In cooperation with the Glen Canyon Dam Adaptive Management Program

Science Plan for Potential 2008 Experimental High Flow at Glen Canyon Dam

Prepared by the Grand Canyon Monitoring and Research Center

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Executive Summary

This science plan describes proposed monitoring and research activities to be conducted by the U.S. Geological Survey's Grand Canyon Monitoring and Research Center (GCMRC), should the Secretary of the Interior approve an experimental high flow at Glen Canyon Dam in spring 2008. A high-flow release from the dam has been proposed in 2008, not only to rebuild sandbars and aid the endangered humpback chub, but also to benefit various downstream resources, including rainbow trout (*Oncorhynchus mykiss*), the aquatic food base, riparian vegetation, and archaeological sites. Additionally, the system is currently enriched with sediment as a result of repeated tributary floods from the Paria River in late 2006 and fall 2007; the current level of sand enrichment is greater than it has been since at least 1998.

The international prominence of Grand Canyon National Park and public concern about the impacts of Glen Canyon Dam resulted in Federal efforts to protect downstream resources. In 1992, the Grand Canyon Protection Act (GCPA) was enacted "to protect, mitigate adverse impacts to and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established." The 1996 Record of Decision on the Operation of Glen Canyon Dam Environmental Impact Statement established an adaptive management program, of which the GCMRC is a part, to ensure that the primary mandate of the GCPA is met.

Before the dam, the Colorado River swelled with spring snowmelt from the Rocky Mountains in most years, producing flood events and transporting large quantities of sediment that created and maintained sandbars in Grand Canyon. In Grand Canyon, sandbars provide camping beaches for river runners and hikers, serve as a source of sediment needed to protect archaeological resources from weathering and erosion, and create habitats used by native fish and other wildlife. Today, the river usually runs clear below Glen Canyon Dam, because Lake Powell traps all of the sediment upstream from the dam (Wright and others, 2005). As a result, Grand Canyon receives 6%–16% of its predam sand supply, which comes primarily from the Paria and Little Colorado Rivers when they enter the mainstem below the dam (Wright and others, 2005).

The native fish community found in Grand Canyon evolved in the large, turbid, and seasonally variable predam Colorado River. Today, three of the eight native fish species have been eliminated from the Colorado River in the study area and two are federally listed as endangered, razorback sucker (*Xyrauchen texanus*) and humpback chub (*Gila cypha*), under the Endangered Species Act of 1973. The razorback sucker is widely thought to no longer be present in Grand Canyon. Only six populations of humpback chub are known to exist, five in the Colorado River Basin above Lees Ferry, Ariz., and the one in Grand Canyon, Ariz., which is the largest population remaining in the basin.

Importantly, the design of the proposed 2008 high flow and the accompanying experimental studies outlined in this plan build on learning that occurred as the result of high-flow experiments conducted in 1996 and 2004. For example, from the 1996 high-flow, scientists learned that tributary-supplied sand does not accumulate on the riverbed over multiyear periods under typical dam operations. In fact, erosion of low-elevation sandbars caused by the 1996 high flow actually resulted in a net reduction in overall sandbar size. Approval of a supplemental environmental assessment (U.S. Department of the Interior, 2004) allowed scientists to evaluate the efficacy of conducting a high flow following tributary floods in 2004 for the first time and generated the following conclusions:

- The 2004 experiment resulted in an increase of total sandbar area and volume in the upper half of Marble Canyon, but further downstream, where sand was less abundant, a net transfer of sand out of eddies occurred that was similar to that observed during the 1996 experiment (Topping and others, 2006).
- More sand will be required than was available during the 2004 high flow (800,000 to 1,000,000 metric tons) to achieve increases in total sandbar area and volume throughout all of Marble and Grand Canyons in the future (Topping and others, 2006).
- Sandbars created by the 2004 high flow increased the windborne transport of sand toward some archaeological sites in Grand Canyon (Draut and others, 2005; Draut and Rubin, 2006). This led to the hypothesis that increased sand carried by the wind from restored sandbars may reduce erosion and increase preservation potential at some archaeological sites.

The sediment-related data that researchers propose to collect for a possible 2008 high flow would facilitate comparison with data collected during the two previous experiments. 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 high-flow experiments, sediment deposition at archaeological sites and camping areas, 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 are required to determine whether greater and more geographically extensive sandbar rebuilding is possible with a future high flow than occurred in 1996 and 2004. The data are also needed to determine if consecutive high flows in the future might cause sand to accumulate through time to reverse erosion documented after the closure of Glen Canyon Dam in 1963.

Sandbar rebuilding is thought to be important in creating backwater habitat that may lead to increased production of young fish by native species. Overall, recruitment of humpback chub has been increasing from 1994 to 2002, a period that includes the 1996 high flow, though the uncertainty in these estimates is large. These data suggest that high flows have not been detrimental to humpback chub. It is also possible that high flows offer advantages to humpback chub, including the temporary displacement of nonnative fishes (Valdez and others, 2001) and the maintenance and construction of backwater habitats, which may offer growth advantages to humpback chub and other native fishes (Arizona Game and Fish Department, 1996).

The best timing to conduct a high flow to maximize resource benefits or to avoid undesirable impacts has yet to be determined. For 2007–08, the earliest practical time for a high flow would be early March 2008, given the logistical, administrative, and compliance requirements associated with conducting the research outlined in this plan.

The GCMRC proposes replication of the 2004 hydrograph in a potential 2008 high flow (41,500 cubic feet per second (cfs) for 60 hours). These conditions would allow scientists to determine whether the locally robust and consistent sandbar-building responses that occurred in upper Marble Canyon in 2004 can be repeated and possibly enhanced. However, a possible 2008 experiment would be different from the two high-flow experiments conducted previously in several important ways. In November 2007, for example, sand supplies in the main channel of the Colorado River were two to three times larger and distributed differently than in 2004. The system is currently enriched with sediment as a result of repeated tributary floods from the Paria River in October 2006 and August–September 2007 that delivered 2,500,000 metric tons (±500,000 metric tons) of sand into the Colorado River ecosystem below Glen Canyon Dam. Based on the entire period of record on the Paria River (1923–present), this annual magnitude of sand supply from the river occurs, on average, once in every 10 years. A second important difference is that a 2008 high flow would be followed by normal Record of Decision operations associated with annual release volumes, unlike previous experiments, which were followed by higher fluctuating flows than would have otherwise occurred.

Additionally, this science plan focuses on a wider range of research questions than previous high-flow experiments. For example, experimental study 1 (parts A–D) addresses questions related to sediment and seeks to determine not only if high-flow releases are an effective tool that will rebuild and maintain sandbars over time, but also if they have the ability to create additional backwater habitats for native fish and how new sand deposits affect archaeological sites. Experimental study 1 expands on work begun with the 2004 high flow to document the connection between high-flow releases and the transfer of sand to cultural sites by the wind and the formation and persistence of backwaters as the result of high flows. Additionally, data gathered as a result of a possible 2008 high-flow experiment would provide information to inform the continued development of a sediment model, which will help determine the optimum frequency, timing, duration, and magnitude of future high flows under varying sediment enrichment conditions. Experimental studies 2–5 address the impacts of high-flow experiments on riparian vegetation, the food base, rainbow trout, and Lake Powell water quality, respectively. Study 7 will provide a comprehensive synthesis of the results of all of the experimental studies conducted in association with a possible 2008 high-flow experiment. A well-calibrated, robust predictive sediment model will help minimize the impacts of high-flow tests on Glen Canyon Dam hydropower production.

The experimental studies outlined in this plan are designed to address strategic science questions identified in the Grand Canyon Monitoring and Research Center's monitoring and research plan; strategic science questions are designed to guide science activities over the next 5 years. Questions specific to the impacts of a high-flow flow are also identified for each study and would be addressed during the 2008 high-flow experiment, if it occurs.

The table that accompanies the executive summary briefly describes the various experimental studies and estimated costs. The total cost of the research activities associated with a possible 2008 high flow is approximately $3.73 million for fiscal years 2008–09. Thus, based on current and anticipated deposits into the experimental fund, additional support will be required to fully implement the science plan.

Based on the two previous high-flow experiments conducted to date, scientists cannot say at this time whether such experiments are an effective strategy for stopping the ongoing erosion of sand and sandbars in the Colorado River ecosystem. A long-term research strategy involving further high-flow experimentation and model development will be necessary to assess whether high flows can effectively conserve sediment and help achieve other related resource benefits (increased humpback chub recruitment, enhanced camping beaches, protection of cultural resource, minimized hydropower impacts, etc). At this time, it is not anticipated that a single high-flow release can answer all such relevant questions: accordingly, it is very likely that additional high-flow experiments will be needed to address the major uncertainties associated with the use such dam operations as an effective long-term management tool.

It is expected that a long-term experimental strategy, including the number and future frequency of high-flow experiments, will be determined through the Glen Canyon Dam Adaptive Management Program.

Table E.1. Description of experimental studies proposed by this science plan, including cost estimates for fiscal years (FY) 2008–09.

Experimental study	Description	FY 2008 cost estimate	FY 2009 cost estimate
	Sediment, archaeological sites, and backwaters		
1.A. Sand budgeting	Data will be collected to determine the amount of sediment available in the system and its availability for restoring sandbars and camping beaches, patterns of erosion and deposition, and changes in sediment grain size	$313,212	$94,102
1B. Eddy-sandbar studies	Data will be collected on the evolution of specific eddy sandbars before, during, and after a high flow. These data may be used to improve the predictive capabilities of the existing sediment model and determine the optimal peak flows of future high-flow experiments.	$103,797	$92,057
1.C. Response of sandbars and select cultural site	Data will be gathered to determine (1) if sandbars throughout the Colorado River ecosystem gain or lose sand as the result of a sand-enriched high flow, (2) if new sand can offset gully erosion, and (3) if enlarged sandbars provide source material for the windborne transport of sand upslope into archaeological sites.	$604,180	$360,374
1.D. Backwater habitats	Measure backwater habitats and sample them for fish in spring and fall to evaluate how (a) backwaters formed by a high flow change over time and (b) how fish, particularly humpback chub, use backwaters.	$851,461	$191,275
	Riparian vegetation		
2. Riparian vegetation studies	Study will document changes in riparian vegetation (native versus nonnative) following a high flow to determine if disturbances influence the success rate of nonnative species.	$42,709	$30,738
	Aquatic food base		
3. Food availability	Data will be collected to determine how high-flow experiments affect the quantity and quality of food available to invertebrates and, ultimately, fish.	$216,903	$44,175
	Rainbow trout		
4.A. Redds study	Data will be collected to determine how high-flow experiments affect spawning and survival of early-life stages of rainbow trout in Lees Ferry	$130,371	$100,861
4.B. Movement study	Study will collect data to determine if high-flow experiments displace rainbow trout from Lees Ferry and if displacement varies by fish length	$110,648	$2,057
	Lake Powell		
5. Lake Powell	Data to determine if a high flow results in higher nutrient releases and changes in the hypolimnion	$35,274	$5,022
	Conservation measures		
6. Kanab ambersnail	To minimize impacts to an endangered species, Kanab ambersnail habitat at Vaseys Paradise will be moved	$16,316	$0
	Knowledge synthesis		
7. Synthesis of knowledge	Data and knowledge gained as the result of the high-flows test will be synthesized in an attempt to address strategic science questions	$0	$258,000[1]
	Logistical support		
8. Logistical support	Logistical support costs not associated with specific research activities	$122,673	$0
Totals		**$2,547,543**	**$1,178,660**

[1] An additional $400,000 will be needed in FY 2010 to complete the synthesis of results from a possible 2008 high-flow test with previous high-flow tests

Science Plan for Potential 2008 Experimental High Flow at Glen Canyon Dam

Prepared by the Grand Canyon Monitoring and Research Center

Part I: Introduction and Background

This science plan describes proposed monitoring and research activities to be conducted by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC), should the Secretary of the Interior approve an experimental high flow at Glen Canyon Dam in early 2008. The study area is the Colorado River ecosystem (CRE), the river corridor that extends from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park (fig. 1). This plan is designed to build upon existing scientific knowledge to inform managers about the efficacy of using high-flow releases from the dam, not only to rebuild sandbars and aid the endangered humpback chub (*Gila cypha*), but also to benefit various downstream resources, including rainbow trout (*Oncorhynchus mykiss*), the aquatic food base, riparian vegetation, archaeological sites, and water quality.

The GCMRC has responsibility for monitoring and research activities for the Glen Canyon Dam Adaptive Management Program (GCDAMP), a Federal initiative to protect and improve resources downstream of Glen Canyon Dam. Because of the lengthy lead time required to plan and execute a high flow, the Adaptive Management Work Group (AMWG)—the Federal Advisory Committee within the GCDAMP that provides recommendations to the Secretary of the Interior on the operation of the dam—recommended that the GCMRC prepare this plan in anticipation of a future experiment. Following this recommendation, the Department of the Interior directed the GCMRC to develop an "off-the-shelf" science plan to take advantage of potential high-flow research opportunities in the future. This plan has been adapted specifically to address a potential high-flow experiment in the spring of 2008; however, the plan may be considered generally applicable to any future high-flow experiment.

Although this science plan primarily focuses on potential experimental studies associated with a 2008 experimental high-flow release, the plan also addresses concerns expressed by GCDAMP participants about issues related to future high-flow experimental research, particularly associated costs and benefits. Issues of concern, relevant information about these issues gathered during the science-planning process, and an assessment of each issue prepared by GCMRC scientists are given in appendix A. Efforts have also been made to identify the pros and cons of a future high-flow experiment, especially related to the duration of the experiment (see appendix A, table A1).

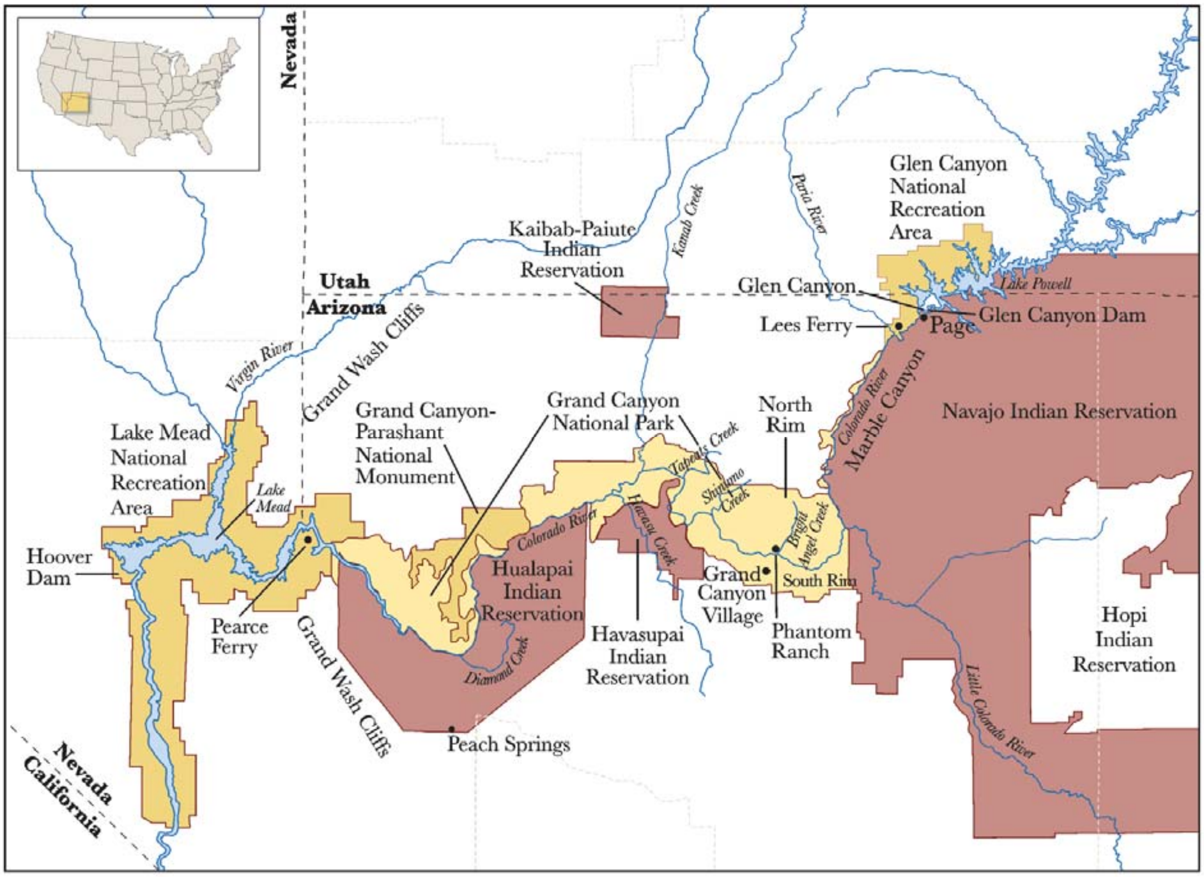

Figure 1. Map of the Colorado River ecosystem, the Colorado River corridor that extends from the forebay of Glen Canyon Dam to the western boundary of Grand Canyon National Park, Ariz.

Background

Glen Canyon Dam, one of the last major dams built on the Colorado River, is located in the lower reaches of Glen Canyon National Recreation Area, approximately 24 km upriver from Grand Canyon National Park. Before the dam, the Colorado River swelled with spring snowmelt from the Rocky Mountains in most years, producing flood events and transporting large quantities of sediment that created and maintained sandbars in Grand Canyon. The native fish community found in Grand Canyon, including species found nowhere else on Earth, evolved in the large, turbid, and seasonally variable predam Colorado River. Today, three of the eight native fish species have been eliminated from the Colorado River in the study area and two are federally listed as endangered, razorback sucker (*Xyrauchen texanus*) and humpback chub, under the Endangered Species Act of 1973. The razorback sucker is widely thought to no longer be present in Grand Canyon. Only six populations of humpback chub are known to exit, five in the Colorado River Basin above Lees Ferry, Ariz., and the one in Grand Canyon, Ariz., which is largest population remaining in the basin.

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

The international prominence of Grand Canyon and public concern about the impacts of the dam resulted in Federal efforts to protect downstream resources. In 1992, the Grand Canyon Protection Act (GCPA) was enacted "to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established." The GCDAMP was established by the 1996 Record of Decision (ROD) on the Operation of Glen Canyon Dam Environmental Impact Statement (EIS) to ensure that the primary mandate of the GCPA is met (U.S. Department of the Interior, 1995). An adaptive management process—initiated following the 1996 Record of Decision—is being used to evaluate the effects of dam operations on the ecosystem below Glen Canyon Dam and to identify future modifications of dam operations to enhance resource conditions. Adaptive management is a systematic process that uses experimentation and monitoring to continually improve management practices.

Beach/Habitat-Building Flows and High-Flow Experimental Releases

One of the experiments identified by the 1995 EIS was the use of beach/habitat-building flows (BHBF) to rebuild high-elevation sandbars, deposit nutrients, and restore backwater channels. Replenishing sandbars requires both a sufficiently large upstream sand supply and higher than normal flows to deposit sand at higher elevations. In the EIS, a BHBF is defined as a release of water from Glen Canyon that is at least 10,000 cubic feet per second (cfs) greater than the allowable peak discharge (30,000 cfs) but not greater than 45,000 cfs. The EIS specified the testing of high-flow experiments prior to their implementation as a long-term management action.[2]

Importantly, the design of the 2008 high-flow experimental release and the accompanying experimental studies proposed in this plan build on learning that occurred as the result of previous high-flow experiments conducted in 1996 and 2004. For example, from the 1996 experiment, scientists learned that tributary-supplied sand does not accumulate on the riverbed over multiyear periods under typical dam operations, as had been hypothesized in the EIS. Additionally, the 1996 experiment was conducted when the Colorado River was relatively sand depleted, especially in Marble Canyon, and, as a result, the primary sources of sand for building high-elevation sandbars were the low-elevation parts of the upstream sandbars and not the channel bed (Andrews and others, 1999; Schmidt, 1999; Hazel and others, 2006). During the 1996 experiment, the erosion of low-elevation sandbars actually resulted in a net reduction in overall sandbar size. Sandbars that

[2] The 1996 Record of Decision (ROD) and 1997 Glen Canyon Operating Criteria address the management framework for the operation of Glen Canyon Dam, including implementation of beach/habitat-building flows (BHBFs) as part of a long-term monitoring, research, and experimental program. The 1996 ROD established an adaptive management framework for future experimentation and management decision making, including experimentation designed to inform future operational changes. The high-flow experiment contemplated for March 2008 identified in this science plan utilizes the hydrologic release elements of a BHBF, but as described herein, would function as a single experimental action, rather than relying on the reservoir level-based triggers that are linked to management implementation of BHBFs. Implementation of this proposed experimental release is subject to completion of appropriate environmental compliance documentation by the action agency (Bureau of Reclamation). Further information regarding the approach and basis for the proposed experiment can be found in the biological assessment prepared for the proposed action by the Bureau of Reclamation (December 2007).

eroded during the 1996 experiment did not recover their former sand volume during the late 1990s, in spite of above-average sand supplies and the implementation of ROD operations.

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

The Importance of Tributary Floods

In September 2002, the U.S. Department of the Interior approved the implementation of a new high-flow experimental approach linked to sand inputs from the Paria River (U.S. Department of the Interior, 2002). Significant sand inputs to Marble Canyon occurred during September–November 2004 that exceeded the sediment trigger established in 2002. Approval of a supplemental environmental assessment (U.S. Department of the Interior, 2004) allowed scientists to evaluate the efficacy of conducting a high-flow experiment following tributary floods for the first time. The second experimental high-flow release was conducted in November 2004 and generated the following conclusions:

- The 2004 experiment resulted in an increase of total sandbar area and volume in the upper half of Marble Canyon, but further downstream, where sand was less abundant, a net transfer of sand out of eddies occurred that was similar to that observed during the 1996 experiment (Topping and others, 2006).
- Substantial increases in total eddy-sandbar area are only possible when high flows are conducted following large tributary floods that enrich sand supplies in the main channel of the Colorado River (Rubin and others, 2002: Topping and others, 2006).
- More sand will be required than was available during the 2004 high-flow experiment (800,000 to 1,000,000 metric tons) to achieve increases in total sandbar area and volume throughout all of Marble and Grand Canyons in the future (Topping and others, 2006).
- Sandbars created by the 2004 high-flow experiment increased the windborne transport of sand toward some archaeological sites in Grand Canyon (Draut and others, 2005; Draut and Rubin, 2006). This led to the hypothesis that increased sand carried by the wind from restored sandbars may reduce erosion and increase preservation potential at some archaeological sites.

The sediment-related data that researchers propose to collect for a 2008 high-flow experiment will facilitate comparison with data collected during the two previous high-flow experiments conducted in 1996 and 2004. Proposed experimental studies will also generate new data that can be compared to previous experiments on the physical processes regulating sandbar erosion and deposition during high-flow releases, sediment deposition at archaeological sites and camping areas, 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 are required to determine whether greater and more geographically extensive sandbar rebuilding is possible with a future high-flow experiment than occurred during the 1996 and 2004 experiments. The data are also needed to determine if consecutive high-flow experiments in the future might cause sand to accumulate through time to reverse erosion documented after the closure of Glen Canyon Dam in 1963.

Humpback Chub Response

The 1996 high-flow experiment occurred in the spring (March 22 to April 8, 1996), which is approximately the same timing considered for a possible 2008 high-flow experiment (The 2004 high-flow experiment was conducted in the fall.). The fish community response to the 1996 high-flow release was studied and reported by Valdez and others (2001). These authors found that the native fish community, including humpback chub, did not experience decreased distribution or abundance as a result of the high-flow experiment; however, there was temporary displacement of nonnative fish species. During the November 2004 high-flow experiment, fisheries scientists attempted to sample the fish community before and after the experiment to further document the response of humpback chub and other fishes to high flows. Unfortunately, the sampling following the event was confounded by a natural flood event in the Little Colorado River, which greatly increased turbidity in the main channel and possibly reduced the efficiency of the sampling gear. Because of the timing and magnitude of the spate from the Little Colorado River, it cannot be determined whether the observed decline in catch rate following the 2004 high-flow experiment resulted from a decline in fish density or a decline in sampling gear efficiency.

The age-structured mark recapture model (ASMR) model (Coggins and others 2006) is used to assess the status and trends of the humpback chub population in Grand Canyon. The ASMR results for the years 1989–2006 indicate that the population of adult (age 4+) humpback chub in Grand Canyon declined to a modern low in 2001 but has been increasing since that time (fig. 2). This period of increasing population includes the November 2004 high-flow experiment. Although the exact cause of the increased population cannot be determined with certainty (Andersen, 2007), the November 2004 high-flow experiment does not appear to have been detrimental to the adult population of humpback chub.

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

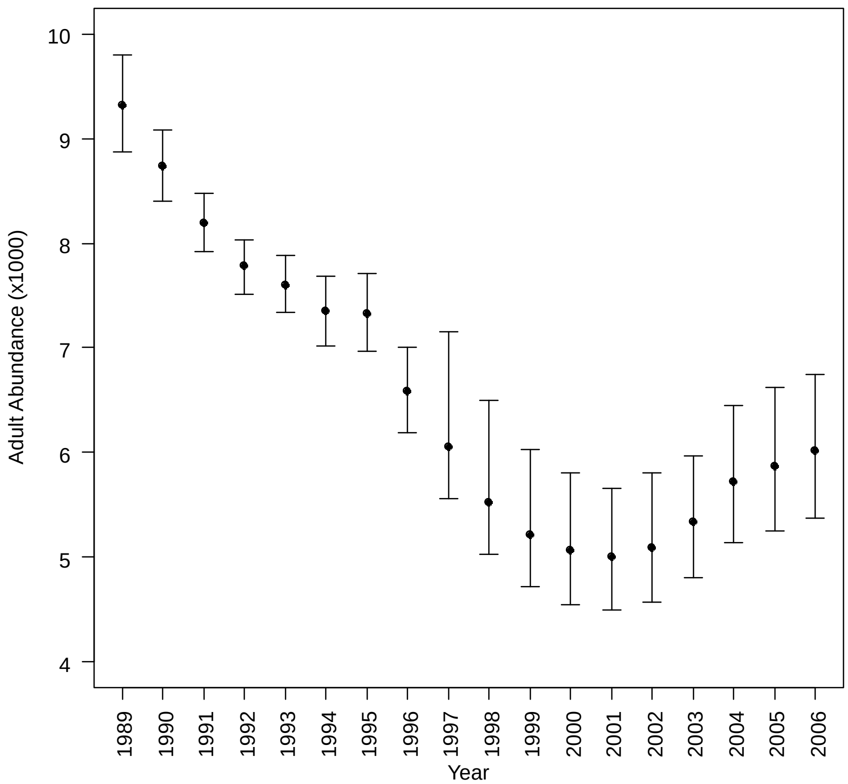

Figure 2. Trend of adult (age 4+) humpback chub population in Grand Canyon modeled by the age-structured mark recapture model of Coggins and others, 2006 (U.S. Geological Survey, unpub. data, 2007). Error bars represent 95% profile confidence intervals.

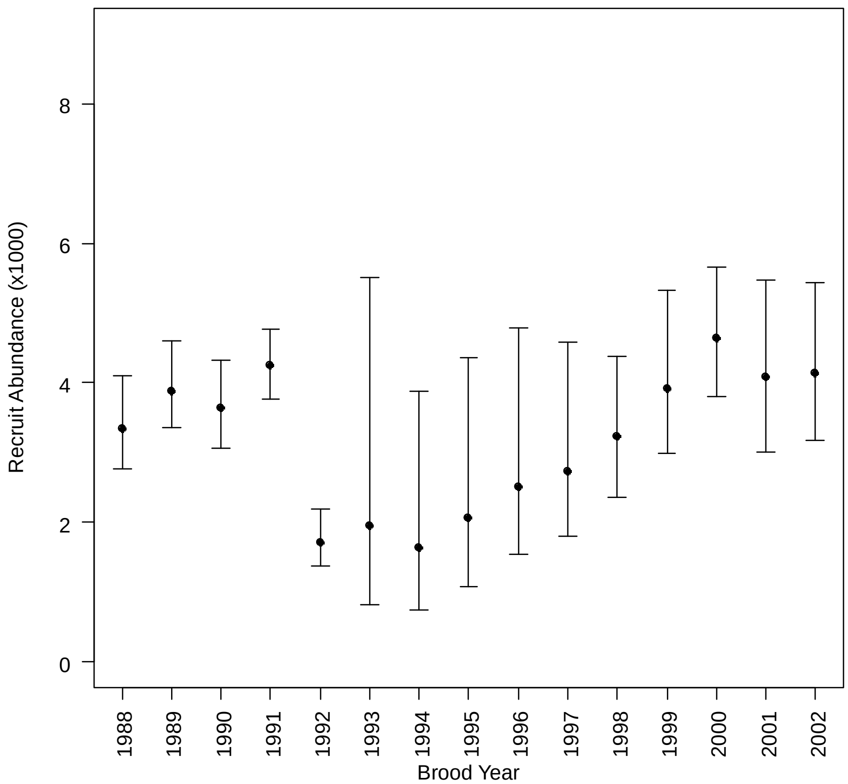

Figure 3. Estimated recruitment to the Little Colorado River humpback chub population from brood years 1988–2002 (U.S. Geological Survey, unpub. data, 2007). Error bars represent 95% profile confidence intervals.

2008 Potential High-Flow Experiment

Timing

The best timing to conduct a high-flow experiment to maximize resource benefits or to avoid undesirable impacts has yet to be determined. For 2007–08, the earliest practical time for a high-flow release would be early March 2008, given the logistical, administrative, and compliance requirements associated with conducting the research outlined in this plan. March 2008 is an appropriate time frame for a high-flow experiment for the following reasons:

1. The system is currently enriched with sediment as a result of repeated tributary floods from the Paria River in October 2006 and August–September 2007 that delivered 2,500,000 metric tons (±500,000 metric tons) of sand into the Colorado River ecosystem below Glen Canyon Dam. As a result, sand supplies in the upper reaches of Grand Canyon National Park now contain approximately two to three times the minimum sand volume that was previously needed to trigger the last high-flow experiment in 2004. Sand production by the Paria River in Water Year 2007 has been twice the long-term average and the current level of sand enrichment is

greater than it has been since at least 1998. Based on the entire period of record on the Paria River (1923–present), this annual magnitude of sand supply from the Paria River occurs, on average, once in every 10 years. Most of this new sand is still retained in Marble Canyon at present because downstream transport of the new sand has been suppressed under minimum dam operations associated with modified low fluctuating flows combined with 8.23 million acre-feet annual release volume.

2. A March experimental release would be expected to be compatible with the life cycles and life histories of many native Colorado River organisms. For example, humpback chub historically spawned on the ascending limb of the spring hydrograph when water temperatures would approach 17°C.
3. High flows that occur when sand supply is abundant in the channel are known to form backwater habitats (Goeking and others, 2003) where young native fish can find refuge from predation and benefit from warmer water temperatures that encourage growth. A March high flow would create backwaters at the onset of the spawning season increasing the likelihood that they would be available for use by larval and juvenile fishes
4. March is before the flowering of the nonnative tamarisk (*Tamarix ramosissima*), and so would reduce the potential for increasing its distribution. Controlling the spread of tamarisk in the CRE is a priority of the National Park Service.
5. A March high-flow experiment is expected to have moderate to low impact on the production of algae and diatoms between the dam and Lees Ferry and, as a result, should not limit the availability of these food sources for the rainbow trout fishery and native fishes. Rather, a March high-flow experiment has the potential to crop off senescent or dead algae and to encourage fresh, new growth as increased solar radiation is available from March through October as compared to other times of the year.
6. A March experimental high-flow release will maximize the potential for newly created sandbars to contribute additional sand to nearby archaeological sites. A March high-flow experiment would create sandbars just before the onset of the spring windy season (April–June).

Peak Flow Magnitude and Duration

The GCMRC proposes replication of the 2004 high-flow hydrograph in a similar experiment in 2008 (41,500 cfs for 60 hours). Flows immediately preceding and following a potential March 2008 experiment are anticipated to be similar to normal modified low fluctuating flow (MLFF) patterns typically released in the transition month of March during 8.23 million acre-feet (maf) release years. The daily range of flows would likely be 6,000 cfs with diurnal peaks flows of 12,000–13,000 cfs. These operations would probably be very similar to the December 2004 MLFF patterns that followed the November 2004 experiment. No experimental fluctuating flows or steady flows are recommended to proceed or follow a possible 2008 high-flow experiment.

A possible 2008 experiment would allow scientists to determine whether the locally robust and consistent sandbar-building responses that occurred in upper Marble Canyon in 2004 can be repeated and possibly enhanced. By reproducing the 2004 hydrograph, scientists would also be able to evaluate whether there are cumulative benefits to sandbar conservation in lower Marble and Grand Canyons each time a sand-enriched high-flow experiment occurs.

The GCMRC and its science cooperators recently evaluated the limitations and benefits of a shorter duration peak at 41,500 cfs. Exact predictions about the outcome of a high-flow experiment with a shorter duration are not possible at this time without field experimentation because current sediment models have limited utility for estimating sandbar responses over long reaches, and there are many factors to consider related to peak-flow duration and peak magnitudes for high-flow experiments. Scientists acknowledge that a potential 2008 high-flow release lasting not less than 30 hours might also result in sandbar-building benefits and would also advance learning about high flows and sediment dynamics. The GCMRC compares the pros and cons associated with a 60-hour versus 30-hour peak high-flow duration in appendix A.1.

Fall dam releases that preceded the 2004 high-flow experiment (5,000 to 10,000 cfs daily range) were very effective in limiting downstream sand transport between September and late November 2004. However, because these releases caused most of the new sand to be stockpiled in the upper section of Marble Canyon, 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. A March 2008 experiment would allow sediment scientists to evaluate whether normal dam operations following the input of new sand effectively redistributes new sand throughout Marble and Grand Canyons. Allowing the sand to be redistributed before a high-flow experiment might produce more optimal sandbar building than occurred during the 2004 experiment. Currently, the sand that has been deposited in the Colorado River by tributary flooding since August 2006 has been subjected to 5–19 months of normal MLFF flows.

2008 Test Includes Important Differences

A 2008 experiment would be different from the two high-flow experiments conducted previously at Glen Canyon Dam in several important ways. As noted above, the 1996 experiment was conducted when sand supplies in the Colorado River were relatively depleted. The 2004 experiment occurred shortly after Paria River flooding had enriched the sand supply in Marble Canyon; however, the amount of sand present in 2004 was insufficient to achieve increases in total sandbar area and volume throughout both Marble and Grand Canyons. In November 2007, sand supplies in the main channel of the Colorado River were two to three times larger and more evenly distributed longitudinally than in 2004. Conducting a high-flow release under current sediment conditions would allow scientists to evaluate the effectiveness of conducting high flows under much enriched conditions that have been followed by 5–19 months of normal MLFF operations.

A second important difference is that a 2008 high-flow experiment would be followed by normal springtime Record of Decision operations associated with annual release volumes, unlike previous experiments, which were followed by higher fluctuating flows than would have otherwise occurred. The daily range of flows would likely be 6,000 cfs with diurnal peaks flows of 12,000 to 13,000 cfs (specific flows would be determined by the Bureau of Reclamation). These operations would probably be very similar to the December 2004 flow patterns that followed the November 2004 high flow and preceded the experimental fluctuating flows of January–March 2005. The 2008 experiment would allow a unique comparison of the relative stability of sandbars and backwaters under the relatively low fluctuating flows associated with normal spring operations versus higher summer monthly operations during a minimum release year (8.23 maf).

Experimental Studies to Address a Variety of Scientific Questions

In December 2005, the AMWG identified concerns and questions about the effects of high flows on a variety of resources. In addition, in August 2007, the AMWG approved the GCMRC monitoring and research plan (MRP), which includes a series of strategic science questions (SSQs) that will guide science activities over the next 5 years. Table 1 describes the SSQs from the MRP and high-flow science questions that would be addressed during the 2008 high-flow experiment, if it occurs. The high-flow science questions are specifically designed to address concerns and questions identified by the AMWG.

For example, this science plan proposes to determine how high flows affect sediment resources and sandbars, backwater habitats used by the endangered humpback chub and other native fishes, the aquatic food base, rainbow trout recruitment and emigration, riparian vegetation, and archaeological resources in close proximity to the Colorado River. For example, experimental study 1 (parts A–D) addresses questions related to sediment and seeks to determine not only if high flows are an effective tool to rebuild and maintain sandbars over time, but also if such experiments have the ability to create additional backwater habitats for native fish and how new sand deposits affect archaeological sites. Experimental study 1 expands on work begun with the 2004 experiment to document the connection between high-flow releases and the transfer of sand to cultural sites by the wind and the formation and persistence of backwaters as the result of high flows. Experimental studies 2–5 address the impacts of high-flow experiments on riparian vegetation, food base, rainbow trout, and Lake Powell water quality, respectively. Study 7 would provide a comprehensive synthesis of the results of all of the experimental studies conducted in association with a possible 2008 high flow.

Table 1. Strategic science questions from the GCMRC monitoring and research plan (MRP), related high flow science questions, and the experimental studies that would address in part or in whole individual questions.

Question	Experimental Studies
Sediment and related resources	
MRP strategic science question: Is there a "flow-only" operation that will rebuild and maintain sandbar habitats over decadal timescales?	
High flow science question: How do conditions of suspended sediment concentration and grain size evolve and vary through time and by reach below Glen Canyon Dam during replication of the 2004 hydrograph under more highly enriched sand supply conditions; and how do these data compare with similar data collected at similar locations during the 1996 and 2004 high-flow experiments? Is the net mass balance of sand following the high flow net positive, negative, or neutral?	1.A
High flow science question: What is the minimum duration for high-flow experiments needed to build and maintain sandbars under sand-enriched conditions?	1B
High flow science question: Can the next high flow increase campable areas at sandbars on a sustainable basis?	1.C
High flow science question: Following a high flow, how Record of Decision (ROD) operations under 8.23 million acre-feet annual release volumes affect the persistence of sandbars and related backwaters compared to non-ROD operations that followed the 2004 high flow?	1.D
Humpback chub	
MRP strategic science question: How important are backwaters and vegetated shoreline habitats to the overall growth and survival of young-of-year and juvenile native fish? Does the long-term benefit outweigh short-term potential costs?	
High flow science question: Do high-flow experiments result in creation of backwater habitats that may benefit humpback chub and other native fishes? To what extent are backwater habitats created by a high flow used by humpback chub and other native fishes?	1.D
Cultural resources	
MRP strategic science question: How effective are various treatments in slowing rates of erosion at archaeological sites over the long term?	
High flow science question: Do sandbars deposited by high-flow experiments contribute to preservation of archaeological sites in the river corridor?	1.C
High flow science question: Do high-flow experiments contribute to added stability or erosion of archaeological sites located in close proximity to the river?	1.C

Table 1. Strategic science questions from the GCMRC monitoring and research plan (MRP), related high flow science questions, and the experimental studies that would address in part or in whole individual questions.—Continued.

Other priority resource issues	
Strategic science questions: What Glen Canyon Dam operations maximize trout fishing opportunities and catchability? Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages?	
High flow science question: How will a high flow affect spawning, survival of early life history stages of rainbow trout (BBT) in the Lees Ferry reach? Will a high flow stimulate downstream migration of age-1 RBT?	4.A, 4.B
Strategic science questions: How is invertebrate flux affected by water quality and dam operations?	
High flow science question: How will a future high flow affect food production and availability for rainbow trout in the Lees Ferry reach? What are the effects of high-flow experiments on aquatic food production? How do these effects impact native fishes?	3
Strategic science questions: How is invertebrate flux affected by water quality and dam operations?	
High flow science question: Will the next high flow result in higher nutrient releases and shrinking of the hypolimnion? Will the operation of the river outlet works and the penstocks at capacity measurably alter Lake Powell hydrodynamics or stratification, or alter release water quality?	5
Strategic science questions: Do dam controlled flows affect rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?	
High flow science question: Are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation following a disturbance?	2

One of the concerns managers have with the possible 2008 high flow is its potential to affect aquatic food resources at lower trophic levels, thereby indirectly affecting native and nonnative fishes. However, the exact effects of these events have not been well studied, so conclusions about them remain speculative. The study of the aquatic food base anticipates monitoring the effects of the 2008 high flow on the primary and secondary producers below Glen Canyon Dam. Monitoring before and after the 2008 high flow would be an important link in the ongoing research and data collection that is being conducted throughout the river corridor to help determine what changes, if any, result from the 2008 high flow.

Other biological activities also build on ongoing scientific research to address key strategic science questions. For example, experimental study 1.D is being used not only to help develop methods for mapping backwater habitats to better understand their creation and persistence in the months following the 2008 high flow, but also is intended to build on existing efforts by expanding the fall sampling of backwater habitat for small-bodied fish to include sampling during the spring. Spring sampling for small-bodied fishes would complement the fall sampling and provide additional insights into the persistence of backwaters and use of backwater habitats by native and nonnative fishes. The GCDAMP is undertaking a diverse program of monitoring for native and nonnative fishes to help evaluate potential longer term effects of the 2008 high flow.

Relation of a Potential High Flow to Sediment Modeling Activities

Besides answering pressing scientific questions, a 2008 high-flows test would provide information to inform the continued development of a sediment model, which would help determine the optimum frequency, timing, duration, and magnitude of future high-flows tests under varying sediment enrichment conditions. Model construction has not been possible with the currently available information. Experimental study 1.B in this science plan is intended to provide the key data on eddy sandbar evolution that is needed to advance modeling within eddies and sand exchanges between eddies and the main channel.

Research on the development of flow and sediment-transport modeling and development have occurred within the previous Glen Canyon Environmental Studies and current GCMRC science programs. Much of the previous effort has been focused on developing models that accurately route dam discharges through the Colorado River channel downstream, as well as simulating sandbar evolution within eddies under varied flow and sand-supply conditions; including fluctuations and high-flow releases. Research efforts have also focused on predicting sand production from key tributaries, such as the Paria River, on the basis of streamflow and river geomorphology. Despite much progress in these areas, only the tributary flow and sediment models, and main-channel flow routing and average temperature models have progressed far enough to provide reliable predictions.

Future advancement of sediment transport models can allow managers and scientists to more efficiently evaluate a range of flow and sediment-supply conditions in the river to identify high-flows options that might meet management objectives for sand conservation. A well-calibrated, robust predictive sediment model would help minimize the impacts of high flows on Glen Canyon Dam hydropower production.

Cost of 2008 High Flow

As shown in table 2, the cost of the research activities associated with the next high flow is approximately $3.73 million for fiscal years 2008–09; the total cost of this science plan is dependent on the scope of studies that are eventually implemented. In 2003, the GCDAMP established an experimental fund to pay for experimental research studies such as the proposed high flow, so that they could be conducted without financially impacting other ongoing aspects of the science program. The balance of the experimental fund in fiscal year (FY) 2008 is approximately $1,450,000. In FY 2009, an additional $500,000 is planned to be deposited into the experimental fund. Thus, based on current and anticipated deposits into the experimental fund, additional support would be required to fully implement this science plan.

In addition to the cost of studies, some portion of the flows needed for a possible 2008 experiment would bypass the powerplant at Glen Canyon Dam. The Western Area Power Administration has estimated that approximately $2 million of replacement power costs would be incurred as a result of a high flow. The extent of these costs would depend on the magnitude, duration, and timing of a possible high flow. It has also been suggested that a high flow could have a negative impact on the Marble Canyon economy, which is dependent on the Lees Ferry trout fishery. However, these economic impacts and the economic benefits associated with potential improvements to resources and recreation in the Colorado River ecosystem have not been fully evaluated or quantified. An assessment of the economic impacts of dam operations, including a potential high-flows test, is outside the scope of this document.

Table 2. Description of experimental studies proposed by this science plan, including cost estimates for fiscal years (FY) 2008–09.

Experimental study	Description	FY 2008 cost estimate	FY 2009 cost estimate
	Sediment, archaeological sites, and backwaters		
1.A. Sand budgeting	Data will be collected to determine the amount of sediment available in the system and its availability for restoring sandbars and camping beaches, patterns of erosion and deposition, and changes in sediment grain size	$313,212	$94,102
1B. Eddy-sandbar studies	Data will be collected on the evolution of specific eddy sandbars before, during, and after a high flow. These data may be used to improve the predictive capabilities of the existing sediment model and determine the optimal peak flows of future high-flow experiments.	$103,797	$92,057
1.C. Response of sandbars and select cultural site	Data will be gathered to determine (1) if sandbars throughout the Colorado River ecosystem gain or lose sand as the result of a sand-enriched high flow, (2) if new sand can offset gully erosion, and (3) if enlarged sandbars provide source material for the windborne transport of sand upslope into archaeological sites.	$604,180	$360,374
1.D. Backwater habitats	Measure backwater habitats and sample them for fish in spring and fall to evaluate how (a) backwaters formed by a high flow change over time and (b) how fish, particularly humpback chub, use backwaters.	$851,461	$191,275
	Riparian vegetation		
2. Riparian vegetation studies	Study will document changes in riparian vegetation (native versus nonnative) following a high flow to determine if disturbances influence the success rate of nonnative species.	$42,709	$30,738
	Aquatic food base		
3. Food availability	Data will be collected to determine how high-flow experiments affect the quantity and quality of food available to invertebrates and, ultimately, fish.	$216,903	$44,175
	Rainbow trout		
4.A. Redds study	Data will be collected to determine how high-flow experiments affect spawning and survival of early-life stages of rainbow trout in Lees Ferry	$130,371	$100,861
4.B. Movement study	Study will collect data to determine if high-flow experiments displace rainbow trout from Lees Ferry and if displacement varies by fish length	$110,648	$2,057
	Lake Powell		
5. Lake Powell	Data to determine if a high flow results in higher nutrient releases and changes in the hypolimnion	$35,274	$5,022
	Conservation measures		
6. Kanab ambersnail	To minimize impacts to an endangered species, Kanab ambersnail habitat at Vaseys Paradise will be moved	$16,316	$0
	Knowledge synthesis		
7. Synthesis of knowledge	Data and knowledge gained as the result of the high-flows test will be synthesized in an attempt to address strategic science questions	$0	$258,000[3]
	Logistical support		
8. Logistical support	Logistical support costs not associated with specific research activities	$122,673	$0
Totals		**$2,547,543**	**$1,178,660**

[3] An additional $400,000 will be needed in FY 2010 to complete the synthesis of results from a possible 2008 high-flow test with previous high-flow tests

Long-term Strategy for Future High-Flow Experimentation and Frequency

The data gathered as the result of the experimental studies proposed in this science plan would feed into the GCDAMP adaptive management process. Figure 4 depicts how information derived from the proposed 2008 high-flow experiment would be used by the GCDAMP to improve decision making and refine predictive models.

Based on the two previous high-flow experiments conducted to date, scientists cannot say at this time whether such experiments are an effective strategy for stopping the ongoing erosion of sand and sandbars in the Colorado River ecosystem. A long-term research strategy involving further high-flow experimentation and model development will be necessary to assess whether high flows can effectively conserve sediment and help achieve other related resource benefits (increased humpback chub recruitment, enhanced camping beaches, protection of cultural resource, minimized hydropower impacts, etc). At this time, it is not anticipated that a single high-flow release can answer all such relevant questions: accordingly, it is very likely that additional high-flow experiments will be needed to address the major uncertainties associated with the use such releases as an effective long-term management tool. For example, additional experiments will likely be needed to further define environmental conditions that affect or contribute to the maintenance of humpback chub habitat and other important ecosystem components, particularly beaches, backwaters, and other nearshore habitat.[4]

Additional experiments will be needed partly because high-flow releases are believed to build sandbars with less efficiency than historical floods, owing to the shorter duration and smaller volume of experimental releases compared to predam floods, as well as the significant loss of upstream sand supplies in the postdam era. And, ROD-based intervening flows export sand from the system. The rate of those exports depends on the volume of flow and the magnitude of daily fluctuations from Glen Canyon Dam. As a management strategy, it is believed that the frequency of high-flow releases would need to be frequent enough so that more sand can accumulate than is being eroded by intervening flows. In addition, sand supplies are greatly reduced over what was available historically, and sand is replenished only from tributary floods that occur on irregular intervals.

Replication is also needed to provide sufficient observations of high flow results under the range of natural conditions that are most likely to occur in the future. It is believed that in addition to future high flow tests, by developing and calibrating additional sediment transport and deposition models, scientists will be better able to interpolate between observed effects and help rule out scenarios that are unlikely to yield positive, sustainable results. Some of the data needed to develop a model could be obtained through laboratory studies or field studies conducted during normal flow conditions. Data from the anticipated 2008 high-flow test would also be very important for the development of additional predictive models. Such an approach would likely reduce the overall research costs and help minimize impacts to hydropower.

It is expected that a long-term experimental strategy, including the number and future frequency of high-flow experiments, will be determined through the Glen Canyon Dam Adaptive Management Program.

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[4] Further information regarding the approach and basis for the proposed experiment can be found in the Biological Assessment prepared for the proposed action by the Bureau of Reclamation (December 2007).

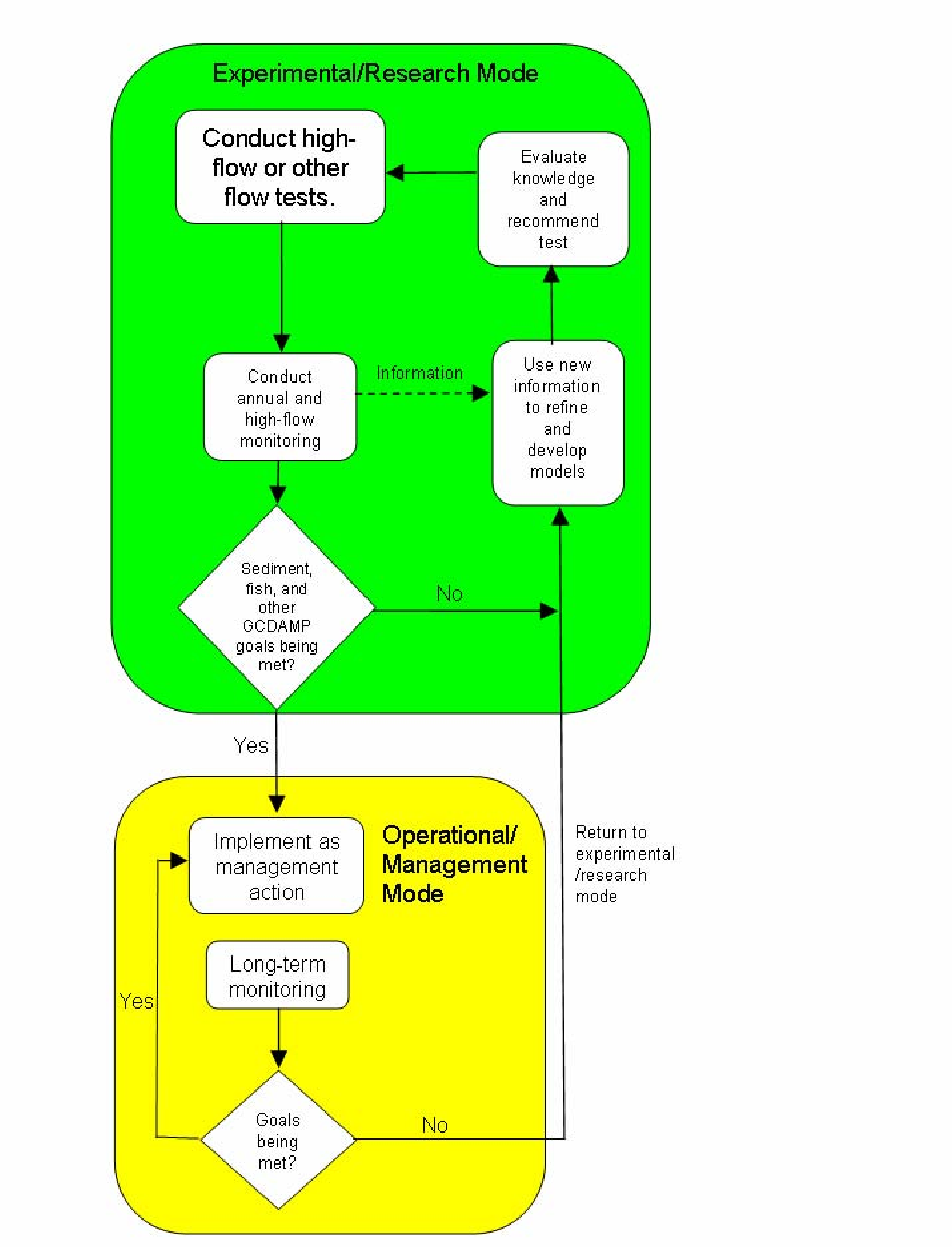


Figure 4. Flow chart showing how field data and modeling information are fed into the adaptive management process and used to improve management of resources downstream from Glen Canyon Dam. Experimental operations must be evaluated over a timeframe sufficient to take into account of natural variability (e.g., decadal scale). (GCDAMP=Glen Canyon Dam Adaptive Management Program)

Part 2: Experimental Study Descriptions

Experimental Study 1.A: Reach-scale changes in the fine-sediment mass balance and grain size during a future high flow

Duration

20 months

Principal Investigators

David Topping, U.S. Geological Survey, Biological Resources Division, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center and David M. Rubin, U.S. Geological Survey, Geologic Division, Western Coastal and Marine Geology

Geographic Scope

River miles 0 through 226

Abstract

The study intends specifically to answer the following two questions: How would conditions of suspended sediment concentration and grain size evolve and vary through time and by reach below Glen Canyon Dam during a March 2008 replication of the 2004 high-flow hydrograph under more highly enriched sand supply conditions, and how would these data compare with similar data collected at similar locations during the 1996 and 2004 high-flow experiments? Would the net mass balance of sand following the 2008 high flow be positive, negative, or neutral? To answer these questions, a series of continuous measurements of suspended sediment concentration and grain size shall be collected before, during, and after the high flow at seven fixed measurement sites throughout the Colorado River ecosystem (between river miles 30 to 226). Simultaneously, two river trips shall collect the same type of data between fixed measurement points from boats whose downstream movement will be timed such that two separate packets of river water and suspended sediment will be repeatedly monitored for changes in suspended sand concentration and grain size. Fixed location and moving location data shall then be compared to sandbar data from experimental study1.C—a study focused mainly on documenting changes in channel storage of sand and eddy sandbars.

Study Goals

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

Need for Study

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

Strategic Science Question

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

High flow Science Question

How would conditions of suspended sediment concentration and grain size evolve and vary through time and by reach below Glen Canyon Dam during a March 2008 replication of the 2004 high-flow hydrograph under more highly enriched sand supply conditions; and how do these data compare with similar data collected at similar locations during the 1996 and 2004 high-flow experiments? Is the net mass balance of sand following the 2008 high flow positive, negative, or neutral?

Working Hypotheses

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

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 high-flow experiments 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 a future high flow relative to the high-flow experiments conducted in 1996 and

2004. If the working hypotheses are supported by these analyses, then rebuilding and maintenance of sandbars might be possible through a future high flow conducted under sand-enriched conditions. If the working hypotheses are rejected by these analyses, then flow and nonflow strategies in addition to high-flow experiments may be needed to restore and maintain sandbars in the Colorado River ecosystem (i.e., further constraint of operations, sediment augmentation, or a combination of both).

Relation to Existing Work and Other Studies

This study 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 high flow-related physical, sociocultural, and biological studies, including experimental studies 1.B (Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during a future high flow), 1.C (Response of sandbars and selected cultural sites to a future high flow conducted under sediment-enriched conditions), 2 (Evaluation of the effect of a future high flow on riparian plant community development at multiple surface elevations and depositional environments), and 3 (evaluation of high-flow effects on lower trophic levels in the CRE). Work conducted under this study will also be used by the USGS's Lew Coggins, Scott Wright, and Nick Voichick for a study relating fish-catch rates to suspended-sediment concentration and grain size.

Information Needs Addressed

The study will directly address multiple information needs 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?
>
> **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 a future high flow within 12–24 months of the next high flow.

Budget Summary

FUNDING PROPOSAL		
Experimental study 1.A: Reach scale changes in the fine-sediment mass balance and grain size during a future high flow (Sand Budgeting)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	35,600	46,500
GCMRC Study Related Travel/Training (19.1% burden)	11,000	5,000
GCMRC Operations/Supplies/Publishing (19.1% burden)	8,100	15,000
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	7,000	0
AMP Logistical Support (19.1% burden)	99,225	0
Outside GCMRC & Contract Science Labor (In this project, sub-allocated - no additional burden charged)	121,550	14,900
Cooperative/Interagency Agreements (6.09% burden)	0	0
Study Sub-Total	**$282,475**	**$81,400**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	30,737	12,702
Study Total (including burden)	**$313,212**	**$94,102**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	61%	18%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 1B: Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during a future high flow

Duration

20 months

Principal Investigators

Scott Wright, U.S. Geological Survey, Water Resources Division, 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)

Abstract

The study intends specifically to answer the following question: What is the minimum duration for high-flow experiments needed to build and maintain sandbars under sand-enriched conditions? To answer this question a series of high-resolution measurements of eddy sandbar depositional rates will be made within a subset of six to eight study sites throughout Marble Canyon and the eddy bar responses will be evaluated during the proposed 60-hour duration of the hydrograph. The variability in depositional rates between sites will be evaluated and the total sandbar responses will be compared to the duration of the test to determine whether or not the duration of the flow test was appropriate relative to sandbar deposition and evolution. These measurements, along with those made for studies 1.A, 1.C, and 1.D, may also be used to support ongoing and future sediment model research; particularly those focused on improvement of multi-dimensional, large-eddy simulations and their verification.

Study Goal

The goal of this study is to improve our understanding of the time evolution of eddy sandbars during a future high flow. Knowledge of the rate of deposition or erosion of eddy sandbars during a future high flow will assist in the determination of the optimal high-flow 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 Study

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 a high flow. The lack of predictive capability has in turn limited our ability to provide definitive recommendations related to experimental high-flow 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 high flow indicated 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 a future high flow, if we are to improve our predictive capabilities and thus improve our ability to identify future high-flow characteristics that can most effectively rebuild and maintain available sand resources and related habitats.

Strategic Science Questions

> **SSQ 4.1-1**—Is there a "flow-only" operation (i.e., a strategy for dam releases, including managing tributary inputs with BHBFs [high-flow experiments], without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?
>
> **SSQ 4.1-1a**—What are the short-term responses of sandbars to BHBFs [high-flow experiments]?
>
> **SSQ 4.1-1b**—What is the rate of change in eddy storage (erosion) during time intervals between BHBFs [high-flow experiments]?
>
> **SSQ 4.1-1c**—What are the effects of ramping rates on sediment transport and sandbar stability?

High Flow Science Question

What is the minimum duration needed for high-flow experiments to build and maintain sandbars under sand-enriched conditions?

Working Hypotheses

Sand deposition rates in eddies during a future high flow 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 high-flow 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 study 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 a future high flow.

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 high flow, but this is not logistically feasible. As a compromise, sites in middle Marble Canyon will be studied because results from the November 2004 high flow indicate that eddies in this reach may provide varied responses, and several eddy sandbars close to each other have been studied previously by the Integrated Fine-Sediment Team (FIST) and through long-term sandbar monitoring conducted by Northern Arizona University.

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 high flow (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 three to four 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 high-flow 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 study 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 a future high flow, during the rising limb, on the peak, during the falling limb, and after a future high flow. The ability to get multiple maps during a given segment will depend on the timing of the next experimental high flow (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 three-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, 2006b). 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.

Relation to Existing Work and Other Studies

This study is linked closely to previous and ongoing work related to numerical modeling eddy-sandbar morphology. The data acquired through this initiative have 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 study is also linked to several other experimental high flow-related physical, sociocultural, and biological studies by providing sediment-transport data, eddy-sandbar bathymetry, and eddy-sandbar hydrodynamics and morphology, including experimental study 1.A (Reach-scale changes in the fine-sediment mass balance and grain size during a future high flow), experimental study 1.C (Response of sandbars and selected cultural sites to a future high flow conducted under sediment-enriched conditions), experimental study 2 (Evaluate effect of a future high flow on riparian plant community development at multiple surface elevations and depositional environments), and experimental study 3 (evaluation of the effects of high flow on lower trophic levels in the Colorado River ecosystem).

Information Needs Addressed

The study 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 during a 12- to 24-month period following a future high flow on findings from this study.

Budget Summary

FUNDING PROPOSAL		
Experimental study 1B: Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during a future high flow (Sandbar Deposition Rates)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Study Related Travel/Training (19.1% burden)	1,000	2,000
GCMRC Operations/Supplies/Publishing (19.1% burden)	11,000	2,000
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	0	0
AMP Logistical Support (19.1% burden)	19,325	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	62,672	82,210
Study Sub-Total	**$93,997**	**$86,210**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	9,800	5,847
Study Total (including burden)	**$103,797**	**$92,057**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	77%	95%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 1.C: Response of sandbars and selected cultural sites to a future high flow

Duration

20 months

Principal Investigators

Jack Schmidt, Utah State University, and Amy Draut, U.S. Geological Survey, Geologic Division, Western Coastal and Marine Geology

Cooperating scientists: Joe Hazel, Matt Kaplinski, and Rod Parnell, Northern Arizona University, Department of Geology; David Topping and Helen Fairley, U.S. Geological Survey Biological Resources Division, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center; and David Rubin, U.S. Geological Survey, Geologic Division, Western Coastal and Marine Geology.

Geographic Scope

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

Abstract

This study intends to answer the following interrelated questions concerning the effects of high flow sediment transport on sandbars and associated resources: (1) Following a high flow, how do Record of Decision (ROD) operations under 8.23 million acre-feet annual release volumes affect the persistence of sandbars compared to non-ROD operations that followed the 2004 high flow? (2) Can the next high flow increase campable areas at sandbars on a more sustainable basis than occurred in conjunction with the 1996 and 2004 high-flow experiments? and (3) Do sandbars deposited by high-flow experiments contribute to preservation of archaeological sites in the river corridor? To answer these questions, a series of sandbars shall be surveyed at 46 long-term study sites and assessed with respect to changes in sandbar topography, area, volume, and net camping area before and after the high flow. Rates of aeolian sand transport and gully incision at selected cultural sites will also be quantified before and after the high flow to evaluate the effects of measured sandbar changes on physical processes affecting cultural sites.

Study Goal

The principal goal of this study is to determine whether a future high flow conducted under sediment-enriched conditions can be used to rebuild/maintain eddy sandbars and associated campsites in the Colorado River ecosystem. This goal is to be achieved during a future high flow through (1) evaluation of whether sandbars throughout the Colorado River ecosystem gain or lose sand above and below the stage associated with a discharge of 8,000 cfs and (2) comparison of the topographic response of sandbars with those observed during two previous high-flow experiments conducted in 1996 and 2004. Secondary objectives of this study include further evaluation of whether (1) sediment deposited in arroyo mouths can offset/reduce gully erosion (Yeatts, 1996) and (2) enlarged sandbars produced during the next high flow result in increased aeolian transport of sand upslope into archaeological sites, thereby offsetting/reducing wind deflation and rill erosion of sediment in and around these sites (Draut and Rubin, 2006).

Strategic Science Questions

In 2007, the Grand Canyon Monitoring and Research Center produced, and the Adaptive Management Working Group subsequently approved, a FY 2007–FY 2011 Strategic Science Plan and an associated Monitoring and Research Plan (MRP) that identified a series of strategic science questions (SSQs).

> **SSQ 4.1**Is there a “flow-only” operation (i.e., a strategy for dam releases, including managing tributary inputs with BHBFs [high-flow experiments], without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?
>
> > **4.1a**What are the short-term responses of sandbars to BHBFs [high-flow experiments]?
> >
> > **4.1b**What is the rate of change in eddy storage (erosion) during time intervals between BHBFs [high-flow experiments]?
>
> **SSQ 2.1** Do dam-controlled flows increase or decrease rates of erosion at archaeological sites and TCP sites, and if so, how?
>
> **SSQ 2.3** If flows contribute to archaeological site and TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?
>
> **SSQ 2.4** How effective are various treatments in slowing rates of erosion at archaeological sites over the long term?
>
> **SSQ 3.9** How do varying flows positively or negatively affect campsite attributes that are important to the visitor experience?

High Flow Science Questions

High flow science questions were subsequently identified as a means of bridging the research and monitoring work that will be conducted in conjunction with a future experimental high-flow test with the strategic questions previously identified in the 5-year science plans. For study 1.C, the underlying strategic science questions and associated high flow science questions are as follows:

> Following a high flow, how do ROD operations under 8.23-maf annual release volumes affect the persistence of sandbars and related backwaters compared to non-ROD operations that followed the 2004 high flow?
>
> Do sandbars deposited by high-flow experiments contribute to preservation of archaeological sites in the river corridor?
>
> Do high-flow experiments contribute to added stability or erosion of archaeological sites located in close proximity to the river?

Can the next high flow increase campable areas at sandbars on a more sustainable basis than occurred in conjunction with the 1996 and 2004 high-flow experiments?

Need for Study

This study is required to document whether a high flow conducted under sediment-enriched conditions can be used to rebuild/maintain eddy sandbars and associated campsites and add sand to archaeological sites in the Colorado River ecosystem, thereby contributing to the sustainability of these valued resources, in keeping with the intent of the Grand Canyon Protection Act and the stated goals of the Glen Canyon Dam Adaptive Management Program.

Working Hypotheses

A future high flow conducted under magnitudes and longitudinal distributions of sand enrichment similar to those before the 2004 high flow will result in sandbar rebuilding and low-elevation gully infilling comparable to that observed during the 2004 high flow. If reaches downstream from river mile 30 are sand enriched relative to their condition before the 2004 high flow, then sandbar building and gully infilling in these downstream reaches will be greater than was observed in these reaches during the 2004 high flow. In addition, if the sandbars produced during a future high flow are (1) larger during the subsequent spring windy season than in the spring windy season preceding the next high flow and (2) dry during the spring windy season following the next high flow, then the aeolian flux of sand derived from these sandbars will be greater than it was before this test (as observed by Draut and Rubin, 2006).

Methods

This study 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. Analyses similar to those described in Rubin and others (1998), Hazel and others (1999, 2006), Schmidt and others (1999b), Topping and others (1999, 2006a), and Draut and Rubin (2005, 2006, 2007) of sandbar topographic response, sandbar stratigraphy, grain-size data, aeolian sand-transport data, and aeolian topographic response at cultural sites will be used to evaluate the results of a future high flow relative to the two previous high-flow experiments conducted in 1996 and 2004.

If the working hypotheses are supported by these analyses, then rebuilding and maintenance of sandbars might be possible through release of additional high-flow experiments that are also implemented under sand-enriched conditions. Furthermore, if the working hypothesis specific to the aeolian sand-transport component of this study is supported by these analyses, preservation of certain archaeological sites might be increased through a strategy of repeated high-flow experiments in the future under sand-enriched conditions. If the working hypotheses are rejected by these analyses, then additional flow and nonflow treatments (i.e., further constraints on dam operations, sediment augmentation, or a combination of both) in association with any future high-flow experimentation may be needed to rebuild and maintain sandbars throughout the Colorado River ecosystem.

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 a future high flow using established methods by scientists from Northern Arizona University (Hazel and others, 1999, 2000, in review; Kaplinski and others, 2000, 2007, in review). 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 29 selected sandbars and cultural sites to document the topographic evolution by fluvial and aeolian processes of these sites during and after a future high flow. River-based arroyos associated with selected cultural sites will also be surveyed as part of this study (see table 3 for locations of various study components).

Previous work has shown that the grain size of the underwater part 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 (Rubin and others, 1998; Topping and others, 2007). Grain size on the riverbed and on sandbar surfaces will be studied using an underwater microscope (Chezar and Rubin, 2004; Rubin and others, 2006, 2007) and digital image processing (Rubin, 2004). Grain size in flood deposits on sandbars will be measured by sampling vertical profiles (Rubin and others, 1998) and using 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 below. Weather monitoring instruments have already been deployed (during February and March 2007) at most of the proposed study sites, in conjunction with the previously funded Cultural Monitoring Research and Development Project. For the possible 2008 high-flow experiment, additional instruments will be deployed at Malgosa, lower Palisades, and in the vicinity of Basalt Canyon. The aeolian monitoring component of study 1.C 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 experiment that high-flow releases in the CRE can increase wind-blown transport of sand toward some of the aeolian deposits that contain archaeological material, thereby increasing their preservation potential.

Table 3. Locations of various study components for experimental study 1.C (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	Surveys of arroyos at selected cultural sites	Cameras
0	-6R				-9 Mile
1	1R, 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, 63L	55R, 63L	58, 60		55.9L, ~58L
7	65R, 68R	65R, 68R	66, 70	66L	66R
8				72R	70L, 72L
9	81L, 84R, 87L, 88R				81.7R,87.6R
10	91R, 93L, 104R				
10	119R, 122R, 123R	122R			104.4L, 119.3L, 123.2R
11	137L, 139R, 145L	139R	135		137.7R, 145.8R
12	166L, 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	46 sites	22 sites			29 camera sites

Relation to Existing Work and Other Studies

This integrated sediment study builds on the large quantity of previous published work on sediment erosion and deposition in the Colorado River ecosystem downstream from Glen Canyon Dam. Study 1.C is a integral part of study 1, which is focused on sediment responses from a high flow, and as such, it is closely linked to the other proposed experimental studies that are part of study 1, including experimental study 1.A (reach-scale changes in the fine-sediment mass balance and grain size during a future high flow), experimental study 1.B (studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during a future high flow), and experimental study 1.D (formation and persistence of backwaters following a high flow). In addition, the data collected by study 1.C will be directly relevant to the interpretation of experimental study 2 (evaluation of the effect of a future high flow on riparian plant community development at multiple surface elevations and depositional environments) and experimental study 3 (evaluation of the effects of a high flow on lower trophic levels in the Colorado River ecosystem). Bed sediment grain-size data collected as part of this study 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. 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). Subsequent evolution of the backwaters will be determined through surveying as part of this study will be evaluated in the spring and fall of 2008, in conjunction with backwater seining trips identified under study 1.D.

The science activities described in this study explicitly integrate several important cultural concerns in recognition of the close interrelationship between physical and biological processes and cultural resource condition outcomes. Specifically, in addition to evaluating high-elevation sand storage resulting from a high flow, the proposed science activities in study 1.C are designed to evaluate (1) the size and distribution of sandbars and open sand areas used as camping sites, and their persistence over time, (2) the potential effect of a future high flow on sediment transport and deposition at archaeological sites and consequent effects on site stability or erosion, and (3) formation and persistence of backwaters associated with eddy-sandbar complexes that may be important habitats for native fish.

The proposed 1.C study activities build upon monitoring data that are already being collected to assess the rate and extent of changes occurring to the ecosystem under ROD operations. Data from focused science activities proposed as part of this experimental study would be analyzed in relation to these previously collected monitoring data. For example, the GCMRC collects data annually on the area, volume, and extent of sandbars and associated campable area at selected sandbar sites distributed throughout the Colorado River ecosystem; additional survey data and documentation collected in conjunction with a future high flow will build on these previous studies and utilize the previous results (as well as future monitoring data) in evaluating how campable area changed in response to a high flow conducted under enriched sediment conditions, compared to results measured in 1996–97 and 2004–05. Likewise, in conjunction with developing an ecosystem-based approach to monitoring archaeological site condition, the GCMRC has established weather monitoring stations at several locations and is collecting aeolian transport and gully erosion data at a sample of archaeological sites within the Colorado River ecosystem. 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 study by Draut and others on the role of aeolian sediment in the preservation of archaeological sites. The 2003–06 study collected similar data (Draut and Rubin 2005, 2006, 2007), and therefore will provide valuable comparison data between the 2004 and a future high flow. In addition, this work will contribute to and complement ongoing investigations by Joel Pederson and Gary O’Brien from Utah State University on geomorphic processes affecting gully incision in Colorado River sediment deposits.

Information Needs Addressed

The study will address various 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?

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?

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

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

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?

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 to 24 months of a future high flow.

Budget Summary

FUNDING PROPOSAL		
Experimental study 1.C: Responses of sandbars and selected cultural sites to a future high flow (Sandbar Fate: Topographic and Grain-size Responses)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Study-Related Travel/Training (19.1% burden)	4,800	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	6,600	19,500
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	14,200	0
AMP Logistical Support (19.1% burden)	127,100	0
Outside GCMRC & Contract Science Labor (In this study, suballocated - no additional burden charged)	147,435	80,200
Cooperative/Interagency Agreements (6.09% burden)	259,100	242,200
Study Subtotal	**$559,235**	**$341,900**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	44,945	18,474
Study Total (including burden)	**$604,180**	**$360,374**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	84%	94%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 1.D (pilot study): Monitoring of biological and physical aspects of backwater habitats

Duration

Monitoring sites at specific times through September of year one; data analysis in year two

Principal Investigators

U.S. Geological Survey, Southwest Biological Research Center, Grand Canyon Monitoring and Research Center scientist to be determined

Geographic Scope

Colorado River in Marble and Grand Canyons

Abstract

This study will investigate the creation and persistence of backwater habitats controlled by sandbars. It will also investigate fish use of these backwater habitats in the spring and fall when fish are most likely to be attracted by backwater warming and when they are most likely to be captured. This study will allow for some comparison of different surveying methods by employing different measurement methods and comparing results. This study will conduct measurements of aquatic primary productivity to assess relative productivity of backwater habitats. Temperature measurements and photography of the backwaters will also be conducted in this study. Resultant information will be important for understanding where and when backwaters created by sandbars occur, information which in turn will help increase understanding of where and when such habitats may be available as habitat for native fishes.

Study Goals

The goals of this study are to increase understanding of how backwater habitats respond to flow changes in Grand Canyon (an issue of fluvial geomorphology) and the use of backwater habitats by native and nonnative fishes (a biological issue). This study seeks to develop and initiate an interdisciplinary approach to the study of backwater habitats in Grand Canyon.

Need for Study

The condition of stagnant flow in a return-current channel in the lee of an emergent reattachment bar is called a “backwater” by aquatic ecologists and fisheries biologists, although this term has no relation to the more long-standing term “backwater” used by hydraulic engineers and geomorphologists to describe flow conditions of the mainstem channel upstream from debris fans. Through the rest of this proposal, the term “backwater habitat” is used in reference to the low-velocity feature defined by ecologists. To increase understanding of backwater habitat availability and persistence, this work will study geomorphic processes that create reattachment bar and eddy return-current channel relief, the processes that rework the initial high-flow-created relief, the volume of water that fills the stagnant eddy return-current channel, thermal insolation of the water in the backwater, and how fish use these sites and whether there is a relation between occupation and physical site characteristics.

In the Colorado River in Grand Canyon, lateral separation eddies downstream of debris fans serve as “sinks,” where suspended sediment is deposited during high flows. Smaller embayments caused by the irregularities of talus and bedrock banks also create small areas of stagnant flows that induce sand deposition. High flows are known to increase the amount of sand deposition in return flow eddies (Goeking and others, 2003). Upon flood recession, the reattachment bar becomes emergent and blocks flow into the return-current channel, creating an area of nearly stagnant flow in the formerly active return-current channel.

Although stagnant flow in eddy return-current channels are the largest and most numerous backwater habitats, these features can also form anywhere mainstem flow is blocked, velocities become low, and temperatures have a chance to warm, attracting age-0 fish as nursery and rearing sites. Schmidt and Brim-Box (2004) identified several backwater habitat situations in alluvial parts of the Green River that occasionally occur in Grand Canyon, and the formative geomorphic processes that create these backwater habitats are unrelated to primary eddy return-current channels. Thus, sampling strategies must recognize that different geomorphic processes may lead to different process response models for different types of backwater habitats. Backwater habitats studied as part of this study will be identified by geomorphologic classifications. This study will focus on those backwater habitats created by sandbars.

Backwater habitats have been hypothesized to offer benefits to humpback chub (*Gila cypha*) and other native fishes because of greater food availability and warmer water temperatures relative to mainstem habitats, (Arizona Game and Fish Department 1996). Arizona Game and Fish Department (1996) observed a higher percent of benthic organic matter and higher densities of zooplankton and benthic invertebrates in backwaters relative to adjacent sandy beach facies. Primary and secondary production represent a better measure of food availability than static measures of biomass. Primary or secondary production is a function of biomass and growth rates (i.e., annual production = biomass*growth). Growth rates for both algae and invertebrates are strongly and positively related to water temperature. Water temperatures in backwaters are typically warmer than the mainstem CRE. Therefore, food availability (i.e., annual algae and invertebrate production) may be considerably higher in backwaters relative to mainstem habitats. Converse and others (1998) found higher densities of subadult humpback chub in low-velocity habitats, such as occur in backwaters and in other habitats, although they found the highest densities of subadult humpback chub in association with vegetated shorelines. Protected backwater habitats are a relatively small portion (approximately 5% or less, depending on conditions and flows) of the nearshore habitat in the Colorado River in Marble and Grand Canyons. The relatively shallow, isolated backwater habitats warm more than the mainstem during summer months. When backwaters are warm, they may offer advantages to humpback chub and other native fishes for increased growth because they foster both higher metabolic and growth rates (e.g., Petersen and Paukert, 2005) and greater available food (e.g., Arizona Game and Fish Department, 1996; Rader and others, 2007).

These advantages may be so important to native fishes that these ephemeral habitats (Goeking and others, 2003; Korman and others, 2004) are of high value in spite of their limited distribution and potential to attract nonnative fishes that compete with, and/or prey on, native fishes (but see

Paukert and Petersen, 2007). The relative value of backwaters for native fishes as compared to other habitats is not evaluated with this study, but this study does endeavor to evaluate (1) the construction and persistence of such habitats in response to a high flow, (2) food availability in backwaters relative to other nearshore habitats, and (3) the presence or absence of fish in these habitats.

Review of previous drafts of this study plan by the GCMRC Science Advisors and by the GCDAMP Technical Work Group resulted in recommendations that investigations conducted in association with any high flow should provide information about the physical characteristics of backwater aquatic habitats formed by a high flow, the persistence of those habitats following the high flow under normal MLFF operations, food availability in these habitats relative to other nearshore environments, and the use of these habitats by native and nonnative fishes. In response to these recommendations, increased physical measurements of backwaters before and after the high flow, investigation of the processes that create and rework backwater habitats, and measurements of food availability have been incorporated into this science plan with study 1.D. Integration of this study with study 1.C should provide information regarding the response of backwater habitats to various flow regimes. This study is will serve as a pilot study that will inform the development of a request for proposals for a broader nearshore ecology study that will evaluate food availability and the use and relative importance of a variety of nearshore habitats by native and nonnative fishes.

This study will monitor as many of the backwaters as possible, with the goal of conducting a complete, or nearly complete, census of these habitats in 2008. The census will be conducted in association with sampling for fishes in the spring and fall, bracketing the summer season of higher fluctuating dam releases. We will assess food availability in a subset of backwaters by measuring, among other things, primary and secondary production. This will yield data that are comparable to the primary and secondary production information being collected by the GCMRC's food base research study. These measurements will take 4–5 hours per site, so we will only be able to measure production on a single backwater each day of the river trips. To increase the information available to study processes, a subset of these habitats will also be surveyed immediately before and after the high flow, and also in October. The focus of the more intensely surveyed subset will be backwater habitats downstream of known humpback chub aggregations. Multiple methods will be employed to allow for assessment of the habitats as well as assessment of the methods.

Strategic Science Questions

Strategic science questions are taken from the GCMRC Strategic Plan.

> Is there a "flow-only" operation that will rebuild and maintain sandbar habitats over decadal timescales?
> How is invertebrate flux affected by water quality and dam operations?
> How important are backwaters and vegetated shoreline habitats to the overall growth and survival of young-of-year and juvenile native fish? Does the long-term benefit outweigh short-term potential costs?

High Flow Science Questions

High flow science questions are high flow-specific questions that would be addressed with the actions described in this study to help achieve answers to the broader strategic science questions.

> Do high-flow experiments result in creation of backwater habitats that may offer physical benefits to humpback chub and other native fishes? To what extent are backwater habitats created by a high flow used by humpback chub and other native fishes?
>
> What are the effects of high-flow experiments on aquatic food production? How do these effects impact native fishes?
>
> Following a high flow, how do Record of Decision (ROD) operations under 8.23 million acre-feet annual release volumes affect the persistence of sandbars and related backwaters compared to non-ROD operations that followed the 2004 high flow?

Working Hypotheses

Previous work by Goeking and others (2003) found that backwater area increases in response to high-flow releases, a conclusion partially supported by the modeling of Korman and others (2004). This study anticipates verifying that finding. We hypothesize that the spring flow operations will only slightly erode the sandbars that constrain backwaters. We also hypothesize that high summer flows associated with MLFF operations will overtop or erode the sandbars that constrain backwater habitats, decreasing the area and volume of these habitats by the time of the return to lower flows, assumed to begin September 1 under MLFF. Backwater habitats may also begin to fill with sediment, reducing their area and volume. The modeling of Korman and others (2004) provides support for the hypotheses regarding changes in backwater habitats with time and various flows. We hypothesize that algal and invertebrate production in backwaters is higher relative to other nearshore environments. We also hypothesize that small-bodied fishes, native and nonnative, will occupy backwater habitats in the spring and fall. A variety of age classes and species is predicted.

Methods

This study will employ a suite of methods to investigate the creation, maintenance, and use of backwater habitats. Four methods will be used: total station surveying, tape surveying, level surveying, and photography (survey record and repeat/fixed). A summary of their relative strengths and weaknesses is presented in table 3, below.

Table 3. Comparison of physical habitat measurement methods for study 1.D.

Method	Relative data collection rate	Backwater area calculated	Backwater volume calculated	Compare results to other flow regimes?	All backwater sites surveyed?
Total station	Slower	Yes	Yes	Yes	No
Tape/level	Faster	Yes	Some	No	Yes
Survey record photography	Faster	No	No	No	Yes
Repeat/fixed photography	Constant	No	No	Yes	No

By combining these methods, GCMRC and cooperating scientists hope to maximize the amount of information collected and learning achieved in association with the high flow.

Total station measurements are more detailed and automated and allow for calculation of the area and volume of the measured backwater not only at the stage discharge encountered, but also at other discharges. Total station measurements include measurement of the site bathymetry (underwater topography). Total station measurements can be referenced to allow for comparison with similar data taken in previous years. Tape and laser level surveys are simpler measurements, using less automated equipment. Tape and level measurements could easily allow for comparison to other tape and level measurements made within the same year, but may be harder to apply to different years and stage discharges because they are more difficult to reference. One of the functions of the study 1.D multiple method deployments will be to assess how comparable these different habitat measurements are. To allow for geo-referencing of the sites, one control trip will be launched in 2009 to geo-reference those sites that are surveyed with the total station.

For the nonreferenced tape and level measurements, the backwater area is defined by measuring the backwater width and length with a tape at multiple locations. The number of width measurements is dependent on the length of the backwater; generally, widths are taken approximately every meter of length. Backwater volume is defined by measuring backwater depth relative to water surface and adjacent bar crest relative to water surface with a level. These measurements are made at each width-measurement location.

For the referenced total station surveys, a stable reference point is established. On the first survey at each site, two stable elevation reference points are established. These may be a mark etched in a rock or an easily defined tip of a rock. Each reference point must be described in notes and photographed, and surveyed to the best possible precision with available GPS.

Two total station survey crews will be deployed on four study trips in an effort to assess as many of the backwaters as possible. These trips are currently anticipated in: February, March, May, and September. The February and March trips will assess a subset of backwater habitats, emphasizing those locations that are downstream of known humpback chub aggregations (Valdez and Ryel, 1995). The May and September trips will conduct a more complete backwater habitat inventory, emphasizing the tape and laser level method, supported at a subset of the sites with total station surveys. Tape and level measurements will be taken at every backwater encountered, as these can be taken more quickly. Tape and level measurements will also be taken in conjunction with GCMRC/GCDAMP sampling trips currently scheduled for the summer months.

Water temperatures will be taken at all backwater habitats sampled. Water temperatures will also be taken in the mainstem river adjacent to the backwaters. During a trip following the high flow, additional water temperature sensors will be deployed to collect continuous temperature data at the subset of backwaters where food production measurements are made (12–15 backwaters). Continuous temperature data will be critical for estimating annual primary and secondary production. Additional water temperature sensors will also allow us to enhance our current sites by including the measurement of lateral thermal gradients, and water-temperature data collection in other nearshore habitats (i.e., talus slopes, low-angle sandy shorelines, and cobble bars), as well as to expand the overall number of nearshore sites. These data will be used to further develop temperature models, improving the capability of assessing the relative value of backwaters for fishes.

At least one photograph will be taken of each backwater in association with the habitat measurements to augment records of site condition. Repeat photography will be taken at 10 preselected sites. At the repeat sites, fixed cameras will be deployed. These cameras will be programmed to take weekly photos of the sites. This will allow for important visualization of the quantitative results, especially to help assess habitat suitability for fishes. Repeat photography will also assist in visualization of the rate of change at these sites, to be correlated with changes in flows. Because of the difficulty and expense of deploying repeat photography cameras, because they are subject to malfunction and vandalism, and because we are trying to deploy the least amount of equipment possible to minimize impacts to Park visitors, approximately 10 sites will be photographed repeatedly during the year, but not more. The number of sites for repeat photography will be dependent, in part, on equipment availability. Site selection for repeat photography will emphasize backwaters where fishes have been captured in previous years.

Habitat monitoring associated with this study will be conducted shortly before and after the high flow in February and March. Because of the difficulty in collecting fishes and interpreting those data, backwater seining will not be conducted in February and March. The habitat sampling for this study will be conducted in association with seining backwaters for fishes, now to be conducted in both May and September/October, so that assessments of fish use of these habitats is conducted immediately before and after the period of high summer flows.

Food production measurements will be collected during the February, March, May, and September trips. We will assess water column chlorophyll, phytoplankton, and zooplankton concentrations in backwaters on all trips. We will measure benthic organic matter, chlorophyll, and invertebrate biomass and density on all trips. During the March, May, and September trips we will measure water column and benthic primary production using light and dark bottles and chambers. During the March, May, and September trips we will also measure invertebrate growth rates for use in secondary production estimates. We will also determine the principal food items consumed by fishes occupying backwaters by analyzing the gut contents for small numbers of native and nonnative fishes. Collectively, these data will allow us to determine food availability in backwaters and the feeding habits of fishes occupying these habitats. These data will be compared with identical data being collected as part of the food base research study to determine whether food production in backwaters is greater than other nearshore habitats.

Sampling for fishes in backwater habitats has been conducted in September and October since 2002, providing an estimate of the extent of these habitats in the fall, as well as an estimate of fish presence or absence in these habitats. This sampling will be maintained for the foreseeable future. If increased load-following flows are initiated on June 1, this study proposes to also sample backwater habitats for fish in May, in advance of the higher summer flows and fluctuations of the current MLFF schedule, developing important information for temporal comparisons. If higher load-following flows are not implemented until July 1, GCMRC would propose delaying this sampling and habitat assessment until June. Sampling in June increases the survivorship of young native fishes encountered because they have had additional time to grow and increase their resistance to the stress caused by handling. Table 4 provides a summary of the schedule for measurements and samples

Table 4. Summary schedule for measurements and samples for study 1.D.

Method	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.
Total Station		X	X		X				X	
Tape & Level		X	X		X		X	X	X	
Survey Photos		X	X		X				X	
Repeat Photos		X	X	X	X	X	X	X	X	X
Temp.		X	X		X				X	
Seining					X				X	

Links/Relationship to Existing Work and Other Studies

Because studies 1.C and 1.D will be deployed to some of the same sites, sampling sites will be compared in advance to help ensure efficient deployment of personnel and equipment. If measurements are scheduled to be taken at a study 1.C site, that site will be dropped from the data collection list for study 1.D. Study 1.C seeks to evaluate sandbar construction and maintenance, factors that are important for this study. 1.D Data collected from this study are anticipated to be useful in the development of a new GCMRC study to study the ecology of nearshore habitats and their relative value for native fishes, especially humpback chub. Overflight imagery, scheduled to be taken in 2009, will allow for comparison of 2005 and 2002 backwater habitat distribution and abundance.

The food base research study is determining whether food availability limits populations of native and nonnative fishes. Study 3 of this science plan will determine whether a high flow has a negative, neutral, or positive effect on food available to fishes. Study 1.D will complement both of the above studies by providing detailed measurements of food production in backwaters.

In support of ongoing water-temperature-modeling efforts, the GCMRC has been collecting continuous water temperature data at 6 backwater sites distributed throughout the river corridor for the last year and a half. Water temperature sensor strings have been deployed in a manner that allows for the calculation of both vertical and longitudinal thermal gradients over time within these backwater habitats. These data are being utilized in the calibration and testing of nearshore water temperature models and are a critical component of the overall thermal modeling work. Additional water temperature sensors will allow us to enhance our current sites by including the measurement of lateral thermal gradients, water temperature data collection in other nearshore habitats (i.e., talus slopes, low-angle sandy shorelines, and cobble bars), as well as to expand the overall number of nearshore sites.

Information Needs Addressed

RIN 2.1.4. What habitats enhance recruitment of native fish in the LCR and mainstem? What are the physical and biological characteristics of those habitats?
RIN 7.4.4. How does flow rate and fluctuation affect habitat availability and utilization by fish and other organisms?

Products/Reports

After the completion of data collection for this study in October (assuming a March 2008 high flow), data will be analyzed and at least one report will be prepared summarizing the data analysis. Data analysis will be focused on answering the following questions:

- Were backwater habitats created and/or expanded at the monitoring sites following the high flow?
- Where they were created, were they maintained until June 1? Were they maintained until September 1? Were they maintained through the final monitoring trip in October?
- What were the area and volume of the backwater habitats monitored? What were the area/volume ratios at various flows encountered during the year?
- What were the temperatures in these habitats throughout the range of flows encountered during the year?
- How does food production in the habitats compare with other nearshore habitats?
- Were native fishes present in these habitats in the spring and/or the fall?
- Were nonnative fishes present in these habitats in the spring and/or the fall?
- Are there any significant correlations between the fishes present and the physical habitat measurements, such as area, volume, area/volume ratio, and temperature?

This study will inform the development of a request for proposals (RFP) to initiate a 2-year study to investigate the relative value of nearshore habitats for native fishes. The RFP will be subjected to review by the Science Advisors and/or other qualified personnel in advance of release. Once responses to proposals are received, these, too, will be subjected to critical technical review. A cooperator will be selected on the basis of technical merit and productivity record. The selected entity will be responsible for conducting the work in future years and providing annual reports on this activity.

Study Site List

To be completed in advance of the first trip; however, the list is subject to modification depending on sites and conditions encountered.

Budget Summary

FUNDING PROPOSAL		
Experimental study 1.D: Monitor physical and biological aspects of backwater and other nearshore habitats in June (Spring Backwater Monitoring)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	11,351	8,727
GCMRC Study Related Travel/Training (19.1% burden)	7,000	2,000
GCMRC Operations/Supplies/Publishing (19.1% burden)	0	500
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	178,500	65,000
AMP Logistical Support (19.1% burden)	205,680	37,136
Outside GCMRC & Contract Science Labor (19.1% burden)	10,407	0
Cooperative/Interagency Agreements (6.09% burden)	340,880	51,000
Study Subtotal	**$753,818**	**$164,363**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	97,643	26,912
Study Total (including burden)	**$851,461**	**$191,275**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	60%	42%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Relation of Potential 2008 High Flow to Long-Term Sediment Monitoring Activities

This science plan was prepared with science integration as an objective. Despite the fact that this science plan is a stand-alone document intended to describe research tied specifically to a 2008 high flow, the GCMRC has specifically designed the study 1 (experimental studies 1.A–1.D) so that they are also supported by four long-term sediment-monitoring protocols that have been recently approved for implementation below Glen Canyon Dam. These long-term sediment monitoring tasks include (1) continuous measurements of flow and suspended-sediment transport at five locations between mid-Marble Canyon and Diamond Creek (river miles 30, 61, 87, 166 and 226), (2) annual measurements of 45 long-term sandbar study sites through the CRE (above the 8,000 cfs stage elevation), (3) below 8,000 cfs, annual topographic mapping of long segments of the river channel between fixed measurement points listed above in 1 (excepting years when a high flow is implemented), and (4) systemwide, orthorectified, digital overflights of the entire CRE (sand and vegetated areas above the 8,000 cfs stage elevation)—missions that are flows once every 4 years. Together, these monitoring data sets provide key information about topographic changes in the river channel related to changes in sand storage at all elevations, as well as the suspended-sand flux (positive, negative, or neutral) that continually influence those topographic changes through the ecosystem. Topographic data throughout the river channel are critical to understanding the evolution and fate of sandbar habitats, such as backwaters, camping areas, marshes, terrestrial environments for vegetation, benthic organisms, and cultural sites. The sand-transport data provide information about constantly changing water quality conditions (turbidity) that are controlled by suspended sand and finer sediment.

The data that would be collected during a 2008 high flow, in combination with these longer term sediment monitoring data, can provide the information that is required to fully address the strategic science question for sediment. This is possible owing to the fact that the four elements of long-term monitoring directly relate to research measurements that will be made during the test under elements A, C, and D of study 1 (sand transport and net flux, plus detailed topographic measurements of the channel bed and shorelines across the full range of elevations). Evaluation of topographic changes and sand-flux data collected during the test, along with similar measurements repeated annually over several years, allows scientists and managers to evaluate (1) how long rebuilt sandbars persist following the 2008 high flow, and (2) whether or not sandbar increases from high-flow experiments are sustainable. These data will allow constraints to be placed on the frequency of high-flow experiments for a given sand supply. Owing to the fact that topographic measurements are made throughout the channel at all elevations and the data cover entire reaches between fixed sediment-transport measurement points, it is possible to determine the net mass balance of sand throughout long reaches of the CRE.

Experimental Study 2: Evaluate effect of a future high flow on riparian plant community development at multiple surface elevations and depositional environments: Following a disturbance, are open patches more susceptible to exotic species colonization and establishment than sites with existing vegetation?

Duration

24 months

Principal Investigator

Barbara Ralston, U.S. Geological Survey, Biological Resources Division, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

Geographic Scope

Glen Canyon Dam to Diamond Creek

Abstract

Determining the relationship between native and nonnative species richness and site susceptibility is important for long-term resource management. A high flow provides a unique opportunity to compare riparian vegetation composition (i.e., native/nonnative ratios) in established vegetation monitoring sites subject to disturbance with large bare sites made available from sediment reworking. Compositional change data (native vs. nonnative species) and soil samples in established and newly bare depositional environments across multiple surface elevations immediately following a high flow and in subsequent months will be collected to test hypotheses about exotic species establishment and expansion. The study addresses a strategic science question about the effects of high flows on traditional cultural properties, which include riparian plants. Data are incorporated into long-term monitoring of riparian vegetation for the Glen Canyon Dam Adaptive Management Program.

Study Goals

The study 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 high flow. The study goal addresses a subcomponent of a larger question posed in the knowledge assessment (Melis and others, 2006b): To what extent and in what respects can high-flow experiments (magnitude and frequency) achieve reduction of exotic species?

Need for Study

Riparian areas are highly susceptible to exotic species introductions and expansions (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 high flow. 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

> **SSQ 2.1**—Do dam controlled flows affect rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?

High Flow Science Question

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

Working Hypotheses

Hypothesis 1: Native/nonnative species richness ratios are the same across all habitats and surface elevations up to 60,000 csf.

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 disturbance caused by a high flow.

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 5) 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: 8,000, 15,000, 25,000, 35,000, 45,000, and 60,000 cfs. At each location, surveys of foliar cover of all species found with four 1 m^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 high flow.

Percent foliar cover will be determined by using 10-cm grids on 1-m 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 high flow as a part of monitoring. Sampling following a future high flow will take place in association with post-flood sandbar monitoring trips, which will occur in midsummer at the height of plant productivity, in the fall in association with regular monitoring, and 1 year following a future high flow.

Bare ground sites: Similarly sized plots will be established in newly identified depositional environments (e.g., sandbars, return current channels). In most cases, these bare ground sites will be the same sites that are identified in experimental study 1.C. Established vegetation plots that are close to sandbar survey beaches will be surveyed. 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 midpoint of each 1-m^2 plot. The sample will be external to 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, which is to be determined. Samples will be collected before and after a future high flow at the established vegetation plots to determine if soil constituents and grain sized changed as a result of the high flow.

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 a one-way analysis of variance (ANOVA) F-test. Established and bare ground sites will be compared using Multiple Response Permutation Procedures (MRPP) (McCune and Grace, 2002). MRPP is a nonparametric test for the hypothesis of no difference between two or more groups; in this case, richness and cover would be compared between bare ground and vegetated sites before and after a high flow. Indicator species analysis would also be used to describe which species might distinguish each group, if differences exist, and, more importantly, identify which species in bare plots may be more successful as invaders. 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. Comparisons using MRPP will also be made between sites located above and below the LCR to see how distance may affect compositional differences.

Table 5. Established vegetation sites and corresponding experimental study 1.C sandbar sites by river mile (R=river right and L=river left)

Established vegetation sites	Corresponding study 1.C sandbar sites by river mile
002.7L	3L
008.1L	8L
035.1L	35L
037.7R	35L
041.2R	41R
043.9L	43L
047.0L	47R
053.2R	56R
056.1R	56R
062.0L	62R
065.4R	65R
068.2R	68R
119.9L	119R
121.1R	122R
122.8L	123R
132.8L	137L
139.1R	139R
143.5R	145L
171.5L	172L
182.7L	183R
193.3R	194L
202.3L	202R
220.1R	220R

Links/Relationships to Existing Work and Other Studies

This study augments general riparian vegetation monitoring because it incorporates existing monitoring locations into data collection efforts. By using surface elevations as site location criteria, the study also links species richness and cover to operational effects on riparian vegetation across surface elevations. In terms of integrating research across resources, this study will produce data that supports experimental study 1.C (Response of sandbars and selected culture sites to future high-flow experiments) 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. The locations for sampling are associated with those sites designated for research associated with sandbar topography, campsite area, and scour chains (experimental study 1.C). This study will also help 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 high-flow experiments may affect culturally important native plant species composition and distributions relative to invasive nonnative species.

Information Needs Addressed

This study 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?

Budget Summary

FUNDING PROPOSAL		
Experimental Study 2: Evaluate effect of future high-flow experiments 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? (Riparian Vegetation Studies)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Study Related Travel/Training (19.1% burden)	3,000	3,000
GCMRC Operations/Supplies/Publishing (19.1% burden)	3,036	500
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	0	0
AMP Logistical Support (19.1% burden)	15,750	7,875
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	15,800	16,000
Study Sub-Total	**$37,586**	**$27,375**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	5,123	3,363
Study Total (including burden)	**$42,709**	**$30,738**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	63%	73%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 3: Effects of high flow on lower trophic levels in the Colorado River ecosystem

Duration

19 months

Principal Investigators

Theodore Kennedy, U.S. Geological Survey, Biological Resources Division, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center; Wyatt Cross and Robert Hall, University of Wyoming; and Emma Rosi-Marshall, Loyola University

Geographic Scope

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

Abstract

We will evaluate whether a high flow on the Colorado River has a negative, neutral, or positive impact on the amount of food available to fishes by making intensive measurements of (1) algal and invertebrate biomass and species composition, (2) invertebrate and fish feeding habits, and (3) invertebrate and fish growth indicators. Because a high flow is likely to alter the systemwide carbon budget we are currently describing, we will also intensively measure transported organic matter during a high flow. This research will take place at Glen Canyon, at Diamond Creek, and in the mainstem Colorado River near the confluence with the Little Colorado River.

Study Goal

The goal of this study is to measure how a future high flow will affect the quantity, quality, and types of food available for invertebrates, and ultimately fish.

Need for Study

Previous food base research has demonstrated that a high flow 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 (e.g., algal biomass, invertebrate biomass) at a relatively coarse temporal scale (i.e., monthly measurements following a high flow). Although biomass of algae and invertebrates will be temporarily reduced following a high flow, it is possible the post-high flow algal assemblage will be faster growing and of higher quality, leading to higher invertebrate growth rates (note: production=biomass* growth). Higher invertebrate growth rates following high-flow experiments could compensate for short-term reductions in invertebrate biomass. That is, short-term (i.e., weeks) negative effects of a future high flow on biomass may be offset by longer term (i.e., months to 1 year) increases in invertebrate growth rates, which would result in more food available to higher trophic levels.

A future high flow is 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 the future high flow experiment. Although these types of measurements have been taken during previous high-flow experiments, none of the data have been linked to whole-system carbon budgets. This information will be critical for ultimately measuring the effect of a future high flow on inputs, retention, and export of organic matter that fuels river food webs.

There is evidence that disturbances that might occur during future a high flow could lead to an algal assemblage 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 high flow. They demonstrated that rates of net primary production and production to respiration ratios were both higher after the high flow, although algal biomass on rocks was lower following the high flow. 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-high flow algal assemblage was of higher quality for invertebrates than the pre-high flow 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 (e.g., 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).

Strategic Science Question

> **SSQ 5-2—**Is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?

High Flow Science Question

How will a future high flow affect food production and availability for rainbow trout in the Lees Ferry reach? What are the effects of high-flow experiments on aquatic food production?

Working Hypotheses

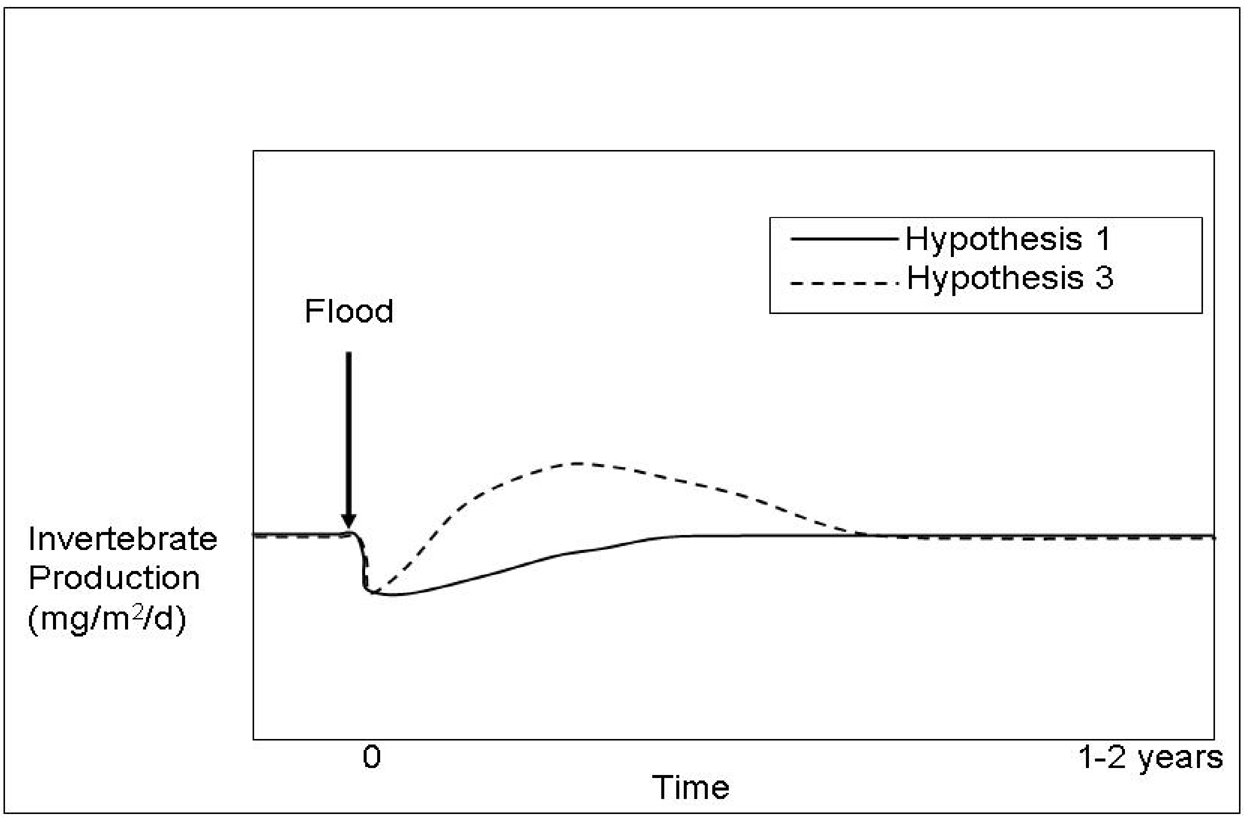
Hypothesis 1: A short-duration high flow in late winter scours the benthos, causing short-term reductions in algal and invertebrate biomass, and results in an overall decrease in annual invertebrate production (see fig. 4).

Hypothesis 2: A short-duration high flow 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 high flow 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 fig. 4).

Our research will test these competing hypotheses of recovery following a high flow. Direct measurements of invertebrate and fish growth before and after a high flow are intractable. However, we may be able to infer how invertebrate or fish growth rates are affected by future high-flow experiments 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 principal food resources. We will also measure whether a high flow changes the quality (i.e., C:N, C:P) of algal assemblages. Collectively, the proposed research will measure how a high flow 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 5. Potential effects of a high flow on invertebrate production.



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 (e.g., nutrient content of basal resources, ribosomal RNA of invertebrates and fish, open-channel metabolism measurements) to test how a high flow 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); the samples will be dried to a constant mass, weighed, ashed in a muffle furnace (at 450°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 high flow 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; Hall and others, 2005). Downstream in Grand Canyon, we will measure metabolism using a one-station technique as part of the food base study (Hall and others, unpublished). Metabolism will be measured continuously at Diamond Creek for a period of a week before, and several months after, a high flow. At the LCR, metabolism will be measured continuously for 1 week before, and 2 weeks after, a future high flow. Coarse and fine organic drift will be quantified using depth-integrated Miller net and grab samples, before, during, and after a future high flow 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 high flow 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 (Elser and others, 2003).

Tasks

1. Measure how a high flow 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 high flow, quantify standing mass of leaf litter between 20-41 k cfs stage elevation
    - Measure organic drift during high flow
2. Measure how a high flow affects invertebrate biomass and production

- Quantify invertebrate composition, abundance, and biomass
- Quantify invertebrate diets and growth indicators (i.e., ribosomal RNA)

3. Measure impact of a high flow 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 high flow, and again in the following year at the same time when no high flow occurs. Frequent measurements before and after a high flow (i.e., -7d, -1d, +1d, +3d, +7d, +14d), ongoing quarterly sampling at the LCR confluence, and monthly sampling at Glen Canyon and Diamond Creek will allow us to measure the short- and long-term effects of a high flow on food quantity and quality.

Relation to Existing Work and Other Studies

One of the main goals of the food base research effort is to determine whether rainbow trout in Lees Ferry and native fishes downstream, particularly humpback chub, are food limited. To answer this question we are quantifying food production at each of six sites and comparing that with fish demand for food. At the time of this writing we are nearing 2 years of data collection on these efforts, both of which have been 8.23 M acre-feet years with no experimental flows or tests. We anticipate that many of the measurements we are making to determine food production would be useful in a future food base monitoring program. A high flow in March 2008 is likely to provide a large contrast in food production relative to the first 2 years of data collection—this should allow us to test the sensitivity of potential food base monitoring measurements that we are currently making as part of our research on food production. Further, the 2 years of data collection under 8.23 M acre-feet hydrology will serve as a valuable baseline for determining whether a high flow has a negative, neutral, or positive impact on food production.

This study is linked to experimental study 1B (Studies of eddy-sandbar hydrodynamics, sediment transport, and bathymetry during future a high flow). We will share transported sediment samples and analyze them for both sediment and organic matter and determine what effect a high flow has on organic matter transport.

Information Needs Addressed

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

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?

Budget Summary

FUNDING PROPOSAL		
Experimental Study 3.: Aquatic Food Base Studies (Lower Trophic Levels)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% burden)	30,130	31,508
GCMRC Project Related Travel/Training (19.1% burden)	2,000	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	0	5,000
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	30,000	0
AMP Logistical Support (19.1% burden)	46,500	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	82,500	0
Project Sub-Total	**$191,130**	**$36,508**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	25,773	7,667
Project Total (including burden)	**$216,903**	**$44,175**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	55%	0%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Studies 4.A and 4.B: Rainbow Trout Studies

Introduction

The Adaptive Management Program includes the maintenance of a rainbow trout sport fishery above the Paria River (Lees Ferry) in its 12 program goals. There are conflicting hypotheses regarding how a beach/habitat-building flows test may affect this fishery. In general, there are those who believe that experimental high flows are an unequivocal detriment to this fishery. Others believe that short-term negative impacts to the fishery are overshadowed by gains, including a rejuvenation of the primary producers in the Lees Ferry reach and a compensatory response of the remaining rainbow trout that can exhibit increased growth in response to reduced intraspecific competition.

To support evaluation of some of the competing claims regarding the effects of a high flow on the rainbow trout fishery, the GCMRC proposes that three studies be conducted in association with a high flow. One of these is the ongoing monitoring of the adult rainbow trout population that the Arizona Game and Fish Department conducts several times each year. Because this work occurs with or without a high flow, it is not described further in this document. The remaining two studies, specific to a high flow, are described in the following text. These studies address early life stages of rainbow trout (study 4.A) and the movement/displacement of young and adult rainbow trout (study 4.B), both in association with a high flow. Together, all three studies of the Lees Ferry rainbow trout population help increase understanding of how high-flow experiments do or do not affect the sport fishery. They also offer opportunities to apply new study methods, especially remote tracking methods and occupancy modeling of fish populations. These two new methods may potentially be applied to native fish populations downstream if either is proven to be effective and useful.

Experimental Study 4.A: Effects of future high-flow experiments 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

24 months

Principal Investigator

J. Korman, Ecometric, Inc., Vancover, British Columbia, Canada (GCMRC cooperator)

Geographic Scope

Glen Canyon Dam to Lees Ferry

Abstract

The goal of this study is to determine how high flows affect rainbow trout spawning and incubation survival, and examine the influence of high-flow experiments on age-1 mortality, downstream migration, and habitat use in the Lees Ferry reach. This work will expand upon the Rainbow Trout Early Life Stage Survival (RTELSS) research conducted by Korman and others (2005). Redd and age-0 and juvenile abundance surveys will be conducted pre- and post-experiment. This study provides a robust evaluation of factors affecting growth, survival, and habitat choice of age-0 rainbow trout, including flow, juvenile density, adult density and the associated predation risk, and food availability.

Study Goals

This study seeks to determine how high flows affect spawning and incubation survival of rainbow trout in the Lees Ferry reach, and the potential of high-flow experiments to influence age-1 mortality and habitat use in the Lees Ferry reach and downstream migration. Hypotheses that will be evaluated are (1) high flows will scour redds (spawning nests), but the effect on the juvenile population will be limited because of compensatory survival responses, and (2) high flows will change in the distribution of age-1 fish within the Lees Ferry reach, and increase mortality and/or result in downstream migration out of the reach.

Need for Study

The size of the adult rainbow trout population in the Lees Ferry reach is very likely regulated by the survival rate and dynamics of early life stages (Houde, 1987). This study 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 et al. 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 et al. 2003). A better understanding of the dynamics of the Lees Ferry population and the effects of high flows, therefore, has implications for the control of trout densities downstream.

Understanding the effects of flow on the vital rates (e.g., growth and survival) of young fish requires an understanding of their habitat use. Certain flow regimes may be harmful in one habitat type (e.g., fluctuating flows in low angle shorelines or backwaters) but inconsequential in others (e.g., steep talus shorelines). The most feasible way to understand habitat use is to compare catch rates across habitats (e.g., Converse et al. 1998); however, this approach requires an understanding of differences in capture probability among habitats (or among habitats sampled by different gear types), and the extent to which capture probability is influenced by fish density, fish size, flow, flow history, and other factors. Such an analysis has already been undertaken for age-0 rainbow in the Lees Ferry reach in 2006 and 2007 (Korman, Walters, Coggins, and Yard, unpublished data). This study would expand that analysis by repeating it for the more challenging age-1 life stage. Lessons learned from this component may assist in understanding nearshore habitats and their ecology in Grand Canyon.

Strategic Science Question

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

High Flow Science Questions

How will a high flow affect spawning and survival of early life history stages of rainbow trout (BBT) in the Lees Ferry reach? 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?

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 due to 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, 2006, and 2007 (Korman and others, 2005, work in progress); and (3) the abundance and distribution of age-1 fish before and after the high-flow event. We predict that (1) redd numbers will be reduced by the flood due to scour; (2) the ratio of fry-to-redds will be similar to other years (2006/7=ROD, 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 flood and there will be a reduction in abundance due to mortality or downstream movement (Korman and others, 2005; U.S. Geological Survey, unpub. 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 (see study 4.B).

Methods

The RTELSS study associated with the high flow will include (1) ten redd surveys to provide a more accurate and detailed estimate of redd numbers and timing of spawning; (2) four 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 (sampling before and after high flow); (3) support for physical modeling to develop a depth and velocity map for a range of discharges for the entire Lees Ferry reach; and (4) two age-1 surveys, one before the high flow and one after the high flow. The juvenile fish survey should occur in the late fall to provide an annual index of age-0 abundance (altering the timing of this survey from previous efforts disrupts the time series).

With regard to item (3) above, as fish grow they use deeper and faster habitats (Gaudin, 2001). Previous 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 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). These habitat types will be sampled 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 high flow. 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 and 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 high flow). Data collected from past RTELSS efforts and a complete topographical map of the Lees Ferry reach developed by the GCMRC would be integrated into an existing 2-D hydrodynamic modeling framework developed by the USGS.

Data collection during 2009 will allow for a more robust evaluation of the factors that affect growth, survival, and habitat choice of age-0 rainbow trout, including flow, juvenile density, adult density and the associated predation risk, and food availability. Further, 2009 data collection will allow for a comparison of potential future flow tests to ROD flows.

RTELSS-Basic

This program would exclusively address hypothesis 1 and be repeated in 2009. Ten redd surveys (January–June) averaging 1.5 days in duration (two crew) and four age-0 surveys (June, August, September, and November) of 4 days length would be completed (two crew plus two boatmen for each survey). The 40 RTELSS index sites would be surveyed for age-0 fish on each fry survey trip (single pass), and, if time allowed, limited mark-recapture (two passes) would be conducted.

Age-1 Parr

This program would exclusively address hypotheses 2 and 3 and be repeated in 2009. Two substantial age-1 surveys would be completed (one before and one after). Each survey would be 8 days duration (two 4-day blocks) and require four crew (and two boatmen). Multipass mark-recapture would be conducted at a series of sites in different habitat types on each survey. In addition, the 40 RTELSS index sites would also be sampled (single pass).

Links/relationship to Existing Work and Other Studies

Food base information will be useful in interpreting changes in age-0 survival estimated from RTELSS-Basic compared to survival rates measured in non-high flow years. Downstream migration of trout from the Lees Ferry reach resulting from high flows will be studied by GCMRC. Trout captured as part of the proposed study could be used as part of GCMRC's downstream movement assessment and their data would be very useful for interpreting our reach-wide assessment of downstream movement/mortality (and the age-1 parr data will be useful for interpreting the telemetry information). Development of techniques and results from capture probability estimates from the age-1 Parr study component is potentially transferable to the upcoming nearshore habitat use study in Grand Canyon.

Determination of how the food web dynamics influence the density and growth of rainbow trout in the Lees Ferry reach is also important. Downstream migration of trout from the Lees Ferry reach resulting from a high flow will be studied by the GCMRC. Trout captured as part of the proposed study will be used as part of GCMRC's downstream movement assessment (see experimental study 4.B). These data will 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?

EIN 4.1.1—How does rainbow trout abundance, proportional stock density, length at age, condition, spawning habitat, natural recruitment, whirling disease and other parasitic infections change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

Budget Summary

FUNDING PROPOSAL		
Experimental Study 4.A: Effects of future high-flow experiments on rainbow trout early life stage survival, and the distribution, mortality and potential downstream movement of age-1 fish in the Lees Ferry reach (Rainbow Trout Redds Study)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Project Related Travel/Training (19.1% burden)	0	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	3,000	3,000
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	0	0
AMP Logistical Support (19.1% burden)	34,000	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	81,350	91,650
Project Sub-Total	**$118,350**	**$94,650**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	12,021	6,211
Project Total (including burden)	**$130,371**	**$100,861**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	83%	0%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 4.B: Evaluate effects of a future high flow on adult rainbow trout distribution in Glen and Marble Canyons

Duration

19 months

Principal Investigator

K.D. Hilwig, U.S. Geological Survey, Biological Resources Division, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center

Geographic Scope

Glen and Marble Canyons (river miles -15 to 225)

Abstract

This study will address strategic science questions and information needs associated with the impacts of flow management on emigration of rainbow trout from Lees Ferry and potential management options to reduce their impact on native species. This study will use abundance indices in combination with acoustic technologies to evaluate the possible displacement of rainbow trout from Lees Ferry during a high flow.

Study Goals

The goals of this experimental study are to (1) determine the effects of a high flow on rainbow trout abundance in Lees Ferry, (2) determine if a high flow causes displacement of rainbow trout of approximately 120-mm total length (TL) and larger from the Lees Ferry reach into Marble Canyon and eastern Grand Canyon; (3) determine if such displacement is experienced differentially among fish of different length; and (4) 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 Study

Native fishes of the Colorado River evolved in a system with a seasonally variable hydrograph, with winter base flows as low as ~1,000 cfs and annual spring floods routinely exceeding 100,000 cfs, and with other large floods often occurring during the summer and early fall (Topping and others, 2003). Although a high flow 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 high flow of 1996, Valdez and Cowdell (1996) observed an increase in catch rates of rainbow trout <152-mm TL in the Little Colorado River (LCR) inflow reach of the Colorado River. They hypothesized that displacement of fish from Lees Ferry and Glen Canyon into Grand Canyon by the high flow was 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 high flow, 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. Once again, however, direct observation of the fate of the fish could not be made. Currently, we do not know if short-duration high-flow experiments displace 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 rainbow trout greater than approximately 120-mm total length during a future high flow. This information in combination with relative-abundance measures will allow for a stronger inference to be drawn during a future high flow about the fate of rainbow trout greater than approximately 120-mm TL. This experimental study also provides an opportunity for scientists to gain 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. Information and experience gained in this study is potentially useful in evaluating and structuring future telemetry-based observations of native fishes dispersal associated with a high flow in downstream sections (e.g., near the LCR confluence) of the Colorado River.

Strategic Science Question

> **SSQ 1.3—**Do rainbow trout emigrate from Glen to Marble and eastern Grand Canyons, and, if so, during which life stages?

High Flow Science Question

Will a high flow stimulate downstream migration of age-1 rainbow trout?

Working Hypotheses

A future high flow will result in displacement of 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 use abundance indices and sonic technologies to evaluate the possible age-specific displacement of rainbow trout larger than approximately 120-mm TL from the Lees Ferry reach during a future high flow. Abundance indices will be established for adult and juvenile rainbow trout before and after the high flow for comparison. Before the high flow, 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-high flow evaluation of adult trout abundance will include the use of AZGFD catch-rate information from 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-high flow juvenile trout abundance. In combination, these catch data will be used to infer changes in the abundance of adult and juvenile rainbow trout associated with a future high flow.

Relative-abundance indices will be combined with direct observations of location and movement from acoustic telemetry to draw inferences about the effects of a future high flow 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 120-mm TL. With the appropriate acoustic transmitter, this represents a tag to fish body weight ratio of 5%, which has been demonstrated to have little to no effect 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 1 week 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 three acoustic receiver gates. These will be deployed at Lees Ferry, Marble Canyon Bridge, and Badger Creek. Fish in the Lees Ferry reach will then be tracked for an additional 3 days to assure data accuracy of the stationary receiver gates. A post-high flow electrofishing sampling protocol will be employed 1 week after the high flow to detect changes in the relative abundance of trout in the Lees Ferry trout fishery.

Caveats on expected study findings: To clarify how this study will address the strategic science questions listed above and the information needs listed below, note that this study will not answer all questions associated with rainbow trout emigration from the Lees Ferry reach because it will only be observing movement of fish larger than approximately 120-mm TL. However, it will potentially provide insight into whether or not larger size classes of rainbow trout are vulnerable to high-flow-related displacement. In addition, the study will provide insight into the vulnerability of rainbow trout larger than approximately 120-mm TL to displacement associated with a BHBF. This information is clearly related to potential management actions that might be considered under strategic science questions 1.4 and 3.2. Additionally, this study will provide only a partial answer to RIN 4.2.1 (below) because the fish under study will be greater than approximately 120-mm TL and observed movement will be associated with a BHBF. Therefore, no direct information will be acquired on smaller sizes of rainbow trout nor associated with routine dam operations. This study will not determine the most effective way (RIN 4.2.2) to detect emigration of rainbow trout from the Lees Ferry reach. However, it will provide insight into how well a combination of catch-rate metrics and telemetry will perform for rainbow trout greater than approximately 120-mm TL. This study will only partially address RIN 4.2.3, since it will be mainly focused on a specific hydrologic event (i.e., a high flow) and the emigration rate of rainbow trout larger than approximately 120-mm TL.

Links/Relationships to Existing Work and Other Studies

This experimental study has direct linkage to experimental study 4.A, the long-term Lees Ferry trout monitoring effort, the FY 2007 sonic tag/gear efficiency evaluation, the FY 2007 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 in relation to a high flow. 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 high flow. 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 high-flow 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 generally 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.

Budget Summary

FUNDING PROPOSAL		
Experimental Study 4.B: Evaluate effects of a future high flow on adult rainbow trout distribution in Glen and Marble Canyons (Rainbow Trout Studies - Juvenile and Adult Distribution)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Project Related Travel/Training (19.1% burden)	9,539	1,200
GCMRC Operations/Supplies/Publishing (19.1% burden)	500	500
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	43,930	0
AMP Logistical Support (19.1% burden)	30,100	0
Outside GCMRC & Contract Science Labor (19.1% burden)	3,000	0
Cooperative/Interagency Agreements (6.09% burden)	6,550	0
Project Sub-Total	**$93,619**	**$1,700**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	17,029	357
Project Total (including burden)	**$110,648**	**$2,057**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	26%	0%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 5: Evaluate effects of a future high flow on water quality of Lake Powell and Glen Canyon Dam releases

Principal Investigator

William S. Vernieu, U.S. Geological Survey, Biological Resources Division, Southwest Biological Science Center, 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

Abstract

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

Study Goal

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 and at the inlet port of the river outlet works. It may require 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 high flow. During a future high flow, additional chemical samples will be taken in the dam, at Lees Ferry, and at the river outlet works depth in the reservoir before and after a high flow.

Need for Study

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 high flow, 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 high flow, the operation of the river outlet 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 high flow 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 high flow 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 high flow were drawn primarily from the surface layers and had little effect on hypolimnetic waters. The February/March timing for a future high flow is more likely to release colder, saline, and hypoxic water from the hypolimnion.

In summary, a future high flow 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.

Strategic Science Question

SSQ 5.2—How is invertebrate flux affected by water quality and dam operations?

High Flow Science Question

Will the next high flow 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?

Methods

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

Links/Relationships to Existing Work and Other Studies

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). The data collected for this study will be provided to the ongoing aquatic food base study to establish baseline values for system nutrient loading. Any changes as a result of the high flow will be important for understanding nutrient levels made available for organisms downstream of the dam. These data are also important for the ongoing Lake Powell monitoring study.

Information Needs Addressed

The following information needs will be addressed by this study:

RIN 7.3.1.a Determine the status and trends of chemical and biological components of water quality in Lake Powell as a function of regional hydrologic conditions and their relation to downstream releases.

RIN 7.3.1.b Determine stratification, convective mixing patterns, and behavior of advective currents in Lake Powell and their relation to Glen Canyon Dam operation to predict seasonal patterns and trends in downstream releases.

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.

Budget Summary

FUNDING PROPOSAL		
Experimental Study 5: Evaluate effects of a future high flow on water quality of Lake Powell and Glen Canyon Dam releases (Lake Powell)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	16,350	4,150
GCMRC Study Related Travel/Training (19.1% burden)	2,640	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	2,627	0
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	8,000	0
AMP Logistical Support (19.1% burden)	0	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	0	0
Study Sub-Total	**$29,617**	**$4,150**
	5,657	872
Study Total (including burden)	**$35,274**	**$5,022**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	0%	0%

Note: Cost estimates for FY2008 are from current year projections; FY2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 6: Kanab ambersnail habitat conservation

Compliance Monitoring (contingent on need only)

In the event of a 2006–07 high-flow experiment, the Arizona Game and Fish Department (AZGFD) can conduct necessary onsite monitoring and compliance at Vaseys Paradise (VP), Grand Canyon, to meet legal and regulatory requirements for the endangered Kanab ambersnail—in coordination with the U.S. Fish and Wildlife Service, U.S. Bureau of Reclamation, and/or National Park Service. Compliance and mitigation efforts will follow stipulations outlined in the most recent Biological Opinion regarding the operation of Glen Canyon and its effects on the Kanab ambersnail population and habitat at VP. We anticipate using the same methods from the November 2004 high flow habitat mitigation effort for VP KAS habitat (referenced in the December 6, 2002 Biological Opinion, which proposes the temporary removal and replacement of 25%–40% of ambersnail habitat).

This proposal outlines the objectives, schedule, and budget summary for an AZGFD-led survey/mitigation team to meet the needs of compliance monitoring for this mollusk for a high flow. We would require boat support (oar or motor) for the proposed activities—either a dedicated trip or passenger space on another science trip (for 3–4 researchers).

Objectives

Conduct a pre-experiment topographical survey of the low-zone affected habitat and work with cooperators to determine estimated incidental take due to a 41,000-cfs high flow (GCMRC survey staff time permitting).

Conduct mitigation efforts for the ambersnails and habitat as necessary—based on recommendations of wildlife regulatory agencies and suggestions from the Kanab Ambersnail Working Group.

Observe the actual flood line along the stage discharge elevation at VP during the peak of the high flow; document loss of snails and habitat with digital photos.

Deliverables

Onsite compliance monitoring and mitigation efforts for ambersnails and habitat following criteria outlined in Biological Opinion.

Trip summary report including photo documentation, which will be followed up after the biannual surveys.

Budget Summary

FUNDING PROPOSAL		
Conservation Measure 6: Kanab ambersnail compliance monitoring and mitigations for ambersnails and habitat following criteria outlined in the USFWS Biological Opinion.		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 19.1% Burden)	0	0
GCMRC Study Related Travel/Training (19.1% burden)	0	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	0	0
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	0	0
AMP Logistical Support (19.1% burden)	8,600	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	5,725	0
Study Subtotal	**$14,325**	**$0**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	1,991	0
Study Total (including burden)	**$16,316**	**$0**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	70%	0%

Note: Cost estimates for FY 2008 are from current year projections; FY 2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

Experimental Study 7: Synthesis of Knowledge—Integrated interdisciplinary reporting on high-flow tests

Duration

The development of the synthesis of knowledge report on the 2008 high flow will be initiated during FY 2009, with completion of the report as a comprehensive chapter in The State of the Colorado River Ecosystem in Grand Canyon (SCORE) 2010 report (proposed USGS circular report) summarizing knowledge about high-flow experiments conducted in 1996, 2004, and 2008

Principal Investigators

Science staff of the U.S. Geological Survey, Southwest Biological Research Center, Grand Canyon Monitoring and Research Center in collaboration with cooperating researchers involved in the 2008 high-flow experiment and previous high-flow experiments

Geographic Scope

Colorado River ecosystem (extending from the forebay of Glen Canyon Dam downstream to western boundary of Grand Canyon National Park, Ariz.)

Abstract

This study is aimed at providing a comprehensive synthesis of knowledge gained from multiple interdisciplinary research studies conducted under implementation of this science plan, assuming a high flow occurs. This integrated science-reporting activity will attempt to summarize and synthesize physical and nonphysical results from not only the 2008 high-flow experiment, but will also attempt, as possible and appropriate, to summarize information previously obtained from earlier high-flow experiments in 2004 and 1996.

Study Goals

The goals of this study are to (1) derive more highly integrated understanding about how high-flow experiments have influenced the sediment and related biological and cultural/recreational aspects of the Colorado River ecosystem, not only associated with the 2008 high flow, but also those associated with two prior tests in 2004 and 1996, and (2) use this synthesized science information to evaluate future management options for using high-flow experiments to achieve management objectives of the GCDAMP in a variety of resource areas linked with sandbar rebuilding and maintenance.

Need for Study

Despite two previous high-flow experiments that were conducted in 1996 and 2004, there is still need for more comprehensive reporting about how high-flow results related to a variety of resource management issues. The 1996 test was reported to have occurred under depleted sand-supply conditions and the 2004 test was conducted under minimally enriched sand-supply conditions. The

2008 high flow will occur under what might be considered highly enriched sand-supply conditions. Hence, a comprehensive synthesis of sediment responses under a full range of sand-supply conditions is needed. Additional biological and cultural/recreational information will be derived from the 2008 test that exceeds information previously derived from the 2004 and 1996 tests, and these results need to be more fully synthesized and integrated with the comprehensive synthesis that will occur for sediment in study 1. Following the third high flow in 2008, the opportunity to fully synthesize learning about the relationship between high-flow experiments and a range of downstream resource responses is vitally needed for managers to evaluate future flow options from Glen Canyon Dam. In addition, a more complete and synthetic reporting of financial costs associated with high-flow experiments is needed for resource managers to fully evaluate and consider options for achieving downstream resource management objectives through use of high-flow experiments.

Strategic Science Question

All strategic science questions included in the preceding sections of this science plan shall be considered as part of the synthesis of knowledge reporting study. Owing to the sediment-focused nature of the 2008 high flow (and those that preceded it); particular emphasis shall be placed on the overarching question:

> **SSQ 4.1—** Is there a “flow-only” operation that will rebuild and maintain sandbar habitats over decadal timescales?

Working Hypotheses

All hypotheses included in the preceding experimental study descriptions shall be revisited and evaluated as part of the synthesis of knowledge study. As an outgrowth of the interdisciplinary collaboration of the writing team members, new hypotheses may be generated as a natural outcome of integrated science writing workshops intended to support development of the draft report on high-flow experiments, especially where appropriate and when linkages between sediment, biological, and cultural/recreational elements are most obvious.

Methods

A critical component of this science plan will be the integrated synthesis of findings from the individual studies in the science plan. During FY 2008, scientists will focus mainly on collection of field data before, during, and following the high-flow release. Data processing and initial analyses will proceed during the remainder of calendar year 2008, along with preparation of preliminary reports to the GCDAMP on test results from each of the studies. Individual draft study reports will be peer reviewed as part of standard GCMRC protocols. Following review, these reports will be revised and finalized during FY 2009 by each of the studies’ lead investigators. As the study reports are being reviewed and finalized, another reporting activity will start in FY 2009 to synthesize the results from all previous high-flow experiments into a comprehensive, integrated report. Lead authors from each of the previous high flow studies will develop this synthesis of knowledge report as members of a writing team in cooperation with the GCMRC staff and its Science Advisors. One or two writing workshops will be convened by the GCMRC during spring and fall of 2009 to guide and focus this integrated science reporting effort. The primary focus of the first workshop will be to review all of the detailed findings from the 2008 high flow, as well as results from the previous two high-flow experiments in 1996 and 2004.

After careful review of the results, the objective for the synthesis team authors will be development of a comprehensive approach to reporting the test results in an integrated format. Discussions among participating researchers are likely to be most effective within the context of a writing workshop approach convened in Flagstaff by the GCMRC. Initially, synthesis efforts will focus on linkages that are intended to be integrated within multipart studies, such as studies 1 and 4; for instance between studies 1.A, 1.B, 1.C, and 1.D. The results of sediment and related studies will then be integrated with terrestrial vegetation and aquatic food web research outcomes (studies 2–5). To the degree possible, linkages among the studies will also be related to native fishes; in particular, 1.D outcomes that relate the distribution, abundance, and fate of backwater habitats will be related to the presence/absence and distribution of humpback chub.

The draft synthesis report will be most effectively developed after the findings from individual study reports have been peer reviewed and finalized, but preliminary findings will likely provide the basis for the first writing workshop. The proposed format for this synthesis of knowledge document will likely be a U.S. Geological Survey report, but might also be a manuscript submitted for consideration to a major scientific journal of appropriate scope. After the first synthesis workshop, the GCMRC will report to the GCDAMP on the progress in developing the 2008 high flow synthesis report. Owing to the nature of the synthesis of knowledge activities, additional costs for completing this crucial element of reporting are most logically covered by the 2009 and 2010 experimental fund.

Links/Relationship to Existing Work and Other Studies

Synthesis of knowledge reporting for the 2008 high flow is specifically intended to provide a comprehensive summary and evaluation of physical and nonphysical influences of high-flow releases from Glen Canyon Dam, and as such, the task relates to all experimental studies. In addition, the synthesis effort will also summarize and evaluate lessons learned from two previous high-flow experiments conducted under differing and similar sand-supply and flow conditions in 1996 and 2004. Finally, the synthesis also allows for longer term monitoring data to be specifically incorporated into the evaluation of the results all three high-flow experiments, both in a physical (flow and sediment) and nonphysical (aquatic and terrestrial organisms) way.

Products/Reports

The current strategy for synthesis of knowledge reporting on the 2008 high flow is to develop a comprehensive report that includes all available physical and nonphysical results from the 2008 test, as well as previously reported results from the 1996 and 2004 high-flow experiments. This report might then be included as one of several chapters of a future USGS circular or SCORE report that would be published in FY 2010.

Budget Summary

FUNDING PROPOSAL		
Study 7. Synthesis of knowledge – Integrated interdisciplinary reporting on high-flow experiments.		
	FY 2009	**FY 2010**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high flow; 21% Burden)	0	0
GCMRC Study Related Travel/Training (21% burden)	5,000	5,150
GCMRC Operations/Supplies/Publishing (21% burden)	0	100,000
GCMRC Equipment Purchases/Maintenance/Replacement (21% burden)	0	0
AMP Logistical Support (21% burden)	0	0
Outside GCMRC & Contract Science Labor (21% burden)	160,000	50,000
Cooperative/Interagency Agreements (6.09% burden)	55,000	200,000
Study Subtotal	**$220,000**	**$355,150**
DOI Customer Burden (combined 6.09% and/or 21% burden)	38,000	44,762
Study Total (including burden)	**$258,000**	**$399,912**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	98%	70%

Note: Cost estimates for FY 2009 are based on a CPI increase of 3% from the current year's cost estimates along with personnel increases as determined by the USGS BASIS+ financial system estimates and an increase in burden to 21%. FY 2010 cost estimates include a CPI increase of 3% from FY 2009 costs and burden estimates are held at 21%.

Support Function 8. Logistics activities in support of experimental studies

Scheduling Considerations

Scheduling a future high flow during the spring period poses several considerations for the GCMRC Logistics Program. The primary logistical constraints for scheduling a high flow in the spring are (1) consideration of scheduling impacts to the existing monitoring program, (2) provision of adequate lead time for preparation for the additional demands required to support high-flow research, and (3) provision of 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.

Year one of this science plan requires launching 11 motorized trips and 1 nonmotorized research trip (plus an additional press/VIP trip) and support of research studies in the Glen Canyon reach and upstream of Diamond Creek (table 6). Trips are initiated 4 weeks prior to the scheduled high-flow peak and up to 12 weeks after the peak flow, encompassing a 4-month time period. During this period in the spring, there are typically three major studies scheduled to conduct field research: mainstem fish monitoring, aquatic food base, and sediment-mass balance. The combination of high-flow trips and regularly scheduled monitoring trips places a heavy demand on the resources available to the GCMRC Logistics Program. The increased demand exceeds the current capacity of the GCMRC Logistics Program, requiring additional equipment, upgrade of current capacities, and coordination of additional external resources.

Year two of the high-flow experiment includes continuation of the components of several studies. Logistical support will require nonmotorized launches and support of research activites in Glen Canyon.

Funding must be made available to the Logistics Program 8 weeks before the scheduled launch of the first high-flow trip so that resources are available to support the experimental high-flow trips while maintaining adequate support for regularly scheduled monitoring trips.

Permitting

The final science plan will be submitted to the Grand Canyon National Park Research Permits Office for review as a study requiring a Research and Collecting Permit. Following approval of a Research and Collecting Permit, individual trip permit applications will be submitted for each of the 11 (should this be 12 with nonmotorized trip, as above? The press trip is showed unnumbered in table 5) trips proposed in this science plan. Requests for permit approval should occur no less than 8 weeks before the first high-flow 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, specifically recreational river and backcountry users, about 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 a future high flow, including a hydrograph of the peak flows, which will be distributed to all river and backcountry users who may be affected. This plan also includes a budget for an unscheduled press river trip.

Logistics

A future high flow will require one nonmotorized and nine motorized trips (Not sure why this is a different number of trips) to support the proposed research activities outlined in this plan. One trip will launch in advance of the high flow. Five trips will be launched before the high flow to be stationed at river mile 30, 45, and 60, Phantom Ranch, and National Canyon to conduct sampling before, during, and after the high flow. One trip launches on the initiation of the peak flow and the final two trips are conducted after the high flow. 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. A post-experiment briefing trip has been planned to provide the opportunity for agency officials and managers and members of the press to observe and discuss the effects of the experiment.

Table 6. Logistical support requirements for proposed experimental studies.

	Study	Boats	Location	Trip length	# Personnel
Trip 1	1.C	2-33’,1-22’ (Eyeball), 1-22’ (Hydro), 1-sport (Osprey)	RM 0–225	18 days	18–20
Trip 2	1.D	2-22’, 2-sport (Achilles)	RM 0-225	18 days	10-12
Trip 3	1.A,3	1-33’, 2-sport (Osprey)	RM 61	20	8–12
Trip 4	1.A	1-22’, 1-sport (Osprey)	RM 166	15	2-4
Trip 5	1B	1-33’, 1-22’ (Hydro)	RM 45	16	6–8
Trip 6	1a,KAS compliance	1-33’, 1-sport (Osprey), 1-sport (Achilles)	RM30	16	10-12
Trip 7	1.A,3	1-33’, 1-22’, 1-sport (Achilles)	RM 87/ Lower Lagrangian	14	6–8
Trip 8	1.A,3	1-33’, 1-22’	Upper Lagrangian	12	6–8
Trip 9	1.C,2,4.B	2-33’,1-22’ (Eyeball), 1-22’ (Hydro), 1-sport (Osprey), 1-18’ (row)	RM 0–225	18	20-22
Trip 10	1.D	2-22’, 2-sport (Achilles)	RM 0-225	18 days	10-12
Trip 11	1.C	2-33’	RM 0–225	18	12–14
Trip 12	1.D,2	6-18’(row)	RM 0–225	16	16-18
Press Trip	8	2-22’	RM 0–225	8	14-16

Recommended Timeline

- Final approval high flow and hydrograph (date and hour specific)
- Permitting and logistical planning initiated (8 weeks prior to trip 1 launch)
- First high-flow research trip launches (4 weeks prior to initiation of high flows)
- High flows initiated
- Press trip launches (1 week following high flows)
- Final post-experiment trip launches (8 weeks following high flows)

Estimated Logistics Costs (using FY 2007 costs)

Experimental studies and associated logistical support activities		**Year 1 projected cost (included in study budgets)**	**Year 2 projected cost (included in study budgets)**
1.A	Sand Budgeting	$99,213	
1.B	Sandbar Depositional Rates	$19,302	
1.C	Sandbar Fate	$127,081	
1.D	Shoreline Habitat Mapping	$122,104	$69,577
2	Riparian Vegetation Studies	$15,750	$7,875
3	Lower Trophic Levels	$46,483	
4.A	Rainbow Trout Studies – Early Stages	$33,934	$33,934
4.B	Rainbow Trout Studies – Adult Distribution	$30,085	
5	Lake Powell	$0	$0
6	KAS Compliance	$8,600	
TOTAL PROJECTED IN-STUDY LOGISTICS COSTS:			

Budget Summary

FUNDING PROPOSAL		
Support Function 8. Logistics activities in support of experimental studies—direct costs (not included in study estimates)		
	FY 2008	**FY 2009**
GCMRC Personnel Costs (includes overtime and additional hires necessary to complete high-flow; 19.1% Burden)	8,000	0
GCMRC Study Related Travel/Training (19.1% burden)	0	0
GCMRC Operations/Supplies/Publishing (19.1% burden)	20,000	0
GCMRC Equipment Purchases/Maintenance/Replacement (19.1% burden)	60,000	0
AMP Logistical Support (19.1% burden)	15,000	0
Outside GCMRC & Contract Science Labor (19.1% burden)	0	0
Cooperative/Interagency Agreements (6.09% burden)	0	0
Study Subtotal	**$103,000**	**$0**
DOI Customer Burden (combined 6.09% and/or 19.1% burden)	19,673	0
Study Total (including burden)	**$122,673**	**$0**
Percent outsourced (not including incorporated personnel costs; including 50% logistical support)	7%	0%

Note: Cost estimates for FY 2008 are from current year projections; FY 2009 are based on a CPI increase of 3% from the current year's costs along with personnel increases as determined by the USGS BASIS+ financial system estimates; and an increase in burden to 21%.

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Appendix A. Responses to issues raised by members of the Glen Canyon Dam Adaptive Management Program about a future beach/habitat-building flows test

During their meeting on December 5–6, 2006, 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 a future high flow experiment. These concerns are summarized below from the meeting minutes and are followed by short responses prepared by GCMRC staff and cooperating scientists.

Issue 1: What are the tradeoffs between the benefits of a future high flow 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 appendix A, table A.1 for a summary of the pros and cons associated with a future high flow in late winter or early spring.

Issue 2: If a proposed future experiment is a new experiment, then what are the new hypotheses?

The proposal for a future high flow is a hybrid of the two previous experiments that have been conducted, incorporating key learning from both the 1996 and 2004 high-flow experiments. The next proposed high flow intends to return more closely to the original timing of spring (if sufficient sand enrichment exists at that time) 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. As proposed, it would also be a second test of the concept of implementing the high flow within a period when new sand supplies are known to exist in the main channel following tributary sand inputs. The 2004 high flow 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 produced a revised hypothesis regarding sand transport. This new hypothesis postulates that new sand inputs that enter the ecosystem from the Paria River should be allowed some limited time to be transported downstream into lower Marble Canyon under the 1996 Record of Decision operations. Hence, there is an evolving question about the appropriate timing for when a high flow 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 results in more uniform and robust sandbar deposition, and (4) the season in which historical flood disturbance occurs (spring).

The exact timing of a future high flow will depend on the magnitude of the sand inputs from the tributaries and the magnitudes of releases from the dam. The timing of a high flow could likely occur in spring if sand inputs greatly surpass the proposed trigger for a high flow and dam releases are lower. This would have been the scenario if a high flow had occurred in spring 2007. However, the timing of a high flow would be much earlier (potentially late fall or winter) to still be above the trigger threshold, if sand inputs equal the minimum required by the proposed trigger and are accompanied by moderate to high dam releases.

The science plan for a future high flow proposes to have additional studies tied to food base, fisheries, and cultural sites. The science questions that will be addressed in a future high flow are identified in table A.1. Specific hypotheses associated with these studies are described in the experimental study descriptions included in this science plan.

Issue 3: What is the reason behind replicating the 2004 (high flow) hydrograph?

The concept of replicating the 2004 hydrograph (i.e., replicating that portion of the 2004 hydrograph consisting of the rising limb, peak, and recession of the November 2004 high flow) 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 using sandbar simulations for a subset of eddies under a scenario of 45,000 cfs peak magnitude and assuming sand concentrations that were measured in the postdam era. This information and data collected from the 1996 high flow were the basis for choosing 60 hours as the duration for the peak flow of a future high flow, a much shorter duration than the 168 hours tested in 1996. The 2004 high flow peak magnitude was limited to 41,500 cfs because one of the eight turbine units at Glen Canyon Dam was undergoing maintenance. The concept of replication of the 2004 hydrograph in a future test is aimed at determining whether or not the robust sandbar-building responses that occurred under the 2004 high flow will occur consistently with sand-enriched conditions. Replication of the 2004 hydrograph during sand-enriched conditions 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 hydrograph under sand-enriched conditions in the spring (following several months of downstream transport under the 1996 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 high flow, then this approach may be interpreted as 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 while conserving new sand inputs before they are exported to the upper Lake Mead delta. On the other hand, if a different high-flow hydrograph is used for the next test and the results are not as good as 2004 high-flow results, then the lack of replication will make it very difficult to determine whether the response was the result of different timing and supply conditions or to the different hydrograph.

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

Issue 4: What would be the pros and cons of a shorter-duration high-flow peak at 41,500 cfs (for instance, 30 hours)?

Discussions among scientists and managers about alternative duration peak flows for future high flow (i.e., shorter than the 60-hour peak tested in 2004) 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 appendix A, table A.2).

Issue 5: Is there a risk of a potential take or impact (of a future high flow) on juvenile humpback chub? HBC recruitment?

Assuming a future high flow will occur in spring, there appears to be little risk to juvenile humpback chub associated with a future high flow, given the results of fisheries studies conducted in association with the 1996 high-flow experiment in Grand Canyon. 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 a future high flow is generally tied to late winter or early spring, 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 a future high flow. Following extensive sampling to measure abundance of fish before and after the spring 1996 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 high flow. Relative abundance of juvenile native fish was also estimated before and after the 2004 high flow downstream of the Little Colorado River confluence (GCMRC unpub. data; Coggins and others, 2005). Unfortunately, the results of the fall 2004 study were highly inconclusive owing to elevated turbidity following the 2004 high flow caused by flooding activity in the Little Colorado River. These conditions rendered catch-rate observations taken before and after the experiment unreliable, which was likely the result of changes in sampling gear efficiency.

The finding that native fish are little affected by high-flow events, which emerged from research associated with the 1996 high flow, is 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. Brouder (2001) found that age-1 native roundtail chub increased or remained high in years following a late winter/early spring flood. Indeed, this differential tolerance to flooding has been suggested as a nonnative control method (Minckley and Meffe, 1987). Although 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 high flow. 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). There is presently insufficient data to arbitrate among these competing hypotheses, although it is certainly valid to hypothesize that a future high flow could hinder recruitment by imposing some direct or indirect mortality source.

Issue 6: Will there be sufficient funds to address the HBC issue (relative to a future high flow)?

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

Issue 7: Will there be negative impacts (from future high-flow experiments) 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 is temporarily reduced following a future high flow, little is known about the effect of a future high flow on productivity (a dynamic process measure). The GCMRC's working hypothesis included in this science plan is that after the initial reduction in food following a future high flow, daily production and turnover of algae, invertebrates, and possibly fish are higher than before the high flow. This positive response by the food base may offset the initial negative 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 at least one additional high flow is needed to pin down quantitative answers for the important questions raised above.

Issue 8: What are the impacts (of a future high flow) on hydropower and other economic interests (i.e., fishing guides and river guides)?

Comprehensive studies to assess the economic impacts of conducting a future high flow have not been conducted, and, therefore, the full range of economic impacts cannot be definitively determined with available information. Based on the recent economic assessment by the Western Area Power Administration (WAPA) for the experimental options study (conducted in 2006 by the 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 a future high flow). There would also be some immediate short-term gains resulting from running the generators at full capacity during a future high flow, although the gains would not be sufficient to offset future lost opportunity costs. In terms of recreational economic interests, short-term impacts are likely to the local fishing guide economy during and probably immediately following a future high flow. 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 nonexistent because the proposed timing of a future high flow will occur before the start of the commercial boating season. The larger question that remains to be determined is whether the combined potential economic impacts of conducting a future high flow outweigh the potential resource benefits and societal value derived from conducting the experiment. The answer to this question is critical for assessing the overall economic implications of a high flow. The GCDAMP is currently lacking up-to-date, comprehensive valuation data to address this larger economic question. A more comprehensive study of the economic impacts of conducting a future high flow considered during development of the Long Term Experimental Plan.

Issue 9: High-flow experiments result in a lot of sediment below Diamond Creek, resulting in economic concerns for the Hualapai Nation. Additionally, there is an archaeological site below Glen Canyon Dam that going to be harmed 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 navigation. Also, the exposure of formerly submerged sandbars has cut off access to a formerly popular takeout point at Pierce Ferry. The Hualapai Tribe is concerned that a high flow 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 the previous 2004 high flow built sandbars and benefited camping beaches in a reach where new sand inputs were located). Assuming the lake remains low, a future high flow 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. It is unknown whether and to what degree sediment would be redeposited in specific shoreline locations used by the Hualapai Nation tour operators, and whether it would have negative consequences for these commercial operations. What is known with certainty is that a future short-term high flow will not solve, nor will it significantly exacerbate, the long-term issue of sediment buildup 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 on archaeological sites, particularly one site located in the Glen Canyon reach. In 1996, before the first high flow, 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, pers. com., December 7, 2006). 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 high flow. During the 1996 mitigation work, there was considerable uncertainty as to whether this site was truly cultural, but the recent reevaluation 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 high flow. Mitigation of potential high-flow impacts is planned to occur in fiscal year 2008, as one component of a larger treatment study being proposed by the Bureau of Reclamation to address impacts of dam operations on archaeological sites.

Issue 10: 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 nonoperational annually through March during a future high flow, although having eight units fully operational would be optimal for sediment studies. A future high flow is not currently proposed for later than March.

Table A.1. Summary of pros and cons associated with conducting a future high flow.

General concerns	Pros	Cons	Uncertainties
Glen Canyon Dam Adaptive Management Program (GCDAMP) Resources	• Probable sandbar restoration and conservation of related physical habitats • Probable improvement of recreational camping sites • Probable enhancement of sediment transport to and mitigation of erosion at 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 • Possible impact to a 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 (to 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 goals related to sediment, humpback chub, food base, cultural resources, camping beaches, and riparian habitat • Provides information about optimal high-flow hydrograph design to maximize benefit and minimize costs • Informs interested public • Information transfer to other scientists and managers working on river restoration	• None	• None
Experimental fund budget	• Credible subset of studies can be implemented to address high-priority needs	• Available experimental funding is currently insufficient to implement all proposed studies	• None
Economic impacts	• Infusion of local economic activity linked to science support, etc.	• Foregone hydropower capacity in later timeframe (to be quantified by BOR/WAPA) • 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?

Table A.1. Summary of pros and cons associated with conducting a future high flow.—Continued.

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 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 (such as backwaters that may benefit 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 high-flow experiments may limit sand export under fluctuating flows that follow • Missed opportunity to gather data on high-flow experiments as related to strategic, experimental questions about sand conservation and effectiveness of high-flow experiments to meet Goal #8 objectives • High-flow experiments 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 a 60-hour to 30-hour peak duration high flow 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 model simulations and recommended by sediment scientists)	~ 93,000 acre feet (91 hours)	• Provides most rigorous direct comparison with 2004 high-flow data • Maximum sandbar restoration predicted from modeling to occur in this timeframe • Resulted in net positive sand balance in 2004 high flow • Allows field scientists time for replicate eddy and SS measurements • 108 hours shorter than 1996 high flow • 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 high-flow 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 high-flow experiments result in less influence on exporting low oxygen from hypolimnion of Lake Powell

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Appendix B: Factors influencing the design of high flow experimental studies for fisheries and water quality

Fisheries Studies Associated with a Future High Flow

The use of beach/habitat-building flows (BHBF) was identified in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS) as a strategy to rebuild 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 Colorado River ecosystem. Evaluating complex and multiyear fish responses that might be associated with infrequent, short-duration high-flow experiments (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 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 (illustrated by the 2007 work plan summarized in table B.1), providing a long-term perspective on the status and trends of these populations. Such a sampling regimen will bracket a future high flow 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.

Study	Timing	Primary Objective
Downstream Native Fishes	March	Monitor native fishes from Lees Ferry to Diamond Creek (spring)
Little Colorado River (LCR) Humpback Chub	April	Population estimate of humpback chub in the LCR (concurrent sample)
Little Colorado River Lower 1,200 meters/PIT tag antennae	April–May	Intensive monitoring of humpback chub in lowest 1,200 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 nearshore 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 high-flow experiments. 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 high flow 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 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 in the results of the 1996 high flow (Valdez and others, 2001). Careful inspection of these results suggests that the statistical power to detect changes in rare species using single-event sampling 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 high flow (U.S. Geological Survey, unpub. 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 was simply a result of fish using different habitats following the 2004 high flow, or of temporary downstream displacement. 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 high flow. Therefore, we conclude that new techniques are required to answer the recurring question asked by managers: What is the fate of juvenile native fish during a future high flow?

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 high flow. 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 the 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 is attributable 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 high flow 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 B.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 high flow because juvenile humpback chub are at their highest abundance in the mainstem Colorado River during and after the monsoon season (middle to late summer), but far fewer fish are expected to be available for study in November–March (the likely timing of future high-flow experiments).

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 in December 2006 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 high flow.

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 high-flow experiments. 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 allow better inferences about the effects of high-flow experiments on humpback chub than the 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 high flow. 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 high flow, and conduct simulation studies using this technique to evaluate its use in estimating fishes before and after any future high flow. 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 adding a study for occupancy estimation for humpback chub in association with a high flow. This proposal and associated budget would be submitted for consideration at least 120 days before a proposed future high flow.

Summary of Challenges in Assessing the Effects of a Future High Flow on Native Fish Populations in the Colorado River in Grand Canyon

Trends in Fish Abundance in Glen and Grand Canyons

- Humpback chub abundance in Grand Canyon showed continuing decline through the 1990s, based on catch-per-effort (CPE) and tagging assessments. Trends in adult abundance observed during the 1990s suggest that recruitment of young humpback chub began declining by the mid-1980s. The more rare a species, the more difficult it is to monitor (Thompson, 2004).
- 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. The timing of the recruitment decline in the mid-1980s does not match the timing of the rainbow trout increase in the mid-1990s, although increasing numbers of rainbow trout may have continued to suppress the humpback chub population.

Glen Canyon Dam Treatments Targeted at Improving Humpback Chub Recruitment

The 1996 Biological Opinion for the EIS recommended modifications to Glen Canyon Dam operations designed to rebuild some elements of downstream physical habitat for humpback chub, including:

- 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.

The most recent experimental flow treatment recommended by the Glen Canyon Dam Adaptive Management Work Group 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.

The use of high-flow experiments to rebuild nearshore sandbar habitats were also described as part of the 1996 Record of Decision, and additional sediment tests were recommended by the GCDAMP as part of integrated physical and biology experimentation in 2002. A second high flow 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 high-flow experiments, is limited for the following reasons:

- 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., difficulty in assessment during the short-term high flow).
- Tagging assessments are more reliable than CPE data, but there is a long lag (3+ years) 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 mean that a future high flow is 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 nonnative fishes, dam operations (including high-flow experiments), or a combination of the two. Our ability to detect fish population responses to a future high flow 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 the GCMRC and cooperating agencies, especially Arizona Game and Fish Department.

Additional Study to Monitor Backwater Habitats

After reviewing earlier iterations of this plan, comments were received from the GCMRC Science Advisors and from GCDAMP stakeholders requesting additional monitoring of the fish community, especially humpback chub, and fish use of backwater habitats. Despite some of the limitations described above, the GCMRC is proposing expanding efforts to monitor backwater habitats each year whether a high flow is conducted or not. A spring backwater monitoring trip has been proposed to respond to the calls for additional monitoring. Funding for this study is included in this document in case a high flow is implemented before this study can be included in the annual work plan because of timing, funding, or other restrictions.

It is believed that in addition to future high flow tests, by developing and calibrating additional sediment transport and deposition models, scientists will be better able to interpolate between observed effects and help rule out scenarios that are unlikely to yield positive, sustainable results. Some of the data needed to develop a model could be obtained through laboratory studies or field studies conducted during normal flow conditions. Data from the anticipated 2008 high-flow test would also be very important for the development of additional predictive models. Such an approach would likely reduce the overall research costs and help minimize impacts to hydropower.

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 the abundance of consumers like fish in those food webs (Carpenter and Kitchell, 1996; Wetzel, 2001).

Scientists hypothesize that operational changes associated with any future high-flow experiments 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 high flow.

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