow event of ~40,000 cfs could affect the nonnative fish community of the Colorado River and provide a management tool. During the BHBF test of 1996, Valdez and Cowdell (1996) observed an increase in catch rates of rainbow trout <152 mm total length in the Little Colorado River inflow reach of the Colorado River. They hypothesized that the presence of fish from Lees Ferry and Glen Canyon that were displaced into Grand Canyon by the BHBF test were likely responsible for these increased catch rates. They did not, however, observe any changes in the catch rates of other species of the nonnative fish community. After the 2004 BHBF test, Korman (pers. com.) observed a decrease in the catch rates of juvenile trout in Lees Ferry, which supports the Valdez and Cowdell (1996) hypothesis of displacement in 1996, but again direct observation of the fate of fish could not be made. Currently, we do not know if short duration BHBF testing displaces young trout from Lees Ferry and cannot infer this from experiments using abundance indices alone. This experimental study would employ the additional technology of acoustic telemetry to make direct observations of movement patterns of young rainbow trout during a future BHBF test. This information in combination with relative-abundance measures will allow for stronger inference to be drawn about the fate of rainbow trout during a future BHBF test. This experimental study also provides an opportunity for scientists to gain the skills and experience with acoustic technologies that may prove important for addressing broader questions about Lees Ferry trout dispersal, movement dynamics, and sampling efficiency of other native and nonnative fish species in the Grand Canyon ecosystem.

Strategic Science Question(s)

1.3 Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and, if so, during what life stages? To what extent do Glen Canyon immigrants support the population in Marble and eastern Grand Canyons?

1.4 Can long-term decreases in the abundance of rainbow trout in Marble and eastern Grand canyons be sustained with a reduced level of effort of mechanical removal or will recolonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action?

3.2 To what extent could predation impacts by nonnative fish be mitigated by higher turbidity or dam-controlled high-flow releases?

3.6 What Glen Canyon Dam operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

Working Hypotheses

Future BHBF tests will result in displacement young rainbow trout from the Lees Ferry reach into Marble Canyon and eastern Grand Canyon. This trout redistribution will be inversely related to the size of fish.

Methods

This experimental study will utilize abundance indices and sonic technologies to evaluate the possible age-specific displacement of adult rainbow trout from the Lees Ferry reach during a future BHBF test. Abundance indices will be established for adult and juvenile rainbow trout before and after the high-flow event for comparison. Prior to the BHBF, the GCMRC will execute a trout sampling trip following the protocol developed by the Arizona Game and Fish Department (AZGFD) for long-term monitoring of adult trout in Lees Ferry (Speas and others, 2002). The post-BHBF testing evaluation of adult trout abundance will include the use of AZGFD catch-rate information from the reoccurring long-term rainbow trout monitoring in the Lees Ferry reach. Additional electrofishing catch-rate information collected by Ecometric, Inc. (experimental study 4.A) will be used for abundance comparisons of pre- and post-BHBF testing juvenile trout abundance. In combination, these catch data will be used to infer changes in the abundance of adult and juvenile rainbow trout because of a future BHBF test.

Relative-abundance indices will be combined with direct observations of location and movement from acoustic telemetry to draw inference about the effects of a future BHBF test on the Lees Ferry trout population. The Colorado River upstream of Lees Ferry will be divided into three strata: upper (river mile -15 to -10), middle (river mile -10 to -5), and lower (river mile -5 to 0). Ten fish of age 1, 2, and 3 will be collected from each strata and tagged via intraperitoneal implantation for a total sample size of 90 implanted individuals. The minimum size fish implanted with a transmitter will be 108mm total length. With the appropriate acoustic transmitter, this represents a tag to fish body weight ratio of 12%, which has been demonstrated to have little to no affect on swim performance of juvenile hatchery-reared rainbow trout (Brown and others, 1999). Tagged fish will be held in net pens for 24 hours to allow recovery from surgeries. Recovery of all fish will be evaluated and individuals recovering poorly will be removed from the experiment. Fish will be released in their river stratum of origin. Released fish will be manually tracked daily for 1week to evaluate movement patterns and longer term response to surgeries. We expect to observe a dispersal pattern after release that stabilizes over the period of tracking. Movement downstream of Lees Ferry will be detected with five acoustic receiver gates. These will be deployed at Lees Ferry, route 89 bridge, Badger Creek, river mile 30, and river mile 60. Fish in the Lees Ferry reach will then be tracked for an additional 3days to assure data accuracy of the stationary receiver gates. A post-BHBF test electrofishing sampling protocol will be employed 1 week after the BHBF test to detect changes in the relative abundance of trout in the Lees Ferry trout fishery.

Links/Relationships to Other Projects

This experimental study has direct linkage to experimental study 4.A, the long-term Lees Ferry trout monitoring effort, the FY07 sonic tag/gear efficiency evaluation, the FY07 warmwater nonnative fish research, and future native fish research. Experimental studies 4.A and 4.B are interrelated because of data and logistics sharing. Conducting these studies in concert will strengthen the inferences drawn from each about the fate of age-1 trout in the Lees Ferry reach as relates to a BHBF test. This study also relies on Lees

Ferry long-term trout monitoring data collected by the AZGFD on relative abundance of adult trout in the Lees Ferry reach after a future BHBF test. Additionally, this study provides a platform for Grand Canyon scientists to gain valuable experience using sonic technologies to address a broader set of biological question. The experience gained from a future BHBF study will be employed in ongoing investigations of gear efficiencies and warmwater nonnative fish. These tools are also expected to be invaluable for future investigations of native fish in the Grand Canyon ecosystem.

Information Needs Addressed

The experimental study will directly address the following research information needs (RIN):

RIN 4.2.1 What is the rate of emigration of rainbow trout from the Lees Ferry reach?

RIN 4.2.2 What is the most effective method to detect emigration of rainbow trout from the Lees Ferry reach?

RIN 4.2.3 How is the rate of emigration of rainbow trout from the Lees Ferry reach to below the Paria River affected by abundance, hydrology, temperature, and other ecosystem processes?

Products/Reports

A peer-reviewed journal article and/or USGS report will be produced based on the findings of this study.

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

FUNDING HISTORY	Fiscal year					
	2006	2007	2008	2009	2010	2011
Outside GCMRC Science/Labor		$10,000				
Logistics Field Support & MPS						
Project Related Travel/Training		$1,000				
Operations/Supplies		$41,850	$3,000			
GCMRC Salaries		$4,560				
Project Subtotal		$56,910				
DOI Customer Burden (6–17%)		$10,269				
Project Total		$70,679				
% Total Outsourced						

Experimental Study 5: Evaluate Effects of a Future BHBF Test on Water Quality of Lake Powell and Glen Canyon Dam Releases

Principal Investigator(s)

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

Geographic Scope

Lake Powell forebay to upstream limit of the hypolimnion (~Oak Canyon, 90 km above the dam), Glen Canyon Dam, and the tailwaters to Lees Ferry

Project Goal(s)

The goal of this experimental study is to determine how the addition of jet tube and full powerplant releases from the dam will alter water quality in the Glen Canyon Dam tailwaters and the hydrodynamics and stratification patterns in Lake Powell. This effort will entail installation of an additional water-quality multiparameter sonde (MPS) at the ring follower gates in the dam, the inlet port of the river outlet works, and may include another MPS located below Glen Canyon Dam at a point where full mixing of combined discharges is achieved. In addition to the regularly scheduled monthly profiling in the Glen Canyon Dam forebay, additional monitoring locations will be added to include the upstream extent of the hypolimnion, between 45 and 90 km above the dam. Additional surveys of these locations will take place immediately before and immediately after a future BHBF test. During a future BHBF test, additional chemical samples will be taken in the dam, at Lees Ferry, and at the river outlets works depth in the reservoir before and after BHBF testing.

Need for Project

Use of the river outlet works, 30 m below the penstocks, draws water from deeper layers of the reservoir than normal powerplant releases. This water is cooler, has higher concentrations of dissolved minerals and nutrients, and has lower concentrations of dissolved oxygen.

Given the most probable timing of late fall to early spring for a BHBF test, this study is likely to occur concurrently with an annual event in the reservoir that has been documented by the Lake Powell monitoring program. During this event, an upwelling of the hypolimnion of the reservoir, driven by winter underflow density currents, is observed at Glen Canyon Dam and influences powerplant releases in the early spring. During a future BHBF test, the operation of the river outlets works, combined with full powerplant releases, could evacuate large volumes of this hypolimnetic water, causing mixing to deeper layers of the reservoir and reduction of the volume of stagnant hypolimnion. For this reason, the BHBF test of 1996 significantly mixed and diminished the stagnant water in the hypolimnion (Hueftle and Stevens, 2001). Development of stagnation of the hypolimnion can produce hypoxic (low oxygen) conditions in the reservoir, which may in turn be discharged below the dam into the tailwaters.

The 2004 BHBF test occurred in November when convective mixing and reduced reservoir elevations brought upper lake layers closer to the release structures. Consequently, net releases during the 2004 BHBF test were drawn primarily from the surface layers and had little effect on hypolimnetic waters. February/March timing for a future BHBF test is more likely to release colder, saline, and hypoxic water from the hypolimnion.

In summary, a future BHBF test has the potential to entrain deeper layers of the reservoir, which could cause enhanced mixing of those layers and reduced stagnation and hypoxia. Releases downstream may deliver more nutrients to the aquatic ecosystem and the river outlet works would re-aerate hypoxic releases.

Methods

Existing methodologies associated with the Lake Powell water-quality core monitoring program will be utilized to accomplish the objectives. Additional multiparameter sondes will be calibrated and deployed according to past standards. Added chemical samples will be collected and processed with monitoring samples; profiles will be conduced using existing equipment and methods.

Links/Relationships to Other Projects

Use of the river outlet works is likely to increase the export of nutrients and ions during the experimental flows, and could alter hypolimnetic mixing patterns and result in the increased evacuation of hypolimnetic water. This could provide additional nutrients to the aquatic food base in Grand Canyon in the recovery period following the experiment (Parnell and others, 1999; Shannon and others, 2001; Stevens and others, 2001; Schmidt and others, 2001).

Products/Reports

A post-experiment report will summarize findings of data collection efforts and a discussion of changes to the stratification and water quality in Lake Powell and changes to the water quality of the Glen Canyon Dam tailwaters as a result of the experimental action.

Costs by Fiscal Year (specific fiscal years shown here are for cost estimating purposes only)

Estimated Costs:
Field work: 2-6 additional person-days
Equipment: possible rental of 1-2 YSI MPS sondes for 2-3 months
Sample analyses: 6-10 additional sets of samples
Analysis: 4-12 additional person-days
Logistics: 1-2 field trips from Wahweap to Oak Canyon

Lake Powell BHBF Projected Budget	Fiscal year			
	2007 range		2007 mean	2008
Outside GCMRC Science/Labor (NPS help 5-10 days)	$-	$-	$-	
Logistics Field Support & MPS (1–2 boat trips to Oak, 1-2 MPS for 3 months	$951	$1,902	$1,427	
Project Related Travel/Training (1–3 days)	$264	$640	$452	
Operations/Supplies (6-10 additional samples)	$-	$-	$-	
GCMRC Salaries (10 field/6 report-20 person days with 20% OH	$9,895	$12,369	$11,132	$6,185
Project Subtotal	$11,110	$14,911	$13,011	$6,185
DOI Customer Burden (6–17%)	$667	$2,535	$1,601	
Project Total	$11,777	$17,446	$14,612	
% Total Outsourced				

Logistics activities in support of experimental studies

Scheduling Considerations

Scheduling a BHBF test during the spring period poses several considerations to the GCMRC Logistics Program. The primary logistical constraints for scheduling a BHBF test in the spring are: (1) consideration of scheduling impacts to the existing monitoring program, (2) providing adequate lead time for preparation to provide for increased capacity for adequate logistical support to respond to the additional demands required to support BHBF research, and (3) provide adequate time to work with the National Park Service on permitting activities and public outreach to address safety concerns for backcountry and river users during periods of high flows.

This draft BHBF science plan requires launching nine motorized research trips (plus an additional press trip) and support of research projects in the Glen Canyon reach and upstream of Diamond Creek. Trips are initiated 5 weeks before the high flow peak and up to 8 weeks after the peak flow, encompassing a 3 month time period. During this period of time in the spring, there are typically three major projects scheduled to conduct field research; mainstem fish monitoring (2 trips), aquatic food base, and sediment-mass balance. The combination of BHBF testing trips and regularly scheduled monitoring trips places a heavy demand on logistical resources available to the GCMRC Logistics Program. The increased demand exceeds the current capacity of the GCMRC Logistics Program requiring additional procurement of equipment, upgrade of current capacities, and coordination of additional external resources.

Funding must be made available to the logistics program 6 weeks before the scheduled launch of the first BHBF trip to that resources are available to support the experimental BHBF trips while maintaining adequate support for our regularly scheduled monitoring trips.

Permitting

The final BHBF science plan will be submitted to the Grand Canyon National Park Research Permits Office for review as a project Research and Collecting Permit. Following approval of a BHBF Research and Collecting Permit, individual trip permit applications will be submitted for each of the nine trips proposed in this science plan. Requests for permit approval should occur no less than 6 weeks before to the first BHBF research trip launch date.

Public Outreach

The GCMRC will collaborate with the National Park Service to establish a public outreach plan to inform the public and specifically recreational river and backcountry users as to safety concerns because of high flows. In collaboration with the National Park Service, a handout will be prepared informing the public on the purpose and effects of any future BHBF tests, including a hydrograph of the peak flows, which will be distributed to all river and backcountry users who may be affected. This plan has also includes a budget for an unscheduled press river trip.

Logistics

Any future BHBF tests will require nine motorized trips to support the proposed research activities outlined in this plan. Two trips will launch in advance of the BHBF test. Four trips will be launched before the BHBF test to be stationed at 30 mile, 45 mile, 60 mile and Phantom Ranch to conduct sampling pre-, post- and during the event. One trip launches on the initiation of the peak flow and the final two trips are conducted post-BHBF test. Additionally, work will take place in the Glen Canyon reach between Lees Ferry and Glen Canyon Dam and upstream of Diamond Creek at river mile 225.

	Project	Boats	Location	Trip Length	# Personnel
Trip 1	4b	22’, 1-sport (Achilles)	RM 0–225	12 days	6–8
Trip 2	1c	2-33’,1-22’ (Eyeball), 1-22’ (Hydro), 1-sport (Osprey)	RM 0–225	18 days	18–20
Trip 3	1a/3	1-33’, 2-sport (Osprey)	RM 61	20	8–12
Trip 4	1b	1-33’, 1-22’ (Hydro)	RM 45	16	6–8
Trip 5	1a/KAS compliance	1-33’, 1-sport (Osprey)	RM30	16	6–8
Trip 6	1a	1-33’, 1-22’, 1-Sport (Achilles)	RM 87/ Lower Langrangian	14	6–8
Trip 7	1a	1-33’, 1-22’	Upper Langrangian	12	6–8
Trip 8	1c	2-33’,1-22’ (Eyeball), 1-22’ (Hydro), 1-sport (Osprey)	RM 0–225	18	18–20
Trip 9	1c	2-33’	RM 0–225	18	12–14

Recommended Timeline

- Final Approval BHBF Test and Hydrograph (date and hour specific)
- Permitting and Logistical Planning Initiated (6 weeks)
- First BHBF Research Trip Launches (5 weeks)
- High Flows initiated (8 weeks)
- Final Post-BHBF Test Trip Launches

Estimated Logistics Costs (using FY 2007 costs)

Experimental studies and associated logistical support activities	Projected cost	Projected cost (included in study budgets)	
1a		$110,000	
1b		$20,000	
1c		$120,000	
2		0	
3		$24,000	
4a		$11,000	
4b		$32,000	
Direct Logistics Costs:			
Equipment (inc. Truck)	$25,000		
Salary (overtime)	$8,000		
Survey Equipment	$10,000		
Hydro Boat Modifications	$5,000		
Public Outreach (press trip)	$15,000		
Burden (19.091%)	$14,890		
TOTAL	**$92,890**		

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Appendix A. Responses to Issues Raised by Members of the Glen Canyon Dam Adaptive Management Program about Future BHBF Tests

During their December 5–6, 2006 meeting, members of the Glen Canyon Dam Adaptive Management Program (GCDAMP) identified issues of concern for the Grand Canyon Monitoring and Research Center (GCMRC) to consider and address in planning for future BHBF tests. These concerns are summarized below from the meeting minutes and are followed by short responses prepared by GCMRC staff and cooperating scientists.

Issue: What are the trade-offs between the benefits of a BHBF test and possible negative impacts?

This is a broad question and one that GCMRC staff worked to address with input from the entire science staff. Please see table A-1 for a summary of the pros and cons associated with BHBF testing in spring.

Issue: If a proposed future test is a new (BHBF) test, then what are the new hypotheses?

The proposal for a future spring high-flow experiment is a hybrid of the two previous experiments that have been conducted and one that tries to incorporate key learning from 1996 and 2004. The next proposed high-flow experiment intends to return to the original timing of spring for such a flow operation as described in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS), a timing that attempts to approximate the spring flood disturbance regime of the ecosystem that typically occurred before the construction of Glen Canyon Dam. It is also a second test of the concept of implementing high-flow experiments within a period when new sand supplies are known to exist in the main channel following tributary sand inputs. The 2004 BHBF test revealed that fall sand inputs from the Paria River were retained in the upper reaches of Marble Canyon under constrained daily dam operations that varied between 5,000 and 10,000 cubic feet per second (cfs). As a result, sediment experts determined that the resulting sandbar building using the sand supply was restricted to the upper half of Marble Canyon and that the new sand did not have time under that 60-hour test to be transported to reaches downstream of about river mile 40 or so.

Analysis of the 2004 results yielded a revised hypothesis regarding sand transport. This new hypothesis postulated that new sand inputs that enter the ecosystem from the Paria River should be allowed some limited time to be transported downstream under Record of Decision fluctuations into lower Marble Canyon. Hence, there is an evolving question about the appropriate timing for when high-flow experiments should optimally be tested and implemented relative to: (1) the seasonal timing of when tributary sand typically is introduced to the ecosystem from the Paria River (late summer to fall), (2) how the new sand gets distributed downstream through Marble and Grand Canyons under Record of Decision operations within the months following inputs, (3) whether redistributing the new sand in a more uniform longitudinal pattern downstream before a high-flow experiment results in more uniform and robust sandbar deposition, and (4) the season in which historical flood disturbance occurs (spring).

Proposed future BHBF tests are intended to have additional studies tied to food base, fisheries, and cultural site preservation; the hypotheses associated with these studies are described in the experimental study descriptions included in this science plan.

Issue: What is the reason behind replicating the 2004 (BHBF test) hydrograph?

The concept of replicating the 2004 BHBF test hydrograph 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. This, along with data collected from the 1996 BHBF test, was the basis for choosing 60 hours, down from 168 hours tested in 1996, as the duration for the peak flow of a future BHBF tests. The 2004 BHBF test peak magnitude was limited to 41,500 cfs, owing because one of the eight turbine units at Glen Canyon Dam was undergoing maintenance. The concept of replication of the 2004 BHBF test hydrograph in a future test is aimed at determining whether or not the robust sandbar-building responses that occurred under the 2004 BHBF test will occur consistently each time a BHBF test is released under sand-enriched conditions. It also allows scientists to evaluate whether there are incremental cumulative benefits to sandbar conservation in lower Marble Canyon and Grand Canyon reaches each time enriched high-flow experiments occur.

If the results from replicating the 2004 BHBF test hydrograph under sand-enriched conditions in the spring (following several months of downstream transport under Record of Decision operations) are as good or better (more uniformly distributed sandbar responses under conditions of more uniformly distributed sand supply downstream) than those measured during the 2004 BHBF test, then this approach may be interpreted at being a sustainable strategy for longer term habitat restoration and maintenance using only downstream sand supplies. Such a replicated, positive result would also indicate that the more natural timing for flood disturbance in spring can be accomplished as well, while conserving new sand inputs before they are exported to the upper Lake Mead delta. On the other hand, if a different BHBF test hydrograph is released and the results are not as good as 2004 BHBF test results, then the lack of replication will make it very difficult to determine whether the response owed to the different BHBF test timing and supply conditions or to the different hydrograph.

Because the 2004 BHBF test hydrograph design was tied to sandbar and eddy simulations made on the basis of measured channel topography and sediment transport data, and because the 2004 test did result in robust sandbar building in the reach (upper Marble Canyon) where the sand supply was locally enriched, it seems reasonable to return to this hydrograph design for future BHBF testing to confirm its effectiveness.

Issue: What would the pros and cons of a shorter-duration BHBF test peak at 41,500 cfs (for instance, 30 hours)?

Discussions among scientists and managers about alternative duration (shorter than the 60-hour peak tested in 2004 BHBF test) peak flows for future high-flow experiments have been ongoing during recent planning activities. There are many factors to consider related to peak-flow duration and peak magnitudes for high-flow experiments (see table A.2).

Issue: Is there a risk of a potential take or impact (of a future BHBF test) on juvenile humpback chub? HBC recruitment?

Based on the spring season for future BHBF tests and the results of fisheries studies conducted in association with the 1996 BHBF experiment in Grand Canyon, there appears to be little risk to juvenile humpback chub associated with future proposed spring BHBF experiments. The abundance of juvenile humpback chub in the mainstem Colorado River is driven, in part, by freshet events in the Little Colorado River. Because the proposed timing of future BHBF experiments is generally tied to late March, scientists at the GCMRC expect few freshet events and therefore few juvenile humpback chub to be present in the mainstem Colorado River. This alone will reduce the number of humpback chub vulnerable to potential displacement or mortality because of future spring BHBF experiments. Following extensive sampling to measure abundance of fish before and after the spring 1996 BHBF experiment, catch-rate metrics showed insignificant differences before and after the experiment for most fish (Valdez and others, 2001). The exceptions were a significant decrease in the abundance of small bodied nonnative fish and a significant increase in the abundance of speckled dace. Additionally, results from telemetry and diet work suggest minimal behavioral or feeding disruptions of adult humpback chub and flannelmouth sucker associated with the spring 1996 BHBF experiment. Relative abundance of juvenile native fish was also estimated before and after the 2004 BHBF experiment downstream of the Little Colorado River confluence (GCMRC unpublished data; Coggins and others, 2005). Unfortunately, the results of the fall 2004 study were highly inconclusive owing to elevated turbidity following that 2004 BHBF test because of flooding activity in the Little Colorado River. These conditions rendered catch-rate observations taken before and after the experiment unreliable owing to likely changes in sampling gear efficiency.

The findings associated with the 1996 high-flow experiment that native fish are little affected by high-flow events are consistent with theory and other published studies. Meffe (1984) found that adapted native fish species tolerated elevated discharge associated with freshets better than introduced species. Indeed, this differential tolerance to flooding has been suggested as a nonnative control method (Minckley and Meffe, 1987). Though these studies view high discharge events as potential displacement mechanisms rather than direct sources of mortality, there is no evidence that humpback chub recruitment would be directly hindered by a future BHBF experiment. On the contrary, one hypothesis is that potential humpback chub recruits might enjoy higher survival rates because of increased food resources (see experimental study 3 description, this plan) and decreased negative interaction with nonnative fishes (Valdez and others, 2001). Though it is certainly valid to hypothesize that a BHBF experiment could hinder recruitment by imposing some direct or indirect mortality source, there is presently insufficient data to arbitrate among these competing hypotheses.

Issue: Concerns about insufficient funds to address HBC issue (relative to BHBF testing)?

The GCMRC believes that funding is not the major impediment to studying the effects of a high-flow experiment on humpback chub. The major challenge is attempting to evaluate changes in distribution and fate of humpback chub without the appropriate techniques and/or technology to field a viable study (see Appendix B).

Issue: Will there be negative impacts (from future BHBF testing) to the food base? Will it clean or refresh the system?

We are uncertain about these important questions. While we know that the biomass (a static measure) of food base components are temporarily reduced following a BHBF experiment, little is known about the effect of a BHBF experiment on their productivity (a dynamic process measure). Our working hypothesis is that after the initial reduction in food following a BHBF test, daily production and turnover of algae, invertebrates, and possibly fish are higher than pre-BHBF testing conditions. This positive response by the food base may offset the negative initial effects such that there is little net loss of material and productivity when viewed on slightly longer time scales (months to a year). This knowledge gap is precisely why we must do more experimental high-flow tests to pin down quantitative answers for the important questions raised above.

Issue: What are the impacts (of a future BHBF test) to hydropower and other economic interests (i.e., fishing guides and river guides)?

Specific studies to assess the economic impacts of conducting future BHBF experiments have not been conducted and can not be definitively determined with available information. Based on the recent economic assessment by the Western Area Power Administration for the experimental options study (conducted in 2006 by the AMWG's Science Planning Group), there would be some short term but significant economic impacts for hydropower in the form of lost revenue generation opportunities (loss of potential marketable power because of water bypassing the generators during future BHBF testing). There would also be some immediate short-term gains resulting from running the generators at full capacity during future BHBF experiments, though not sufficient to offset future lost opportunity costs. In terms of recreational economic interests, there are likely to be short-term impacts to the local fishing guide economy during and probably immediately following future BHBF tests. Based on the proposed timing and duration of the event, however, and considering the hypothesized response of the aquatic food base over the long term (short-term decline followed by relatively rapid rebound and potentially increased productivity), the economic impact to recreational fishing is uncertain and yet to be studied. Projected economic impacts to commercial river runners, on the other hand, are likely to be very minimal to non-existent, because the proposed timing of a future BHBF experiment is before the start of the commercial boating season. The larger question that remains to be determined, and that is most critical for assessing the overall economic implications of a high-flow experiment, is whether the combined potential economic impacts of conducting a BHBF experiment outweigh the potential resource benefits and societal value derived from conducting the experiment. Unfortunately, the GCDAMP is currently lacking up-to-date, comprehensive valuation data with which to address this larger economic question.

Issue: BHBF experiments result in a lot of sediment below Diamond Creek, resulting in economic concerns for the Hualapai Nation. Additionally, there is an archeological site below Glen Canyon Dam that going to be harmed and unless there is a plan for that site.

In recent years, with the lowering of Lake Mead because of drought and ongoing water withdrawal, formerly submerged sand deposits at the head of Lake Mead have become increasingly shallow, creating serious challenges for down-lake navigation. Also, the exposure of formerly submerged sandbars has cut off access to a formerly popular take-out point at Pierce Ferry. The Hualapai Tribe is concerned that a high-flow experiment could exacerbate these current problems by displacing sand from the main channel into areas used as harbors and launch sites by their boat operators. At Diamond Creek and other eddies immediately downstream, sand is very likely to be transferred into the eddies (this is why BHBF tests build sandbars and benefit camping beaches.) Assuming the lake remains low, a BHBF test released into Lake Mead is also likely to generate a strong current in the upper part of the lake, which would remobilize some of the channel-clogging sediment and help to redefine a clear channel through the sandbars in the upper part of the lake, but whether and to what degree sediment would be re-deposited in specific shoreline locations used by the Hualapai Nation tour operators, and whether it would have negative consequences for these commercial operations, is unknown. What is known with certainty is that a short-term BHBF experiment will not solve, nor will it significantly exacerbate, the long-term issue of sediment build up in upper Lake Mead, with its concomitant implications for future navigability.

The second part of the comment expresses concern about possible negative impacts of a high-flow experiment to archaeological sites, particularly one site located in the Glen Canyon reach. In 1996, before the first BHBF experiment, the Bureau of Reclamation funded a series of studies to evaluate and mitigate potential effects of high-flow experiments on cultural sites in the river corridor. Following completion of these compliance-driven studies, the Arizona State Historic Preservation Office issued a formal determination of "no adverse effect" for experimental flows up to 60,000 cfs (Nancy Coulam, personal comm., December 7, 2007.). Recently, a team of archaeologists and one geomorphologist from the Navajo Nation Archaeology Department (NNAD) completed a geomorphic evaluation of all archaeological sites in the Glen Canyon reach, and they concluded that one site (AZ C:2:32) has the potential to be eroded by a future BHBF test. During the 1996 mitigation work, there was considerable uncertainty as to whether this site was truly cultural, but the recent re-evaluation by NNAD confirms that this is a potentially significant archaeological site containing deposits dating to the late Archaic period, approximately 3,000 years BP. The NNAD archaeologists recommend that a portion of this threatened site adjacent to the river be excavated before conducting a future BHBF experiments. A draft mitigation plan has been prepared for the Bureau of Reclamation to implement, if warranted. The author of this draft plan estimates that mapping and excavation of the site could be accomplished over two 10-day field sessions with an 8-person crew (Kim Spurr, personal comm., January 22, 2007.)

Issue: Time is constrained by the possibility of one dam unit being down for maintenance after March.

From our understanding of the proposed annual maintenance schedule at Glen Canyon Dam, we do not see a problem with having one of the eight turbine units at the dam non-operational annually through March during proposed, future BHBF experiments, although having eight units fully operational would be optimal for sediment studies. Future BHBF experiments are not currently proposed for later than March.

Table A.1. Summary of pros and cons associated with conducting future BHBF Tests

GENERAL CONCERNS	PROS	CONS	UNCERTAINTIES
AMP RESOURCES	• Sandbar restoration and conservation of related physical habitats • Improvement of recreational camping sites • Preservation of some archeological sites through secondary wind deposition • Creation of backwater habitats used by native fishes • Mimics seasonal flood disturbance to river ecosystem	• Lost hydropower capacity and revenue owing to bypass and monthly volume re-scheduling • Impact to cultural site in Glen Canyon (to be mitigated) • Impact to Kanab ambersnail habitat (endangered species) at Vaseys Paradise (to be mitigated) • Increased use of motorized watercraft during Colorado River Management Plan non-motor season in Grand Canyon National Park that can be mitigated through public outreach)	• Aquatic food abundance • Impacts and/or benefits to humpback chub remain uncertain • Impacts on rainbow trout fishery • Impacts on native and nonnative terrestrial vegetation
SCIENCE (Learning by Doing)	• Advances learning about options for achieving GCDAMP Priority Goals, especially sediment, trout fishery, food base, cultural resources and riparian habitat • Provides information about optimal BHBF hydrograph design to maximize benefit and minimum costs? • Informs interested public • Information transfer to other scientists and managers working on river restoration	• None	• None

EXP BUDGET	• Credible subset of studies can be implemented to address high-priority needs	• Available funding is currently insufficient to implement all proposed studies	• None
ECONOMIC	• Infusion of local economic activity linked to science support, etc.	• Foregone hydropower capacity in later timeframe (to be quantified by Bureau of Reclamation and Western Area Power Administration) • Potential short-term disruption of Lees Ferry angling recreation	• Financial impact is not yet fully quantified • Non-use values derived from resource effects are not known?
INFLUENCE ON ANNUAL WORK PLAN	• Shifts emphasis from solely monitoring to EXP research learning activities in a given year • New information will better inform GCDAMP process	• Number of non-experimental planned activities will need to be delayed/deferred • Impacts timing of some normal monitoring activities	• Full impact on a given typical annual work plan schedule is not completely known?
NO HIGH-FLOW EXPERIMENTS (BHBF) ALTERNATIVE (SCIENCE/RESOURCE PERSPECTIVE)	• Would not impact annual work plan tasks of monitoring • Monitoring data on downstream fate of new sand supplies under modified low fluctuating flow (MLFF) • No hydropower impacts	• No opportunity to benefit sand and related physical habitats resources (such as backwaters and possible benefit to juvenile humpback chub) • Already have abundant data on export of sand under MLFF, hence little new learning would occur • No opportunity to learn more about how BHBFs may limit sand export under fluctuating flows that follow • Missed opportunity to gather data on BHBFs as related to strategic, experimental questions about sand conservation and effectiveness of BHBFs to meet Goal #8 objectives • BHBFs are dependent on meeting the sediment input trigger	• There is great uncertainty about when conditions in the future will trigger an enriched high-flow experiment owing to the fact that sand inputs from the tributaries cannot be predicted

Table A.2. Comparison of 60-hour to 30-hour peak duration BHBF Test at 45,000 cubic feet per second (cfs)

High-flow peak duration at 41,500 cfs	~ Glen Canyon Dam bypass volume (Hours)	PROS	CONS
OPTION A 60 hours (as determined by BHBF model simulations and recommended by sediment scientists)	~ 93,000 acre feet (91 hours)	• Provides most rigorous direct comparison with 2004 BHBF test data • Maximum sandbar restoration predicted from modeling to occur in this timeframe • Resulted in net positive sand balance in 2004 BHBF test • Allows field scientists time for replicate eddy and SS measurements • 108 hours shorter than 1996 BHBF test • Greatest influence on exporting low oxygen from hypolimnion of Lake Powell	• Bypass volume is larger than suggested alternatives (below) • Highest impact on hydropower • Highest impact on recreational users
OPTION B 30 hours (alternative BHBF test hydrograph)	~ 56,000 acre feet (61 hours)	• Reduces bypass volume • Reduced impact on hydropower • Reduced impact on recreational users • Reduces potential export of new sand supply relative to option A	• Potentially limits benefits to downstream sandbar restoration • Limits data capture potential • Shorter BHBF tests result in less influence on exporting low oxygen from hypolimnion of Lake Powell

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Appendix B: Factors Influencing the Design of BHBF Related Experimental Studies for Fisheries, Cultural Resources, and Water Quality

Fisheries Studies Associated with Future BHBF Tests

The use of BHBFs was identified in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS) as a strategy to conserve sediment resources tied to physical, nearshore habitats thought to be important to native fish in the mainstem Colorado River below Glen Canyon Dam. Short-term experimental releases have previously been reported to have limited immediate influence on long-lived fishes (Valdez and others, 2001). It is still unclear what role the abundance, size, and distribution of nearshore sandbar features, such as backwaters, play in the life history of humpback chub in the CRE. Evaluating complex and multiyear fish responses that might be associated with short-duration, high-flow experiments that occur infrequently (mostly designed with sediment studies in mind) is difficult. Simply put, the capture and enumeration of rare fishes in a large, turbid river are difficult tasks that, despite recent advances, continue to be associated with high uncertainty.

The GCMRC and its cooperators continue to work on this problem and are improving both the capture and estimation techniques for the rare native fishes, especially humpback chub. Because of the high level of interest in these species, monitoring for humpback chub and other native fishes occurs throughout the year annually (illustrated by the 2007 work plan summarized in table C.1), providing a long-term perspective of the status and trends of these populations. Such a sampling regimen will bracket a future BHBF test whenever it is scheduled and provide a valuable, long-term perspective on the fate of humpback chub and other native fishes.

Table B.1. Native fish monitoring below Glen Canyon Dam in 2007.

Project	Timing	Primary Objective
Downstream Native Fishes	March	Monitor native fishes from Lees Ferry to Diamond Creek (spring)
Little Colorado River Humpback Chub	April	Population estimate of humpback chub in the LCR (concurrent sample)
Little Colorado River Lower 1200 meters/PIT tag antennae	April-May	Intensive monitoring of humpback chub in lowest 1200 meters of the LCR/test remote PIT tag antennae
Downstream Native Fishes	April	Population estimate of humpback chub in the mainstem Colorado River (concurrent sample)
Little Colorado River Humpback Chub	May	Population estimate of humpback chub in the LCR (concurrent sample)
Downstream Native Fishes	May	Population estimate of humpback chub in the mainstem Colorado River (concurrent sample)
Above Chute Falls	June	Monitor the translocated population of humpback chub upstream in the LCR
Warm Water Fishes/Sonic Tags	June	Monitor channel catfish in lower Colorado River/test application of sonic tags
Above Chute Falls	June-July	Monitor the translocated population of humpback chub upstream in the LCR
Downstream Native Fishes	March	Monitor native fishes from Lees Ferry to Diamond Creek (autumn)
Backwater Monitoring	September-October	Monitor small-bodied fishes in near-shore habitats, primarily backwater eddies
Little Colorado River Humpback Chub	September	Population estimate of humpback chub in the LCR
Little Colorado River Humpback Chub	October	Population estimate of humpback chub in the LCR

Fisheries scientists attempted to evaluate changes in distribution of native and nonnative fishes using catch-rate metrics from conventional sampling gear (e.g., hoopnets, electrofishing, etc.) used during the 1996 and 2004 BHBF tests. This common strategy was based on the assumption that catch-rate (number of fish captured per each unit of sampling effort) is directly proportional to fish abundance. However, this assumption will be violated if the efficiency of the sampling gear (catchability) is substantially affected by any uncontrollable variables (e.g., temperature, turbidity; reviewed by Arreguin-Sanchez, 1996). Therefore, comparisons of catch rate before and after an event like a future BHBF test are only valid to infer changes in abundance if it can be safely assumed that catchability was equal between the two samples. Violations of this assumption are particularly problematic when comparisons are made between only two events as opposed to inferring trend in abundance from a extensive time-series data where variability in catchability can sometimes be taken into consideration. Additionally, catch-rate estimates for rare fishes are frequently estimated with low precision. This is clearly illustrated considering the results of the 1996 BHBF test (Valdez and others, 2001). Careful inspection of these results suggests that for the rare species the statistical power to detect change is very low.

A further problem with this type of study is that displacement does not necessarily imply mortality. For instance, even if the decline in catch rate associated with the 2004 BHBF test (GCMRC, unpublished data; Coggins and others, 2005) was related to a change in abundance rather than a change in catchability, it is unknown whether the change in abundance was because of mortality. It is also possible that this change is simply a result of fish using different habitats following the 2004 BHBF test or that downstream displacement was temporary. Regardless of which of these hypotheses is correct, this type of study cannot ultimately provide information on the fate of fish associated with a future BHBF test. Therefore, we conclude that new techniques are required to answer the recurring question asked by managers, namely: “What is the fate of juvenile native fish during a future BHBF test?”

We propose that direct measurement of individual fish movement, accomplished through telemetry studies, would be the most conclusive method for inferring the fate of fish associated with a future BHBF test. Telemetry techniques have advanced substantially in the last decade and we are considering their use to investigate a host of fisheries related questions (see section 2, experimental study 4.B). However, using telemetry requires substantial training and trial applications. We are currently engaged in trials of this technology and initial results are encouraging.

Historically, the Lees Ferry reach has provided an ideal environment for the application of new technologies, suggesting a high probability of success. This owes, in part, to the ease of logistics, the small spatial scale, and the presence of large numbers of study animals (rainbow trout) in a relatively clear aquatic environment. Experimental study 4.B proposes to study the effects of a BHBF test on the distribution of juvenile and adult rainbow trout in the Lees Ferry reach using both indices of abundance and acoustic telemetry (this gear is being studied in 2007; see table 1). A study of this nature has a high probability of success for multiple reasons. One benefit of launching this type of study in the Lees Ferry reach is that working with rainbow trout provides ample study organisms that can be collected with little effort. This not only promotes the ability to detect small experimental effects but also incurs modest logistical costs. Alternatively, attempting such a study for humpback chub would likely require a large effort and cost to attain enough organisms. This would be difficult given the proposed timing of a BHBF test because juvenile humpback chub are at their highest abundance in the mainstem Colorado River during and after the monsoon season (mid to late summer) but far fewer fish are expected to be available for study in November–March (the likely timing of future BHBF tests).

The mortality risk associated with telemetry studies on juvenile rainbow trout is less than that for juvenile humpback chub because of the broad experience with surgical techniques for juvenile salmonids. The GCMRC and associated cooperators have experimented with sonic telemetry equipment in the Lees Ferry reach to determine its effectiveness under those specific conditions. Initial experimentation was very successful in that experimental sonic tags could be readily tracked in the Lees Ferry reach.

Sonic tags will be tested further in 2007, under more demanding conditions, especially in the presence of higher turbidities than occur in the Lees Ferry reach. The value of the sonic tag technology to the GCDAMP will increase if it can be shown to perform well under the more turbid conditions of the Little Colorado River inflow and below Diamond Creek. Investigators will also gain expertise with implanting these tags in 2007. If the tags are still detectable in turbid conditions, and if investigators achieve good survival rates for fish implanted with the tags during 2007 studies, the GCMRC will propose that this technology be used with individual humpback chub, subject to regulatory agency approval. The 2007 results, and results in future years, will help determine the minimum size of humpback chub that would be proposed for tagging and tracking; however, there is general agreement among the cooperators that younger, smaller fish are of greatest concern and therefore would be most important to track. Specific recommendations for use of sonic tag technology, including an associated budget, will be prepared, reviewed, and distributed at least 120 days in advance of a proposed future BHBF test.

The thoughtful review of the GCDAMP Science Advisors clearly articulates the opinion that additional work on humpback chub should be a priority associated with future experimental high flows. We attempted to highlight the problems and shortcomings associated with fish sampling and monitoring connected with past experimental high flows and outline our approach to overcoming these issues using telemetry (see above). Subsequently, we have also identified a relatively new set of estimation techniques that could also allow better inferences about the effects of experimental high flows on humpback chub than index-based methods used in the past.

Since 2000, much work has been done to characterize change in fish population size, distribution, and habitat use in situations where it is not practical to estimate or index abundance (Mackenzie and others, 2006). These newly developed techniques hold promise for quantifying change in fish density and habitat use before and after an experimental BHBF. The basic idea is that rather than comparing abundance indices (such as catch per unit effort) before and after some event where the critical assumption of equal capture probability is typically not testable, occupancy models estimate not only the proportion of sampling units occupied, but also the detection probability. As such, probability of occupancy becomes a comparable state variable between, for instance, two time periods. If sampling units are further grouped by a covariate such as habitat type, occupancy rates become a measure of habitat use. Finally, since detection probability is likely influenced by abundance, methods have also been developed to extract abundance.

We are intrigued by this novel approach because of its potential for monitoring small-bodied fish. We plan to analyze several existing datasets, including the data collected in association with the 2004 BHBF test, and conduct simulation studies using this technique to evaluate its use in estimating fishes before and after any future BHBF tests. Pending these evaluations, we may propose further sampling to estimate occupancy and associated parameters to better understand the effects of experimental high flows on humpback chub. If these methods are shown to be applicable for use in Grand Canyon, then we would propose to add a project for occupancy estimation for humpback chub in association with a BHBF test. This proposal and associated budget would be submitted for consideration at least 120 days before a proposed future BHBF test.

Summary of Challenges in Assessing the Effects of Future BHBF Tests on Native Fish Populations in the Colorado River in Grand Canyon

Trends in Fish Abundance in Glen and Grand Canyon

- Humpback chub abundance in Grand Canyon, based on catch-per-effort (CPE) and tagging assessments, shows continuing decline through the 1990s. Trends in adult abundance observed during the 1990s suggest recruitment of young humpback chub began declining by the mid-1980s

- Reductions in daily fluctuations and increased minimum flows beginning in the early 1990s likely caused the large increases in rainbow trout in Glen Canyon and in Grand Canyon near the Little Colorado River confluence where humpback chub are most abundant
- There is considerable uncertainty about the cause of the decline in humpback chub recruitment – timing of the recruitment decline in mid-1980s does not match the timing of the rainbow trout increase in mid-1990s, though increasing rainbow trout may have continued to suppress the humpback chub population

Glen Canyon Dam Treatments Targeted at Improving HBC Recruitment

- The 1996 Biological Opinion for the EIS recommended modifications to Glen Canyon Dam operations designed to restore some elements of downstream physical habitat for humpback chub:
    - Seasonally adjusted steady flows to increase shoreline habitat stability and increase water temperature to stimulate mainstem spawning and improve juvenile survival rates
    - Testing of thermal modification of releases from Glen Canyon Dam
- These hypotheses were based on very limited data at the time they were formulated. Impacts of fluctuating flows on humpback chub recruitment are not supported by the timing of decline in humpback chub abundance and increase in rainbow trout abundance.
- The most recent experimental flow treatment recommended by the Glen Canyon Dam Adaptive Management Workgroup called for increased daily flow fluctuations (5,000–20,000 cfs) from January–March in 2003 and 2004. The increase in daily fluctuations was intended to limit rainbow trout abundance and associated negative interactions with humpback chub.
- BHBFs to rebuild nearshore sandbar habitats were also described as part of the 1996 ROD and additional sediment tests were recommended by the GCDAMP as part of integrated physical and biology experimentation in 2002. A second BHBF experiment was then conducted in fall 2004 when the Paria River delivered new sand to the ecosystem in Marble Canyon.
- The potential for improving our understanding of the effects of dam operations, particularly BHBFs, is limited by:
    - Assessments of juvenile abundance based on catch rate metrics (CPE) are difficult to interpret because of uncontrollable changes in gear efficiency (catchability), particularly for fishes in low abundance and over short time intervals (e.g., BHBF)
    - Tagging assessments are more reliable than CPE data, but there is a long (3+ years) lag between the time a change in recruitment occurs and when it can be observed using the tagging assessment data. The occupancy estimation models being investigated by GCMRC and others may be employed to help address earlier life stages
    - Imprecision in all available assessment methods makes it difficult to detect year-to-year differences in recruitment unless they are extremely large

- Experimental flows need to be replicated over multiple years to account for environmental variability and the limitations in available assessment methodology
- The short-term single-year approach to experimental management currently adopted by the AMWG greatly reduces the chance of measuring native fish responses and does not embrace recommendations from the broader scientific literature on adaptive management experimental design. Further, the natural variability of annual sand production from the tributaries and other considerations typically means that future BHBF tests are likely to occur relatively infrequently under sand-enriched conditions and that annual replication is unlikely.

Evaluating the status and trends of native and nonnative fish populations in Grand Canyon is extremely difficult because of sampling logistics and the low abundance of native fishes, especially in the early months of the year. Application of stock assessment modeling procedures, originally developed for managing commercial fisheries, has been helpful for estimating population trends from the historical fisheries data (Coggins and others, 2006), but tagging based assessments involve considerable lag time before reliable assessments of recruitment responses to management actions are available. However, the sonic tagging of fish being studied by GCMRC and cooperators has the potential to provide some short-term information on individual fish movements. Tagging will be especially valuable if it proves to be useful in evaluating whether native fishes displaced by temporary high flows retain the ability to return to an area following the flows. Tagging methods are generally not sufficient to resolve whether declines in native fish populations have been caused by the increasing abundance of exotic fishes, dam operations (including BHBFs), or a combination of the two. Our ability to detect fish population responses to future BHBF tests is limited in spite of the lessons learned from stock assessment modeling and expanded monitoring efforts. Additional methods are needed and are currently under development by GCMRC and cooperating agencies, especially Arizona Game and Fish Department.

Cultural Resources

Future BHBF tests have the potential to change ecosystem dynamics in ways that may affect the condition and biophysical attributes of many culturally important resources located in the Colorado River corridor, including archaeological sites, traditional cultural properties, and individual species of special concern to Native American tribes. Additionally, future BHBF tests may alter camping beaches used by park visitors and other ecosystem attributes that influence the quality of the visitors' experience (e.g., navigability of rapids, abundance and distribution of rainbow trout.) For example, it has been hypothesized that the periodic replenishment of sandbars above the level of normal Record of Decision flows reduces crowding and competition for campsites, thereby improving the quality of visitor experience. It has also been hypothesized that the creation of larger, higher, and drier sandbars as a result of periodic high flows increases the available sediment sources for aeolian transport to higher elevations in the ecosystem, thereby potentially offsetting some of the ongoing erosion of archaeological sites caused by rainfall run off, social trailing, and surface deflation.

The science activities described in this plan explicitly integrate several important cultural concerns within individual study plans in recognition of the close interrelationship between physical and biological processes and resource condition outcomes. Specifically, proposed science activities are designed to evaluate the potential effects of future BHBF tests on sediment transport and deposition at archaeological sites and consequent effects to the sites' stability or erosion; evaluate the size and distribution of sandbars and open sand area used as camping sites and their persistence through time; trout dispersal in response to future BHBF tests; and the distribution of native and nonnative riparian species, many of which are culturally important to local Native American tribes.

Most of the proposed BHBF studies are designed to build upon monitoring data that are already being collected to assess the rate and extent of changes occurring to the ecosystem under Record of Decision operations. For example, in conjunction with developing an ecosystem-based approach to monitoring archaeological site condition, the GCMRC has established weather monitoring stations and is collecting aeolian transport and gully erosion data at a sample of archaeological sites within the Colorado River ecosystem. Data from focused science activities proposed as part of this experimental BHBF science plan, (experimental study 1.C) would be analyzed in relation to these previously collected monitoring data. Likewise, the GCMRC annually collects data on the area, volume, and extent of available campable area at selected sandbar sites distributed throughout the Colorado River ecosystem; additional survey data and documentation collected in conjunction with a future BHBF test will be analyzed in relation to these pre-existing monitoring data.

This science plan targets a limited set of key questions and issues that have been consistently identified by resource managers and GCDAMP stakeholders as being most critical to study through implementation of future BHBF tests. Future BHBF testing and associated science activities are designed to improve understanding of the geomorphic and biological effects of BHBF tests conducted under sediment-enriched conditions as they relate to the goal of improving the potential for in situ maintenance and protection of culturally valued resources, in keeping with the stated intent of the GCDAMP. This information will have direct relevance to ongoing resource management and legal compliance issues.

Water Quality

Any investigation of the dynamics of the Colorado River ecosystem in Grand Canyon must not only document and understand the water quality in Grand Canyon itself, but also the water quality in Lake Powell, the reservoir created by Glen Canyon Dam. The impoundment of a river system in a reservoir alters downstream water quality in many ways (Nilsson and others, 2005). The formation of Lake Powell in 1963 was accompanied by reductions in suspended sediment and nutrient transport and by changes in seasonal temperatures, discharge levels, and benthic community structure of the Colorado River (Paulson and Baker, 1981; Stevens and others, 1997; Topping and others, 2000a; 2000b). More recently, reservoir and downstream water quality has been affected by reservoir drawdown from a 5-year basinwide drought in the Western United States. Water released from Glen Canyon Dam in 2003 and 2004 was the warmest recorded since August 1971, when Lake Powell was in its initial filling period (initial filling of the reservoir began in 1963 with the closure of Glen Canyon Dam; the reservoir reached full pool of 3,700 ft for the first time in 1980).

Water temperature, nutrient concentrations, turbidity, and other water-quality parameters are of interest to managers and scientists because these parameters influence a range of ecosystem components, from support of aquatic microorganisms and invertebrates to the behavior of native and nonnative fishes. For example, water quality is an important determinant of food-web structure in aquatic habitats and abundance of consumers like fish in those food webs (Carpenter and Kitchell, 1996; Wetzel, 2001).

Scientists hypothesize that operational changes associated with any future BHBF tests could have significant effects on the quality of water released from Glen Canyon Dam. The experimental work proposed in this science plan will measure changes in water-quality characteristics for the water leaving the dam and the water in the tailwaters during and immediately following a future BHBF testing.

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