Assessment of the Estimated Effects of Four Experimental Options on Resources Below Glen Canyon Dam

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Chapter 1: Introduction

This report is designed to provide a scientific assessment of the estimated effects of four experimental options currently being considered by the Glen Canyon Dam Adaptive Management Program (GCDAMP). Each of the four options outlines revised operating criteria for Glen Canyon Dam and various nonflow actions that would be implemented or tested during the next 10 years. The purpose of this assessment is to provide GCDAMP participants and Department of the Interior (DOI) decision makers with information about how each of the four experimental options is likely to (a) affect downstream biological, physical, and sociocultural resources of the Colorado River ecosystem (Glen Canyon Dam to upper Lake Mead) and (b) contribute to the understanding of the relationships between management actions and resource conditions.

Background

The GCDAMP was established in 1996 by the Secretary of the Interior to implement the Grand Canyon Protection Act of 1992 (GCPA), the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (final EIS), and the 1996 Record of Decision (ROD). Adaptive management in Grand Canyon was envisioned as a new paradigm for addressing the complex environmental problems related to the operation of Glen Canyon Dam through the dynamic interplay of stakeholder collaboration, resources management, and scientific research. As a result, GCDAMP consists of five major components, including:

- The Adaptive Management Work Group (AMWG) is a Federal Advisory Committee composed of 25 stakeholders that was established to facilitate the implementation of the GCDAMP. After careful review, the AMWG makes recommendations to the Secretary of the Interior on how to best alter dam operating criteria or other management actions in order to fulfill the Department of the Interior's obligations under the GCPA.

- The Secretary of the Interior's Designee serves as the chair of the AMWG and provides a direct link between the AMWG and the Secretary of the Interior.

- The Technical Work Group (TWG) translates AMWG policy and goals into information needs, provides questions that serve as the basis for long-term monitoring and research activities, and conveys research results to AMWG members.

- The U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) provides credible, objective scientific information on the effects of the operation of Glen Canyon Dam and related factors on natural, cultural, and recreational resources along the Colorado River from Glen Canyon Dam to Lake Mead.

- The independent review panels (IRPs) provide independent assessments of program proposals and accomplishments to ensure scientific objectivity and credibility. For example, a formal group of Science Advisors (SAs) consisting of academic experts in fields germane to studies within the scope of the GCDAMP serves as an IRP.

This document will be reviewed by the SAs, TWG, and AMWG (in that order). AMWG recommendations concerning the experimental options will be forwarded to the Secretary's Designee. The eventual preferred alternative will be implemented following completion of appropriate environmental compliance (e.g., National Environmental Policy Act, Endangered Species Act) and approval by the Secretary of the Interior.

The 1996 ROD implemented a modified low fluctuating flow (MLFF) regime as the basis for the operation of Glen Canyon Dam, following an extensive National Environmental Policy Act review process. In selecting the MLFF alternative (also known as ROD operations), the ROD noted that the goal was to "permit recovery and long-term sustainability of downstream resources while limiting hydropower capacity and flexibility only to the extent necessary to achieve recovery and long-term sustainability." In the intervening decade, the MLFF operating regime and a variety of experimental projects have been implemented to meet this goal. In keeping with its role in the program, GCMRC and its cooperators have evaluated the effects of MLFF operations and various experimental efforts. The State of the Colorado River Ecosystem in Grand Canyon (Gloss and others, 2005), prepared by the GCMRC to meet the information needs of GCDAMP participants, summarizes the results of these studies and the state of the resources in the Grand Canyon based on relevant scientific data collected between 1991 and 2004.

In 2005, an ad hoc Science Planning Group (SPG) was established to provide a forum for GCDAMP participants and GCMRC scientists to work collaboratively to develop an effective long-term direction for the future experimental research activities. Over the course of a year, three experimental options were developed by various GCDAMP participants through the SPG process. In October 2006, a fourth option was added to the list of options under consideration at the request of the TWG. As a result, this assessment considers four experimental options (table 1.1), referred to as Options A, A Variation, B, and C. Each option reflects very different philosophies and policies related to conservation and use of Grand Canyon resources, and the role of science in the GCDAMP. As a result of these differences, the primary flow regimes advocated by the four options vary greatly. For example, Options A and A Variation provide for wider fluctuating flows throughout the year primarily to benefit hydropower generation. By contrast, Option B proposes to incrementally implement and test steady flows and equalized monthly volumes of flows primarily to protect downstream resource values. Option C includes both steady flows in the late summer/early fall and wider fluctuating flows during other times of the year.

In addition to variations in flow regime, the experimental options also have nonflow components that vary. However, all the options share several common flow and nonflow actions, including:

- Implementation of a temperature control device (TCD) to elevate mainstem water temperatures and promote humpback chub spawning and recruitment;
- Nonnative fish management to reduce predation on and competition with native fishes; and
- Beach/habitat-building flows (BHBF), or controlled floods, under enriched sand supply conditions to conserve sand resources.

A fundamental tenet of adaptive management is "learning by doing," meaning that science is used to better understand the relationships between actions—natural events, anthropogenic change, or experimental treatments—and desired resource conditions. A properly designed experimental program implemented over a long time frame is most likely to yield definitive information on the relationships between specific actions and the condition of target resources. The four options vary significantly in their proposed experimental design or approach. Options A and A Variation provide for implementation of a suite of actions at the earliest possible time frame to achieve a positive resource response, and deem learning about the relationship between actions and resource responses to be a secondary priority. Options

B and C advocate a more structured experimental design that is intended to improve downstream resources while facilitating an understanding of the effectiveness of different management actions.

Table 1.1 Authors/proponents on the various experimental options, and approval mechanism.

Option	Author/Proponent	Approved
A	Arizona Game and Fish Department Federation of Fly Fishers U.S. Department of Energy, Western Area Power Administration	SPG
A Variation	Colorado River Energy Distributors Association	TWG
B	Grand Canyon River Guides Grand Canyon Trust	SPG
C	Bureau of Reclamation National Park Service U.S. Fish and Wildlife Service	SPG

It should be noted that the four experimental options that are the subject of this evaluation reflect different policy options related to the Glen Canyon Dam experimental program that were defined primarily by GCDAMP stakeholders. These experimental options should not be confused with an experimental science plan that articulates specific science questions, hypotheses, and technical approaches. These will be defined in detail in a long-term experimental plan (LTEP) that will be developed by GCMRC once the preferred experimental option is determined by the Secretary of the Interior. The LTEP will be integrated into the Monitoring and Research Plan to Support the Glen Canyon Dam Adaptive Management Program, Fiscal Years 2007–11, which describes the scope and objective of a 5-year monitoring and research program to address priority goals, questions, and information needs specified by the GCDAMP.

General Methods

The assessment of the possible influence of the four options on downstream resources is made primarily through the use of information reported in the 2005 knowledge assessment final report (Melis and others 2006b; KAR). In making their assessments, GCMRC scientists relied on the peer-reviewed literature, both sources cited in the KAR and elsewhere, and the range of expert opinions from well-known scientists that were shared during the 2005 workshop that culminated in the KAR. The estimated resource responses to the proposed experimental options are of a generalized nature and made with admission of the numerous uncertainties that were identified during the knowledge assessment workshop.

New models for simulating the effects of downstream water temperature (see appendix D, this report) and diurnal stage variation (see appendix B, this report) have been completed since the KAR was finalized. The results generated by these models were used to inform the analysis presented in following chapters. Simulation results for diurnal stage variation, as derived from a new version of the HEC-RAS model containing 2,200 cross sections (Magirl, in press), were used in assessing the options. In addition, information pertaining to release temperatures from the dam and downstream thermal characteristics is derived from new and existing models for Lake Powell and downstream flow and temperature conditions.

The temperature models are also being used to simulate the amount of downstream warming under several TCD design options.

All options were evaluated over a range of simulated hydrologic conditions for the upper Colorado River Basin in order to evaluate the influences of the four options under a realistic range of variability. The hydrologic conditions included in the assessment range from 8.23 million acre-feet (MAF), the minimum amount of water needed to meet delivery requirements under various treaties and agreements, to most-probable and wet conditions. The hydrologic scenarios for these three conditions were derived from output data generated by the Bureau of Reclamation using a Colorado River Storage System (CRSS) simulation model based on 20th century hydrologic conditions (see appendix A, this report). Monthly release volumes projected for each of the options under the 8.23 MAF annual release pattern, most-probable conditions, and wet scenarios were used by the Western Area Power Administration to generate hourly hydrographs for each of the experimental scenarios over the 10-year simulation period.

Finally, the 2005 KAR process identified a critical need to evaluate the economic implications to hydropower resources associated with various experimental plans. Following this recommendation, an economic assessment of the four options has also been undertaken independently by the Western Area Power Administration. The results of the economic evaluation are reported in appendix E; however, chapter 3 of this report presents a summary of those findings. This assessment and the economic evaluation will be subjected to external peer review by knowledgeable experts.

Report Organization

The report is designed to provide GCDAMP participants and DOI decision makers the relevant information that they need to evaluate the effects of the four options on downstream resources. To limit the primary report length and complexity, technical scientific discussions (e.g., methods used to develop models and estimate temperature change) have been placed in the appendices for readers who are interested in more detailed information.

Chapter 2 of the report provides a description of each of the four options under consideration. Chapter 3 evaluates the flow-related effects of each option on downstream resources, including physical resources (i.e., sediment, temperature, and diurnal stage variation), aquatic and fisheries resources, riparian biological resources, recreation and cultural resources, and hydropower. Chapter 4 assesses the influence of the nonflow experimental components of each option on downstream resources, while chapter 5 compares the proposed experimental designs. Chapter 6 closes the report with a presentation of GCMRC's most important conclusions that emerged for consideration during the preparation of this assessment.

Chapter 2: Experimental Options Descriptions

This chapter provides general descriptions of the four experimental options under consideration by the Glen Canyon Dam Adaptive Management Program (GCDAMP). Each option alters the current operating criteria for Glen Canyon Dam (flow component) and specifies other nonflow treatments to be implemented during the next 10 years.

Because released water flows from Glen Canyon Dam vary with hydrological conditions, a detailed description of release patterns is provided in appendix B for each option under various conditions: (1) an annual release of 8.23 million acre-feet (MAF), the minimum amount of water needed to meet delivery requirements under various agreements and treaties; (2) most-probable hydrological conditions; (3) wet hydrological conditions.

The nonflow treatments recommended by each option are based on modification of activities that have been developed over time through the GCDAMP process and are described generally in the first section of this chapter. Specific differences in nonflow actions among the options are identified in the individual experimental option descriptions. Many of the nonflow actions relate to the management and conservation of the Grand Canyon population of humpback chub (*Gila cypha*), a native fish species that is federally listed as endangered under the Endangered Species Act. The summary descriptions for experiments related to humpback chub were drawn from the September 2006 Draft Comprehensive Plan for the Management and Conservation of Humpback Chub in Grand Canyon.

Component Descriptions

Flow Components

Beach/Habitat-Building Flows (BHBF)

BHBFs are infrequent high releases that are at least 10,000 cubic feet per second (cfs) greater than currently allowable peak discharge in a minimum release year (30,000 cfs) but not greater than 45,000 cfs. Under current Glen Canyon Dam operations, BHBFs occur under the hydrologic triggering criteria recommended by the GCDAMP in 1998, which restricted these high flows to years of high reservoir conditions and high inflows. Thus, under current operations, a BHBF would occur in years when there was an expectation of having a very full reservoir. However, in September 2002, the U.S. Department of the Interior approved for research purposes changes linking restoration floods to triggering thresholds based on sand inputs. Significant sand inputs to Marble Canyon that exceeded the triggering threshold for an experimental high flow occurred during September–November 2004. Approval of a supplemental environmental assessment paved the way for the experimental high flow (BHBF) that began on Sunday, November 21, 2004.

Under all four of the experimental options, BHBFs could continue to be tested under a recently revised sediment trigger. The proposed sediment trigger would be met when 0.5 million metric tons of sand are introduced by the Paria River and retained above river mile (RM) 30, and an additional “weighted” 0.5 million metric tons of sand are delivered by the Paria River, Little Colorado River (LCR), or sources in between these two primary tributaries. To calculate the weighted input, sand from the Paria River is given full value, and sand from the LCR and other sources is valued at 50% of the actual input. Thus, a BHBF could be triggered with an input of 1.0 to 1.5 million metric tons of sand depending on how much of the sand is derived from the Paria River.

Nonflow Components

Temperature Control Device

Installation of a Glen Canyon Dam temperature control device (TCD), or selective withdrawal structure, would provide dam operators with flexibility to draw water from different depths of the reservoir, including warmer water from near the surface of the reservoir. The goal of the TCD would be to provide a combination of cold and warm water withdrawals to benefit the endangered humpback chub while minimizing negative impacts to other resources. The implementation of a TCD as part of the long-term experimental plan will be subjected to National Environmental Policy Act review. Construction and operation of a TCD will be dependent on the outcome of that process and the availability of construction funding. The Bureau of Reclamation proposes to modify two of the eight penstocks on Glen Canyon Dam and test the effects of using selective withdrawal through implementation of the long-term experimental plan. There is a high probability that low reservoir levels in the next several years, coupled with the two modified penstocks, will allow sufficiently warm dam releases to adequately test the effects of higher water temperatures on the downstream ecosystem.

Control of Nonnative Coldwater Fish

This project was implemented to test whether removal of rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and other nonnative fish species would benefit humpback chub. The experiment was conducted in a 17-mile reach of the mainstem Colorado River above and below the confluence with the Little Colorado River for 4 years, 2003–6. Monitoring of humpback chub and nonnative fish continues in order to evaluate population responses to the removal of competitor and predator fishes. All four experimental options support continued control of nonnative, coldwater fish, but the options vary in detail provided on when and how control efforts would be implemented.

Control of Nonnative Warmwater Fish

Because of the natural warming of the releases from Glen Canyon Dam that have occurred as a result of lowered reservoir levels in Lake Powell (2003–current), managers and scientists have expressed concern that populations of nonnative fishes adapted to warm water, most of whom are already present in Grand Canyon, may increase at the expense of native fishes. Species such as common carp (*Cyprinus carpio*), fathead minnow (*Pimephales promelas*), plains killifish (*Fundulus zebrinus*), and channel catfish (*Ictalurus punctatus*) may pose the greatest risk to native species, but other nonnatives may also pose important threats, whether through direct predation, competition for resources, habitat alteration, or a combination of all three threats. All of the option proponents support continued research on how to best address this threat with concomitant monitoring of the native fishes, especially humpback chub.

Humpback Chub Disease/Parasite Research

This project includes two phases: (1) development and implementation of a monitoring plan for fish diseases and parasites in the Colorado River and its tributaries, with emphasis on those infecting humpback chub and (2) investigation of mechanisms for control and suppression of important diseases and parasites.

Humpback Chub Translocation

This activity would transplant young-of-year humpback chub produced in the Little Colorado River to appropriate tributaries within Grand Canyon National Park and adjoining tribal lands. Based on evaluations conducted by Valdez and others (2000), the probability of establishing sustainable humpback chub populations in these tributaries is small, but proponents believe that any reproduction and/or survival in locations other than the Little Colorado River decreases the risk of losing the entire Grand Canyon humpback chub population to a catastrophic event

Humpback Chub Refuge(s)

This activity would create an off-river refuge population for the Grand Canyon population of humpback chub. Larval and young-of-year humpback chub currently experience high mortality and few survive to adulthood. Collection of young humpback chub for use in a refuge population provides a safeguard against future catastrophic loss with very low risk to the overall population. This activity will (1) refine the methods for transportation of wild-caught humpback chub to a refuge facility, (2) refine the methods for holding humpback chub in captivity, (3) establish a refuge to protect the genetic integrity of wild humpback chub from the Grand Canyon population, and (4) potentially provide a source of humpback chub for use in *ex situ* experiments.

Humpback Chub Population Augmentation Planning

This activity proposes to evaluate the efficacy and need for augmenting (stocking) humpback chub in Grand Canyon and developing an appropriate plan. Elements of the plan would include the completion of a genetics management plan, the identification of facilities to support an augmentation program (i.e., grow-out ponds), and the development of a stocking plan. Option A and A Variation call for the implementation of humpback chub population augmentation should the humpback chub population in Grand Canyon be reduced below a threshold, or trigger, that is yet to be determined. Option C focuses on planning and evaluation, with implementation to be determined based on the results of further study and the completion of the Comprehensive Plan for the Management and Conservation of Humpback Chub in Grand Canyon. Option B does not advocate the augmentation of the wild humpback chub population.

Mini Experiments

Mini experiments are short-term field experiments are intended to assist in providing answers to science questions related to the uncertainties of implementing an option.

Experimental Options Descriptions

This section provides descriptions of each of the four options under consideration. Hydrological modeling for all options was done under three different hydrologic conditions (see appendices A and B). Water temperature modeling was done for each of the four options based on the varying flow regimes, including the operation of two units on a proposed temperature control for water years 2012–16 (see appendix D). Table 2.1 provides the reader an overview of the flow and nonflow components of the four options considered by this assessment.

Table 2.1 Summary of flow and nonflow components of the four experimental options under consideration by the Glen Canyon Dam Adaptive Management Program. BASE operations (modified low fluctuating flow regime) are provided for comparison.

	Flow/Nonflow Treatment	BASE operations	Option A	Option A Variation	Option B	Option C
Flow	Increased daily flow fluctuations	No	Yes (increased by 50% to 66% in winter months and by 25% in summer months)	Yes (increased by 25% to 66% in all months except April and May)	No	Yes (increased by 50% to 66% in winter months)
Flow	Stable flows	No	No	No	Yes, (tests of 4, 8, and 12 months)	Yes, (September through October)
Flow	Beach/habitat-building flows	Possible, but only under hydrologic triggers	Yes, as tests under sediment input triggering	Yes, as tests under sediment input triggering	Yes, as tests under sediment input triggering	Yes, as tests under sediment input triggering
Flow	Alternative ramping rates	No	Yes (hourly downramping rate increased 100% in all months)	Yes (hourly downramping rate increased 100% in Apr–Oct and 167% in Nov–Mar)	No	Yes (hourly downramping rate increased by 100% in Nov–Jul only)
Nonflow	Temperature control device	No	Yes	Yes	Yes	Yes, 2 units assumed
Nonflow	Control of nonnative coldwater fish	No	Yes, as needed	Yes, as needed	Yes, as needed	Yes
Nonflow	Control of nonnative warmwater Fish	No	Yes, as needed, with R&D starting in 2007	Yes, as needed, with R&D starting in 2007	Yes, as needed, with R&D starting in 2007	Yes, with R&D starting 2007
Nonflow	Humpback chub disease/parasite research	No	Yes	Yes	Yes	Yes, with R&D starting 2008
Nonflow	HBC translocation	No	Yes	Yes	No	[1]Yes
Nonflow	Humpback chub refuge(s)	No	Yes	Yes	Possibly	[1]Yes
Nonflow	HBC population augmentation planning	No	Yes, Planning efforts toward implementation, as needed	Yes, Planning efforts and implementation	No	[1]Yes, planning phase
Flow and Nonflow	[2]Mini experiments	No	Yes	Possibly	Yes	[1]Yes
Experimental Design		Not applicable	Reverse Titration	Reverse Titration	Factorial	Forward Titration

NOTE: 1) For Option C: Ancillary projects not considered part of the main experiment; implementation decision includes consideration of confounding the main experiment. 2) Mini experiments are short-term field experiments that do not confound main experimental treatment effects. For Option C: These experiments are considered undefined concepts and would be incorporated if defined and not in conflict with the main experiment.

BASE Operations

Dam operations under the modified low fluctuating flow (MLFF) alternative, which was implemented by the 1996 Record of Decision (ROD), are presented to provide an understanding of current baseline conditions and operations at Glen Canyon Dam. Referred to as BASE operations throughout this evaluation, current Glen Canyon Dam operations provide the basis for relative resource response evaluations for the four experimental options considered.

The MLFF operating regime, or BASE operations, has been the dominant mode of Glen Canyon Dam operation since August 1991, when the interim operation criteria for Glen Canyon Dam were implemented. Given more than a decade of implementation and research, data associated with BASE operations have been accumulated relative to an array of resource performance measures. For these reasons, BASE operations provide a good baseline against which to compare the four experimental operations. BASE operations are generally treated as the “no action” alternative with respect to current GCDAMP experimental planning efforts.

Daily and Hourly Operations

Under normal BASE operations, the daily range in release rates is no more than 8,000 cubic feet per second (cfs) and the release peak fluctuation generally cannot exceed 25,000 cfs except during periods of high regional runoff or for experimental flows. The hourly rate at which flow changes can be made under current operations is 4,000 cfs/hr for upramp and 1,500 cfs/hr for downramp.

Beach/Habitat-Building Flows

Under BASE operations, beach/habitat-building flows might occur, but only under the hydrologic triggering criteria recommended by the GCDAMP in 1998. The trigger allows a BHBF if the January forecast for the April through July unregulated spring runoff into Lake Powell exceeds 13 MAF (about 140% of normal) when the January 1 storage is 21.5 MAF, or if any later monthly forecast for spring runoff into Lake Powell would require a powerplant monthly release greater than 1.5 MAF.

Option A

Daily and Hourly Operations

Option A would increase daily flow fluctuations compared to BASE operations for 5 of 12 months. These increases would be greatest in February with a 66% increase over BASE operations (10,000 vs. 6,000 cfs range), while December and January would increase 50% compared with BASE operations (12,000 vs. 8,000 cfs). There would also be a 25% increase in the flow variations compared with BASE operations in July and August (10,000 vs. 8,000 cfs). The flow variations would remain the same as BASE operations from September through November and from March through June.

Compared to BASE operations, the hourly upramp rate would remain unchanged at 4,000 cfs/hr under Option A, but the hourly downramp rate would be increased by 100% in all months of the year to 3,000 cfs/hr instead of 1,500 cfs/hr.

Beach/Habitat-Building Flows

BHBFs could be tested under the recently revised sediment trigger.

Additional Flow Experiments

Option A includes a number of other experiments that could be used to refine operations to perform specific tasks. Examples are nonnative fish management flows (e.g., summer stranding flows) to reduce the Glen Canyon Dam rainbow trout population, and tests of the effects of ramp rate on sediment transport. The specifics of the flows that would be tested in these experiments would be subject to reservoir levels, powerplant maintenance, economic considerations, and the adaptive management process, but could include:

1. **Summer Stranding Flows**: A stranding flow would maintain elevated flows (e.g., 15,000 cfs) for 2 or 3 days, followed by a very sharp drop in flows to a minimum level (i.e., 7,000 cfs). A stranding flow would be considered in the period of June, July, or August.

2. **Ponding Flows**: Ponding flows are those relatively high flows that produce slackwater areas in tributary mouths for the benefit of humpback chub.

3. **Electrical Power Production Experiments**: Power production experiments are short-term flow experiments intended to investigate alternative fluctuating flow parameters that might be compatible with downstream resource objectives.

Nonflow Components

1. **Temperature Control Device** (two units)

2. **Humpback Chub Augmentation**

3. **Humpback Chub Translocation** with translocation efforts focused on other priority tributaries, such as Bright Angel and Shinumo Creeks, plus other possible side streams that are suitable

4. **Mechanical Removal of Nonnative Fishes**, including both coldwater and warmwater nonnative species, as needed

Experimental Design

Option A seeks to implement as many treatments as possible as soon as feasible. In terms of design, Option A incorporates reverse titration, meaning that all treatments are implemented to achieve resource benefit until such time that a positive response in targeted resources is detected. That is, treatments may be systematically removed one at a time under continued monitoring until benefits are observed to diminish (learning by undoing). Although learning through this process may be more complicated, beneficial resource response is posited as a priority above establishing cause-effect science results.

Option A Variation

As its name implies, Option A Variation is a slightly modified version of Option A described above. The differences between the two experimental options are confined to the daily and hourly operations of Glen Canyon Dam designed to increase hydropower production during periods of high consumer demand. All other flow-based experiments and nonflow components are the same as Option A.

Daily and Hourly Operations

Option A Variation would increase daily flow fluctuations compared to BASE operations for 10 of 12 months. These increases would be greatest in February with a 66% increase over BASE operations (10,000 vs. 6,000 cfs range), while December and January would increase 50% compared with BASE operations (12,000 vs. 8,000 cfs). In September through November and in March through June, Option A Variation would increase daily flow fluctuations by 25% compared to BASE operations (8,000 vs. 6,000 cfs). A 25% increase would also occur in July and August (10,000 vs. 8,000 cfs). The release flows would remain unchanged relative to BASE operations only in April through May (6,000 cfs).

The hourly upramp rate would remain unchanged at 4,000 cfs/hr under Option A Variation compared to BASE operations. However, the hourly downramp rate would be increased by 100% compared to BASE operations in April through October (3,000 csf/hr compared to 1,500 cfs/hr) and by 167% in November through March (4,000 cfs/hr compared to 1,500 cfs/hr).

Beach/Habitat-Building Flows

Same as Option A.

Additional Flow Experiments

Same as Option A.

Nonflow Components

Same as Option A.

Experimental Design

Same as Option A.

Option B

Daily and Hourly Operations

Compared to BASE operations, Option B would gradually implement stable flows on a seasonally adjusted basis. Initially, Option B would implement fluctuating flows under current MLFF operations during periods when monthly release volumes are approximately equalized throughout the year. Over time, operations under this option would evolve to progressively increased implementation of seasonally stable flows. Table 2.2 summarizes the flows associated with Option B.

Table 2.2 Summary of flows associated with Option B for WY2007 to WY2013.

Dates	Flow	Monthly volume[1] (KAF)	Discharge (cfs)[2]	BHBF[3]
October 2006 to July 2007	A	700	ROD fluctuations (7,500–13,500)	No
August 2007 to November 2007	B	620	Steady (10,000)	No
December 2007 to July 2008	C	720	Constrained fluctuations (⦸ 4,000 daily)	One or more if triggered
August 2008 to November 2008	B	620	Steady (10,000)	No
December 2008 to July 2009	C	720	Constrained fluctuations (⦸ 4,000 daily)	One or more if triggered
August 2009 to March 2010	B	620	Steady (10,000)	No
April 2010 to July 2010	C	820	Constrained fluctuations (⦸ 4,000 daily)	One or more if triggered
August 2010 to March 2011	B	620	Steady (10,000)	No
April 2011 to July 2011	C	820	Constrained fluctuations (⦸ 4,000 daily)	One or more if triggered
August 2011 to March 2012	D	620	Steady (10,000)	No
April 2012		1,060	Steady (14,285)	One if triggered
May 2012		800	Steady (13,300)	No
June 2012		790	Steady (13,160)	No
July 2012 to March 2013	D	620	Steady (10,000)	No
April 2013		1,060	Steady (14,285)	One if triggered
May 2013		800	Steady (13,300)	No
June 2013		790	Steady (13,160)	No
July 2013 to September 2013		620	Steady (10,000)	No

[1]Monthly volume is based on the assumption of an 8.23 MAF release year. If more than 8.23 MAF will be released, then discharge will be adjusted proportionally so that monthly volumes remain approximately equal.
[2] Minor fluctuations are allowed for Automatic Generation Control purposes.
[3] BHBF are 41,000 to 45,000 for 1–3 days depending on research objectives.

For water year (WY) 2007 through WY 2013, Option B starts by equalizing monthly volumes with MLFF fluctuations (Flow A), and then combines steady and constrained fluctuating flows of different durations (Flows B and C) with seasonally adjusted steady flows (Flow D). Flows B, C, and D are replicated twice; the pattern of flows is described in table 2.4. For the purposes of the 10-year evaluation, Option B design returns to MLFF operations after WY 2013, while results of the experiment are being evaluated.

1. **Flow A (Equalized monthly volumes):** This pattern of flows tests the level of sediment accumulation under equalized monthly volumes and MLFF flows. Equalizing monthly volumes is intended to eliminate months with high sediment export rates, maintain a higher minimum flow throughout much of the year for increasing food base productivity, and retain daily MLFF fluctuations for load following. These flows are also aimed at creating conditions that would allow for some evaluation of the level of nearshore stability needed to restore mainstem rearing habitat for humpback chub. No BHBF will occur in conjunction with these flows.

2. **Flow B (Short-term steady flows):** This pattern of flows tests whether 4 or 8 months of steady flows are sufficient to provide humpback chub rearing habitat in the mainstem. The short-term steady flows begin in August when the highest numbers of young-of-year normally enter the mainstem. The steady flows are intended to provide a stable nearshore environment and an increase in water temperature (especially in backwaters). These flows are intended to maximize food base productivity, but be low enough to allow for sediment accumulation. No BHBF will occur in conjunction with these flows.

3. **Flow C (Constrained fluctuations):** Fluctuations are constrained to reduce sediment transport and enlarge the food base while still allowing some fluctuations to minimize impacts on hydropower generation. These flows are also intended to provide some indication of the level of nearshore stability needed to restore mainstem rearing habitat for humpback chub.

4. **Flow D (Seasonally adjusted steady flows):** These flows are designed to mimic, in part, a "natural" hydrograph. A BHBF will occur in April of 2012 and 2013 when it is likely to have the least impact on young-of-year humpback chub and other native fish. The BHBF is contingent on the accumulation of 1.0 million metric tons of tributary supplied sand in Marble Canyon. No "supply conditioning" fluctuating flows will occur.

Beach/Habitat-Building Flows

BHBFs would be implemented under a new sediment trigger. Under Option B, a BHBF would occur immediately once the sediment input trigger was met. However, a BHBF would not occur if there was a high risk of unacceptable negative impacts to young-of-year humpback chub residing in the mainstem (the criteria for this determination are currently undefined).

Experimentation with limited duration "supply conditioning" fluctuating flows could occur before the BHBF to test whether prescribed fluctuations would more evenly distribute the sediment input and thus conserve a larger proportion of the accumulated sediment. In addition, if a subsequent sediment input trigger was met during the same block of experimental flows, another BHBF test would immediately occur.

Nonflow Components

1. **Temperature Control Device**: Option B calls for the testing of a TCD with three or four units instead of two as currently proposed.

2. **Nonnative Species Control**: Option B includes the control of warmwater and coldwater nonnative species control, as needed, through WY 2016.

3. **Humpback Chub Translocation**: The translocation of humpback chub to other tributaries and the development and management of an off-site genetic refuge at Willow Beach (and/or other sites) could be considered under Option B pending a risk analysis and an evaluation of the options available to meet the perceived need.

Experimental Approach

Option B is intended to be a factorial approach with replication of stable and fluctuating flow elements. The approach was chosen to attempt the greatest degree of statistical rigor possible under large-scale field experimental conditions with as few confounding treatments as possible. Under the limited scope of the experiment considered in this evaluation, the treatments appear to be implemented as a forward titration for both temperature and habitat stability, but each annual stable flow period is replicated once during the sequence shown in table 2.2.

For experimentation starting in WY 2014, Option B includes a reassessment of the status and trends of resource conditions; a reassessment of the effects of flows, temperature, and nonnative control; and further testing (as needed) of both daily and seasonal flow variability, temperature (using a TCD), BHBFs, and nonnative control in a factorial design.

Option C

Daily and Hourly Operations

Compared to BASE operations, Option C relaxes the MLFF operating criteria in three months for daily fluctuations and nine months for ramping rates. Daily flow fluctuations would be increased from December through February compared to BASE operations, up from 8,000 cfs to 10,000 cfs or 12,000 cfs. The downramp rate would be increased from 1,500 cfs/hr to 3,000 cfs/hr during November through July. At a minimum, stable flows (up to 2,000 cfs daily fluctuations) would occur during September and October of each year. The intent of implementing small fluctuations in September and October is to provide the opportunity for experiments to begin defining “ecologically stable flows” that would allow some hydropower generation, but also limits destabilization of downstream nearshore native fish rearing habitats.

Option C would be implemented in three 5-year segments with the final year of each segment being used to evaluate, report, and determine whether to proceed as planned with the next experimental segment. The evaluation of experimental efforts would be accomplished through updating *The State of the Colorado River Ecosystem in Grand Canyon* report (SCORE, see Gloss and others, 2005) and knowledge assessment report, followed by tradeoff analysis in 2017 for use in planning the final 5-year segment (2017–21). Evaluation includes determination of whether resource triggers have been reached with subsequent expansion or contraction of factors (actions) determined to be impacting key resources.

Option C includes consistent hydrology from WY 2007 through WY 2016 to allow for an assessment of the effects of the TCD, which is scheduled to be operational between the end of the first segment and the beginning of the second in WY 2012. Table 2.3 summarizes the flows proposed for the first two 5-years segments proposed by Option C to test the effects of a TCD. Option C assumes the number of units to be two and that the device will be operated from May through October at full capacity.

The Option C approach includes a biological trigger for humpback chub to be determined by the GCMRC in coordination with other scientists and the Science Advisors. The trigger is to be based on numbers of humpback chub in the Grand Canyon population and the population trend of humpback chub, such that if the population declines to the trigger or below the trigger, the Bureau of Reclamation would immediately reinitiate consultation with U.S. Fish and Wildlife Service to determine a course of action to reverse the decline. One of the considerations of that consultation would be a determination of whether sufficient evidence exists to justify the expansion of the steady flow period from September and October into August. If the identified trigger is not realized during the first 10 years of the experiment, re-consultation would still occur prior to the initiation of the third segment in 2017 to determine what changes, if any, would be recommended for dam operations or other actions.

Beach/Habitat-Building Flows

BHBFs would be implemented under a new sediment trigger and with experimentation to determine whether conditioning flows preceding the BHBF can be used to purposefully transport and deposit fine sediment to desired locations downstream of the input.

Nonflow Components

Actions described in the humpback chub comprehensive plan will be considered for implementation based on completion of planning, attainment of technology threshold, and prioritization of budget; the potential for confounding of the experimental plan would be considered prior to implementation of each action (WY 2007–WY 2012). Actions deeded likely for implementation at this time include:

1. **Control of Nonnative Coldwater Fish:** Option C includes experimentation to determine relative efficacy of mainstream and tributary control, and evaluation of levels of control (WY 2007–WY 2012).

2. **Temperature Control Device:** Option C assumes the number of units to be two and that the device will be operated from May through October at full capacity.

3. **Control of Nonnative Warmwater Fish:** This activity is considered in Option C to be a component of the experimental plan and one for which treatments will be developed; however, it is not sufficiently developed for treatments to be assigned at this time. Under Option C, this project is initially treated as research and development project and is then integrated as a treatment. After WY 2012, Option C would place emphasis on warmwater nonnative fish control with elevation of release temperatures from selective withdrawal (WY 2012–WY 2021).

4. **Humpback Chub Disease/Parasite Research:** Option C considers this component a research and development activity, which likely will be conducted largely in laboratory settings during the first phase. Following the first 5-year phase of research and development, this activity could move to a field phase with well-defined treatments.

Ancillary Projects

Option C defines several experimental activities as ancillary projects, meaning that the individual activity is not a treatment in the experimental design, but one that would be analyzed for its confounding effect on the main experiment. The following activities are defined as ancillary projects:

1. **Humpback Chub Translocation:** Appropriate precautions would be taken to minimize confounding the main experiment with the effect of translocation (e.g., it may be possible to mark humpback chub emerging from tributaries so that their contribution to the mainstream population could be documented).

2. **Humpback Chub Refuge(s):** Removal of fish for this purpose and any repatriation would be accomplished under the guidelines and criteria identified in the humpback chub genetics management plan now being written.

3. **Humpback Chub Population Augmentation Planning:** Option C supports planning for augmentation with a first step being completion of a genetics management plan. If the humpback chub trigger described above is met, augmentation may be considered as part of a suite of actions necessary to reverse the decline of humpback chub in Grand Canyon.

Experimental Design

Implemented in three 5-year segments, Option C makes use of an experimental approach referred to as a forward titration. New treatments would be added incrementally to improve knowledge of the relationships among treatments and the resources affected by those treatments. For example, steady flows in September and October would be implemented in segment 1, a TCD in segment 2, and an August steady flow trigger in segment 3 under certain conditions. Option C calls for the services of a biostatistician to identify much more specifically how this design, which is not to be found in the statistical literature, would actually be implemented. None of the treatments proposed under Option C are considered “management actions,” as defined by TWG and AMWG for the long-term experimental plan, in recognition of the large uncertainty associated with the effects of most actions as identified in the 2005 knowledge assessment report. The evaluation of experimental efforts would be accomplished through updating SCORE and knowledge assessment reports every 5 years. Option C does not support mini experiments until they are better described and analyzed for their confounding effects on the main experiment.

Table 2.3 Monthly and daily flows associated with the first two 5-year segments proposed by Option C. Flows assume 8.23 million acre-feet annual release volume. Daily ranges and ramping rates in green are consistent with current Record of Decision (ROD) limitations and those in red indicate changes proposed by Option C.

	Monthly Volume (acre-feet)	Mean Daily Flow (cfs)	Max Monthly Flow (cfs)[1]	Min Monthly Flow (cfs)[2]	Daily Range (cfs)[3]	Upramp/ Downramp (cfs/hr)[3]	Within ROD Daily Fluctuation Limits? Yes/No	Within ROD Ramp Rates? Yes/No
Oct	500	8,100	9,100	7,100	**~2,000**	**4,000/1,500**	Yes	Yes
Nov	650	10,900	13,900	7,900	**6,000**	**4,000/3,000**	Yes	No
Dec	800	13,000	18,500	6,500	**12,000**	**4,000/3,000**	No	No
Jan	800	13,000	17,000	5,000	**12,000**	**4,000/3,000**	No	No
Feb	675	11,000	15,000	5,000	**10,000**	**4,000/3,000**	No	No
Mar	650	10,600	13,600	7,600	**6,000**	**4,000/3,000**	Yes	No
Apr	625	10,500	13,500	7,500	**6,000**	**4,000/3,000**	Yes	No
May	625	10,200	13,200	7,200	**6,000**	**4,000/3,000**	Yes	No
Jun	725	12,200	15,200	9,200	**6,000**	**4,000/3,000**	Yes	No
Jul	825	13,400	17,400	9,400	**8,000**	**4,000/3,000**	Yes	No
Aug[4]	800	13,000	17,000	9,000	**8,000**	**4,000/1,500**	Yes	Yes
Sep	555	9,300	10,300	8,300	**~2,000**	**4,000/1,500**	Yes	Yes
Annual (ac-ft X 1000)	8230							

[1] Beach/habitat-building flows of 41,000 cfs or more can occur January through April using combined Paria River-Little Colorado River input triggers proposed by the GCMRC; if dam releases can not be managed between attainment of triggers and BHBFs to conserve sediment adequately and not unduly impact other resources, earlier dates for BHBFs should be considered.

[2] Assumes "no drop" Sunday operation as has characteristically occurred under the ROD.

[3] Daily ranges and ramping rates in green are with ROD limitations; those in red are not.

[4] Note that in any given year if triggers are met with regard to humpback chub steady. August flows might be a condition through re-consultation with U.S. Fish and Wildlife Service.

Chapter 3: Estimated Effects of Proposed Flow Regimes on Downstream Resources

This chapter presents the estimated effects on downstream resources of the flow regimes proposed by the four experimental options under consideration by the Glen Canyon Dam Adaptive Management Program. Downstream resources considered by this assessment include physical resources (i.e., sediment, water temperature, and diurnal stage variation (DSV)), aquatic and fisheries resources, riparian biological resources, recreation and cultural resources, and hydropower. The estimates presented here rest primarily on information reported in the 2005 knowledge assessment workshop final report (Melis and others, 2006b; KAR), but additional scientific information has also been considered, when appropriate. As a result, the estimates are of a generalized nature and made with the admission that numerous uncertainties were identified during knowledge assessment workshop.

Since the knowledge assessment report was finalized, new models for simulating the effects of diurnal stage variation and downstream water temperature have been completed. The results generated by these models were used to inform the analysis presented in this chapter. All four options were evaluated over a range of simulated hydrologic conditions for the upper Colorado River Basin in order to estimate the influences of the four options under a more realistic range of variability (see appendix B, this report). Additionally, in modeling temperature responses, each of the experimental regimes is assumed to include operation of a TCD for 5 consecutive years starting in 2012 (see appendix D, this report).

Part 1: Physical Resources

Executive Summary

In this section, evaluations are presented regarding the estimated effects of the four experimental options compared to BASE operations (modified low fluctuating flow, or MLFF) for fine-sediment storage, downstream water temperatures, and diurnal stage variation. Evaluations were conducted by sediment researchers and physical scientists from the GCRMC science staff on the basis of information contained in the 2005 knowledge assessment report and peer-reviewed literature referenced in that report. Numerical modeling was only used to estimate the information provided for DSV and for evaluations of downstream, main channel water temperature associated with dam releases without a temperature control device (TCD) for the first 5 years of the 10-year evaluation (2007–11). Numerical simulations for a two-unit TCD were also conducted and evaluated and those results are reported in chapter 4 under nonflow treatments related to TCD operation in the last 5 years of the evaluation period (2012–16).

For fine-sediment storage, the primary difference between BASE operations and the experimental options is related to the triggering mechanism for beach/habitat-building flows (BHBF). Under BASE operations, BHBFs may only be triggered by hydrologic conditions leading to full lake levels in Lake Powell. In contrast, under all experimental options, BHBFs are triggered by above average tributary sediment inputs and mainstem retention. Because previous research and monitoring have shown that BHBFs must be linked to sediment-enriched conditions in order to have any chance of building eddy sandbars at all elevations, all experimental options are considered superior to BASE operations from the standpoint of fine-sediment storage. In addition, BHBFs may temporarily (over timescales of months) reduce the subsequent transport/export of sand by coarsening the sand on the surface of the channel bed and lower parts of sandbars. Comparison of the flow regimes of the individual options indicates that Option B has the greatest likelihood of increasing sandbar volume over the long term because it contains significant periods of steady flows and constrained fluctuations such that it will have the slowest rate of sandbar erosion during periods between BHBFs and the greatest potential to retain tributary inputs leading up to BHBFs. Options A, A Variation, and C are thought to rank substantially behind Option B for their likelihood of increasing sandbar volume over the long term because of high-volume fluctuating releases in summer and winter, which are known to be significantly net erosional. Option C ranks above Options A and A Variation because of it includes steady flows in September and October, which are more conducive to retention of tributary inputs that typically occur during this time of year, and owing to lower fluctuations that likely reduce sandbar erosion during these months.

For downstream water temperatures in the main channel, it is known that lower release volumes promote downstream warming because of increased residence time, particularly in the late spring, summer, and early fall months when air temperatures are significantly warmer than release water temperatures. Based on numerical modeling results, the differences in monthly volumes between the options are not large enough to result in significant differences in mainstem temperatures. That is, the simulated differences in mainstem temperatures between the options are within the uncertainty of the model such that it cannot be concluded that there are significant differences between the options.

It is also known that more stable flows result in warmer nearshore areas (particularly backwaters) during the late spring, summer, and early fall months when air temperatures are significantly warmer than release water temperatures, which results presumably because mixing with the colder mainstem is inhibited by stable flows. Because of this effect, Option B is expected to have warmer nearshore temperatures than the other options during much of the year because of the prevalence of steady flows and constrained fluctuating flows. Option C ranks second owing to stable flows in September and October. Because Options A and A Variation contain no stable flows, they rank behind Options B and C. However, because daily ranges are expanded in months where the daily ranges are relatively high under BASE operations as well, Options A and A Variation are not expected to result in significantly different nearshore water temperature from BASE operations.

Diurnal stage variation is defined as the difference in stage between the daily low flow and the daily peak flow. Estimates of diurnal stage variation using a step-backwater numerical model indicate that Option B would result in decreases in stage variation compared to BASE operations of about 3 ft on average for steady flow months, and about 1.5 ft on average during constrained fluctuating months. Option C steady flow months (October and November) would result in similar decreases (~ 3 ft) compared to BASE operations. Increased fluctuations in winter months proposed by Option C would lead to an increased diurnal stage variation of about 2 ft on average compared to BASE operations. Options A and A Variation would lead to similar increased variation in the winter as well as approximately 1 ft increased variation in the summer expanded daily range months. These estimates are based on averages over the entire river corridor (from Glen Canyon Dam to Diamond Creek, river miles -15 to 226) and for minimum release hydrology. For the first 10 miles downstream from the Little Colorado River (LCR), the DSV is typically around 1 ft less than this average because of local geometry.

Fine-Sediment Storage

(all flows up to 45,000 cfs)

Options

Options A and A Variation: Because Option A increases the hourly downramping rate by 100% compared to BASE operations, the resulting higher sand-export rates associated with expanded fluctuations or prolonged periods of peaking operations between BHBFs will most likely have the influence of accelerating erosion of sandbars. This is also estimated to be the case for Option A Variation because the DSV is increased by 25% to 66%, along with a 100% to 167% increase in the hourly downramping rate relative to BASE operations.

Option B: This option contains a combination of stable flows and fluctuating flows that are more constrained that those under BASE operations. As a result, annual sand inputs from tributaries are likely to be more effectively conserved before and after BHBF tests. Sandbars built during sand-enriched BHBFs are also likely to erode at slower rates between BHBF tests. During consecutive years of 8.23 million acre-feet (MAF) releases, tributary sediment inputs are likely to accumulate over multiyear periods compared with BASE operations. Hence, BHBF tests that occur during protracted periods of minimal release hydrology when annual sediment inputs are likely to accumulate may result in more robust sandbar restoration responses than under BASE operations or other options having less constrained diurnal fluctuations.

Option C: The stable flows that occur in September and October of each year in this option may allow for multiple tributary sediment inputs to accumulate in late summer and fall more than would occur under fluctuating flows for similar monthly volumes under BASE operations. The fall flow stability would be a larger influence in sediment accumulation before BHBF tests in fall through spring as hydrology becomes wetter and September and October monthly release volumes increase. This is particularly important for Paria River sediment inputs that occur mostly in late summer and fall. Summer fluctuations are similar to BASE operations, but sand-transport data collected under MLFF operations indicate that those summer operations result in elevated sand export, even under minimal annual release volumes of 8.23 MAF. Relaxed fluctuations in winter months are estimated to increase erosion rates of sandbars that might be formed during fall or winter BHBF tests. Such winter fluctuations may elevate sand export downstream prior to spring BHBF tests, but the downstream transport of new tributary sand could also effectively distribute new sediment throughout the ecosystem and result in more consistent patterns of sandbar deposition, compared with the results measured in the 2004 BHBF test.

Fine-Sediment Summary

Besides differences in how BHBF responses may vary under the four options, there are also substantial differences expected between Options A, A Variation, B, or C in terms of sand export during normal operations (i.e., non-BHBF), particularly during lower dam release years (i.e., ~8.23 MAF). Because stable flows transport less sand than fluctuating flows, Option B will transport less sand than Option C, and Option C will transport less sand than Options A or A Variation. Existing data indicate that the fluctuating and stable flows proposed in Option B tend to accumulate tributary sand in the mainstem, while the winter and summer fluctuations of Options A, A Variation, and C tend to be net erosional. As a result, during minimum release years with sediment-triggered BHBF tests, Option B would be the most likely to increase sandbar area and volume (over decades), Option C would be the second most likely, and Options A and A Variation, the third and fourth most likely, respectively. It is not yet possible to assign probabilities for increasing sandbar area and volume to each option. The basic differences between the options are expected to hold during wet hydrologic conditions, but the likelihood of increasing sandbar area and volume would decrease because sand export increases with higher flow releases. Because under wet hydrologic conditions the sand budget for Marble and Grand Canyons is predicted to be negative for all four options, the details of the hydrographs may be less important, except that deposition at higher elevations during frequent BHBFs may offset erosion occurring during the rest of the year. Also during wet years (when the reservoir is full) it may be desirable to test higher BHBFs under enriched conditions to evaluate whether depositing sand at higher elevations than is possible during 45,000 cfs BHBFs results in a more effective method for maintaining larger sandbars.

In conclusion, the sediment conservation strategy of a BHBF consists essentially of three fluvial process responses: (1) transfer inputs of tributary-supplied sand from the channel of the Colorado River to where it is needed (on the parts of the sandbars that will be emergent at typical dam releases) and will persist for longer timescales than on the channel bed, (2) temporarily (over timescales of months) reduce the subsequent transport/export of sand by coarsening the sand on the surface of the channel bed and lower parts of sandbars, and (3) maintain the increased sandbar size and maintain sediment in upstream reaches of the river until a subsequent BHBF can be released from the dam. Releasing more-frequent BHBFs could benefit the sediment budget by enlarging sandbars and suppressing subsequent sand transport by coarsening the bed of the river. The next section provides additional insight on the proposed strategy for scientifically evaluating the BHBF concept so that managers can better identify management options that are likely to achieve identified resource objectives for sand resources below Glen Canyon Dam.

Strategy for BHBF Tests Following Tributary Sand Enrichment

The most important science question identified by sediment scientists at the 2005 knowledge assessment workshop was: *Is there a "flow only" operation that will restore and maintain sandbar habitats over decadal timescales?*

One significant outcome of the knowledge assessment workshop was that the information and models are not yet available to answer this question, despite the great deal of learning that has occurred regarding sediment transport, sandbars, and dam operations in this system. The question can only be answered through a program of rigorous experimentation that utilizes BHBF tests whenever triggered by large amounts of new sediment being supplied to the system by tributaries downstream from Glen Canyon Dam. The rationale for conducting BHBFs under sediment-enriched conditions has been documented in several peer-reviewed outlets, including Webb and others (1999), Topping and others (2000a), Rubin and Topping (2001), Rubin and others (2002), Schmidt and others (2004), Wright and others (2005), Hazel and others (2006), and Topping and others (2006). The flow chart below was developed at the knowledge assessment workshop to guide experimentation toward answering the sediment science question.

In this sediment resource assessment, we consider eddy sandbar deposits as a whole (i.e., we do not differentiate strictly between different elevation ranges). This approach has been taken primarily for two reasons. First, because of the considerable uncertainty regarding system response to operations over decadal time scales, we have attempted to simplify the assessment as much as possible. Second, existing data (and general theory) indicate that sand deposits in different elevation ranges are not independent from each other, and that the system tends to erode from the bottom up. Thus, if a given operation is expected to be depositional (or erosional) in lower parts of eddies, then it's likely to be depositional (or erosional) at high elevation as well (in the long term, with BHBFs). That said, in some instances we discuss eddies at "lower" elevation versus "higher" elevation; in these cases, we are referring to roughly below and above powerplant capacity, respectively.

Can sand resources be sustained by operational treatments?

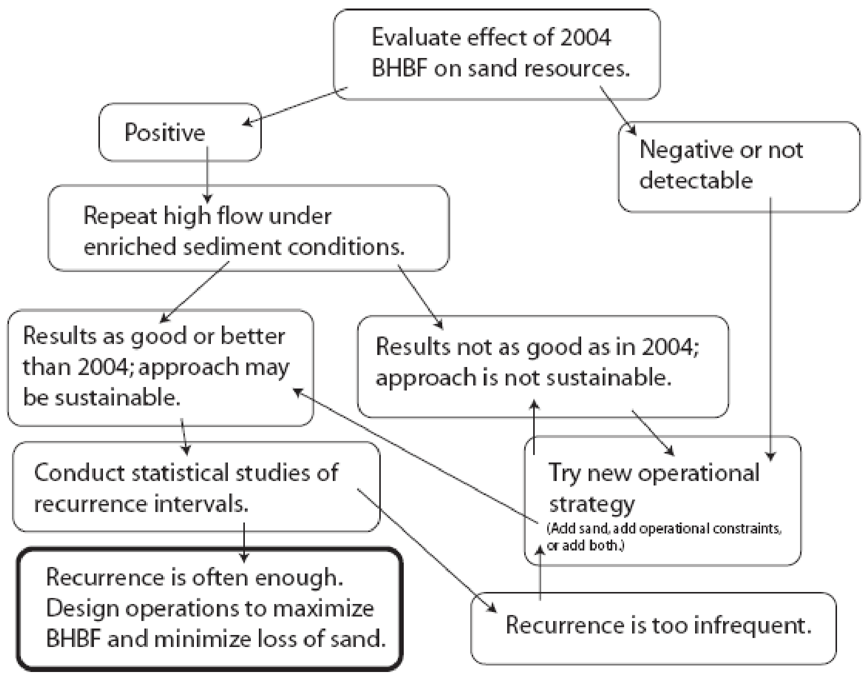


Figure 3.1. Flow chart developed at the knowledge assessment workshop to guide experimentation toward answering the sediment science question.

For sand resources, the greatest difference between BASE operations and the four experimental options is that BHBF tests will occur based on sediment triggers under Options A, A Variation, B, and C, and only under hydrologic triggers under BASE operations (relatively high storage conditions in Lake Powell combined with forecasted April through July runoff from the upper Colorado River Basin of 30% or greater than average). Under BASE operations, with no chance of a BHBF until Lake Powell is full and no correlation between conducting a BHBF and the degree of sediment enrichment, the amount of sand in all three elevations is expected to decrease over decadal time scales because (1) during the powerplant releases until the reservoir fills, sand will continue to be eroded from sandbars at all elevations; (2) during the first BHBF (not tied to the degree of sediment enrichment), sand may be deposited at higher elevations (above 25,000 cfs) but eroded from the lower elevations of the sandbars (like during the 1996 experiment); and (3) following this BHBF, the lower elevations of the sandbars that were scoured during the BHBF would not be expected to fully recover under normal powerplant releases (as observed after the 1996 experiment). Therefore, over decades, BASE operations will probably result in there being less sand at all elevations.

In contrast, Options A, A Variation, B, and C all include the possibility of BHBF tests when triggered by large new inputs of tributary sand. As observed during the 2004 experiment, BHBFs conducted under enriched conditions may increase the amount of sand in sandbars at all elevations. During the intervening powerplant releases, sand will be eroded from the lowest elevations in the sandbars first, but this erosion could be offset by new deposition during the next BHBF (if frequent enough). During the 2004 experiment, we learned that more sand than was available during that test would be required to achieve increases in the total area and volume of eddy sandbars throughout all of Marble and Grand Canyons, not just in the upper 40 miles of Marble Canyon. Given that the sand budget in Marble and Grand Canyons is likely to be negative under all moderate and higher powerplant releases, the only possible "flow only" option to evaluate is whether frequent BHBFs conducted under enriched conditions can ultimately offset the erosion of sandbars occurring during the intervening powerplant releases.

There are also substantial differences expected between Options A, A Variation, B, and C in terms of sand export during normal operations (i.e., non-BHBF), particularly during lower dam release years (i.e., ~8.23 MAF). Because stable flows transport less sand than fluctuating flows, Option B will transport less sand than Option C, and Option C will transport less sand than Options A or A Variation. Existing data collected during consecutive 8.23 MAF annual releases under the MLFF regime (2000–5) indicate that the fluctuating and stable flows as proposed in Option B and associated with minimal annual releases, tend to accumulate tributary sand in the mainstem, while the winter and summer fluctuations of Options A, A Variation, and C tend to be net erosional. It is uncertain whether the constrained fluctuations and stable flows under Option B during most probable or wet hydrologic conditions would result in accumulation of tributary sand inputs. Thus, during minimum release years with sediment-triggered BHBF tests, Option B would be the most likely to increase sandbar area and volume (over decades), Option C would be the second most likely, and Options A and A Variation the third and fourth most likely. It is not yet possible to assign probabilities for increasing sandbar area and volume to each option. During wet hydrologic conditions, the basic differences between the options are expected to hold, but the likelihood of increasing sandbar area and volume would decrease because sand export increases with higher flow releases. Also during wet years (when the reservoir is full) it may be desirable to test higher BHBFs under enriched conditions to evaluate whether depositing sand at higher elevations than is possible during 45,000 cfs BHBFs results in a more effective method for maintaining larger sandbars.

It is not yet possible to predict whether there is a "flow only" operation that can restore and maintain sandbar habitats over decadal time scales. Long-term experimentation (combined with monitoring and further numerical model development) is required to answer this question. Of the experimental options currently under consideration, all options with sediment-triggered BHBFs (A, A Variation, B, and C) are preferable to BASE operations, which incorporate only hydro-triggered BHBFs. Of the four options with sediment triggers, Option B has the greatest likelihood of increasing sandbar area and volume over decades because of the prevalence of steady flows and moderate fluctuations; Option C has a slightly greater likelihood than Options A and A Variation owing to fall steady flows. Though it is not possible to assign expected probabilities of increasing sandbar area and volume to each option, it is likely that Options A, A Variation, and C are more similar to each other than they are to Option B. During wet hydrologic conditions, the differences between the options become less important because the likelihood for increasing sandbar area and volume decreases as the total flow release from the dam increases (i.e. export is more likely to exceed tributary inputs during wet years, regardless of the dam operation).

The benefits of BHBFs to the Grand Canyon native fish community remain undocumented. Published studies on humpback chub use of Little Colorado River habitats indicates that shallow, near-shore habitats are heavily used by young of the year and juvenile humpback chub (Stone and Gorman, 2006). If additional sediment delivered to the mainstem by a BHBF increased the frequency and/or extent of these habitats in the mainstem Colorado River, then BHBFs might be expected to support survival of these important life history stages. Recently completed analysis indicates that the Grand Canyon humpback chub population has stabilized, albeit below historic levels (Melis and others, 2006a). A secure humpback chub population would allow for increasing the amount of effort applied to conservation and protection of other resources, especially the retention of sediment in the system. More sediment in the Grand Canyon aquatic ecosystem may benefit humpback chub, as well as other resource areas, such as beaches for recreation, especially if shallow, slack water habitats are enhanced, as these have been shown to be of benefit to young humpback chub (Stone and Gorman, 2006).

Downstream Water Temperatures: Main Channel and Nearshore (without temperature control device)

Assessing Water Temperature for BASE Operations versus Experimental Options

The objective of this experimental options assessment is to evaluate the four experimental flow options with respect to desired downstream water temperature regimes thought to be most beneficial to biological resources. To conduct the evaluations, we rely on our current understanding of the physical processes controlling downstream temperature patterns as described in the final 2005 knowledge assessment document (see 2005 Knowledge Assessment of the Effects of Glen Canyon Dam on the Colorado River Ecosystem: an experimental planning support document; Melis and others, 2006b), as well as a recently developed mainstem water temperature model to simulate the fate of flow releases stipulated in the four experimental flow options. These simulations provide a quantitative comparison of the effects of variable flow regimes and release temperatures on the fate of the mainstem thermal regime. Comparable numerical modeling capabilities are not currently available for nearshore environments (scheduled for development in FY 2007). Therefore, the effects of the experimental options are evaluated using a numerical model for the main channel, and using current state-of-knowledge for nearshore environments.

Main channel: The detailed methods and results for the mainstem modeling component are contained in appendix D. The basic conclusion of the modeling is that the differences between the options are relatively small, and in most cases are probably within the uncertainty of the model calculations (~ 0.5–1ºC depending on location; see appendix D). Example model results are shown below.

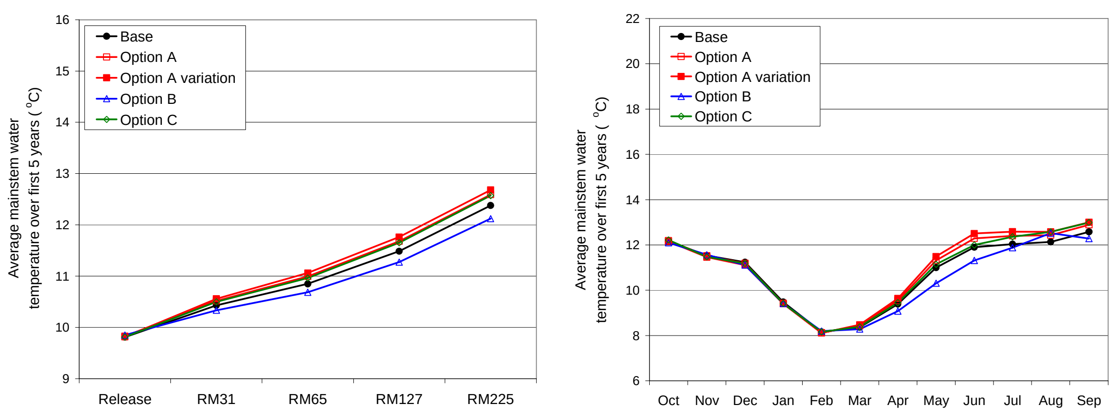


Figure 3.2 Average mainstem water temperatures at five locations (left) and average monthly temperatures at river mile 65 (right) for the first 5 years of the simulation period (i.e. period without temperature control device) for most probable hydrologic scenario.

In April through June, when Option B contains higher volume releases than the other options, the greatest difference between options in terms of monthly average temperatures (~ 1ºC) occurs. The higher volume releases lead to higher flow velocity in the mainstem, which decreases the amount of time available for warming as the water moves downstream leading to slightly cooler mainstem temperatures. These differences, however, should be interpreted with caution given how close they are to the model uncertainty, as well as because the model is still considered to be in the final stages of testing and validation. Indeed, some of the results generated by this study have revealed model components that need further investigation (in particular, the relationship between discharge and velocity during steady and fluctuating flows). Thus, the most appropriate interpretation of the modeling results is that there are not significant differences between the experimental options with respect to mainstem water temperatures. Here, significant is defined as being resolvable by the model given the uncertainty in the calculations. A further outcome of the modeling is related to the effects of hydrology on mainstem water temperatures. The reader should refer to appendix D for details. The effects of the TCD are considered separately in chapter 4.

Nearshore Environments: It is generally known that steady flows promote more warming than fluctuating flows in nearshore areas, particularly backwaters. This is thought to be a result of less water exchange with the (typically colder) mainstem during stable flows, such that backwater temperatures can more closely equilibrate with atmospheric conditions. During fluctuating flows, backwaters may flush more quickly and the sandbars that isolate the backwaters may even be overtopped on a daily basis resulting in complete volume exchange with the mainstem. The exact relation between daily range in flow and amount of backwater warming is as yet undefined owing to a lack of data and numerical models (currently under development); also, this relation is expected to be highly variable and site-specific.

Several studies have attempted to characterize the differences between mainstem and nearshore water temperatures, but all have been faced with similar obstacles in adequately quantifying these differences (e.g. Hoffnagle, 1996; Trammell and others, 2002; Korman and others, 2005a; Vernieu and others, 2005, Kaplinski, 2006). Confounding factors, such as highly variable Glen Canyon Dam release temperatures, ambient air temperatures, and release volumes, have made analysis and subsequent interpretation of the data complex. Despite these complexities, most of the data indicate that, in general, backwater environments have the potential to warm substantially compared to associated mainstem locations. Korman and others (2005a) found that, on average, maximum backwater temperatures at three locations during the fall of 2005 were 2–3°C warmer than the mainstem with instantaneous differences of up to 7°C. Other studies have found similar ranges of differences between the mainstem and nearshore environments with maximum differences occasionally exceeding 7°C in specific locations.

Common sense dictates that nearshore temperatures are directly linked to mainstem temperatures such that, in most instances, warmer mainstem temperatures will result in warmer nearshore temperatures. Finally, it is important to note that nearshore habitats are dynamic entities whose abundance and persistence are complicated functions of discharge, stage, and channel geometry and that further monitoring and modeling work is needed to expand our current knowledge of the complex linkages between the mainstem and the nearshore thermal environments of the Colorado River.

Options

Option A: Main channel temperatures are not expected to be significantly different from BASE operations or other options. Increased daily range in July and August reduces the potential for warming of nearshore areas during this time of year because increased fluctuations promote exchange of (typically colder) mainstem water with backwaters. However, the differences between this option and BASE operations will probably be small since relatively large fluctuations occur during these months under BASE operations.

Option A Variation: Same as Option A except for the slightly reduced potential for nearshore warming is extended to June, September, and October because of expanded daily ranges during these months.

Option B: Main channel temperatures are not expected to be significantly different from BASE operations or other options. This option, however, contains substantially more periods of stable flows and would thus be expected to result in generally warmer nearshore areas than BASE operations and other options. Constrained fluctuations occurring in non-stable flow months may also result in warmer nearshore temperatures, particularly in the spring and summer months.

Option C: Main channel temperatures are not expected to be significantly different from BASE operations or other options. Steady flows proposed for September and October are expected to promote warming in nearshore environments. More warming is expected in September than October when little downstream warming typically occurs because release water temperatures are similar to air temperatures. Increased daily range in the winter months is not expected to have a large effect because very little warming, and sometimes slight downstream cooling, occurs during this time of year.

Downstream Water Temperature Summary

Numerical modeling of main channel water temperatures indicates that only small differences are expected to result from differences in flow releases between the options. Because these differences are in the same range as the model uncertainty, it cannot be concluded that there are differences between the options with respect to mainstem temperatures. Because it is generally thought that wider variation in daily fluctuating flows will tend to reduce warming in nearshore environments owing to increased exchange between colder mainstem water and warmer water in nearshore environments (such as backwaters), Option B ranks first in terms of nearshore temperatures because it has many more periods of steady flows than Options A, A Variation, and C. Option C ranks second owing to stable flows in September and October. Option A and Option A Variation rank third and fourth, respectively, and are not expected to result in significant differences in nearshore water temperatures compared to BASE operations.

Estimates of Diurnal Stage Variations by Geomorphic Reach

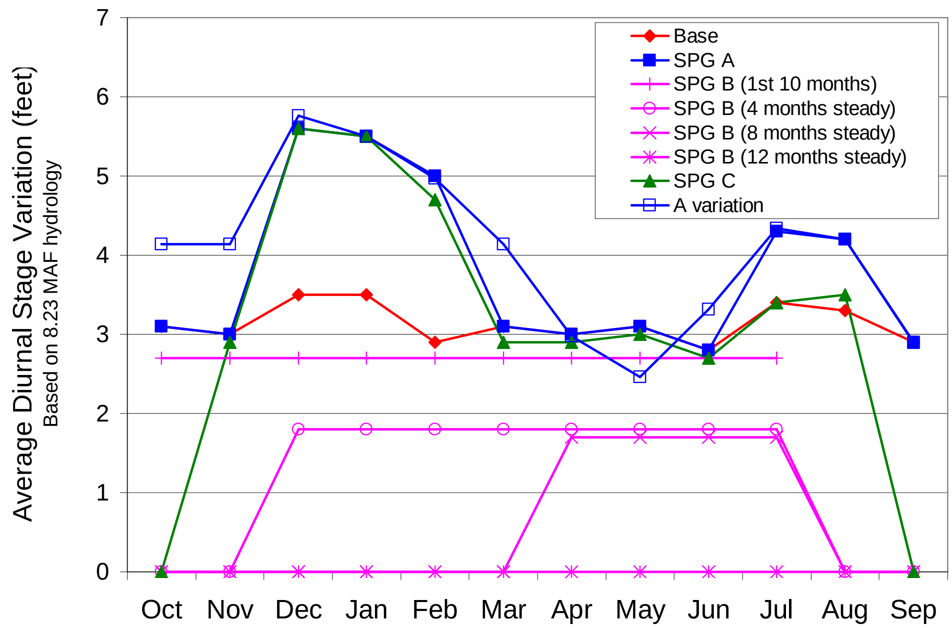
Diurnal stage variation is defined as the difference in stage between the daily low flow and the daily peak flow. To estimate DSV for each experimental option on a monthly basis, water surface (i.e., stage) profiles were computed for 1,000 cfs increments using the recently developed HEC-RAS model for the Colorado River between Glen Canyon Dam and Diamond Creek (Magirl, in press). The HEC-RAS model computes stage profiles for steady flow using more than 2,000 cross sections based on LiDAR-derived topography above 8,000 cfs. Model calibration was accomplished by constructing synthetic trapezoidal bathymetry at the LiDAR cross sections; the bathymetry was adjusted to achieve less than 65 cm differences between the model and the measured water surface profile at 8,000 cfs. Model validation was completed by comparing model predictions with measured stage-discharge relationships at 18 Northern Arizona University long-term sandbar monitoring sites. The average difference between the model and measurements at the 18 sites was about 75 cm for flows below powerplant capacity.

The DSV was evaluated by computing the stage profile associated with the peak and low flows for each option for each month based on typical weekday operations (table 3.1). Subtracting one profile from the other results in a DSV for each cross section in the model. For simplified presentation of the results and comparison of the options, the average DSV was computed for two reaches: (1) the entire model domain (from the dam to Diamond Creek) and (2) the first 10 miles downstream from the LCR (i.e., known humpback chub habitat). The DSV deviates longitudinally from the two reach-based averages depending on specific reach geometry. The results of these calculations, averaged over the entire model domain, for minimum release years of 8.23 MAF, are plotted below (fig. 3.3) along with a table (table 3.1) summarizing the differences between each experimental option and BASE operations, followed by a summary of the differences for the reach downstream from LCR.

Table 3.1: Comparison of average diurnal stage variation for each experimental option relative to BASE operations. Relative comparisons are segregated by season for presentation purposes (see fig. 3.3 for monthly values).

Option A (relative to BASE)	No difference in fall (Sep–Nov) and spring (Mar–Jun)
	Increased in winter (Dec–Feb) by about 2 ft on average
	Increased in summer (Jul–Aug) by about 1 ft on average
Option A Variation (relative to BASE)	Increased by about 1 ft on average in Oct–Nov, Mar, and Jul–Aug
	Increased in winter (Dec–Feb) by about 2 ft on average
	Increased by about 0.5 ft in Jun; decreased by about 0.6 ft in May
Option B (relative to BASE)	For the first 10 months (block 1), reduced by about 0.5 ft on average
	For steady flow months, reduced to ~ 0 from about 3–3.5 ft on average
	For fluctuating months (except 1st 10), reduced by about 1.5 ft on average
Option C (relative to BASE)	Reduced during Sep–Oct steady flows, from about 3 ft to ~ 0
	Increased in winter (Dec–Feb) by about 2 ft on average
	Very slight difference (~ 0.1 ft) in Nov, spring and summer (Mar–Aug)

Figure 3.3: Average diurnal stage variation by month for BASE operations and the four experimental options for an 8.23 million acre-feet (MAF) annual release volume, or minimum release hydrology.



Options

Option A: Daily Stage Variation associated with experimental operations in this option is similar to BASE operations during fall and spring months each year. However, in winter months, the DSV increases by an average of about 2 ft throughout the river corridor. In summer months, the DSV also increases, but only by about 1 ft on average throughout the river corridor.

Option A Variation: This is the only option that expands the daily range in October, November, and March, resulting in about 1 ft increased DSV as compared to BASE operations. The maximum daily range is expanded in June and September as well, but not fully implemented during 8.23 MAF years. Increased DSV in December through February and July and August are the same as Option A.

Option B: This option results in decreased DSV when compared to BASE operations because of the stable flow elements in dam operations. During initial fluctuating flow tests under equalized monthly release volumes associated with 8.23 million acre-feet annual releases, there is a reduction in DSV of about 0.5 ft on average. With the onset of stable flows, DSV is reduced on average by about 3–3.5 ft. During fluctuating flows that occur following the initial test of equalized monthly release volumes, DSV is reduced by about 1.5 ft from BASE operations, on average.

Option C: Experimental flows in this option reduce DSV by about 3 ft on average throughout the river corridor in fall stable flow months, but the DSV is increased on average by about 2 ft in winter months when experimental fluctuations occur. During late fall, spring, and throughout summer, there is little to no change in daily stage ranges when compared to BASE operations.

Summary of Reach Downstream from LCR

The diurnal stage variations over the first 10 miles downstream from the LCR are generally less than those averaged over the entire domain because of local reach geometry. For BASE operations, the DSV is about 0.6–0.7 ft less for the reach downstream from the LCR for all months. For Options A, A Variation, and C, the difference in DSV is greatest in the winter months when the daily range is expanded. In December through February, the DSV in the reach downstream from the LCR is 1.0–1.6 ft less than the average over the entire reach from the dam to Diamond Creek. In other months, the differences for Option C are similar to BASE operations. Options A and A Variation also have expanded daily ranges in July and August; during these months, the DSV is about 0.8 ft less in the reach downstream from the LCR. For Option B, DSV during fluctuating months is 0.3–0.5 ft less for the reach downstream from the LCR as compared to the entire model domain.

Diurnal Stage Variation Summary

Option B is expected to result in generally less diurnal variation in stage throughout the river corridor compared to the BASE operations as well as Options A, A Variation, and C because of the prevalence of stable flows and constrained fluctuating flows. Options A and A Variation would expand the diurnal stage variation in the summer and winter months. Option A Variation also expands the maximum daily range in September through November, March, and June. Option C would expand the diurnal stage variation in winter months and reduce the variation in stable flow months of September and October.

During years when annual release volumes exceed 8.23 MAF, diurnal stage variations are expected, in general, to be less than for minimum hydrology. This is because (1) high steady flows may occur during summer months of high release years, and (2) when monthly volumes are increased, daily lows and peaks are increased while holding the daily range constant, and diurnal stage variations tend be slightly less for higher flows (with the same daily range) owing to canyon geometry (i.e., stage increases less rapidly with flow at higher flows).

Part 2. Aquatic and Fisheries Resources

Executive Summary

Managers of Grand Canyon aquatic organisms need to determine the impacts of various dam operations on these organisms in the Colorado River and its tributaries to support management decision making. While the available literature allows for some informed predictions regarding how these organisms will respond to various flow options, the knowledge assessment workshop concluded with many areas of uncertainty that remain to be investigated.

The available literature definitively concludes that cold water is limiting to primary and invertebrate productivity (Benke and others, 1988; Huryn and Wallace, 2000), native fish reproduction (Hamman, 1982; Valdez and Ryel, 1995; Clarkson and Childs, 2000), and native fish swimming ability (Ward and others, 2002). Current temperatures of water released from Glen Canyon Dam are below optimum not only for native fishes but also for the population of rainbow trout introduced there. Warming dam release water temperatures would be expected to increase the growth and survival of aquatic organisms, including native and nonnative fishes. Because none of the four flow options considered results in measurably warmer water temperatures, the installation and operation of a temperature control device, continued natural warming of release temperatures because of drought, or both will be necessary if natural resource managers expect to realize any benefits to aquatic organisms from increased water temperatures. Reduced DSV can be expected to increase habitat stability, which allows for more permanently wetted area that can support algae and invertebrates. Option B proposes the most constrained flow fluctuations and, therefore, could be expected to increase habitat stability more than options A, A Variation, or C. Because there is reduced productivity in the winter, increased flow fluctuations would not be expected to have much measurable effect on the aquatic food base at this time of year. Of the aquatic organisms evaluated, rainbow trout would be most likely to suffer from increased winter fluctuations proposed in Options A, A Variation, and C because of habitat destabilization that can disrupt reproductive activities (Korman and others, 2005b).

A number of large-scale experimental treatments have been implemented in Grand Canyon since 2000, including low summer steady flows (2000), beach/habitat-building flows (2004), and removal of rainbow trout and other nonnative fishes (2003–6). All of these treatments were implemented with the intention of benefiting multiple Grand Canyon resources, including aquatic organisms. Ecosystems generally take months to years to completely respond to such experiments and so the impacts of these treatments on the Colorado River ecosystem are still being assessed, especially regarding their effects on the food base and native fishes. During this time period, the population size of a nonnative snail has increased dramatically, further confounding analysis. While the dam operation options being considered may all be evaluated for their degree and direction of impact on the aquatic ecosystem, all except for BASE operations will introduce some confounding in the analysis of the impacts of previous treatments that will take additional years to completely resolve. The assessments presented below were largely based on the conclusions of the 2005 GCMRC knowledge assessment report (Melis and others, 2006b), unless otherwise stated.

Aquatic Food Base: Glen Canyon and Grand Canyon

While the response of the food base (primary and secondary producers in the aquatic food web) to some dam operations could be determined from information available to the knowledge assessment workshop participants, the food base response to factors could not be predicted with certainty (Melis and others, 2006b). A strategic science question developed by the participants and presented below reflects this uncertainty. A multiyear food base monitoring project focused on tracking the fate of carbon in the Colorado River Ecosystem has been initiated and will provide information regarding the impacts of dam operations on this important resource.

Science Question

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

Conducting analysis of the aquatic food base under the BASE operations will provide some information to answer this question. Implementation of one of the flow options being considered would provide comparative data for additional assessment, though implementation of any of the flow options will complicate efforts to determine specific cause and effect relationships.

Options

BASE Operations: Because the BASE operations are a continuation of the modified low fluctuating flow regime, they will not result in any changes to the aquatic food base. This flow scenario represents the best option for learning about the aquatic food base because the new food base research project has collected 1 year of data with this operational regimen in place.

Option A: This option is likely to reduce the productivity of the aquatic food base relative to the BASE operations because of lower daily low flows and a greater DSV. Daily low flows will be lower during the months of December through February and July and August and this will decrease the area of permanently wetted bottom available for algae and invertebrates (Melis and others, 2006b). Increasing the DSV during the same months will negatively affect the aquatic food base in Grand Canyon, but it is unclear how this will affect the food base in Glen Canyon (Melis and others, 2006b). The effects of a BHBF on the aquatic food base are unclear (Melis and others, 2006b). Changes in downramp rates associated with this option are unlikely to affect the aquatic food base.

Option A Variation: The effects of this option relative to BASE operations are expected to be the same as Option A. Changes in ramping rates are unlikely to affect the aquatic food base.

Option B: This option is likely to increase the productivity of the aquatic food base relative to BASE operations because of increases in daily low flows. Blinn and others (1995) estimated that increasing the daily low flow from 5,000 cfs to 8,000 cfs would increase the amount of *Cladophora* energy present in the Glen Canyon reach from ~12 billion joules to ~18 billion joules, a 50% increase. Daily low flows under this option are higher than BASE operations in 7 of the 10 months for Block 1, 22 of 24 months for Block 2, 22 of 24 months for Block 3, and 23 of 26 months for Block 4. Although the steady flows or lower fluctuations associated with this option may reduce rates of invertebrate drift, they are likely to be offset by substantial increases in invertebrate biomass associated with increases in the daily low flow. The effects of a BHBF on the aquatic food base are unclear (Melis and others, 2006b).

Option C: This option is likely to increase the productivity of the aquatic food base relative to BASE operations because of higher daily low flows. Daily low flows are slightly higher in November and February through June, which will increase the total standing mass of algae and invertebrates. Although this option entails a greater DSV, which is likely to have a negative impact on the food base in Grand Canyon (Melis and others, 2006b), this increase in daily range will only occur for three months in the winter when primary productivity is typically reduced. The effects of a BHBF on the aquatic food base are unclear (Melis and others, 2006b). Changes in downramp rates associated with this option are unlikely to affect the aquatic food base.

Fish

Science questions

While the knowledge assessment workshop concluded that increased mainstem water temperatures would have a positive impact on the spawning and rearing of young native fishes, the most important factor or factors limiting the overall humpback chub population have not been definitively determined (Melis and others, 2006b). The current uncertainty is reflected in the strategic science question developed at the knowledge assessment workshop and in a related question developed by the Science Advisors, both presented below.

SSQ 1-1. To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?

SA 1. What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young-of-year and juveniles, habitat (water temperature), pathogens, adult maturation, food availability, competition?

The GCDAMP has also established a goal of supporting the recreational angling for rainbow trout in the Lees Ferry reach of the Colorado River below Glen Canyon Dam. The primary strategic science question regarding this resource is:

SSQ 3-6. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

Maximization of trout fishing opportunities is related to the quality (i.e., size) of rainbow trout that can be caught. The need to manage this resource for high quality fish is reflected in the following GCDAMP research information need:

RIN 4.1.1. What is the target proportional stock density (i.e., trade-off between numbers and size) for rainbow trout in the Lees Ferry reach?

The primary effects of increased flow variations are expected to be the physical displacement of fishes and habitat instability. The larvae and young-of-year of both native and nonnative fish species are most susceptible to flow displacement because of their poorly developed swimming ability. Increased flow variability is expected to reduce the Glen Canyon rainbow trout population spawning success, especially regarding the deposition, development, and hatching of eggs, because the stationary redds (nests) and eggs are especially susceptible to displacement and desiccation (Korman and others, 2005b).

Humpback Chub

Options

BASE Operations: Under BASE operations, the Grand Canyon adult (> 4 years old) humpback chub population appears to have stabilized beginning in about 2000 (Melis and others, 2006a). This is relatively new information that was not available to the knowledge assessment workshop participants, who did not reach any conclusions about the effects of various flows on the adult humpback chub population, indicating instead that additional research was needed before more definitive statements could be made. The observation that the adult humpback population has stabilized in recent years while mainstem temperatures have been warming (especially 2000 and 2003–6) is consistent with the knowledge assessment workshop conclusion that warmer temperatures would increase survival of young humpback chub.

One metric of the mainstem spawning success of humpback chub is captures of young-of-year humpback chub in the mainstem. Monitoring of humpback chub in the mainstem Colorado River below the Little Colorado River is confounded because young fish may be produced in the mainstem or in the Little Colorado and washed into the mainstem. Catch rates of young humpback chub in the mainstem above the mouth of the Little Colorado River increased each year from 2003 through 2006, indicating an increase in mainstem spawning in this reach. This may be associated with increased mainstem water temperatures, stable flows in September in some years, and/or the mechanical removal of rainbow trout and other nonnative fishes. Temperature has been described as limiting to spawning of humpback chub by many authors, including Hamman (1982), Valdez and Ryel (1995), and Clarkson and Childs (2000), suggesting that this parameter may be of critical importance. However, numbers of young humpback chub are still very low. For example, sampling with seines and hoopnets of numerous backwater habitats above the Little Colorado River inflow in September 2006 captured only 57 humpback chub less than 100 mm total length. It will be difficult and/or expensive to determine where young humpback chub were spawned, whether in a tributary or the mainstem, when they are captured in the mainstem below the Little Colorado River.

Option A: The increased fluctuations characteristic of this option cannot be determined to have a negative or positive effect on adult humpback chub at this time based on the results of the knowledge assessment. Humpback chub evolved in a system with great flow volume variability in most years, so this species might be expected to have some adaptations that help it resist physical displacement by high flows.

The knowledge assessment workshop participants determined that young-of-year humpback chub would be negatively affected by increased fluctuations, owing to the high potential for displacement, habitat destabilization, and less than ideal temperatures, though additional study is warranted based on the level of uncertainty associated with this conclusion.

High winter flows might temporarily displace young humpback chub, but this effect would not be predicted to depress the population over the long term because this species evolved in an environment where high spring flows occurred. Relatively high DSV is not an historical condition, and so may be expected to have greater potential to displace young humpback chub, especially during summer and fall, than options with a lower DSV. In the near term, if young humpback chub do not have habitats available to them that allow them to avoid high flows (e.g., backwaters, boulders, tributaries), and their population numbers are low, then high flows may interfere with maturation.

Option A Variation: The potential for physical displacement and habitat destabilization described above for Option A would also apply to Option A Variation. Increased ramping rates might magnify this effect.

Option B: The knowledge assessment participants could not conclude whether the reduced fluctuations that are the primary flow feature of this option would have a negative or positive impact on adult humpback chub. The knowledge assessment concluded that steady flows and reductions in monthly volume, as are described by this option, would favor growth and survival of young humpback chub in nearshore habitats.

Option C: The knowledge assessment workshop participants could not draw conclusions about the impacts of flows on adult humpback chub. The steadier fall flows described in this option would, according to knowledge assessment participants, be expected to provide benefits to young humpback chub in nearshore habitats during September and October, habitats that are thought to be important to survival of young humpback chub (Stone and Gorman, 2006). The increased winter flows described in Option C would not be predicted to have much impact on young humpback chub because smaller numbers of this age class are in the system at that time of the year, though this might change if there were a large increase in the density of this age class of humpback chub. Because this species evolved in a system with occasional high-volume floods on an annual basis, it would be reasonable to predict that young fish would generally survive high winter flows, though high DSVs would not be expected to favor native fishes, especially younger fish. Under this option, ongoing monitoring of the humpback chub population will provide an assessment of this population that will help determine whether August steady flows are required. If the population is observed to be in decline, steady August flows may help increase survivorship of young humpback chub in the mainstem, which would in turn be expected to help the population size increase. Quantification of the exact population size trigger value(s) or parameter(s) remains to be determined. It should be noted that the population size of adult humpback chub appears to have stabilized from 2000 to 2005.

Flannelmouth Sucker

Options

Base Operations: Flannelmouth sucker are common in Grand Canyon (Gloss and Coggins, 2005), generally spawning in tributaries but feeding and maturing in the mainstem Colorado River (Gloss and Coggins, 2005; Ward and others, 2002). They were found in all reaches of the river in Grand Canyon in 2006. It cannot be determined whether individual flannelmouth sucker captured in the mainstem Colorado River were produced there or were produced in tributaries and have moved into the mainstem, so the current level of spawning success for this species cannot be readily assessed, though it is thought to occur in some years when conditions are favorable. There is no monitoring in place at this time to determine which of these fish were produced in tributaries and which were produced in the mainstem. The knowledge assessment concluded that flannelmouth sucker would have the same responses to nearshore rearing habitat conditions as humpback chub.

Option A: Participants in the knowledge assessment workshop could not determine whether the increased flow variations characteristic of this option, relative to BASE operations, would have a negative or

positive impact on adult flannelmouth sucker. The knowledge assessment workshop participants concluded that increased flow fluctuations described in this option would decrease mainstem spawning, incubation, and rearing by flannelmouth sucker. This conclusion was coded with a moderate level of certainty. Increased flow variability, especially during the summer and fall, when the numbers of young flannelmouth sucker entering the mainstem increases, would likely have a negative impact; winter high flows likely would have less of a negative impact, at least in the near term.
Option A Variation: This option would be expected to have similar impacts to resources as in Option A, above. The increased ramping rates described by Option A Variation have the potential for greater habitat disturbance and physical displacement of young fishes than Option A or BASE operations.

Option B: The knowledge assessment workshop participants could not determine the impacts that increased flow variability would have on adult flannelmouth sucker. The reduced fluctuations described in this option would be expected to have a neutral to beneficial impact on mainstem spawning and incubation by this species. The knowledge assessment concluded that steady flows and reduced variation in monthly volume, as are described by this option, would favor young flannelmouth sucker in nearshore habitats by increasing habitat persistence. The knowledge assessment participants were very certain that low summer steady flows would have a positive effect on nearshore rearing by flannelmouth sucker.

Option C: The knowledge assessment workshop does not provide sufficient guidance to evaluate the impacts of the variable flows described in this option on adult flannelmouth sucker. Because the spring flows described by this option are relatively consistent with BASE operations, and because most flannelmouth sucker spawning is in tributary streams, this option would not be expected to impact flannelmouth sucker differently than BASE operations for much of the year.

The steadier fall flows described in this option would, according to knowledge assessment participants, be expected to provide benefits to young flannelmouth sucker in nearshore habitats during September and October. The increased winter flows described in Option C would not be predicted to have much impact on young flannelmouth sucker because smaller numbers of this age class are in the system at that time of the year, though this might change if there were a large increase in the density of this age class of flannelmouth sucker. Because this species evolved in a system with occasional floods, it would be reasonable to predict that at least some of the young fish would survive high winter flows.

Rainbow Trout

Options

BASE Operations: Electrofishing catch rates (catch per unit effort) for rainbow trout in Glen Canyon have been decreasing since 2001, decreasing by more than one half from 2005 to 2006. Factors contributing to the decline may include high fish density leading to heavy competition for resources, very low oxygen levels in water released from the dam in the fall of 2005, and/or the introduction of New Zealand mudsnails. [Very low oxygen levels, less than 5 mg/l, were observed in the Glen Canyon Dam releases in November 2005 (W. Vernieu, unpublished data, 2005), a physical parameter value that would be expected to reduce survivorship of aquatic organisms]. Fisheries management theory (e.g., Griffith, 1999; Moyle and Cech 2004) would predict that when competition for available resources among rainbow trout, or other fish species, becomes so great that the population decreases, then condition (a measure of relative weight compared to length) of remaining fish may be expected to increase. The mean condition factor for rainbow trout in the Lees Ferry reach increased in 2006 compared to 2004 and 2005 (Hunt and others, 2006), and three distinct year classes were captured during the June 2006 electrofishing (the most recent survey for which data are available, but a cause-and-effect relationship for the 2006 Lees Ferry trout population observations has not been established.

In general, the flow fluctuations implemented under BASE operations encouraged natural reproduction of rainbow trout (Gloss and Coggins, 2005), though redd counts in 2006 decreased to about 10% of that observed in 2005, so recent spawning success by rainbow trout in Glen Canyon decreased. Individual survivorship among remaining larvae experienced greater rates of survival compared to previous years, as counts of young rainbow trout were about 30% of that observed in 2005 despite the much lower redd count in 2006 (J. Korman, unpublished data, 2006).

The abundance of rainbow trout decreases with distance from Glen Canyon Dam. This longitudinal change in fish abundance is likely a function of environmental conditions including increasing turbidity of the river with increasing distance from the dam. Data collected during 2003–6 demonstrate that the nonnative fish mechanical removal project dramatically decreased trout abundance around the confluence of the Little Colorado and Colorado Rivers. This decrease in abundance was coupled with a decrease in the condition of trout. The abundance of trout in the Marble Canyon reach of the Colorado River is less than in the Glen Canyon reach. Relative abundance indices indicate a riverwide decrease in the rainbow trout population starting in 1999 that persists through 2006. Currently, the abundance of rainbow trout in the Marble Canyon reach has decreased by two thirds since 2000. The knowledge assessment reached few conclusions about what factors most affect this fish population.

Available information suggests that rainbow trout do not spawn in Marble Canyon, at least at any regular frequency. Catches of mostly larger size classes of rainbow trout in this river reach support this conclusion (J. Korman, unpublished data, 2006). Substrates in this reach are thought to be too coarse to provide for consistent rainbow trout spawning. Available information suggests that the rainbow trout present in this reach are spawned upstream in Glen Canyon, but this assertion should be subjected to additional investigation.

Option A: The increased flow fluctuations proposed in this option are expected to have a negative impact on the numbers of adult rainbow trout in Glen Canyon, according to the option proponents and the knowledge assessment workshop conclusions. Korman and others (2005b) concluded that 5,000–20,000 cfs fluctuations had only minor negative impacts on trout egg survival. In response to lower cohort numbers, surviving adults are expected to have less competition for resources and therefore to have improved condition (Moyle and Cech, 2004) under this flow scenario, an expectation supported, but not proven, by observations in 2006.

The increased DSV that are characteristic of Option A would be expected to have a negative impact on the adult rainbow trout population in Marble Canyon. Proponents of this option state that the increased winter fluctuations described would reduce nearshore rearing success by rainbow trout in Glen Canyon by decreasing habitat stability, a contention supported by the knowledge assessment workshop conclusions and Korman and others (2005b). Fewer rainbow trout in the system would be expected to lead to reduced competition with associated higher condition factors in the remaining fish.

Although limited numbers of rainbow trout exist in Marble Canyon, the knowledge assessment concluded that increased flow variations, as described by this option, would not affect the very limited amount of spawning of rainbow trout in Marble Canyon, but did expect that increased flow fluctuations would have a negative impact on young-of-year and juvenile nearshore rearing in Marble Canyon through habitat destabilization.

Option A Variation: The impacts of Option A on Glen Canyon rainbow trout would be magnified by Option A Variation. The increased ramping rates described in the latter would have greater potential for habitat disturbance and depression of overall population numbers.

Option B: Relative to the BASE operations, Option B proposes reduced flow variability. The decreased flow variations would be expected to increase habitat stability in Glen Canyon and thereby have a positive effect on mainstem spawning and incubation of rainbow trout in this reach. Greater flow stability would reduce risk of loss of redds and eggs due to desiccation or lethal temperatures. If survivorship increases dramatically, the resulting condition of survivors may decrease in the face of increased competition for resources. However, this option may also be expected to yield more annual primary production and higher numbers of invertebrates that may allow the system to support a larger population of rainbow trout above Lees Ferry.

Because the knowledge assessment concluded that increased fluctuations would have a negative impact on the Marble Canyon rainbow trout population, it is reasonable to conclude that reduced fluctuations would have a neutral to positive impact on this fish population.

The conclusion of the knowledge assessment that increased fluctuations would not affect rainbow trout spawning in Marble Canyon suggests that the decreased flows described in this option would have limited or no impact.

Option C: The reduced fall flow variability, relative to BASE operations, described in Option C can be expected to have a positive impact on adult rainbow trout in Glen Canyon, according to the knowledge assessment participants. Reduced displacement would likely accompany these flows increasing the potential for survivorship.

The increased ramping rates proposed in this option may have a destabilizing effect on nearshore habitats and therefore would reduce nearshore rearing success of rainbow trout. The increased flow fluctuations described by this option during the winter months might have some limited negative effect on whatever small numbers of rainbow trout that may spawn in Marble Canyon. The steady flows proposed for September and October by this option might displace relatively fewer of these fish, resulting in an overall neutral impact from flow Option C to rainbow trout.

Invasive Fish: Coldwater and Warmwater Species

Options

BASE Operations: The GCDAMP recently concluded a 4-year experiment (2003–6) to remove rainbow trout and other nonnative fishes from the reach of the Colorado River near the mouth of the Little Colorado River, the tributary where humpback chub are known to spawn. This experiment was very successful at removing rainbow trout, the species with the largest presence in this reach. Ongoing monitoring will assess whether this removal had the desired effect of increasing the survivorship of humpback chub. Because the temperature of water released from Glen Canyon has been above average since 2002, warmwater nonnative fish species may have increased with a concomitant negative impact on native fishes. Small numbers of warmwater nonnative fishes are currently captured in the course of other fish monitoring efforts, especially in the lowest reaches of the Colorado River in Grand Canyon. The GCDAMP has embarked on efforts to investigate the threats posed by warmwater nonnatives and methods that may be helpful in controlling these species. This effort will conclude with preparation of a plan to control both warmwater and coldwater nonnative fishes.

Option A: The proponents of this option anticipate that spawning success of rainbow trout in Glen Canyon will be reduced, thereby reducing the numbers of this species that will require removal in the future. The knowledge assessment participants concluded higher fluctuations would likely have a negative effect on both cold water and warmwater nonnative fishes because of the likelihood that these flows would displace nonnative species that are not adapted to the Colorado River, where flooding was historically common.

Option A Variation: The displacement and habitat disruption expected by the flow variation proposed for Option A would also be expected in this option. The increased ramping rates of this option might magnify these effects.

Option B: The reduced fluctuations and increased minimum flows proposed in Option B would likely have positive impacts on the aquatic food base, thereby increasing food availability for both native and nonnative fishes, warmwater and coldwater species alike. Steadier flows would reduce physical displacement of fishes. If this allowed nonnative species to increase, they would be expected to compete with and prey on the native species. If the reduced fluctuations described in this option allowed native fishes to increase at the expense of nonnatives, the outcome anticipated in the knowledge assessment workshop, the natives would benefit. It would be most conservative to predict a net neutral impact on nonnatives as a result of this option because both natives and nonnatives would benefit from greater habitat stability and increased food supply.

Option C: This option departs from BASE operations by implementing higher winter fluctuations, which the knowledge assessment participants predicted would have negative impacts on nonnative fishes through physical displacement. This option also differs from BASE operations by promoting lower September and October flows, which could be expected to favor both native and nonnative fishes because of reduced displacement. Because of these two contrasting effects, this option can be expected to have a net neutral effect with respect to nonnative fish populations.

Disease and Asian Tapeworm

Options

BASE Operations: The introduced intestinal fish parasite Asian tapeworm is currently known to infect humpback chub and other native fishes in Grand Canyon. This parasite likely entered this system in common carp. A large-scale parasite study is under way to further investigate Asian tapeworm and other parasite infection rates. Results of this study are expected to become available in Federal fiscal years 2007 and 2008.

Because of its prevalence in western North America, whirling disease, which infects trout species, could become a concern, but to date has not been detected in trout in Grand Canyon.

The knowledge assessment concluded that the effect of temperature on these two parasites was the only impact that could be predicted with any certainly. The effects of other possible system modifications, including increased or decreased DSV on these parasites are not well known.

Part 3. Terrestrial Biological Resources

Executive Summary

Terrestrial biological resources evaluated with respect to the flow options being considered include riparian vegetation segregated by surface elevations (<25,000 cfs surface elevation, 25,000–45,000 cfs, and >45,000 cfs) and two endangered terrestrial animal species: the southwestern willow flycatcher (*Empidonax traillii extimus*) and Kanab ambersnail (Succineidae: *Oxyloma haydeni kanabensis*). Riparian vegetation located below the 25,000 cfs surface elevation will be most directly affected by the flow options being considered. Effects on vegetation in this zone for options A, A Variation, and C may include an expansion of marsh vegetation (cover and diversity) in association with increased winter and summer fluctuations. Option B and BASE operations may maintain marsh vegetation at current levels or marsh area may decline with reduced inundation levels. Under Option B, vegetation would advance shoreward with possible drying of vegetation along the upper edge of the 25,000 cfs surface elevation.

Woody riparian vegetation between 25,000 cfs and 45,000 cfs is expected to become denser under options A, A Variation, and possibly Option C, but is likely to change little under BASE operations. These same plants may decline under Option B because of reduced inundation levels and possibly reduced ground water availability associated with reduced fluctuations and steady flows. Seasonal changes in water availability would likely manifest itself in compositional shifts in zones below 45,000 cfs.

Beach/habitat-building flows largely affect vegetation up to and slightly above 45,000 cfs surface elevation through scour, burial, and temporary delivery of water. Timing of a BHBF after early April may increase salt cedar (*Tamarix ramosissima*) establishment and spread, particularly when associated with Option B. Results associated with an ill-timed BHBF could include channel narrowing because of shoreward expansion of vegetation largely affected by a BHBF in combination with Option B.

Endangered southwestern willow flycatcher and Kanab ambersnail are most affected by magnitude and timing of BHBFs. Conservation measures associated with snail habitat, which involve temporary removal of vegetation during flooding and subsequent replacement, appear to be a successful in alleviating habitat loss at Vaseys Paradise. The potential introduction of New Zealand mud snails (NZM) to the spring area during a high flow may be a concern, but how the potential introduction of NZM may affect ambersnails and their habitat is unknown. Willow flycatcher habitat is most likely affected by late season (June–August) BHBFs, specifically for fledglings that may be shaken from their nest. These potential effects are applicable to BASE operations and all experimental options.

Riparian Vegetation: Stage Elevation of Base Flow to 25,000 cfs (marsh and obligate riparian vegetation)

Operations

BASE Operations: Vegetation occupying areas between base flow and the 25,000 cfs surface elevation is directly affected by dam operations (Stevens and others, 1995, p. 1032; Kearsley, 2006, p. 183–185; Melis and others 2006b, p. 37). Marsh vegetation occupies low-lying, fine-grained habitats often associated with upper pools of return current channels and bar platforms, although it can also be found along channel margins (Stevens and others, 1995, p. 1032). It is the most dynamic area within the riparian zone and an area that is more susceptible to nonnative species introduction and expansion. A primary factor that makes this area susceptible to nonnative introductions is its daily exposure to disturbance and its close proximity to water during the growing season (April–September). Fluctuations transport seeds and allow species introductions within this zone through subsequent germination. Sediment redistribution under MLFF appears to consist largely of removal of sediment above base flow and deposition of sediment into eddies below 8,000 cfs (Melis and others, 2006b, p.10). Observations indicate that marsh vegetation has decreased in area with implementation of MLFF (Stevens and others, 1995, p. 1033),

Vegetation response to a BHBF was studied under sediment-starved conditions in 1996 (Kearsley and Ayers, 1999; Stevens and others, 2001; Melis and others, 2006, p. 38). Vegetation response to a BHBF conducted under sediment-enriched conditions has yet to be studied in detail. In 1996, vegetative cover changed significantly immediately following the BHBF as a result of burial, reworking, and subsequent vegetative growth, but species composition was little affected (Kearsley and Ayers, 1999). The direction of change was dependent on the zone evaluated. Marshes increased in number and extent following the high flow, but these increases were not statistically significant. Substrate grain size was more homogeneous following the high-flow event and was largely devoid of seeds (Kearsley and Ayers 1998). In general, high flows would likely result in some reworking of return channel/marsh sites. High flows are likely to deliver large amounts of dissolved and particulate nitrogen and phosphorus to these areas, which would probably benefit riparian vegetation (Melis and others, 2006b, p. 38).

Option A: Relaxation of flow operations in summer months would result in an expansion of marsh vegetation in the summer because of an increased area of daily inundation (Stevens and others, 1995, p. 1033). These flows may also increase species diversity and cover within this zone as a result of greater water availability during the growing season. Greater fluctuations during winter months may affect water availability in soil seed banks and result in an increase in seedling density within the zone and for areas located above the area of daily inundation (Kearsley and Ayers, 1998, p. 20). Seed banks may include exotic herbaceous perennials such as pepperweed (*Lepidium latifolium*) or other weedy species that grow well in soils that are less saturated as would occur under a fluctuating flow discharge (Laubhan and Shaffer, 2006). Seed banks below the 25,000 cfs zone that are subject to daily disturbance are likely to be exported and the total number of seeds should be lower in the zone. Areas with woody phreatophytes that can expand clonally and by seed germination (salt cedar *Tamarix ramosissima*, arrowweed *Pluchea sericea*, seepwillow *Baccharis emoryi*, coyote willow *Salix exigua*, cheat grass *Bromus spp.*) may expand with increased inundation levels (Stevens and Ayers, 1993, p.7; Stevens and others, 1995, p. 1030).

Increased vegetation density and area within this zone could increase the density of terrestrial plant arthropods densities. Terrestrial arthropods are a food source for both terrestrial and aquatic species (Yard and others, 2004).

Option A Variation: Effects of Option A Variation are likely similar to Option A.

Option B: The reduced fluctuations and stable flows that are entailed in this option would provide a stable shoreline for shoreward plant species colonization and expansion in this zone. Plant movement toward the channel would occur as plants forage for water (Hutchings and deKroon, 1994), and drying out and dying of plants, and subsequent replacement by plants more tolerant of drier condition, at the upper end of the zone would also be expected (Porter, 2002). The density of nonnative plants such as saltcedar is likely to expand along the shoreline (Melis and others 2006b, pp. 38–39). Peppergrass, another invasive species, may also expand in this zone (Laubhan and Shaffer, 2006).

If BHBFs are timed after March and early April, then the incidence of salt cedar seed transport and subsequent establishment increases. The long-term effect of shoreward expansion of woody vegetation in the absence of disturbance could include channel narrowing (Graf, 1978).

Pepperweed may expand into the open spaces of the upper end of this zone through rhizomatous growth, if it is present prior to the implementation of this option (Laubhan and Shaffer, 2006). The open sand that becomes available through reduced fluctuations provides an open niche for occupation by both native and exotic plant species.

Expansion of vegetated area within this zone could increase terrestrial plant arthropod densities. Terrestrial arthropods are a food source for both terrestrial and aquatic species (Yard and others, 2004). Stabilized shorelines will also provide habitat to shoreline terrestrial invertebrates that are less abundant under fluctuating flows (Lightfoot and others, 2006, p. 71). Increases in shoreline vegetation associated with this option will increase habitat complexity and may benefit riparian breeding birds (Holmes and others, 2005).

Option C: The continuation of fluctuating flows with stable flows in the fall would have a slightly dampened effect on marsh vegetation compared to Option A. Vegetation is not expected to expand shoreward appreciably, as in Option B, but it may become more dense and increase in diversity since more water will be available prior to the growing season, similar to Option A. The composition of the vegetation in this zone may be different than those encountered under BASE operations or Option B because the timing and volume of available water shifts slightly, possibly favoring spring and early summer species (Bermuda grass *Cynodon dactylon,* sedges, salt cedar) over later flowering species (seepwillow, reedgrass).

A BHBF would have similar affects on plants in this zone as those described for BASE operations. If a BHBF was timed later in the spring then this option might benefit salt cedar germination over native species (Stevens, 1986).

Riparian Vegetation: Stage Elevation 25,000–45,000 cfs (facultative herbaceous and woody riparian vegetation)

Options

BASE Operations: Riparian vegetation located between 25,000 cfs and 45,000 cfs surface elevations is indirectly affected by MLFF operations. However, plants located above this surface elevation are affected more by amounts of local precipitation. Stevens and Ayers (1993) recorded the effect of surface elevation on growth and water stress of salt cedar and coyote willow. Coyote willow exhibited a negative response to stage elevation and a positive response to higher discharges. Under BASE operations, compared to dam operations before 1991, salt cedar should be maintaining or expanding in area while the opposite would be true for coyote willow (Stevens and Ayers, 1993).

During the 1996 BHBF, understory cover was eliminated in this zone, largely through burial (Kearsley and Ayers, 1999), and total cover in this zone significantly decreased. Six months after the BHBF cover values were not significantly different than those values recorded prior to the BHBF (Kearsley and Ayers, 1999). Recovery from burial was by species that could withstand burial and included native species such as coyote willow and introduced species such as salt cedar (Kearsley and Ayers, 1999; Stevens and others, 2001). Seedling germination within this zone following a BHBF would be depended on depth of burial and local precipitation that followed. A seed bank study associated with the 1996 BHBF showed reduced numbers of seeds and seedlings after the BHBF suggesting that burial or scour evacuated seeds and aggraded sand was primarily sterile (Kearsley and Ayers, 1998). Seeds that are located near the surface in this zone and that are removed by a BHBF may temporarily affect seed predators and higher trophic levels. Timing of the BHBF as it affects foraging by higher trophic levels requires consideration: later season BHBFs may affect riparian bird foraging and subsequent nesting success if these resources are depleted in May, June, and July.

Option A: Relaxation of fluctuations would increase the area of inundation, expand the area of available ground water and differentially affect plants located above 25,000 cfs. Woody riparian vegetation would increase in density (Kearsley, 2006; Melis and others, 2006b p. 37), and clonal species (arrowweed, coyote willow, seepwillow) would expand with increased water availability. It is unknown which species (natives vs. nonnatives) would benefit from long-term availability of water to this zone, though species that flower later in the season (seepwillow) may benefit over early season species (salt cedar). Nonnative perennial herbs (peppergrass, camelthorn *Alhagi maurorum*) that span this zone and the previous zone may also expand locally and downstream. The area of potential expansion would likely be below 35,000 cfs surface elevation.
A BHBF would deliver water to vegetation above daily fluctuations, remove and bury ground litter and possibly mechanically scour seeds (mesquite *Prosopis glandulosa*) for subsequent germination. This may results in increased areas occupied by mesquite, a species associated with predam vegetation. The same consequences mentioned above about time of year for BHBFs and potential tamarisk expansion are possible under this option. As for BASE operations, seeds that are located near the surface in this zone and that are removed by a BHBF may temporarily affect seed predators (arthropods and birds) and higher trophic levels. Timing of the BHBF as it affects foraging by higher trophic levels requires consideration: later season BHBFs may affect riparian bird foraging and subsequent nesting success if these resources are depleted in May, June, and July.

Option A Variation: Similar to the responses predicted for Option A.

Option B: Reduced fluctuations would reduce the area of inundation and ground water availability and would affect vegetation differentially depending on a species water requirements (Taiz and Zeiger, 1991). Salt cedar is better adapted to withstand water stress than other riparian species (coyote willow) (Stevens and Ayers, 1993) and may have higher survival relative to other species. Vegetative growth would generally be reduced because of decreases in available ground water. Vegetation expansion could be slower than under other experimental options, which may be a benefit to campsite area. However, vegetation might migrate shoreward following the shoreward movement that would be observed below the 25,000-cfs zone.

A BHBF would deliver water to vegetation above the zone of daily fluctuations, remove and bury ground litter, and possibly mechanically scour seeds for subsequent germination. Establishment of seedlings located at higher stage elevations may be less likely than under other options being considered. Litter accumulation, a potentially important source of carbon for the aquatic ecosystem, within this zone may be reduced as a result of lower productivity. The same consequences mentioned above about time of year for BHBFs and potential tamarisk expansion is possible under this option.

Option C: The continuation of fluctuating flows with stable flows in the fall would have a similar to slightly greater affect on vegetation within the prescribed surface elevation relative to BASE operations or a slightly dampened response when compared with option A. Vegetation would be expected to expand in area and foliar density (Kearsley, 2006) but not to the extent that might be observed under Option A. Just as in the previous zone (<25,000 cfs) species composition may change. The increased winter fluctuations and slightly reduced summer fluctuations may benefit early season herbaceous and woody perennial species like salt cedar more than later season species. Changes in species composition and litter fall accumulation under this option and other options should be monitored and evaluated for ecosystem implications.

A BHBF would deliver water to vegetation above the zone of daily fluctuations, remove and bury ground litter, and possibly mechanically scour seeds for subsequent germination. Establishment of seedlings located at higher stage elevations may occur at a rate similar to BASE operations and Option A. The same consequences mentioned above about time of year for BHBFs and potential tamarisk expansion is possible under this option.

Riparian Vegetation: Stage Elevation Above 45,000 cfs (facultative woody riparian vegetation and relict predam riparian vegetation)

Options

BASE Operations: Vegetation occupying areas above the 45,000 cfs surface elevation is affected more by local precipitation than by daily operations (Kearsley, 2006, p. 183–185; Melis and others, 2006, p. 37). Ground water accessible to species with taproots sustains established plants, but seeds that require scour for germination, like mesquite, do not readily germinate at this elevation. Bunch grasses (*Aristida purpurea*, three awn) and annual species (*Bromus rigidus)* are affected by local precipitation. A BHBF would deliver water to vegetation above the zone of daily fluctuations, but litter above 45,000 cfs would not be removed or buried by a BHBF. A flow that exceeds 1260 cms (45,000 cfs) may be beneficial to the predam high water zone, but this statement is associated with some uncertainty (Melis and others, 2006b, p. 37). A lack of high flows has limited recruitment in the predam high water zone (Anderson and Ruffner, 1988).

Option A: Vegetation occupying areas above the 45,000-cfs surface elevation is affected more by local precipitation than by daily operations (Kearsley, 2006, p. 183–185; Melis and others, 2006b, p. 37). Ground water accessible to species with taproots sustains established plants, but seeds that require scour for germination, like mesquite, do not readily germinate at this elevation. Bunch grasses (*Aristida purpurea*, three awn) and annual species (*Bromus rigidus)* are affected by local precipitation. A BHBF would deliver water to vegetation above the zone of daily fluctuations, but litter above 45,000 cfs would not be removed or buried by a BHBF. A flow that exceeds 45,000 cfs may be beneficial to the predam high water zone, but this statement is associated with some uncertainty (Melis and others, 2006b, p. 37). A lack of high flows has limited recruitment in the predam high water zone (Anderson and Ruffner, 1988).

Option A Variation: Similar to Option A.

Option B: Vegetation occupying areas above the 45,000 cfs surface elevation is affected more by local precipitation than by daily operations (Kearsley, 2006, p. 183–185; Melis and others, 2006b, p. 37). Ground water accessible to species with taproots sustains established plants, but seeds that require scour for germination, like mesquite, do not readily germinate at this elevation. Bunch grasses (*Aristida purpurea*, three awn) and annual species (*Bromus rigidus)* are affected by local precipitation. A BHBF would deliver water to vegetation above the zone of daily fluctuations, but litter above 45,000 cfs would not be removed or buried by a BHBF. A flow that exceeds 45,000 cfs may be beneficial to the predam high water zone, but this statement is associated with some uncertainty (Melis and others, 2006b, p. 37). A lack of high flows has limited recruitment in the predam high water zone (Anderson and Ruffner, 1988).

Option C: Vegetation occupying areas above the 45,000 cfs surface elevation is affected more by local precipitation than by daily operations (Kearsley, 2006, p. 183–185; Melis and others, 2006, p. 37). Ground water accessible to species with taproots sustains established plants, but seeds that require scour for germination, like mesquite, do not readily germinate at this elevation. Bunch grasses (*Aristida purpurea*, three awn) and annual species (*Bromus rigidus)* are affected by local precipitation. A BHBF would deliver water to vegetation above the zone of daily fluctuations, but litter above 45,000 cfs would not be removed or buried by a BHBF. A flow that exceeds 45,000 cfs may be beneficial to the predam high water zone, but this statement is associated with some uncertainty (Melis and others, 2006b, p. 37).

A lack of high flows has limited recruitment in the predam high water zone (Anderson and Ruffner, 1988).

Wildlife Resource Linkages

Two wildlife resources of concern are the southwestern willow flycatcher and Kanab ambersnail. Both are impacted by high flows (Melis and others, 2006b, p. 39). The impacts to southwestern willow flycatchers are associated with inundation of rearing habitats located in the upper riparian zone (located above 35,000 cfs) and possibly foraging habitats within the fluctuation zone (8,000–20,000 cfs). The latter is more uncertain. The willow flycatcher is a riparian breeding bird that has nested along the river corridor since 1963 and possibly before the dam (Sogge and others, 1997; Holmes and others, 2005). Their nests are usually found in tamarisk trees, at heights well above inundation levels (Sogge and others, 1997; Stevens and others, 2001). The timing and magnitude of high flows are the most important variables that might impact willow flycatchers. If flows exceed 1,274 cms (45,000 cfs), and occurred during the breeding season or into the period when young birds fledge (May–August or September), then this species could be affected with some certainty. Stevens and others (2001) reported nominal impacts associated with the March 1996 high flow including reduction in groundcover and branches located lower than 0.6 m. The high flows did not reach nest trees. Stevens and others (2001) speculated that the high flows might have had an impact on foraging habitat (i.e., marsh areas), but Holmes and others (2005) point out that studies that make these linkages directly are not available.

The habitat of Kanab ambersnail at Vaseys Paradise is affected by the discharge of the spring and river stage elevations. Spring discharge influences available wetted area above river stage elevation, while river stage determines how far down the slope vegetation can become established. The available wetted area and amount of moisture influences plant composition, which in turn influences snail distribution (Stevens and others, 1997b; 1998; Meretsky and Wegner, 2000). High flows that occur with low frequency may temporarily reduce snail habitat for several years (Stevens and others, 2001). However these impacts may be alleviated through temporary removal and replacement of vegetation. A conservation effort associated with the 2004 BHBF involved temporary removal and replacement of habitat and appears to have promise for the conservation of this species (Cox and others, 2005). High flows that transport New Zealand mudsnails into habitats occupied by Kanab ambersnail may be of some concern because of to resource competition between these snail species, but this is unknown.

Part 4. Recreation and Cultural Resources

Executive Summary

Effects of flows on recreation and cultural resources are multi-dimensional. Studies that evaluate the trade-offs between attributes that are important for maintaining a high-quality recreational experience or maintaining cultural site integrity are very limited, therefore the multi-dimensional effects of flows on recreation and cultural resources are difficult to quantify. Nonetheless, the available data on flow impacts to single attribute components are fairly robust in some areas, allowing for a general evaluation of the four proposed experimental options in relation to the BASE operations (MLFF). In general, Option B appears to have the most potentially beneficial outcomes for recreation in terms of maintaining campable area, maintaining the types and volumes of flows that are preferred by most recreational boaters and anglers, and increasing safety, navigability, and the overall quality of recreational experience. In terms of cultural resources, Option B also offers the best possibility of restoring and maintaining sandbars at both lower and higher elevations, and it would allow the most dry sand to be available during optimal times of year for redistribution to the higher elevation old high water zone within the CRE where most archaeological sites occur. Option C offers a less optimal experimental approach for maintaining campable area and a high-quality recreation experience, while Options A and A Variation appear to have mostly negative impacts in terms of both recreation and cultural resources. The one area in which Options A and A Variation may be superior to the others is in terms of reducing potential pathogen loads near campsites; the higher daily ranges and steeper ramping rates throughout the year will constantly rework the shoreline sediments and thereby potentially maintain more optimal sanitary conditions in the vicinity of campsites.

Strategic Science Questions

3-6. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

3-7. How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE?

3-8.What are the drivers for recreational experiences in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?

3-9. How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?

3-11. How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids?

2-1. Do dam controlled flows increase or decrease rates of erosion at arch sites and TCP sites, and if so, how?

2-3. If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?

2-7. Are dam controlled flows affecting TCPs and other tribally-valued resources in the CRE, and if so, in what respects are they being affected, and are those effects considered positive or negative by the tribes who value these resources?

Angling Opportunity, Quality, and Access

Options

Option A: The Option A flow regime, which is characterized by increased fluctuations, both in terms of higher daily ranges at least 5 out of 7 months (more often under most probable and wet scenarios) and higher downramping rates throughout the year, is expected to reduce angling opportunities, quality, and access.

Increasing the daily flow to above approximately15,000 cfs significantly reduces the number of angling locations, while increases in the daily maximum and range in flows, as well as decreases in the daily minimum flow, will increase the distance between the areas where adult fish are holding and angler access points. Both of these factors decrease angling opportunity and access, especially for shore-based anglers.

In the past, AMWG stakeholders have advocated for increased winter fluctuations based on the hypothesis that high winter fluctuations may benefit the Glen Canyon trout fishery by reducing spawning and the survival of trout redds, thereby reducing trout numbers and intraspecies competition and ultimately improving trout condition. Recent observations by the Arizona Game and Fish Department (Hunt and others, 2006) indicate an increase in the average condition of Lees Ferry rainbow trout in 2006 compared to the same value in 2004 and 2005. However, a number of biotic and abiotic factors besides wider winter fluctuations were at work in 2005 and 2006, so a direct cause-and-effect relationship between improved trout condition and wider winter fluctuations has not been established that explains these observations. Greater fluctuations in DSV may increase food availability by increasing drifting organic debris, assuming that primary productivity has been successful in preceding months; however, the work of Korman and others (2005b) also showed decreased growth in young-of-year rainbow trout with higher DSV that could offset potential benefits of higher drift levels. Questions that remain to be answered through experimentation concern whether increase drift of organic debris is sustainable on a long term basis under higher fluctuating flows and whether increased drift translates into improved fishing quality.

Two different social science studies (Bishop and others, 1987; Stewart and others, 2000) conclude that increased fluctuations do not improve angling opportunity, quality, or access. These studies relied on statistically reliable social science survey methods to determine angler preference for certain types of flows. In both studies, most anglers expressed preference for constant flows over fluctuating flows. Changes in flow (rising or falling water) were considered an important attribute of an excellent fishing experience for slightly more than half of all anglers, but rising or falling water ranked behind several other attributes that were considered more important for an excellent trip, such as “good weather” and “low water” (Stewart and others 2000, p.40). In the Bishop and others (1987, p.124–127) study, anglers were specifically asked to consider the likelihood that fluctuating flows promoted more drift, and therefore improved feeding behavior, when making their assessment of flow preferences. Even when presented with this information on the potential benefits of increased drift for angling quality, the majority of respondents preferred stable flows over fluctuating flows. Dissatisfaction with fluctuating flows among anglers generally increased as flow volumes increased (Bishop and others 1987, p. 132).

In both studies, anglers expressed a strong preference for flows in the 10,000–15,000 cfs range. As flow levels increased above 15,000 cfs, angler satisfaction ratings decreased ((Bishop and others 1987, p. 132–133; Stewart and others, 2000, p.44–45.) At flows of 20,000 cfs and 25,000 cfs, the percentage of anglers characterizing these flows as “very unsatisfactory” was 19% and 39%, respectively (or 36% and 56% when “very unsatisfactory” and “somewhat” unsatisfactory responses were combined), compared with 6% “very unsatisfactory” responses for flows in the 15,000 cfs range (Stewart and others, 2000, p. 193.) The percentage of unsatisfactory responses continued increasing as flows increased above the 25,000-cfs flow level. Conversely, one third of all respondents (33%) applied the “very satisfactory” rating to flows in the 15,000 cfs range, whereas 17% rated flows in the 20,000 cfs range as “very satisfactory” and only 5% of anglers rated flows of 25,000 cfs as “very satisfactory”(Stewart and others, 2000, p. 193.) Under the 8.23 MAF annual release scenario, flows at or above 25,000 cfs are more frequent under Option A than under MLFF, and this also holds true for the most probable and wet hydrologic scenarios, (although the differences between frequency of high flows eventually disappears in the wettest of the wet years, when steady high flows at or above 25,000 cfs are required under all the options.)

Anglers also expressed preference for moderate (10,000–15,000 cfs) and moderately low (7,500–10,000 cfs) flows over lower (<7,500 cfs) flows. In the Stewart study (2000, p. 193), 39% of anglers rated flows of 7,500 cfs as very or somewhat satisfactory, 38% rated 7,500 cfs as "neutral" (neither satisfactory nor unsatisfactory), and less than a quarter (24%) rated this flow level as somewhat or very unsatisfactory. As flow levels decreased below 7,500 cfs, anglers expressed increasing dissatisfaction (e.g., 40% rated flows of 5,000 cfs as somewhat or very unsatisfactory, 50% rated flows of 4,000 cfs as somewhat/very unsatisfactory, 54% were very or somewhat unsatisfied with 3,000 cfs, and 56% somewhat to very unsatisfied with 2,000 cfs). According to the Bishop and others (1987), the increasing dissatisfaction with lower flows has to do with increasing difficulty of boat access upriver and increasing potential for equipment (motor/prop) damage as flows decreased, rather than with concerns about decreasing drift or fish catchability (Bishop and others, 1987, p. 116). In fact, about half the respondents in the Bishop study (1987, p. 117) believed that chances of catching fish increased with lower flows, but only up to a certain point (10,000 cfs). Flows lower than 10,000 cfs were viewed progressively less favorably by the majority of respondents (Bishop and others, 1987, p. 133). Given that under the 8.23 MAF annual release scenario, Option A includes more frequent lower minimum flows than BASE operations (more flows less than 7,000 cfs), this aspect of the flow regime is also interpreted as having a negative impact on angler opportunity, quality, and access.

Option A Variation: Under Option A Variation, **t**he assessment of effects to angler opportunity, quality, and access are generally similar to those described under Option A; although, the negative repercussions are potentially somewhat greater because of wider fluctuations, increased downramping rates, and more frequent lower minimum flows relative to both BASE operations (MLFF) and Option A.

Option B: The effects of steady flows and equalized monthly volumes are projected to have a mostly beneficial effect on angler opportunity, quality, and access. These predictions are supported by both empirical evidence and data collected from statistically reliable social science surveys of Lees Ferry anglers; although, they are countered to a certain degree by information collected during the 2005 knowledge assessment workshop (Melis and others, 2006b).

According to participants in the 2005 knowledge assessment workshop (Melis and others, 2006b), steady flows will reduce the availability of drifting organic debris and hence, will reduce the catchability of trout. Additionally, lower steady flows during summer are likely to promote the establishment of seedling tamarisk trees along the shoreline and on low elevation sandbars, and these seedlings may temporarily hinder fishing activity following a return to higher flows. These predictions from the knowledge assessment workshop are based exclusively on anecdotal observations, and have not been verified through independent, peer-reviewed studies. On the other hand, participants in the 2005 knowledge assessment workshop also concluded that stabilizing monthly volumes would likely result in a more stable food supply for rainbow trout in the Glen Canyon reach and likely improvement in angling opportunity and access due to a decrease in distance between the bank and the areas where fish are feeding. The potential for increased growth in trout under stable flows is also supported by the work of Korman and others (2005b, p. v) who found a 25% increase in otolith ring width that correlated with periods of Sunday steady flows.

The knowledge assessment predictions of steady flow impacts need to be balanced in relation to previous findings by Bishop and others (1987) and Stewart and others (2000). In both of these studies, which were based on statistically reliable social science survey methods to determine angler preference for certain types of flows, anglers expressed preference for moderate (10,000–15,000 cfs) and moderately low (7,500–10,000 cfs) stable flows over lower (<7,500 cfs), higher (>15,000 cfs), or fluctuating flows. In both the Bishop and others (1987) and Stewart and others (2000) studies, anglers expressed a strong preference for flows in the 10,000–15,000 cfs range. As flow levels increased above 15,000 cfs, angler satisfaction ratings decreased, with the highest levels of dissatisfaction correlated with the highest flows. Anglers also expressed a preference for steady flows over fluctuating flows. This preference was maintained even when respondents were reminded that higher fluctuations promoted drift, which could increase catchability of the fish. Thus, although there may be a reduction in drift under Option B, the available social science data does not support the view that steady flows would have a negative impact on angler opportunity or quality.

Option C: Increased daily ranges in winter months and increased downramping rates in November through July are hypothesized to reduce angling opportunities, quality and access. Increasing the daily flow to above approximately 15,000 cfs significantly reduces the number of angling locations, while increases in the daily maximum and range in flows, or a decrease in the daily minimum flow, will increase the distance between the areas where adult fish are holding and anglers access points (Melis and others, 2006b.) This increase in distance leads to the conclusion that there will be reduced angling opportunity and catchability under Option C. Although winter fluctuations are hypothesized to benefit the trout fishery by reducing trout spawning success and thereby ultimately improving trout condition through reduced competition, this relationship has not been demonstrated through recent evaluations of the 2003–5 winter fluctuating flow experiment (Korman and others, 2005b). The 2005 knowledge assessment workshop and the study by Korman and others (2005b) found that the destabilizing impact of higher fluctuating flows on trout rearing habitat and trout growth rates counteracted some of the hypothesized benefits to the sport fishery (Melis and others, 2006b.)

The assessment that wider fluctuations are detrimental to angling opportunity, quality, and access is supported by two different studies (Bishop and others, 1987; Stewart and others, 2000) that relied on statistically reliable social science survey methods to determine angler preference for certain types of flows. In both studies, most anglers expressed preference for constant flows over fluctuating flows. Changes in flow (rising or falling water) were considered an important attribute of an excellent fishing experience for slightly more than half of all anglers, but rising or falling water ranked behind several other attributes that were considered more important for an excellent trip, such as “good weather” and “low water” (Bishop and others 1987, p.114). In the Bishop and others (1987) study, anglers were specifically asked to consider the likelihood that fluctuating flows promoted more drift and therefore improved feeding behavior, when making their assessment of flow preferences, yet even when presented with this information, the majority of respondents preferred moderate (15,000–10,000 cfs) to moderately low (10,000–7,500 cfs) stable flows over fluctuating flows (Bishop and others,1987, p.123–127.) Fluctuating flows were also perceived to be more problematic at higher flows (at or above 25,000 cfs) than at lower volume flows (Bishop and others,1987, p.132.)

According to participants in the 2005 knowledge assessment, low steady flows in September and October will reduce the availability of drift and hence, Option C flows are hypothesized to reduce trout catchability. This negative assessment must be qualified, however, based on previous findings by Bishop and others (1987) and Stewart and others (2000). As noted above, most anglers expressed preference for stable flows over fluctuating flows. This preference was maintained even when respondents were reminded that higher fluctuations promoted drift, which could increase catchability of the fish. Thus, although there may be a reduction in drift with steady flows in the fall, the available social science data do not support the view that these flows would have a negative impact on angler opportunity or quality.

Effects of Beach/Habitat-Building Flows on Angling Opportunity, Quality, and Access

BHBFs are included as an element of all four experimental options, as well as BASE operations, and in all instances, BHBFs are considered to have a negative impact on angling opportunity, quality, and access (Bishop and others, 1987, p.129; Stewart and others 2000, p. 193.) This negative outcome is because high flows eliminate angling opportunities during the high-flow event and may result in reductions in food availability for weeks to months following the high-flow event. However, reduction in food availability depends on the timing of the flood in relation to antecedent food base conditions and season; floods occurring in the fall or winter months are more likely to have longer term effects than those that occur in the spring or early summer, when conditions are better for algae growth and faster recovery.

The negative effects of BHBFs on angling experience are documented in two different social science studies (Bishop and others, 1987; Stewart and others, 2000) that relied on statistically reliable samples and survey methods to determine angler preference for certain types of flows. In both studies, high flows (flows of 25,000 cfs or more) were considered by the majority of anglers to be “somewhat” or “very unsatisfactory,” with the percentage of “very unsatisfactory” responses increasing steadily as flow levels increased (Bishop and others, 1987, p.129; Stewart and others, 2000, p. 193.) The highest levels of dissatisfaction correlated with the highest flows. At flows of 40,000 cfs, 50,000 cfs, and 60,000 cfs, the percentage of anglers characterizing these flows as “very unsatisfactory” was 65%, 69%, and 71%, respectively (or 72%, 74%, and 74% when “very unsatisfactory” and “somewhat unsatisfactory” responses were combined, respectively).

Campsites (campable area availability)

Options

BASE Operations: As documented by Kaplinski and others (2005) in the 2005 The State of the Colorado River Ecosystem in Grand Canyon (SCORE) report (Gloss and others, 2005) campable area above 25,000 cfs has diminished under MLFF at the rate of about 15% per year. These findings are congruent with findings of Topping and others (2003) that flows above ~9,000–10,000 cfs promote transport of sediment out of the system. The only deviation from the general downward trend in campable area occurred following the beach/habitat-building flows in 1996 and 2004, leading Kaplinski and others (2005) to conclude that “provided that enough sediment is available for deposition, high-flow events are the only mechanism by which sandbars used as campsites above the 25,000-cfs stage elevation can be built and maintained.”

Option A: The effects of increased daily fluctuations on sediment transport and sandbars are reasonably well known from sandbar measurement data collected sporadically during the 1980s and early 1990s (Beus and Avery, 1992; Kaplinski and others, 2005), as well as from recently and historically compiled sediment transport data (Topping and others, 2000a, 2000b, 2003, 2006). It is well established that increased fluctuations will result in higher sediment transport rates, with sediment derived primarily from eddy storage complexes, the primary setting of most campsites in the CRE. However, as discussed by Beus and Avery (1992) responses of sandbars to higher fluctuating flow regimes are complex, highly variable, and dependent on antecedent conditions. The work of Beus and Avery (1992, chapters 6 and 10) suggests that under sediment-enriched conditions, short-duration higher flows or higher fluctuating flows could potentially result in aggradation of some sandbars, while others would either continue to erode, or show minimal measurable change. Under sediment depleted conditions, however, fluctuating flows will generally increase the rate of erosion of sandbars.

Given the wider fluctuating flows proposed under Option A and the known relationship to increased rates of sediment export under fluctuations, Option A will likely translate into smaller camping beaches over time, even if BHBFs occur whenever a sediment trigger is met. However, this hypothesis requires future testing. Given what is known today about sandbar responses under highly fluctuating flow regimes, the prediction is that campable area would continue to decline under Option A, although perhaps at a somewhat reduced rate relative to BASE operations, provided that BHBFs are implemented more frequently under sediment-enriched conditions. When these predicted outcomes are couple with the proposed higher fluctuations in summer, however, which effectively prohibit camping in areas below the highest flow level (which under Option A would be up to 19,000 cfs in summer under the minimum release scenario and 25,000 to 33,000 cfs under the wet scenario), campable area throughout the system would likely be reduced compared with BASE operations that have less extreme fluctuations, lower daily maximums, and generally higher daily minimums.

Option A Variation: Under Option A Variation, **t**he assessment of effects to campsites is generally similar to Option A; although, the reduction of campable area is likely to be somewhat greater than Option A because of the wider fluctuations occurring during more months of the year and the increase in downramping rates during November through March.

Option B: Sustained low flows below 9,000–10,000 cfs are known with certainty to constrain the amount of sediment transported out of the system to negligible amounts (Topping and others, 2003). As documented by Wright and others (2005), Schmidt and others (in review), Hazel and others (2006), and Topping and others (2006), new tributary sand inputs are conserved and will accumulate in the main channel at stable flows of 8,000 cfs (based on results of summer 2000 low summer steady flow test) and under fluctuating flows ranging between 5,000 and 10,000 cfs (based on monitoring sand transport during the fall of 2004 before the November 2004 high-flow test). Thus, a stable flow regime that constrains flows to around 10,000 cfs much of the time and reduces fluctuations is likely to promote sediment retention and slow the rate of campable area decline. In addition, sustained low flows would expose more campable area on a sustained basis, increasing the amount of campable area exposed at lower elevations (Hazel and others, 2001). However, over time, without occasional higher flows (BHBFs), sustained low steady flows could result in decreases to the size and volume of sandbars above the low-flow level because of the cumulative effects of repeated cut bank failures and the consequent redistribution of higher elevation sediment to lower elevations (at or slightly below the level of the highest flows). In other words, unless low steady flows are accompanied by occasional periods of higher flows or periodic BHBFs (as is proposed under Option B), the conserved sand would, over time, likely end up being stored in the river system below a level that is beneficial for use by campers.

In general, under all hydrologic scenarios, the flow pattern proposed under Option B appears to benefit campsite availability, particularly in the highest-use recreational seasons (summer). However, one drawback of stabilizing flows in summer is that low steady flows would permit tamarisk and other vegetation to encroach on sandbars (Porter and Kearsley, 2001; Porter, 2002), which could eventually offset any gains resulting from greater bar exposure at lower elevations. On the other hand, drying out and dying of some plants and replacement by more drought-tolerant species at the edges of the riparian zone, as observed in 2000 by Porter (2002) could potentially open up additional areas for camping. Unfortunately, measured information that would allow us to quantify rates of vegetation encroachment and/or loss on sandbars under steady (or any other) flows, is lacking, so the overall impact of vegetation changes on campable area is unknown.

Option C: Option C includes a couple of months of stable flows in September and October, higher daily ranges in winter months, and steeper downramping rates in November through July compared to BASE operations. As previously noted, Topping and others' (2003) analysis of historical sediment transport data shows that sediment retention will occur at flows below 9,000–10,000 cfs. Therefore, it is reasonably certain that low, stable fall flows will reduce the rate of transport of sediment compared with the more variable flows of typical BASE operations, or even higher fluctuating regimes. On the other hand, higher fluctuating flows are known to increase the rate of sediment export out of the system (Topping and others 2000a, 2000b, 2006; Rubin and others, 2002), so higher fluctuations in the winter–spring months will likely translate into smaller camping beaches over time, even with occasional sediment-triggered BHBFs coupled with fall steady flows. Considering these factors in combination, the effect on campable area from the Option C flow regime compared with BASE operations is uncertain but is most likely to result in a continuing reduction of campable area over time, though possibly at a slightly reduced rate compared to BASE operations. Once again, this assessment is predicated on the assumption that BHBFs would be implemented under sediment-enriched conditions more frequently than in the past, and that BHBF implementation under these conditions is in fact sustainable over multiyear time scales.

Effects of Beach/Habitat-Building Flows on Campable Area

BHBFs are an important element of all four experimental options, as well as BASE operations. BASE operations include hydrologically triggered BHBFs, while the four experimental options include sediment-triggered BHBFs. Sediment-triggered BHBFs are likely to result in aggradation of many sandbars and increased sand deposits at higher elevations, with consequent increases in campable area, provided that the floods occur under sufficiently sediment-enriched conditions. Sandbar responses will not be uniform throughout the ecosystem, but overall, BHBFs occurring under sediment-enriched conditions are likely to have a positive impact on campable area, BHBFs that occur in the spring (Option B), that are preceded by an extended period of lower, steady flows (Option B and potentially Option C) and that are not immediately followed by high fluctuating flows (as proposed in Options A, A Variation, and potentially Option C) are likely to increase campable area the most and for the longest period of time.

Quality of Water and Human Health

There is a high degree of uncertainty about effects of the four experimental options on water quality and human health. This uncertainty is due to a shortage of basic research on how dam operations affect human health in the CRE.

Options

Option A: The relatively higher flow volumes and higher fluctuations proposed in summer and winter compared to BASE operations, will promote recirculation of nearshore sediments (Melis and others, 2005), therefore the prediction is that Option A flows would decrease concentrations of human pathogens in the water, especially in the shoreline zones near popular campsites, thereby likely reducing the threat of waterborne pathogens on human health.

Option A Variation: As with Option A, the relatively higher flow volumes and higher fluctuations proposed throughout most of the year, as compared with BASE operations, will promote recirculation of nearshore sediments (Melis and others, 2006b), therefore the prediction is that Option A Variation would decrease concentrations of human pathogens in the water, especially in the shoreline zones near popular campsites, thereby likely reducing the threat of waterborne pathogens on human health.

Option B: With lower, more stable flows throughout most years, and the accompanying increases in nearshore temperatures under the 8.23 MAF annual release hydrologic scenario, concentrations of human pathogens in the water, especially in the shoreline zones near popular campsites, are likely to increase, thereby increasing risks to human health (Melis and others, 2006b).

Option C: The relatively high-flow volumes and fluctuations in winter and moderate fluctuations in summer will promote recirculation of nearshore sediments, therefore the prediction is that these flows would decrease concentrations of human pathogens in the water, especially in the shoreline zones near popular campsites, thereby likely benefiting human health (Melis and others, 2006b).

Effects of Beach/Habitat-Building Flows on Water Quality and Human Health

In the short term, BHBFs may stir up concentrations of bacteria and temporarily cause a deterioration in water quality from the standpoint of visitor health. After flood waters subside, however, a reduction in concentrations of pathogens near campsites is expected.

Visitor Safety and Rafting Navigability

While there is considerable anecdotal information concerning the effects of very low (<7,000 cfs) and very high (>33,000 cfs) flows on navigability, relatively little peer-reviewed research is available on these topics; therefore, considerable uncertainty surrounds the effects of flows on navigability and safety. Given the shortage of peer-reviewed studies that specifically address the effects of flows on navigability, effects to this important aspect of visitor experience must be considered somewhat uncertain.

Options

Option A: Highly fluctuating flows are predicted to increase safety risks somewhat and decrease navigability, although actual data supporting this conclusion are very limited (Brown and Hahn-O'Neill, 1987). At flows above the 31,500-cfs range and below 9,000 cfs, Brown and Hahn-O'Neill documented an elevated risk of having a safety-related incident, compared with flows in the 9,000 to 31,500-cfs range, which were rated as the safest flows by Brown and Hahn-O'Neill (1987, p.45). Fluctuations make rapids less predictable and boats more vulnerable to stranding as flows decrease more rapidly than currently allowed under BASE operations, although no existing studies unequivocally demonstrate an increased risk to boaters from fluctuating flows (Brown and Hahn-O'Neill, 1987, p.45). As noted in the 2005 knowledge assessment (Melis and others, 2006b), some boaters maintain that fluctuations can improve navigability by increasing the available options for running rapids under varying flows. There is anecdotal information suggesting that steeper ramping rates may increase safety risks for anglers, but it is unclear whether the perceived increased risks to anglers would be substantiated upon further study.

There is a high degree of certainty that lower flows (<9,000 cfs) increase the probability of boats hitting rocks, sustaining equipment damage (especially to motors), and getting stranded in rapids (Brown and Hahn-O'Neill, 1987), and under Option A, very low flows (<7,000 cfs) would occur more often and for longer duration than currently occur under BASE operations. The potential benefits to navigability that come with the moderately high daily maximums in winter and summer under the 8.23 MAF annual release scenario are likely to be offset by the effects of higher fluctuations and lower minimum flows under the same scenario. As hydrology becomes wetter, flows become higher and eventually stable, topping out at a steady 33,000 cfs in the summertime under the wettest hydrology. This flow level is one of the most dangerous for boaters, according the Brown and Hahn-O'Neill study.

Option A Variation: Under Option A Variation, effects to navigability and safety are generally similar to Option A, although safety risks may be slightly greater than Option A due to the wider fluctuations occurring during more months of the year and the increase in downramping rates during November through March.

Option B: Effects of sustained steady flows on safety and navigability are considered to be positive because the stage at which flows would be constrained under Option B are considered to be safer than higher or lower volume flows (Brown and Hahn-O'Neill, 1987) and the river on average would be slightly slower (particularly during 8.23 MAF annual release years), and runs in the rapids would be more predictable, in comparison to BASE operations, during the high-use seasons. Previous studies (Bishop and others, 1987) documented that moderate, stable flows of 10,000 to 15,000 cfs were generally preferred by whitewater boaters, and flows in the range of 9,000 to 31,500 cfs are the safest for boaters (Brown and Hahn, 1987, p. 45), compared with both higher and lower flows. In the absence of fluctuations, and with the volumes being proposed under this experiment, the technical difficulty of most rapids would be reduced relative to higher, lower, or highly fluctuating flows, hence improving navigability and safety.

Option C: Effects of Option C on safety are uncertain, but likely would be positive in some respects and negative in others. The potential benefits to navigability that come with the relatively high daily maximums are offset by the higher fluctuations associated with winter ramping rate experiments, as higher fluctuations make rapids less predictable and boats more vulnerable to stranding when flows decrease more rapidly than under normal BASE operations. The fall steady flow regime may also affect navigability in a negative way, as many rapids become more challenging with lower volume (<9,000 cfs) flows. Note that there is relatively little difference between Option C and Option A under the wet hydrology scenario, when flow volumes in summer peak at a steady 33,000 cfs under both options. As noted above, the study by Brown and Hahn-O'Neill in 1987 found flows above the 31,500 cfs level to be the most dangerous for recreational boaters, and in a separate study, Jalbert (1996, p. 16) concluded that more accidents were likely to occur under flows of 31,500–33,000 cfs than at 45,000 cfs.

Effects of Beach/Habitat-Building Flows on Visitor Safety and Rafting Navigability

BHBFs are an important element of all four experimental options, as well as BASE operations, and in all instances, the impact of sediment-triggered BHBFs on visitor safety and navigability is considered to be neutral. The effects of high flows above powerplant capacity on navigability and safety are not well documented in the peer-reviewed literature, but anecdotal information and several in-house National Park Service studies that have not yet been subject to peer review (Jalbert, 1996, 2001) suggest that higher flows improve the navigability of most rapids by covering rocks that would otherwise be exposed and by creating more channels for boaters to chose from as they navigate downstream. Also, Webb's work (1999) shows that BHBFs can clear channels of rock debris accumulations, which generally, but not always, creates easier passage for boats after flows diminish.

Several "in-house" studies have been undertaken by the National Park Service to evaluate effects of high flows at or above powerplant capacity on safety (e.g., Brown and Hahn-O'Neill, 1987; Jalbert, 1996.) The results of the 1996 study are somewhat difficult to evaluate because the study was relatively short term, the sampling strategy was not random, the study did not take into account nonflow factors such as boater experience, and the results were not subject to rigorous independent peer review. In addition, various studies have evaluated boaters' perceptions of risk at high flows (e.g., Bishop and others, 1987; Shelby and others, 1992; Stewart and others, 2000), but the findings from these studies have not been independently evaluated through actual monitoring of safety incidents during non-experimental flow events. Based on a comparison of data from 1987, when flows in the low 30,000-cfs range were common, with incident data collected during the 1996 BHBF, Jalbert (1996, p. 16) concluded that more accidents were likely to occur under flows of 31,500–33,000 than at 45,000 cfs. The 1996 National Park Service study concluded that despite observing a slight increase in boat flips and unintentional swims at a couple of rapids during the 1996 BFBH, the overall numbers of incidents at 45,000 cfs were not significantly different from those reported during non-experimental flow conditions (Jalbert, 1996.) Studies specifically designed to evaluate safety issues at a variety of different flows are needed to substantiate these conclusions.

Recreational Experience Quality (including access to attraction sites)

Options

BASE Operations: The consensus of experienced Grand Canyon boaters is that BASE operations (MLFF) noticeably improved the recreational experience in the CRE for whitewater recreationists relative to the pre-EIS period (historical dam operations from 1963 through 1991). This improvement was largely due to the reduction in daily range and ramping rates of daily fluctuations and the constraining of flow volumes (lower highs and higher lows) compared to pre-EIS conditions; therefore, a flow regime that moves toward further reduction in daily fluctuations is likely to be perceived more positively by a majority of experienced Grand Canyon boaters than one that moves in the opposite direction. Effects of BASE operations on angler experience are less clear cut, although the documented flow preferences of anglers (Bishop and others, 1987; Stewart and others, 2000) indicate a preference for BASE operations over the more variable and extreme pre-EIS fluctuating flow conditions.

Option A: The pattern of higher fluctuating flows (higher daily ranges and steeper downramping rates) proposed by Option A is contrary to the documented preferences of most boaters and many anglers (Bishop and others, 1987; Stewart and others, 2000). Minimum flows would be lower than historical BASE operations under this alternative, and more highly fluctuating flows are proposed throughout most of the year. All of these flow elements are perceived to have negative impacts to recreational experience, based on the results of social science surveys of boaters and angler preferences by Bishop and others (1987) and Stewart and others (2000).

In terms of access to attraction sites, a somewhat negative effect is predicted due to the increased fluctuations in both summer and winter, which make boat mooring near attraction sites unpredictable. This impact is likely to be felt more by private boaters and commercial guides (the people who manage the boats) than by commercial passengers.

Given that many factors contribute to recreational experience quality besides flows, it is currently difficult to assess how Option A would ultimately affect overall recreational experience quality, but when one considers the likely impact of the proposed operating regime under Option A, with its wider fluctuations and steeper downramping rates, a decrease in the quality of the both angling and whitewater boating recreation experience quality is predicted.

Option A Variation: The effects to recreational experience quality of Option A Variation are generally similar to those of Option A, although likely somewhat more pronounced (and negative), due to wider fluctuations occurring during more months of the year and an increase in downramping rates during November through March, as compared with Option A.

Option B: When one considers the flows alone, the proposed Option B operating regime is likely to have an overall positive effect on recreational boating experience and a mixed effect on angling opportunity and quality, because Option B proposes flows that are most consistent with the documented preferences of the majority of whitewater rafters and anglers.

Based on anecdotal accounts and limited social science survey data, a generally positive effect on access to attraction sites is predicted under Option B, due to the predictable nature of equalized volumes and stable flows. With stable flows, boaters will spend less time dealing with changing mooring conditions and therefore have more time and a potentially more enjoyable experience visiting attraction sites. In addition, the warmer nearshore water temperatures that would likely accompany stable summer and early fall flows is considered to be a beneficial effect by many boaters (Stewart and others, 2000; Jonas and Stewart, 2002). The effects of warmer water and stable flows may benefit trout condition as well, but only up to a certain degree (~°16 C).

Many factors besides flows contribute to recreational experience quality, and the trade-offs associated with specific flows have never been thoroughly evaluated, so an accurate assessment of how this proposed experiment would ultimately affect overall recreational quality is difficult to predict without collecting more data that specifically evaluates trade-offs among the various attributes contributing to the overall quality of recreational experiences in the CRE. However, when one considers the flows alone, the proposed operating regime under Option B is likely to have a positive effect on both angling and whitewater boating experience quality, in comparison to BASE operations.

Option C: The proposed operating regime of Option C is likely to have a mixed effect on both angling opportunity and whitewater boating experience quality. The pattern of fluctuating flows proposed for winter in Option C is contrary to the documented preferences of most boaters and many anglers (Bishop and others, 1987; Stewart and others, 2000). In addition, flows lower than 10,000 cfs are generally not preferred by most boaters, so implementing two months of low fall steady flows may negatively impact the boating experience. On the other hand, the warmer water that would likely accompany lower fall steady flows may counteract some of the negative aspects of the fall flow regime.

In terms of access to attraction sites, effects of Option C are both negative and positive, due to the counteracting effects of winter fluctuations and fall stable flows. The negative effects of increased fluctuating flows are likely to impact private boaters primarily, as few if any commercial trips would be on the water in the winter months when the highest fluctuations are proposed, while the beneficial effects of fall stable flows on attraction site access would be experienced by both private and commercial boaters.

As noted above, many factors besides flows contribute to recreational experience quality, so it is difficult to precisely assess how Option C would ultimately affect overall recreational quality without undertaking additional focused studies. Based on currently available data, there is likely to be very little difference in terms of overall recreational experience quality in comparison to BASE operations.

Effects of Beach/Habitat-Building Flows on Recreational Experience Quality (including access to attraction sites)

BHBFs are an important element of all four experimental options, as well as BASE operations, and in all instances, the impact of sediment-triggered BHBFs on the whitewater recreational experience is considered to be mostly positive, with certain caveats. Impacts to the angler experience (discussed elsewhere) are considered to be largely negative.

As noted previously, studies by the National Park Service have evaluated the effects of high flows at or above powerplant capacity on visitor safety, an important component of visitor experience. The 1996 National Park Service study found no significant difference in numbers of incidents resulting in injury or death (Jalbert, 1996.) Studies by Bishop and others (1987) and Stewart and others (2000) specifically evaluated the effects of different flows on recreational experience, and these studies concluded that for both boaters and anglers, moderate flows of 10,000 to 20,000 cfs were preferred over higher flowers; however, Jalbert (1996) found that most boaters who were interviewed during the 1996 BHBF were excited to be running on the high experimental flows, and some deliberately scheduled their trip to maximize time spent on the high flow. The results of the Jalbert study, which were not subject to independent peer review, plus additional anecdotal information from river guides, indicates that flows over 40,000 cfs are perceived as both positive and negative by different user groups, with boaters with more experience generally having a more positive perception of the high-flow experience than the less experienced boaters. This issue warrants a future focused study.

The effects of high flows at or above powerplant capacity on access to attraction sites is not well documented, but anecdotal information suggests that it would have neither a generally positive nor negative effect. At specific attraction sites, pulling over and parking boats may be easier or more difficult, but available anecdotal information does not indicate a dominant trend in one direction or another.

Some additional likely positive benefits of BHBFs that relate to the overall quality of the recreation rafting experience include increased numbers and sizes of camping beaches and improved sanitary conditions near camps.

Archaeological Sites and Traditional Cultural Properties (TCPs)

Effects of flows on archaeological sites are evaluated primarily in terms of the degree to which sediment would be deposited and retained at higher elevations, either via direct deposit from high flows or via indirect redeposition by aeolian transport from lower elevation sandbars to eroding terrace surfaces where most archaeological sites occur.

Options

Option A: Effects to cultural resources are uncertain but likely would have negative implications for archaeological site stability and TCP integrity relative to BASE operations, even with the likely beneficial effects of sediment-enriched BHBFs. This is due to the higher sediment transport rates that would accompany wider fluctuating flows and steeper downramp rates, and the fact that the sandy, nearshore deposits would be subjected to frequent, repeated inundation and therefore would not be available for redistribution to higher elevations via wind transport.

Option A Variation: The effects to archaeological sites and traditional cultural properties from Option A Variation are generally similar to those of Option A, although perhaps slightly more pronounced (and negative), due to wider fluctuations occurring during more months of the year and an increase in downramping rates during November through March, as compared with Option A.

Option B: Effects to cultural resources are uncertain but possibly positive due to greater sediment retention with stable flows and more flows that are consistently less than 10,000 cfs during large portions of each year. Minimizing the extent to which daily flows vary with respect to stage may allow for larger portions of nearshore sandbars to remain desiccated throughout the year, permitting the dry sand to be redistributed beyond the zone of inundation. Once sand deposits are dried out and remain dry, wind transport of sand and silt may occur in directions that transport fine sediment upslope in to cultural site preservation areas. Unresolved uncertainties relate to effects of vegetation encroachment on open sand areas under stable flows and the sustainability of repeated BHBFs over time.

Option C: Effects to cultural resources are uncertain but probably neutral relative to BASE operations, or perhaps slightly positive, due to implementation of sediment-enriched BHBFs coupled with greater sediment retention with low stable flows in the fall; however, the sediment conservation effects of fall steady flows may be largely offset by the higher sediment transport rates accompanying the wider fluctuations in winter relative to BASE operations.

Effects to TCPs from Options A through C are uncertain, due to lack of specific data about TCP locations and specific qualities of TCPs that are being affected by flows. With regards to effects to native plants (a major interest of several Native American tribes), short duration BHBFs may benefit native vegetation in the higher terrestrial zones by temporarily elevating ground water levels and by increasing disturbance to the vegetation, which has the potential to encourage regeneration of many new high-water zone and old high-water zone native species.

Effects of Beach/Habitat-Building Flows on Archaeological Sites and Traditional Cultural Properties

BHBFs under sediment-enriched conditions are an important element of all four experimental options, as well as BASE operations, and in all instances, the impact of sediment-triggered BHBFs on archaeological sites and TCPs are considered to be mostly positive, although this assessment requires verification through additional research and monitoring. A number of short-term studies undertaken to evaluate the effects of the 1996 experimental flood on historical properties within the CRE, and on the basis of a few site-specific studies, the conclusion was that there was either no effect, no adverse effect, or potentially beneficial effects from the BHBF (Balsom and Larralde, 1996.) In the future, effects of BHBFs should be evaluate for a sample population of sites, in order to more fully characterize BHBF effects to archaeological sites on a systemwide basis.

The effects of flows above powerplant capacity on sandbars and high elevation sediment supply is relatively well documented (Webb and others, 1999; Kaplinski and others, 2005; Hazel and others, 2006). BHBFs appear to be the only mechanism available for restoring large volumes of sand to elevations above the highest level of normal dam operations, and restoring the sand supply at higher elevations within the CRE is probably the only flow-based action that can significantly alter the downward trajectory of archaeological site integrity in the CRE. BHBFs have been shown to increase higher elevation sandbar areas systemwide, at least on a temporary basis (Hazel and others, 1999, 2006; Kaplinski and others, 2005b), and these sandbars can potentially serve as sources for sediment to be redistributed across archaeological site areas by wind, provided that subsequent flows do not rapidly erode the newly built sandbars (as was the case in the winter–spring of 2004–5.) BHBFs have also been demonstrated to deposit sand in arroyo mouths up to the highest flow level (Yeatts, 1997; Hazel and others, 2000), thereby temporarily reducing the gradient of arroyos and potentially slowing rates of down cutting in the lower reaches of the drainage. Once again, however, more focused studies are needed to quantify the long-term effects of BHBFs on cultural resources in the CRE.

Part 5: Hydropower Resources

(Please see table 3.2 and appendix E, this report, for details on methods and assumptions.)

Summary Table

Table 3.2. Summary comparison of flow-related resource effects estimated for four options under consideration by the Glen Canyon Dam Adaptive Management Program compared to BASE operations (modified low fluctuating flow). The table provides, where possible, the potential effects of each option on individual resources are ranked 1 (most) through 4 (least) where possible.

	Option A	**Option A Variation**	**Option B**	**Option C**
Fine-sediment Storage				
Fine-sediment storage (all flows up to 45,000 cfs)	(3) Potential increase over BASE with BHBF effects, however, the relaxed constraints on fluctuating flows increase sand export and may offset BHBF influences	(4) Potential increase over BASE with BHBF effects, however, these most relaxed constraints on fluctuating flows increase sand export and may offset BHBF influences	(1) Overall, provides greatest potential increase in sand conservation over BASE with BHBF effects, and sand habitats might be more stable following BHBFs	(2) Potential increase over BASE with BHBF effects, fall stable flows help limit sand export, but relaxed constraints on fluctuating flows might offset reduced sand export during stable flow months
Water Temperatures				
Water Temperatures (mainstem) (based on numerical modeling)	No significant change over BASE without temperature control device (TCD)	No significant change over BASE without TCD	No significant change over BASE without TCD	No significant change over BASE without TCD
Water Temperatures (nearshore) (based on existing data and state-of-knowledge)	(3.5) No significant change over BASE without TCD	(3.5) No significant change over BASE without TCD	(1) Greatest potential increase overall – see text for potential range of increase	(2) Potential increase in Aug (when stable flows triggered), Sep – Oct; otherwise no significant change over BASE without TCD
Diurnal Stage Variations (DSV) Downstream	Increase in DSV over BASE in winter (Dec – Feb and summer (Jul – Aug)	Increase in DSV over BASE in all months except Apr – May	Decrease in DSV over BASE in all months	Increase in DSV over BASE in winter (Dec – Feb) and decrease in Sep – Oct (steady)
Aquatic food base				
Aquatic Food Base (Glen)	(3) Decrease relative to BASE from Dec. through Feb. and July through Aug	(4) Decrease relative to BASE for all months except April and May	(1) Increase relative to BASE in 74 of 84 months	(2) Decrease relative to BASE from Dec. through Feb.
Aquatic Food Base (Grand)	(3) Decrease relative to BASE from Dec. through Feb. and July through Aug	(4) Decrease relative to BASE for all months except April and May	(1) Increase relative to BASE in 74 of 84 months	(2) Decrease relative to BASE from Dec. through Feb.
Adult Fish Populations				
Adult Population (HBC)	Uncertain	Uncertain	Uncertain	Uncertain
Adult Population (FMS)	Uncertain	Uncertain	Uncertain	Uncertain
Adult Population (RBT #'s in Glen)	(3) Potential decrease	(4) Potential decrease	(1) Potential increase	(2) Potential increase

Adult Population (RBT size in Glen)	(2) Potential increase	(1) Potential increase	(4) Potential decrease	(3) Potential decrease
Mainstem spawning and incubation				
Mainstem Spawning & Incubation (HBC)	(3) Potential decrease	(4) Potential decrease	(1) Potential increase	(2) Potential increase
Mainstem Spawning & Incubation (FMS)	(3) Potential decrease	(4) Potential decrease	(1) Potential increase	(2) Potential increase
Mainstem Spawning & Incubation (RBT - Glen)	Potential decrease (no ranking: value dependent)	Potential decrease (most) (no ranking: value dependent)	Potential increase (no ranking: value dependent)	Potential increase (no ranking: value dependent)
Mainstem Spawning & Incubation (RBT - Marble)	No change	No change	No change	No change
YOY/Juvenile nearshore rearing				
YOY/Juvenile Nearshore Rearing (HBC)	(3) Potential decrease	(4) Potential decrease	(1) Potential increase	(2) Potential increase
YOY/Juvenile Nearshore Rearing (FMS)	(3) Potential decrease	(4) Potential decrease	(1) Potential increase	(2) Potential increase
YOY/Juvenile Nearshore Rearing (RBT - Glen)	Potential decrease (no rank: value dependent)	Potential decrease (no ranking: value dependent)	Potential increase (no ranking: value dependent)	Potential increase (no ranking: value dependent)
YOY/Juvenile Nearshore Rearing (RBT - Marble)	No change	No change	No change	No change
Invasive Fish Species (cold water species; downstream)	(2) Potential decrease	(1) Potential decrease	(4) Potential increase	(3) Potential increase
Invasive Fish Species (warm species)	(1.5) No change	(1.5) No change	(4) Potential increase	(3) Potential increase
Disease (Asian Tapeworm)	No change	No change	No change	No change
Disease (Whirling Disease)	No change	No change	No change	No change
Terrestrial Riparian Resources				
Marsh and obligate riparian vegetation (below 25,000 cfs)	Potential increase of marsh vegetation	Potential increase of marsh vegetation	Marsh vegetation maintained or decreased; vegetation advancing shoreward	Marsh vegetation maintained or decreased
Lower Riparian Habitat (24,000 to 45,000 cfs)	Increased dense woody vegetation	Increased dense woody vegetation	Woody vegetation maintained or decreased; vegetation advancing shoreward	Increased dense woody vegetation, but less than Options A and A Variation
Upper Riparian Habitat (45,000 to 60,000 cfs)	No change; vegetation most affected by precipitation	No change; vegetation most affected by precipitation	BHBFs after April could spread tamarisk shoreward	No change; vegetation most affected by precipitation

Recreational Resources				
Angling opportunity, quality, and access	(3) Potential decrease	(4) Potential decrease	(1) Potential increase (improved fishability)	(2) Potential increase
Campsites	(3) Potential decrease over base, even with BHBF effects	(4) Potential decrease over BASE, even with BHBF effects	(1) Greatest potential increase over base with BHBF effects	(2) Potential increase over base with BHBF effects
Human Health	(1.5) Potential decrease in pathogen concentrations near camps over BASE	(1.5) Potential decrease in pathogen concentrations near camps over BASE	(4) Greatest potential increase in pathogen concentrations near camps overall	(3) Potential increase in pathogens in September (and August when stable flows are triggered), otherwise potential decrease over BASE
Visitor Safety/Rafting Navigability	Potential reduction	Potential reduction	Potential improvement	No net change
Recreational Experience	Potential reduction	Potential reduction	Potential improvement	No net change
Cultural Resources				
Archeological Site Preservation	(3) Potential increase over base with BHBF effects	(4) Potential increase over base with BHBF effects	(1) Greatest potential increase over base with BHBF effects	(2) Potential increase over base with BHBF effects
Traditional Cultural Property Conservation	Unknown	Unknown	Unknown	Unknown
Hydropower Resources				
Increased Hydropower Load-Following Capacity	(2) Yes, capacity is increased (see Appendix E for details)	(1) Yes, greatest increase in capacity (see Appendix E for details)	(4) No, greatest decrease in capacity (see Appendix E for details)	(3) No, capacity is decreased (see Appendix E for details)
Decreased Hydropower Replacement Costs	(2) Yes, costs are decreased (see Appendix E for details)	(1) Yes, greatest decrease in costs (see Appendix E for details)	(4) No, greatest increase in costs (see Appendix E for details)	(3) No, costs are increased (see Appendix E for details)

Chapter 4: Estimated Effects of Proposed Nonflow Actions on Downstream Resources

Temperature Control Device

Part 1. Physical Resources

Downstream Water Temperatures

Because all four experimental options include the use of a temperature control device (TCD) starting in water year 2012, the effects of the TCD are primarily evaluated with respect to BASE operations, which do not use a TCD. However, because the TCD affects release temperatures for all options, it may also affect the differences between the options since the amount of downstream warming is dependent on the release temperature.

Main Channel

The numerical modeling detailed in appendix D can be used to evaluate the effects of the TCD by analyzing the last 5 years of the simulation period (i.e., the period when the TCD is in operation). Example model results are shown below.

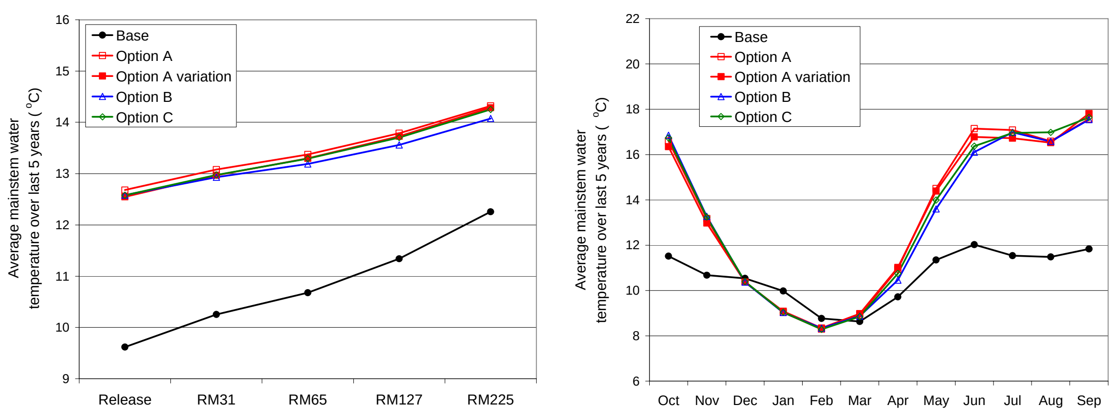


Figure 4.1 Average mainstem water temperatures at 5 locations (left) and average monthly temperatures at river mile 65 (right) for the last 5 years of the simulation period (i.e. period with TCD) for most probable hydrologic scenario.

The effects of the TCD are clearly evident in figure 4.1 where it is seen that all options have significantly warmer water throughout the system as compared to BASE operations. The warming is greatest in the summer months and typically negligible in the winter.

Nearshore Environments

Because nearshore environments are connected to the mainstem, increased mainstem temperatures are expected to translate to similar increases in nearshore temperatures. Stable flows during months when release temperatures are cooler than air temperatures (i.e., months when downstream warming is expected) are still expected to promote warmer nearshore environments (particularly backwaters). However, because the TCD will tend to bring the mainstem and nearshore temperatures closer to equilibrium with the atmosphere, the impacts of stable flows on nearshore temperatures will tend to be reduced. Mainstem modeling results indicate that downstream warming is expected to continue to occur in spring, summer, and fall months with the TCD in operation.

Options

Option A: Main channel temperatures are expected to be significantly warmer than would be present as the result of BASE operations during spring, summer, and fall. Because nearshore environments are connected to a warmer mainstem they are expected to be warmer as well.

Option A Variation: Same as Option A.

Option B: Same as Option A.

Option C: Same as Option A.

Downstream Water Temperature Summary

A TCD is expected to significantly increase mainstem and nearshore temperatures throughout the system for all options during the spring, summer, and fall. Because release temperatures are increased, the differences between the options, in terms of mainstem and nearshore temperatures, tend to be reduced because the differences are driven by downstream warming and downstream warming is less when release temperatures are warmer. Thus, the ranking of the options presented in chapter 3 is expected to hold with a TCD in operation, with the differences between the options being reduced from the no-TCD case.

Part 2. Aquatic and Fisheries Resources

Executive Summary

The addition of a TCD would increase water temperatures, which would generally be a benefit to native and nonnative aquatic organisms. The primary benefits of increased water temperatures would be increased annual aquatic primary production and invertebrate production and increased metabolic rates for native and nonnative fishes, which are likely to result in increased growth rates, especially in the presence of increased food (vegetation and invertebrates) availability.

Increased mainstem temperatures, the goal of the implementation and operation of a TCD were generally thought by the knowledge assessment participants to be of benefit to fishes, native and nonnative. Operation of the TCD may also increase the numbers and persistence of Asian tapeworm. The only resources for which the knowledge assessment did not draw conclusions in response to a TCD were: rearing of young rainbow trout in Marble Canyon, the adult rainbow trout in Marble Canyon, and adult humpback chub. The proponents of all options being considered recognize that a TCD may benefit both desired and undesired species, in both desired and undesired locations, and so support research and development of methods to control species where and when it is necessary to benefit native fishes. The Science Advisors have also concluded that while there are risks to operation of a TCD, the potential benefits to native organisms render the risk acceptable. The results of the knowledge assessment workshop support the implementation of a TCD to benefit many resources, including the Grand Canyon food base, and mainstem spawning and rearing by humpback chub and other native fish.

Aquatic Food Base: Glen Canyon and Grand Canyon

Options

Option A: Installation of a TCD will have a positive effect on the aquatic food base in both Glen and Grand Canyon by increasing growth rates of both algae and invertebrates (Melis and others, 2006b). Although the instantaneous benthic biomass of algae and invertebrates may not increase with installation of a TCD, more algae and invertebrate biomass will be produced annually because of faster growth rates in warmer water.

Option A Variation: Installation of a TCD will have a positive effect on the aquatic food base in both Glen and Grand Canyon by increasing growth rates of both algae and invertebrates (Melis and others, 2006b). Although the instantaneous benthic biomass of algae and invertebrates may not increase with installation of a TCD, more algae and invertebrate biomass will be produced annually because of faster growth rates in warmer water.

Option B: Installation of a TCD will have a positive effect on the aquatic food base in both Glen and Grand Canyon by increasing growth rates of both algae and invertebrates (Melis and others, 2006b). Although the instantaneous benthic biomass of algae and invertebrates may not increase with installation of a TCD, more algae and invertebrate biomass will be produced annually because of faster growth rates in warmer water.

Option C: Installation of a TCD will have a positive effect on the aquatic food base in both Glen and Grand Canyon by increasing growth rates of both algae and invertebrates (Melis and others, 2006b). Although the instantaneous benthic biomass of algae and invertebrates may not increase with installation of a TCD, more algae and invertebrate biomass will be produced annually because of faster growth rates in warmer water.

Fish

Humpback Chub

Adults: Participants in the knowledge assessment workshop could not conclude whether or not the TCD would result in a net benefit to adult humpback chub because of potentially conflicting results. The value of the TCD for adult humpback chub, described in all options being considered, requires additional assessment. The increase of mainstem water temperatures has been thought to be a benefit to adult humpback chub by many authors, including Hamman (1982), Valdez and Ryel (1995), and Clarkson and

Childs (2000), among others, by promoting survival, growth, and maturation as a result of increased metabolic rates. However, if warmer water temperatures had the predicted effects of increasing nonnative warmwater fishes and/or Asian tapeworm, then the net effects on adult humpback chub could be neutral. Managers responsible for operating a TCD will likely want to maintain the option of reducing or eliminating the use of the TCD in some years, thereby using cooler water temperatures to help control the proliferation of nonnative fishes and Asian tapeworm. Modeling of mainstem water temperatures suggests that when basin hydrology is higher the maximum water temperature released even with operation of the TCD will be less than in years with lower flows, which is expected to result in less than optimum water temperatures for both native and nonnative fishes in high-flow years. The net influence of these various factors requires additional investigation.

Mainstem Spawning and Incubation: Warming mainstem temperatures resulting from a TCD were thought by the knowledge assessment participants to be of benefit to mainstem spawning and incubation by humpback chub. Adult humpback chub could be expected to grow and mature more quickly in a warmer environment, thereby increasing gamete maturation. Available literature (e.g., Hamman, 1982; Clarkson and Childs, 2000) suggests increased survival of humpback chub eggs in warmer water temperatures. All four options being considered would be expected to have a positive effect on this resource area because of their support for the installation and operation of a TCD. However, this benefit could be negated if predatory nonnative fishes increased, thereby increasing loss of eggs and larvae to predators.

Young-of-year and Juvenile Nearshore Rearing: The knowledge assessment workshop participants found that warmer mainstem temperatures would have a positive effect on nearshore rearing by humpback chub through increased metabolism leading to increased growth and survival. All options being considered therefore offer positive benefits to this resource area due to their inclusion of a TCD. However, if nonnative predatory fishes increase in response to warmer water temperatures, predation on young life stages of native fishes could increase, potentially negating the benefits to natives.

Other Native Fish

Adults: Flannelmouth sucker was the native fish species other than humpback chub considered during the knowledge assessment workshop. This species was thought to generally benefit from TCD operation. Increased mainstem temperatures may be expected to increase growth and maturation rates of flannelmouth sucker through increasing food supply, increased metabolic rates, and increased ability to avoid predation through improved swimming capacity (Ward and others, 2002). Proponents of all options support the TCD and therefore may all be expected to provide benefits to flannelmouth sucker adults. If warmer water temperatures also benefit predatory nonnative fishes, these benefits could be reduced or lost.

Mainstem Spawning and Incubation: The knowledge assessment workshop participants found that warmer mainstem temperatures would have a positive effect on nearshore rearing by native fishes through increased metabolism leading to increased survival and growth. All options being considered therefore offer positive benefits to this resource area due to their inclusion of a TCD. If warmer water temperatures also benefit predatory nonnative fishes, these benefits could be reduced or lost.

Rainbow Trout

Numbers and Condition in Glen Canyon: Colorado River temperatures in Glen Canyon are generally near the bottom of the ideal range for rainbow trout. Therefore, if water temperatures were increased through the operation of a TCD, metabolic rates for adult rainbow trout would likely increase, leading to increased growth rates (Moyle and Cech, 2004). Because sunlight is not limiting in Glen Canyon (Yard and others, 2005), the warmer temperatures produced from TCD operation would be expected to increase annual primary productivity, thereby increasing food availability for rainbow trout. The TCD supported by all options would be expected to benefit this resource.

Mainstem Spawning and Incubation: The knowledge assessment workshop participants thought that mainstem warming of the Colorado River would not have a measurable effect, positive or negative, on mainstem spawning by rainbow trout in Glen Canyon. While metabolic rates would increase, dissolved oxygen decreases with increasing temperature, a critical physical parameter for developing fish eggs. Therefore, all options are neutral with respect to this resource area.

Invasive Fish Species (coldwater and warmwater species)

Because the knowledge assessment workshop participants found that warmer mainstem temperatures would result in improved conditions and therefore increased survival of both coldwater and warmwater nonnative fishes, all options being considered offer benefits to this resource area due to their inclusion of a TCD. Because these species compete with and/or prey upon native fishes, increases in nonnative fishes increase risks to native fishes.

Disease and Asian Tapeworm

Because the knowledge assessment workshop participants found that warmer mainstem temperatures would increase the survival, growth, (Oskinis, 1994) and infection rates of Asian tapeworm and whirling disease (were it present), all options being considered may be expected to increase these parasites due to the warmer release temperatures resulting from the operation of a TCD. Because Asian tapeworm infects native fishes, it may be assumed that this would increase morbidity and mortality of native fishes.

Part 3. Terrestrial Biological Resources

Executive Summary

The effect of warmer temperature on riparian habitat is largely unknown for vegetation in the CRE. The zone most likely to be affected by warmer temperatures under all flow options is the zone most proximal to the river (base flow to 25,000 cfs). Potential changes could include expansion of salt cedar or other nonnative species adapted to warmer temperatures following a late season BHBF; Option B may promote this possibility the most. All vegetation is expected to grow more extensively with warmer water and nutrient exchange rates between the land and water would likely increase, which may be a benefit to the ecosystem. Changes in the terrestrial flora would likely accompany a change in invertebrate density and diversity which may also benefit terrestrial and aquatic systems.

Riparian Vegetation: Stage Elevation to 25,000 cfs (Marsh and obligate riparian vegetation)

Options

BASE Operations: The effect of warmer temperature on riparian habitat is largely unknown for vegetation below the 45,000-cfs stage elevation in the CRE (Melis and others, 2006b, p. 37). Studies in the Walker River Delta in Nevada (Young and others, 2004) indicate that tamarisk germinates throughout a range of seed bed temperatures (0–40°C). These temperatures may be constant or vary diurnally. Optimal germination was diurnal with 16 hours of 10°C and 8 hrs of 20°C. Germination was variable by seed lots. A similar response was noted for coyote willow (*Salix exigua*) a species native to the CRE (Young and Clement, 2003). Other factors contributing to the uncertainty include physiological responses associated with germination and clonal growth of wetland and riparian species (Farnsworth and Meyerson, 2003; Güsewell and others, 2003).

Option A: Vegetative growth rates would likely increase under a warmer regime, resulting in denser marsh and riparian vegetation within the fluctuation zone. Besides temperature, nutrient concentrations in water also come into play and would likely differentially affect native and nonnative species found in the fluctuation and lower riparian zones (Biondini, 2001; Farnsworth and Meyerson, 2003; Güsewell and others, 2003). This effect would likely be more pronounced in the fluctuation zone that is also subject to daily disturbance. These changes could cascade up the trophic food web by changing invertebrate composition and types of plant species that provide nearshore cover for aquatic species.

Option A Variation: Vegetation response to this option would be very similar to the response described for Option A.

Option B: Nonnative species may grow more rapidly under warmer water conditions, particularly following a BHBF that may redistribute silts and clays and provide open areas for colonization.

Option C: The responses by riparian vegetation to warmer water conditions under Option C would likely be similar to those observed for the BASE operations and Option A. Vegetative growth rates would likely increase under a warmer regime, resulting in denser marsh and riparian vegetation within the fluctuation zone. Besides temperature, nutrient concentrations in water also come into play and would likely differentially affect native and nonnative species found in the fluctuation and lower riparian zones (Biondini, 2001; Farnsworth and Meyerson, 2003; Güsewell and others, 2003). This effect would likely be more pronounced in the fluctuation zone that is also subject to daily disturbance. These changes could cascade up the trophic food web by changing invertebrate composition and types of plant species that provide nearshore cover for aquatic species.

Wildlife Resource Linkages

Southwestern willow flycatcher would likely benefit from the increased invertebrate densities that would accompany vegetation growth associated with warmer water temperatures. Kanab ambersnail may be little affected by the TCD because the majority of snails appear to occupy habitat above the 25,000-cfs elevation.

Part 4. Assessment of Effects to Recreation and Cultural Resources

Executive Summary

An increase in water temperature through implementation of a TCD will likely benefit both angling and whitewater recreation for a variety of reasons (bigger trout, more enjoyable swimming opportunities, safer conditions for recreationists); although, the potential impacts of increased pathogen loads on both fish and humans remain highly uncertain and could potentially negate some of the beneficial effects of warming the water. There are also uncertainties regarding how warmer water may effect the trout population as warmwater species increase and potentially compete with the trout for a limited food supply.

Angling Opportunity, Quality, and Access

In addition to improving the water temperature from the standpoint of wading anglers, increased water temperature is predicted to increase the size and abundance of rainbow trout in Glen Canyon up to about 16° C. Therefore, implementation of a TCD is likely to result in benefits to the trout fishery, unless temperatures significantly exceed 16° C for extended periods of time or parasites and pathogens counteract the beneficial effects to primary productivity (food base) and trout growth from warming (see the food base section for specific references on the expected relationships between water temperature and aquatic productivity). Increased temperature will also increase metabolic demand and the consequent increase in feeding rate may improve "catchability." Possible negative impacts include increased diseases, such as whirling disease, or increased competition from warmwater nonnatives in a food-limited environment.

Quality of Water and Human Health

An increase in waterborne pathogens is likely to occur with warmer water temperatures. During the 2000 low summer steady flow experiment, river guides and private boaters experienced a notable increase in incidents of waterborne viral infections among passengers and crew, adding further anecdotal support to the notion that warmer flows are not conducive to maintaining optimal human health conditions.

Visitor Safety

Hypothermia and heart attacks due to thermal shock are some of the greatest risks to boaters and anglers who come out of their boats in the CRE (Meyers and others, 1999, p. 37). Under normal dam release temperatures of 7–12°C, people can lose muscle control in a matter of minutes and may lose consciousness in less than 10 minutes. This reality forces potential rescuers to take additional risks in their attempts to get swimmers out of the water as quickly as possible. Although no specific studies have been done in the CRE to document the relationships between water temperature and safety incidents, the well-known and well-documented hypothermia risks associated with typical dam release temperatures (Meyers and others, 1999, p. 37) leaves little room for doubt that warmer water would significantly reduce safety risks associated with Colorado River recreation.

Recreational Experience Quality

Studies documenting the relationship between water temperature and recreational experience are lacking, but anecdotal information, plus some social science survey data, indicate that warmer water would likely improve the boating and angling experience because warmer water would allow visitors to enjoy being in the water and getting soaked in the rapids, and both anglers and whitewater boaters are less likely to die from hypothermia-related issues if they inadvertently fall out of their boats. Anecdotal information suggests that most visitors currently manage to enjoy their recreation experience *in spite of* the very cold water temperatures. The Stewart and others (2000, p. 161) study found that a small majority of commercial passengers (53%) did not believe that their trip would have been any more enjoyable with warmer water, but a slightly larger majority of private boaters and river commercial guides shared the opposite opinion (i.e., 57% of private boaters and 58% of commercial guides felt that warmer water would have improved their overall experience.) The trade-offs associated with different aspects of visitor experience affected by warmer water (i.e., improved "swimmability" versus possible increase in viral or bacterial infections) have never been studied and remain unknown.

There is certainty that warmer temperatures decrease water viscosity, allowing fine sediment to settle out faster, and thereby reducing the suspension of sediment in the water column and the amount of sediment available for downstream transport (Lane and others, 1949; Hubbell and Ali, 1961; ASCE, 1975). In theory, warmer water reduces the amount of sediment transported from sandbar deposits (S. Wright, personal comm., 2006), and therefore could have a slightly beneficial effect for recreation by increasing the longevity of sandy deposits used as camping beaches.

Nonnative Fish Control

Part 1. Aquatic and Fisheries Resources

Executive Summary

The only effect of nonnative control that the knowledge assessment participants thought predictable with certainty was the negative effect on populations of coldwater nonnatives in response to their removal. This is consistent with the data available in 2006 that indicate that over 90% of the rainbow trout population previously present in the reach of the Colorado River near the mouth of the Little Colorado River has been removed by the four year GCDAMP effort. The knowledge assessment participants concluded that mechanical removal of warmwater nonnatives would have negative impacts on that population. The adult humpback chub population has stabilized beginning in about 2000, and has remained so through 2005 (the most recent year for which data are available; Melis and others 2006a), suggesting that mechanical removal focused on coldwater species has not hurt the humpback chub population. Continued monitoring is needed to fully assess whether the mechanical removal effort benefits the native fish population.

All of the options being considered include control of nonnative fish populations, as needed. All of the options, therefore, may be expected to have a neutral to positive effect on the native fishes from implementation of nonnative control actions, as needed, especially for early life stages.

Aquatic Food Base: Glen Canyon and Grand Canyon

Options

All Options: Nonnative fish control might benefit native fishes by affecting the amount of food available for native fishes or by affecting native fishes' ability to effectively feed. Competition between native and nonnative fishes for food or feeding arenas has not been demonstrated in the CRE. However, if competition for food is occurring between native and nonnative fishes, then nonnative fish removal has the potential to increase the amount of food available for native fishes. If native and nonnative fishes are competing for feeding arenas (e.g., areas of slower water such as eddy fences that are in close proximity to faster water), then removal of nonnative fishes might make it easier for native fishes to effectively feed.

Fish

Humpback Chub: Adults

Option A: The increased flows and daily fluctuations described in this option would not, in the absence of a TCD, be expected to raise water temperatures, and higher flow variations may displace nonnative fishes (Li and Moyle 1999), so threats to native fish by nonnative warmwater species would likely be limited under this option. The knowledge assessment did not have sufficient information to judge whether or not mechanical removal of nonnatives was of benefit to adult humpback chub. Proponents of this option suggest, consistent with the knowledge assessment, that the increasing flows described would limit the rainbow trout population, which would reduce the need for active control of this species.

Option B: This option may implement conditions that are favorable for warmwater nonnatives by reducing displacement by high flows. Efforts to control warmwater species are indicated by this information and are supported by the proponents of this option, but benefits to adult humpback chub are uncertain.

Option C: The departures from BASE operations proposed in Option C suggest that rainbow trout population numbers might be slightly reduced and warmwater species might benefit slightly from the Option C flows. Efforts to control nonnative species are indicated by this information and are supported by the Option C proponents, but benefits to adult humpback chub are uncertain.

Humpback Chub: Mainstem Spawning and Incubation

Removal of nonnative fishes was generally thought by the knowledge assessment workshop participants to have positive effect on mainstem spawning and incubation of humpback chub; although, additional investigation is needed. All options support this action, as needed, and so all offer some positive impacts to this resource area.

Humpback Chub: Young-of-Year and Juvenile Rearing

The knowledge assessment concluded that young humpback chub rearing in nearshore habitats benefited from nonnative control efforts by reducing predation and competition; although, this conclusion needs additional investigation. All options, because they propose nonnative control as needed, would be expected to provide a benefit to this resource.

Other Natives

Adults: The knowledge assessment workshop did not have sufficient information to conclude whether or not nonnative control would benefit adult flannelmouth sucker. However, it is logical to think that reduced competition and/or predation could be beneficial to native species.

Mainstem Spawning and Incubation: Removal of nonnative fishes was generally thought by the knowledge assessment workshop participants to have positive effect on mainstem spawning and incubation of flannelmouth sucker; although, additional investigation is needed. All options support this action, as needed, and so all offer some positive impacts to this resource area.

Young-of-Year and Juvenile Rearing: The knowledge assessment concluded that young flannelmouth sucker rearing in nearshore habitats benefited from nonnative control efforts through reduction of competition and predation; although, this conclusion needs additional investigation. All options, because they propose nonnative control as needed, would be expected to provide a benefit to this resource.

Rainbow Trout

Numbers and condition in Glen Canyon: Removal of rainbow trout in Marble Canyon has a negative impact on that species in that reach, but the impact of this removal on the Glen Canyon rainbow trout population has not been determined.

Invasive Fish Species (Coldwater and Warmwater)

The knowledge assessment workshop participants concluded that removal of rainbow trout had had a negative effect on that species, consistent with the study objectives and design. They also concluded that they did not have enough information to conclude whether or not a similar effect would be observed on warmwater species. Because all options include nonnative control, they would all have similar effects on these resources.

Part 2. Assessment of Effects to Recreation and Cultural Resources

Executive Summary

There are localized negative impacts to angling opportunity and quality from removal of trout from tributaries and selected reaches of the river, and trout removal has been identified by several Native American tribes as a negative impact to TCP values in the CRE. Impacts to recreation experience are undocumented and therefore unknown, but are likely to be minimal for whitewater recreationists and negative for trout anglers who fish the reaches below Less Ferry.

Angling Opportunity, Quality, and, Access

Mechanical removal of rainbow trout in Marble Canyon has been shown to significantly reduce the population of trout in this section of the river, and the extent of the reduction can be quantified (GCMRC, unpublished data). Thus, for the relatively few anglers who frequent Marble Canyon, the impact of trout removal is expected to be negative. However, mechanical removal of rainbow trout in lower Marble Canyon or near the mouth of the Little Colorado River is not believed to significantly affect the trout population in Glen Canyon where most angling is currently concentrated due to the hypothesized “site fidelity” of these fish; this hypothesis has not been formally tested though, so effects of trout removal on the Glen Canyon reach are considered to be uncertain. Removal of brown trout from tributary creeks in Grand Canyon would have a negative impact on angling opportunity and quality in those specific tributaries, as well as in the mainstem. The effect of reducing the abundance of warmwater nonnative fishes on the population of rainbow trout is currently unknown. Removal of rainbow trout in Glen Canyon could potentially benefit the sport fishery, when fish numbers and/or condition warrant a reduction in population size to increase condition of the remaining population.

Recreational Experience Quality (including access to attraction sites)

Aside from the hypothesized effects to angling opportunity and quality discussed above, the effects of mechanical trout removal (or mechanical removal of nonnative species in general) on visitor experience is a subject of continuing speculation, but one for which no actual data are currently available. During the 2005 knowledge assessment workshop, several participants expressed the opinion that there were increased risks to visitors because of the use of electricity in the water near shorelines and camps, and there were concerns about potential negative impacts to the wilderness-like experience; however, other workshop participants argued that these risks and impacts were mitigated through public outreach and education, and therefore, recreational experience was not adversely effected by this activity. No data relevant are currently available to resolve these debates, and further evaluation of this issue is probably warranted.

Traditional Cultural Properties

The killing of trout and other life forms in the vicinity of the mouth of the Little Colorado River has been identified by Native American tribes (Hopi and Navajo) as an issue of concern and a potentially detrimental impact to traditional cultural property values associated with this area. The Grand Canyon. as a whole, has been identified as a TCP by most of the tribes involved with the Glen Canyon Dam Adaptive Management Program, so mechanical removal in other parts of the CRE could also potentially be viewed as having a negative impact by the tribes. Trout removal does not directly affect the physical integrity of archaeological sites, many of which are also considered to be TCPs by Native American tribes, but there is some (slight) potential of impacts to archaeological sites from onshore base camp activities associated with the trout removal project; however, on shore impacts can and largely have been mitigated through educational outreach efforts to the cooperators who engage in this work.

Translocation of Humpback Chub

Part 1. Aquatic and Fisheries Resources

Executive Summary

The translocation of humpback chub above Chute Falls in the Little Colorado River has, as of 2006, been shown to be successful in that the translocated fish have survived well and have spawned. This suggests that this species may be amenable to physical relocation, and that therefore the translocation may be expected to add numbers to the overall adult humpback chub population in Grand Canyon; although, long-term monitoring has not been conducted to confirm this assumption. The spawning success of the population above Chute Falls, and the small number of emigrants to this population from below Chute Falls, suggests that translocated populations in other tributaries might begin to reproduce and contribute to future generations.

Translocation and any associated reproduction of humpback chub confound the assessment of impacts of various natural and man-made conditions on humpback chub because population increases or decreases cannot be ascribed to only one factor. The stabilization of the humpback chub population in Grand Canyon (Melis and others 2006a) suggests that this population is not in a critical situation at this time and so more dramatic management actions, such as translocation, may be premature if scientists and managers are to be given sufficient time to determine single or limited numbers of factors affecting the size of the humpback chub population. The knowledge assessment was inconclusive regarding the effects of translocation.

The options offer a distinct contrast with regard to this action. Options A and A Variation call for continued translocation and Option B does not favor translocation. The proponents of Option C only favor translocation if it can be shown to not confound an overall experiment and assessment, which remains to be shown as of October 2006.

Fish

Humpback Chub: Adults

Option A: Although it is impossible to evaluate and compare absolute numbers from this vantage point in time, the humpback chub moved to Colorado River tributaries other than the Little Colorado River and surviving there might compensate for humpback chub not produced or lost after hatching under this option due to other effects, such as displacement.

Option A Variation: Although it is impossible to evaluate and compare absolute numbers from this vantage point in time, the humpback chub moved to Colorado River tributaries other than the Little Colorado River and surviving there might compensate for humpback chub not produced or lost after hatching under this option due to other effects, such as displacement.

Option B: Any potential benefits to the humpback chub population that might be realized by additional translocations would not be demonstrated if this option is adopted. By not expending resources on translocation, there would presumably be more resources available for conservation and management actions in Grand Canyon aimed at improving the existing population and its habitat.

Option C: This option would refrain from implementing this action until its potential impact on an experimental design and impact assessment are known with greater certainty; although, Option C proponents favor consideration of translocation, they do not advocate immediate implementation.

Humpback Chub: Mainstem Spawning and Incubation

Option A: Translocation of humpback chub above Chute Falls on the Little Colorado River may have already played some minor role in supporting the overall Grand Canyon population of this species through the production of small numbers of young in the translocated population. If translocations to other tributaries were similarly successful, or more so, more humpback chub might be expected in the mainstem. The presence of additional humpback chub in the mainstem would only be expected to lead to increased spawning and incubation if other habitat parameters were conducive to these activities. The increased flow fluctuations proposed in Option A are not expected to contribute to increases in mainstem spawning and incubation, whether from humpback chub naturally present or present because of human-mediated translocation.

Option A Variation: Translocation of humpback chub above Chute Falls on the Little Colorado River may have already played some minor role in supporting the overall Grand Canyon population of this species through the production of small numbers of young in the translocated population. If translocations to other tributaries were similarly successful, or more so, more humpback chub might be expected in the mainstem. The presence of additional humpback chub in the mainstem would only be expected to lead to increased spawning and incubation if other habitat parameters were conducive to these activities. The increased flow fluctuations proposed in Option A are not expected to contribute to increases in mainstem spawning and incubation, whether from humpback chub naturally present or present because of human-mediated translocation.

Option B: This option does not support translocation, so no effect of translocation can be evaluated.

Option C: Because this option only supports translocation under specific conditions it may not be implemented, reducing any chance that translocation would affect mainstem spawning and incubation under implementation of this option.

Other Native Fish: Adults

Translocation of humpback chub above Chute Falls of the Little Colorado River and to other tributaries would not be expected to impact other native species, given the current population sizes. If translocation were to result in very dramatic increases of the number of humpback chub in the Colorado River, then there might be some issues of increased competition between native fish species, but that potential seems very remote from the vantage point of 2006. Because these species evolved together, it is unlikely that there would be competition that would result in the decline of one species to the detriment of another.

Other Native Fish: Mainstem Spawning and Incubation

The small numbers of all native fishes in the Colorado River in Grand Canyon in 2006 suggest that it is unlikely that any humpback chub translocation will affect mainstem spawning and incubation of natives other than humpback chub under any of the options being considered. Physical factors are more likely than translocation of one species to have effects on mainstem spawning and incubation. Humpback chub and other native fish species evolved together in the Colorado River and so would be assumed to have developed strategies for coexistence.

Invasive Fish Species (Coldwater and Warmwater)

All options being considered support control of nonnative fishes, as needed, to benefit native fishes. If humpback chub were physically relocated or propagated and released, actions supported primarily under Options A and A Variation, they could provide some resource competition to nonnative fishes. The translocated humpback chub population would have to increase to a relatively high number before this effect could be measurable. In the near term, impacts to nonnative fishes from translocated humpback chub would likely be very minimal.

Part 2. Assessment of Effects to Recreation and Cultural Resources

Executive Summary

Depending on where translocations occur, there could be some negative impacts to recreational experience and Native American TCPs from translocation of the endangered humpback chub. For example, translocation into a tributary canyon such as Shinumo Creek could potentially result in decreased access for recreational use (if human use is subsequently found to have negative impacts to fish habitat or water quality or otherwise conflicts with sustaining this species in its new habitat). More intrusions of fish biologists and resource managers and their associated mechanized gear in an area that is being managed for a wilderness-type experience could also have potentially negative impacts for recreation experience. Furthermore, translocations in the Little Colorado River gorge or in other tributaries of Grand Canyon could potentially result in impacts to as yet unidentified Native American traditional cultural properties because of increased incidental use of these areas, either as a direct result of the research and monitoring activities associated with the translocation effort or as a result of increased publicity about the area that would inevitably accompany a successful translocation program.

Humpback Chub Refuge, Propagation, and Genetics Management Planning

Part 1. Aquatic and Fisheries Resources

Executive Summary

The GCDAMP Humpback Chub Ad-hoc Group (HBCAHG), has identified catastrophic loss as an important threat to the Grand Canyon humpback chub population. This threat is also identified in the 2002 Recovery Goals promulgated by the U.S. Fish and Wildlife Service (In 2006, a court ordered this version of recovery goals set aside and also ordered that the goals be revised in 2007.). This threat has been the primary motivation for the development of plans to establish one or more refuge populations of humpback chub outside of Grand Canyon. A small stock of humpback chub has been established at Willow Beach National Fish Hatchery, Arizona, on the Colorado River below Hoover Dam.

The GCDAMP Humpback Chub Ad-hoc Group, with support from the TWG and AMWG, has contracted for the preparation of a genetics management plan for humpback chub that includes planning for refuge populations and approaches to propagation and augmentation; although, the HBCAHC does not propose augmentation of the wild population at this time. Options A, A Variation, and C support the planning for a refuge, propagation, and augmentation, but they do not call for immediate augmentation. Option B proponents do not favor such actions based on the premise that such efforts divert resources from protection and improvement of the wild population and their habitat.

The knowledge assessment was inconclusive regarding the effects of humpback chub augmentation.

Humpback Chub

BASE Operations: The GCDAMP has contracted for the preparation of a genetics management plan for humpback chub. Some segments of the plan should be ready for review during 2007, with the final plan scheduled for completion and submittal in December 2007.

Option A: A humpback chub refuge helps address the concern over the potential for catastrophic loss of large numbers of humpback chub by maintaining a population outside of Grand Canyon that could be used as brood stock, if required. This option supports the establishment of a refuge as insurance against large-scale loss.

The planned humpback chub genetics management plan meets the prescription in this option for planning to be conducted toward augmentation, as this plan is an important precursor to augmentation of the wild population. If there were losses of humpback chub due to any of the flow elements of this option, augmentation with wild fish could help maintain the size of the Grand Canyon humpback chub population.

Option A Variation: Same as Option A

Option B: The proponents of Option B are concerned that energy and resources expended outside of Grand Canyon on humpback chub protection may be unwise uses of resources. For this reason, Option B

proponents offer only tentative support for the concept of establishing a humpback chub refuge outside of Grand Canyon.
The proponents of this option are concerned that any moves towards propagation and/or augmentation of the wild humpback chub population divert energies and resources from protection and improvement of the natural habitat and wild population. For this reason Option B proponents do not propose propagation, augmentation, or planning for augmentation.

Option C: Same as Option A

Summary Table

Table 4.2. Summary comparison of nonflow-related resource effects estimated for four options under consideration by the Glen Canyon Dam Adaptive Management Program compared to BASE operations (modified low fluctuating flow). The table provides, where possible, the potential effects of each option on individual resources are ranked 1 (most) through 4 (least) where possible.

	Option A	**Option A Variation**	**Option B**	**Option C**
TEMPERATURE CONTROL DEVICE				
Water temperature				
Water Temperatures (mainstem) (based on numerical modeling)	Increase over BASE by about 4 – 5 ºC in summer/fall, on average	Increase over BASE by about 4 – 5 ºC in summer/fall, on average	Increase over BASE by about 4 – 5 ºC in summer/fall, on average	Increase over BASE by about 4 – 5 ºC in summer/fall, on average
Water Temperatures (nearshore) (based on existing data and state-of-knowledge)	Increase over BASE similar to mainstem	Increase over BASE similar to mainstem	Increase over BASE similar to mainstem plus enhanced warming nearshore most of the year	Increase over BASE similar to mainstem plus enhanced warming nearshore in Sep – Oct
Fine-sediment storage				
Fine-sediment storage	Potential increase; significant uncertainty in magnitude	Potential increase; significant uncertainty in magnitude	Potential increase; significant uncertainty in magnitude	Potential increase; significant uncertainty in magnitude
Aquatic food base				
Aquatic Food Base (Glen Canyon)	Annual productivity likely increases	Annual productivity likely increases	Annual productivity likely increases	Annual productivity likely increases
Aquatic Food Base (Grand Canyon)	Annual productivity likely increases	Annual productivity likely increases	Annual productivity likely increases	Annual productivity likely increases
Adult fish populations				
Adult Population (HBC)	May increase	May increase	May increase	May increase
Other Natives	May increase	May increase	May increase	May increase
Adult Population (RBT #'s in Glen Canyon)	Likely decreases	Likely decreases	Likely increases	Likely increases

Adult Population (RBT size in Glen Canyon)	Likely increases	Likely increases	Likely decreases	Likely decreases
Mainstem spawning and incubation				
Mainstem Spawning & Incubation (HBC)	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely
Other natives	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely
Mainstem Spawning & Incubation (RBT – Glen Canyon)	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely	Increased spawning success likely
YOY/Juvenile nearshore rearing				
YOY/Juvenile Nearshore Rearing (HBC)	Increased rearing success likely	Increased rearing success likely	Increased rearing success likely (threats from predation could increase)	Increased rearing success likely (threats from predation could increase)
YOY/Juvenile Nearshore Rearing (Other natives)	Increased rearing success likely	Increased rearing success likely	Increased rearing success likely (threats from predation could increase)	Increased rearing success likely (threats from predation could increase)
YOY/Juvenile Nearshore Rearing (RBT – Glen Canyon)	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success
Invasive Fish Species (coldwater species downstream)	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success
Invasive Fish Species (warmwater species)	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success	Increased potential for rearing success
Disease (Asian Tapeworm)	Infestation may increase	Infestation may increase	Infestation may increase	Infestation may increase
Disease (Whirling Disease)	No change	No change	No change	No change
Terrestrial riparian resources				
Marsh and obligate riparian vegetation (below 25,000 cfs)	May increase, but unknown	May increase, but unknown	May increase, but unknown	May increase, but unknown
Lower Riparian Habitat (25,000 to 45,000 cfs)	No effect expected, but unknown	No effect expected, but unknown	No effect expected, but unknown	No effect expected, but unknown
Upper Riparian Habitat (45,000 to 60,000 cfs)	No effect expected	No effect expected	No effect expected	No effect expected
Recreational Resources				
Angling opportunity, quality, and access	Likely improves	Likely improves	Likely improves	Likely improves
Quality of water and human health	Possibly deteriorates	Possibly deteriorates	Likely deteriorates	Possibly deteriorates
Visitor Safety	Improves	Improves	Improves	Improves
Recreational Experience Quality	Likely improves	Likely improves	Likely improves	Likely improves
DOWNSTREAM NONNATIVE FISH CONTROL				
Aquatic food base				
Aquatic Food Base	No change	No change	No change	No change

(Glen Canyon)				
Aquatic Food Base (Grand Canyon)	May increase	May increase	May increase	May increase
Adult Fish Populations				
Adult Population (HBC)	Unknown	Unknown	Unknown	Unknown
Other Natives	Unknown	Unknown	Unknown	Unknown
Adult Population (RBT #'s in Glen canyon)	Unknown	Unknown	Unknown	Unknown
Adult Population (RBT size in Glen Canyon)	Unknown	Unknown	Unknown	Unknown
Mainstem spawning and incubation				
Mainstem Spawning & Incubation (HBC)	Likely increases	Likely increases	Likely increases	Likely increases
Other natives	Likely increases	Likely increases	Likely increases	Likely increases
Mainstem Spawning & Incubation (RBT – Glen Canyon)	Unknown	Unknown	Unknown	Unknown
YOY/Juvenile nearshore rearing				
YOY/Juvenile Nearshore Rearing (HBC)	Likely increases	Likely increases	Likely increases	Likely increases
YOY/Juvenile Nearshore Rearing (Other natives)	Likely increases	Likely increases	Likely increases	Likely increases
YOY/Juvenile Nearshore Rearing (RBT - Glen)	Unknown	Unknown	Unknown	Unknown
Invasive Fish Species (cold water species downstream)	Decreases	Decreases	Decreases	Decreases
Invasive Fish Species (warm species)	Decreases	Decreases	Decreases	Decreases
Recreational Resources				
Angling opportunity, quality, and access	Decreases	Decreases	Decreases	Decreases
Recreational Experience Quality	Decreases angling opportunity; possible impact to wilderness experience values	Decreases angling opportunity; possible impact to wilderness experience values	Decreases angling; possible impact to wilderness experience values opportunity	Decreases angling; possible impact to wilderness experience values opportunity
Traditional cultural properties	Potentially detrimental	Potentially detrimental	Potentially detrimental	Potentially detrimental
TRANSLOCATION OF HUMPBACK CHUB				
Adult HBC	Likely increase	Likely increase	Same as BASE	Likely increase, if implemented

Adult; Other natives	Unknown	Unknown	Same as BASE	Unknown
Mainstem spawning and incubation - HBC	Unknown	Unknown	Same as BASE	May improve if implemented
Invasive fish species – coldwater	Decrease	Decrease	Same as BASE	May decrease if implemented
Angling opportunity, quality, and access	Likely no impact	Likely no impact	Same as BASE	Likely no impact
Traditional cultural properties	Potentially detrimental	Potentially detrimental	Potentially detrimental	Potentially detrimental
HUMPBACK CHUB REFUGE, PROPAGATION, AND GENETICS MANAGEMENT PLANNING				
HBC	Increased security	Increased security	Same as BASE	Increased security

Chapter 5: Evaluation of Proposed Experimental Designs

Introduction

A fundamental tenet of adaptive management is "learning by doing," or using science to determine the cause-and-effect relationship among natural events, anthropogenic change, and/or experimental treatments in relation to desired resource conditions. This tenet is reflected in the specific approach to adaptive management that is articulated in the Glen Canyon Dam Adaptive Management Program (GCDAMP) Strategic Plan, which is as follows:

1. Models are developed to reveal the potential effects of policies, activities, or practices that are being considered for implementation;

2. Questions are formulated as testable hypotheses regarding the expected responses or linkages of the Colorado River ecosystem to dam operations and other management actions;

3. Experiments are conducted to test hypotheses and answer questions;

4. Management activities reveal, through monitoring and evaluation of results, the accuracy or completeness of the earlier predictions; and

5. New knowledge and information produced through experimentation are incorporated into management discussions and recommendations to the Secretary of the Interior.

As defined in the GCDAMP strategic science plan and monitoring and research plan, long-term experimental activities are a suite of flow and nonflow treatments and/or management actions designed to improve the condition of target resources (e.g., humpback chub, cultural sites, sandbars, etc.) *and,* through monitoring and research, improve the understanding the relationship between treatments/management actions and target resources. Designing experiments that yield statistically valid results is a major challenge in the Colorado River ecosystem (CRE) where variability is high and unpredictable owing to a variety of factors such as changing basin hydrology and water quality, climate change, and introductions of nonnative species. However, a properly designed experimental program implemented over a long time frame is more likely to yield more definitive information on the relationship between specific actions and the condition of target resources.

Chapters 3 and 4 address the likely effect of the experimental options on the condition of target resources in the CRE. The purpose of this section is to evaluate the general strengths and weaknesses of each option with respect to their likelihood to yield information that will improve the understanding the relationship between proposed treatments/management actions and target resources. The strengths and weaknesses of the proposed experimental design or approach associated for each option are evaluated relative to the amount of learning that is likely to occur under each of the proposed options.

Option A and Option A Variation Experimental Design

The approach employed by Options A and A Variation is referred to as a reverse titration, meaning that a suite of management actions or experiments are implemented as soon as feasible to achieve resource benefits. Table 5.1 illustrates the timing for implementation of various actions over time. Resource response would be evaluated through ongoing monitoring programs. Then, following an assessment, treatments will be systematically removed one at a time under continued monitoring until benefits are observed to diminish (learning by undoing). Under Options A and A Variation, the priority goal is to achieve positive resource responses for a number of resources, but especially hydropower, rainbow trout, and humpback chub; understanding the relationship between actions and resource responses is a secondary priority. The option includes several so called mini experiments to better understand the fate of young humpback chub in the mainstem, use of BHBFs to conserve sand resources, and use of fluctuating flows to suppress trout reproduction. The purpose of the mini experiments is to determine the effectiveness of these actions, before being implemented as management actions.

Strengths

1. Tests implementation of a suite of actions on overall resource responses, including:
    a. Wider flow fluctuations with associated hydropower generation benefits
    b. Steeper ramping rates with associated hydropower generation benefits
    c. Minimum flows to protect food base
    d. Implementation of a temperature control device (TCD) to elevate mainstem water temperatures and promote humpback chub spawning and recruitment
    e. Nonnative fish management to reduce predation on and competition with native fishes
    f. Translocation of humpback chub to other tributaries in the Grand Canyon to provide insurance against population loss

Weaknesses

1. The approach presumes, contrary to conclusions contained in the knowledge assessment report, that the actions needed to achieve GCDAMP goals are known
2. The approach of simultaneously implementing multiple management actions or "mini experiments" will greatly confound the ability to assess the effectiveness of specific management or experimental actions for achieving a desired resource response
3. Implementing a new flow regime and other actions at this time will confound the assessment of the effects of elevated water temperatures and reduced trout populations on native and nonnative fishes under BASE operations.
4. The option provides for no testing of steady flows to protect/restore downstream resources
5. There is no basis in the literature for the reverse titration concept. GCMRC is unaware of how the effects of removing an action could be evaluated statistically.

Option B Experimental Design

The Option B experimental approach is referred to as a factorial research design where several treatments would be systematically implemented over a 7-year period and then replicated under different hydrologic conditions for an additional 7 years. The factorial approach is intended to provide the greatest possible degree of statistical rigor under large-scale field experimental conditions while limiting confounding effects. Option B is aimed primarily at testing the effects of steady flows and increased water temperatures in combination with several other treatments (BHBF, nonnative fish control) on target resources. Table 2.1 illustrates Option B's proposed plan for implementing steady/fluctuating flows and BHBFs over time. Specification of how nonnative fish control and implementation/operation of a TCD will be factored into the design is not provided.

Strengths

1. Incrementally tests the effects of progressively longer periods of stable flows (habitat stability) and increased water temperatures in combination with other treatments (nonnative fish management, BHBF, etc) on target resources (humpback chub, camping beaches, archeological sites, food base, etc). Option B includes implementation of a TCD.
2. The proposed design provides for testing under two hydrologic scenarios (i.e., replication of the experiment over period of 14 years).
3. Provides a robust test of the effects of steady flows (habitat stability) on target resources (humpback chub, camping beaches, food base, etc) by implementing progressively longer periods of stable flows

Weaknesses

1. Natural factors may confound the results of the experiment
2. Implementing a new flow regime at this time will confound the ongoing assessment of the effects of elevated water temperatures and mechanically reduced trout populations on native and non native fishes.
3. The option does not include testing of the effects of wider fluctuating flows on hydropower resources and downstream resources
4. Length (2 years) and timing of steady flow increments may not be sufficient to evaluate the effectiveness on target resources, particularly if hydrologic conditions vary significantly between years.
5. Specification of how non native fish control and implementation/operation of a TCD will be factored into the experimental design is not provided.

Option C Experimental Design

Option C proposes implementation of various treatments over three 5-year phases. The experimental approach is referred to as a forward titration whereby new treatments would be added incrementally to improve knowledge of the relationships among treatments and the resources affected by those treatments. For example, steady flows in September and October would be implemented in segment 1, a TCD in segment 2, and an August steady flow trigger to benefit young humpback chub in segment 3, if needed. The services of a biostatistician would be employed to identify more specifically how this design would actually be implemented. None of the treatments proposed under option C are consider "management actions" in recognition of the large degree of uncertainty associated with the effects of most actions as identified in the 2005 knowledge assessment. Option C specifically incorporates assessments, and adaptation at 5 year intervals, of relevant findings of a new The State of the Colorado River Ecosystem in Grand Canyon (SCORE) report and knowledge assessment. Option C does not support mini experiments until they are analyzed for their confounding effects on the main experiment.

Strengths

1. Tests implementation of a series of treatments to improve knowledge of the relationships among treatments and the resources affected by those actions, including:
    a. September/October steady flows to provide habitat stability and benefit humpback chub
    b. Possible August steady flow trigger to benefit HBC recruitment
    c. Wider fluctuations December to February to benefit hydropower
    d. Relaxed ramping rates in 9 months to benefit hydropower
    e. BHBFs to conserve sand resources.
    f. Implementation of a TCD to elevate mainstem water temperatures and promote HBC spawning and recruitment
    g. Nonnative fish management to minimize competition/predation with native fish
2. Includes a formal review at 5 year interval based on updated SCORE report and knowledge assessment
3. Limits implementation of treatments and mini experiments that may confound the results of the experiment (e.g., translocation)

Weaknesses

1. Natural factors may confound the results of the experiments
2. Implementing a new flow regime at this time will confound the ongoing assessment of the effects of elevated water temperatures and reduced trout populations on native and non native fishes.
3. Specific details on implementation of various treatments using the forward titration design are not provided. The scientific/statistical basis for forward titration concept is unclear.

Table 5.1 Experimental program elements under Options A and A Variation from 2007 to 2016, with prior treatments shown for 201 through 2006[1].

Water Year	Dominant Dam Operation	Mechanical Removal	Temperature Control Device (TCD)	Beach/Habitat Building Flow	Humpback Chub Comprehensive Plan Research	Humpback Chub Comprehensive Plan Habitat
2001	MLFF only	No removal	No TCD	No BHBF	No activities	No activities
2002	Same as previous	No removal	No TCD	No BHBF	No activities	No activities
2003	MLFF with experimental fluctuating flows	Trout removal	No TCD	No BHBF	No activities	No activities
2004	Same as previous	Same as previous	No TCD	No BHBF	No activities	No activities
2005	MLFF with experimental fluctuating flows and fall testing	Same as previous	No TCD	Fall BHBF	No activities	No activities
2006	Modified MLFF [see text for description][2]	Trout and possibly warmwater species removal[3]	Complete Draft EIS/BO	Fall BHBF dependent on sediment input from Paria and Little Colorado Rivers	Research and development of augmentation approach	Expansion of humpback chub habitat (e.g., translocation to Colorado River tributaries)
2007	Same as previous	Same as previous	Complete FEIS/BO	Same as previous	Same as previous	Same as previous
2008	Same as previous	Same as previous	Initiate construction	Same as previous	Same as previous	Same as previous
2009	Same as previous	Same as previous	Continue construction	Same as previous	Continue research or begin implementation if appropriate	Same as previous
2010	Same as previous	Same as previous	TCD operations	Same as previous	Same as previous	Same as previous
2011-2016	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous	Same as previous

[1] Orange indicates element not implemented, green indicates element is implemented during a particular year. MLFF = modified low fluctuating flow alternative, BHBF = beach/habitat building flow.

[2] Modifications relative to ROD flows include lower minimum flows during weekdays, but relatively higher minimum flows on Sundays with flows never dropping as low as ROD flows on Sundays; faster downramp rates; and experimentation with summer stranding flows and fall flows.

[3] Adaptively managed to be shifted to control of warmwater nonnative species as necessary.

Chapter 6: Scientific "Take Home" Points for Selecting an Experimental Option

Given the information presented in the first five chapters of this report, it is clear that the selection of an experimental option and an experimental design is not simple. Decision makers must make their choice in the face of scientific uncertainty, and the need to balance scientific learning against potential resource benefit, while also considering cost and legal and policy concerns. Additionally, a great deal rests on this decision: How will Glen Canyon Dam be operated for the next 5 to 20 years? Given the scientific expertise of the Grand Canyon Monitoring and Research (GCMRC), and the fact that it has not advanced one of its own experimental option alternatives, GCMRC has the ability and responsibility to provide decision makers with some important insights and recommendations relevant to the selection of an experimental option.

The complexity, and associated uncertainty, confronted when attempting to evaluate the net outcome of any one of the proposed experimental option makes it difficult for scientists to recommend one of the four options over the others. Additional confounding influences, such as climate change, only magnify the uncertainty. The need for experimentation comes when predictions cannot be made within bounds of acceptable risk and uncertainty, yet knowledge is still required to support decisions. As the Colorado River ecosystem continues to integrate all of the forces acting on it, one important goal of the science providers is to fully integrate efforts to study experimental treatments that managers have at their disposal, such as artificial floods or a temperature control device. One element of the science program that can foster such integration during and between treatments is a well integrated monitoring program that is linked with ongoing conceptual modeling and research. The foundations for both of these have been established within the adaptive management program over the last decade.

The primary "take home" points that GCMRC developed in the course of preparing this document are related to sound ecosystem science practices. GCMRC's recommendations are also informed by its extensive experience with the research that has been undertaken over the past decade for the Colorado River ecosystem. Ultimately, selecting an experimental approach is tied to one or more value based-decisions; however, GCMRC provides the following recommendations with the intention of providing a few scientific insights.

1. Complete the Current Experiment

GCMRC recommends that managers continue implementing the modified low fluctuating flow (MLFF) regime for at least another 2–4 years. Such a strategy will provide scientists with the time and data required to fully evaluate the biological responses tied to experimental treatments (mechanical removal of nonnatives) and natural variability (water temperature) imposed on the river ecosystem during 2003 through 2006.

Following years of heated public debate concerning the operation of Glen Canyon Dam, the 1996 Record of Decision selected the MLFF regime as a means of permitting "recovery and long-term sustainability of downstream resources while limiting hydropower capacity and flexibility only to the extent necessary to a achieve recovery and long-term sustainability." Based on data that has been gathered and analyzed by GCMRC to date it is unclear whether MLFF has achieved this goal. The State of the Colorado River Ecosystem in Grand Canyon (SCORE; Gloss and others, 2005) report provided a 10-year progress report that suggested that several of the predictions contained in the final environmental impact statement (final EIS) had not yet been realized. However, the report also identified several issues that remained unresolved. One issue was whether sediment conservation goals could be realized using beach/habitat-building flows (BHBF) under tributary enriched sand supply conditions and continued MLFF operations. This issue will only be resolved through additional BHBF testing under MLFF operating regime.

The evaluation of MLFF as it relates to humpback chub conservation is still a work in progress. For example, data published since the SCORE report was finalized indicate that the humpback chub population has stabilized over the past 4 years at about 5,500 adult fish. These findings are in sharp contrast to the SCORE report finding and suggest that it may be possible to support a self-sustaining population of humpback chub in the Grand Canyon under a MLFF regime. A major experiment was completed in 2006 in which over 90% of the trout population in the vicinity of the Little Colorado River was removed mechanically. In addition, beginning in 2002, water temperatures in the Colorado River have undergone significant warming owing to drought conditions which results in warmer releases from Glen Canyon Dam. Within the next 2–4 years, the effects of these actions on humpback chub recruitment will become evident based on the results of ongoing monitoring programs. Changing to an alternative flow regime will provide a potentially confounding influence on the scientific interpretation of the effects of mechanical removal and natural warming under the MLFF regime.

2. Evaluate Experiments Relative to Managers' Future Desired Conditions

Members of the Adaptive Management Work Group recently asked: "What is the Best Flow Regime?" Presumably, the best operating regime for Glen Canyon Dam would be one that best meets all of the management objectives for both upstream and downstream resources, but this question cannot be answered by scientists unless managers provide clearly defined resource response conditions that are both measurable and attainable.

Managers are responsible for deciding objectives for desired future resource conditions. Scientists can provide managers with a range of viable alternatives for trying to achieve the desired downstream conditions, but the performance measures must be clearly identified and associated with measurable responses. Most important of all, the objectives must be achievable within this highly altered ecosystem. Adaptive Management identifies all management policies as experiments owing to uncertainty in ecosystem response. To be meaningful to resource managers, a dam operating regime worthy of the effort expended for scientific evaluation must have potential for benefiting downstream resources while also maintaining other pre-existing resources or values. To address GCDAMP managers' needs it seems most responsive that evaluations focus on potential resource benefits that are documented to occur under a fluctuating flow regime (presumably, the MLFF since it was selected as the preferred alternative). Future evaluations should therefore be made in conjunction with a flow regime that can be implemented long term under the natural range of hydrologic flow conditions that occur in the upper Colorado River Basin and within the physical and legal dam operating criteria that constrain managers. If desired future conditions are defined, but cannot be achieved under MLFF or alternative fluctuating flows, then either new flow constraints need to be considered (e.g., stable flow testing) or nonflow alternatives for achieving downstream resource objectives will require consideration, such as sediment augmentation strategies for sustainable sandbar restoration. Unfortunately, a full evaluation of the MLFF regime is not yet completed, particularly with respect to biological responses.

3. Implement and Scientifically Test a Temperature Control Device

Whatever experimental option is selected, the GCMRC maintains that it should include a science strategy for resolving the issue of temperature as a limiting factor in humpback chub life history. The rationale for such testing is tied to a need to better understand early humpback chub life history in the main channel, as well as potential influences on recreational safety, primary and secondary productivity in the food web, etc.

All of the four experimental options include construction and testing of a temperature control device (TCD) with two or more units at Glen Canyon Dam. The GCMRC cannot predict the ultimate ecosystem response to implementation of a TCD at Glen Canyon Dam, but if such a device were available for testing, then it could illuminate questions about the role of cold water in limiting the early life survival of native fishes. The Science Advisors echoed the need for such testing in 2003, as did the participants in the 2005 knowledge assessment workshop. Simulation results for a two-unit TCD presented in chapter 4 indicate that such a device will likely result in significantly warmer temperatures in the main channel below Glen Canyon Dam, especially during periods of minimal annual releases. The TCD simulation provides a sharp contrast compared to flow-only strategies.

Recommendations forwarded by the Science Advisors in their 2003 report should be considered carefully as a TCD science plan is developed and implemented. This would include proceeding cautiously with tests and with anticipation that warmer water may result in undesired benefits to warmwater adapted nonnative fishes, parasites, and diseases. The GCMRC recommends that testing should be conducted under a flexible design which allows the device to be turned on and off on basis of findings and results related to fishery responses. Research and development of a program aimed at warmwater, nonnative fishes control is strongly advised by scientists. Both in terms of cost and ecosystem risk, scientists have identified this experimental element as one that requires perhaps the greatest level of planning, model support, and statistical rigor.

4. Continue Testing of Sand-Enriched BHBFs

Resolving whether or not tributary sand-enriched beach/habitat-building flows achieve sediment conservation should be a high priority. Testing should be continued under recommendations by sediment scientists as opportunities of tributary sand enrichment occur.

Because managers have identified a priority need to know more about the loss of sediment in the Colorado River ecosystem and implications associated with ongoing erosion of sand habitats, the GCMRC recommends that testing of BHBFs under tributary-enriched sand supplies should proceed as opportunities occur. This recommendation was also made during summer 2006 by the protocol evaluation panel on sediment resources (SEDS-PEPIII; Wohl and others, 2006, written communication). In addition, the high costs identified in a recent draft report on the feasibility of sediment augmentation from upstream sources to the Colorado River ecosystem (Randle and others, in review), suggest that all feasible flow strategies for sandbar restoration and maintenance using downstream tributary sand supplies need to be evaluated before importing additional sediment is considered.

5. Consider the Role of Hydrologic Variability and Dam Operating Constraints

Variation in natural hydrology of the upper Colorado River Basin and its further expression through physically constrained dam operations may "mask" the influence of flows associated with all of the proposed experimental options being currently considered.
While the differences between operations may be clear during years with minimal release volumes, these differences may be greatly reduced when annual release volumes increase because of wetter basin hydrology. The response of some or all downstream resources may actually be affected more by variation in basin hydrology and dam operating constraints than by the releases under any specific dam operating regime over decade-long timescales. One example of the possible influence of natural variability is presently occurring with respect to elevated water temperatures released from the dam. The influence of the drought that has decreased storage in Lake Powell since 2000 may be more of a significant treatment effect than MLFF or nonnative removal effects during the 2003–6 experiment.

6. Attempt to Limit Confounding Variables

To the degree that it is possible, GCMRC recommends that treatments (flow and nonflow) be isolated from one another to promote learning about causative responses to dam operations and other treatments. The GCMRC recommends taking a disciplined and structured approach to implementing new treatments.

Learning is an inherent part of the adaptive management strategy; one that is considered to have value to resource managers, especially if lessons about resource responses are transferable to other ecosystem settings. The challenge for learning is already great enough when scientist attempt to evaluate treatment responses under "field condition" experiments. Adding to the complexity through implementation of a "kitchen sink" approach, which has been referred to as "the fool's gamble" by Carl Walters, can lead to unexplained responses that may also be opposite to the desired resource benefit direction. Such dramatic experimentation is especially risky when the objects of the experiment are finite natural resources such as sediment or fish. Experiments that are designed with the goal of obtaining statistically rigorous results may require additional time and cost, but such results may also provide longer-lasting benefits to natural and cultural resources and those who manage those resources.

7. Approach Stable Flow Tests Logically

General evidence suggests that a more stable flow regime *may* benefit a variety of GCDAMP resources (i.e., humpback chub, rainbow trout, sand bars, food base, etc.); however, further testing is recommended to determine if such perceptions are in fact reality.

If increased recruitment of chub is not detected in the next several years, then it might be reasonable to conclude that testing of stable flows is the next logical flow treatment to implement for evaluation. Stable flows that are implemented prior to complete evaluation of chub response to the 2003–6 experimental treatment and natural variability in temperature may result in confounding of the evaluation while also resulting in unnecessary costs. If the "future desired conditions" for downstream resources of the Colorado River ecosystem can be achieved under the modified low fluctuating flow regime, then stable flow testing is presumably unnecessary.

8. Continue Model Development to Support Management Decision Making

Use of modeling can help eliminate false starts and blind paths for experimental evaluation. Flow, temperature, and sediment transport are prime areas where modeling has already provided planning-support benefits and as such should continue to be explored, defined, and supported regardless of which experimental option is recommended next.

To the extent possible, existing and future numerical models for the Colorado River ecosystem should be developed and tested by both scientists and managers. The flow and temperature models for the system have already been integrated and have allowed for the inclusion of decade-long evaluations of various experimental flow scenarios with and without a temperature control device in this report. Such simulation results provide new perspectives to both managers and scientists about the range of options available to manage temperatures in this river ecosystem.

The science recommendations outlined above cannot ensure absolute learning about cause-and-effect relationships among dam operations and downstream resource responses. Likewise, such recommendations cannot guarantee that resource benefits will be achieved below Glen Canyon Dam. However, taking an approach that attempts to build on the previous knowledge gained over the nearly two decades of available monitoring and research data may be the most effective strategy available to the Glen Canyon Dam Adaptive Management Program.

Building on learning about sediment conservation options derived from the 1996 and 2004 BHBF tests can presumably occur at the same rate that tributaries provide new sand supplies below the dam, but only if the tests are conducted in response to new sand deliveries. In the realm of fishery biology, learning may build on the data collected before, during, and after the significant period of 1999 through 2010, when the adult humpback chub population began to stabilize and the period of warmest dam releases in over 30 years commenced in parallel with the application of nonnative fish control. Only time and additional monitoring and modeling results will provide the basis for evaluating the outcome of this significant experiment. Such an evaluation may be best constrained by continuing the MLFF operation for the next few years as a means of providing continuity in understanding the influence of both flows, nonflow treatments and natural variability under a backdrop of the preferred alternative operating regime.

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Appendix A: Methods for Determining Flows

Development of Monthly Lake Powell Inflow and Release Sequences for the Assessment of Experimental Options

Overview

The Science Planning Group (SPG) was charged with completing an assessment of long-term experimental flow proposals for the operation of Glen Canyon Dam. Three long-term experimental flow proposals are being evaluated. These proposals are labeled: Option A, Option B, and Option C. Additionally, a fourth option, a variation of Option A, is also being analyzed.[1]

The SPG concluded that the proposals needed to be analyzed under a broad range of hydrologic scenarios. The agreed upon methodology was to study the effects under three 10-year hydrologic sequences: a dry sequence (90 percent exceedance), a most probable sequence (50 percent exceedance), and a wet sequence (10 percent exceedance).

The monthly release volumes for the three options were developed by the SPG under the assumption of an 8.23 million acre-feet (maf) water year release from Lake Powell. While over the past 6 years (2001 through 2006 inclusive) this has been the actual water year release from Lake Powell, studies using the Colorado River Simulation System (CRSS) model reveal that future releases will likely be greater than the 8.23 maf objective in approximately 50 percent of the years.

The CRSS model was used to develop the inflow and release sequences for the dry, most probable, and wet sequences. Input to the CRSS model includes monthly natural flow and current and future water demands throughout the Colorado River Basin. The Bureau of Reclamation (Reclamation) currently has 99 years of natural flow data (1906–2004) for use as input data. Colorado River reservoirs in the CRSS model behave according to policy rules that are created using RiverWare software.

Several methods are available for ascertaining the range of possible future inflows. In the Colorado River, a particular technique (called the Indexed Sequential Method) has been used since the early 1980s and involves a series of simulations, each applying a different future inflow sequence (USBR, 1985: Ouarda, *and others*, 1997). Each future inflow sequence is generated from the historical natural flow record by “cycling” through the record. For example, the first simulation assumes that the inflow for the 2007 through 2016 period will be the 1906 through 1915 historical record, the second simulation assumes the inflow for 2007 through 2016 will be the 1907 through 1916 historical record, and so on. As the method progresses, the historical record is assumed to “wrap-around” (i.e., after 2004, the record reverts back to 1906, yielding a possible 99 different inflow sequences). The result of the Indexed Sequential Method is a set of 99 separate simulations referred to as “traces.” This enables an evaluation of proposed criteria over a broad range of possible future hydrologic conditions. Evaluations can utilize all 99 traces

[1] These proposals are described in detail elsewhere in this assessment.

with statistical techniques, or alternatively, a set of analogues (a set of model traces) can be used to represent a range of future hydrologic conditions.

Development of the Dry, Most Probable, and Wet Sequences

A CRSS model run was performed on July 25, 2006. The initialization date for the model run was January 1, 2007. The initial conditions (storage in Colorado River reservoirs) used in the simulation were those values as predicted from Reclamation's July 2006 24-month study. The model was run for 19 years (2007 through 2025). A total of 99 traces were generated.

The policy rules in the CRSS model run were those consistent with Reclamation's "no action" rule set as of July 2007. It is important to note that an National Environmental Policy Act (NEPA) process which in part addresses the operation of Glen Canyon Dam is currently underway. A Draft Environmental Impact Statement (EIS), *Lower Colorado River Basin Shortage Guidelines and Coordinated Management Strategies for Lake Powell and Lake Mead* (Shortage EIS), is being prepared and contains alternatives which propose coordinated operations between Lake Powell and Lake Mead under low reservoir storage conditions. A possible outcome of the Shortage EIS is the implementation of operations at Lake Powell that deviate from no action. The draft Shortage EIS is scheduled to be released in February 2007. The final Shortage EIS is expected to be released in September 2007 with a Record of Decision completed in December 2007. Implementation of a coordinated operating strategy through this NEPA process could modify future annual release volumes from Lake Powell.

Lake Powell operations under the no action rule set in CRSS follow the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs. The objective to maintain a minimum release of 8.23 maf governs the operation when Lake Powell storage is lower than storage at Lake Mead or Upper Basin storage is below 602(a) storage.[2] Storage equalization releases (releases greater than 8.23 maf/year) are made to equalize storage between Lake Powell and Lake Mead on September 30, when Lake Powell is projected to be greater than storage in Lake Mead and Upper Basin storage is greater than 602(a) storage. Additionally, when Lake Powell fills, Lake Powell is operated under a spill avoidance strategy, whereby water is released in the January through June time frame to allow a July fill without the unnecessary spillage of water.

Three analogues (three model traces) representing the minimum probable (90 percent exceedance), most probable (50 percent exceedance), and maximum probable (10 percent exceedance) derived from the 99-trace CRSS simulation form the hydrologic basis for this assessment.

To develop the dry, most probable, and wet sequences, the average 10-year Lake Powell inflow volume from 2007 through 2016 (ten years) was calculated for all 99 traces. This average 10-year inflow ranged for a low of 7.70 maf to a high of 13.92 maf. The mean ten-year Lake Powell inflow for all 99 model traces was 10.26 maf.[3] The 10-year volumes were ranked. The dry, most

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[2] For further information on 602(a) storage, refer to *Adoption of an Interim 602(a) Storage Guideline Final Environmental Assessment* (March 2004) at http://www.usbr.gov/uc/library/envdocs/ea/pdfs/EA_602a.pdf.

[3] Simulated average inflow is less than the historical average inflow due to increasing water demands in the Upper Basin.

probable, and wet sequences were selected from the 90th, 50th, and 10th exceedance percentiles, respectively. The three selected analogues are displayed in Table A-1.

Table A-1
Dry, Most Probable, and Wet Lake Powell Inflow Sequences

	Dry Sequence	Most Probable Sequence	Wet Sequence
Exceedance Percentile	90 %	50 %	10 %
CRSS Numeric Trace	Trace 55	Trace 31	Trace 5
Analogue Period	1961–1970	1937–1946	1911–1920
Average Powell WY Inflow	8.56 maf	9.77 maf	12.8 maf

Plots of Lake Powell water year inflow for 10 years for the three hydrologic conditions (dry, most probable, and wet) are displayed in Figures A-1, A-2, and A-3.

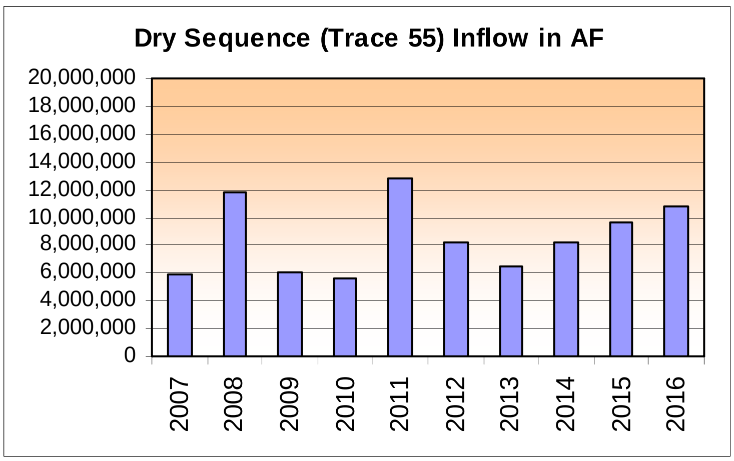

Figure A-1
Lake Powell Water Year Inflow for 2007 Through 2016 Under the Dry Sequence

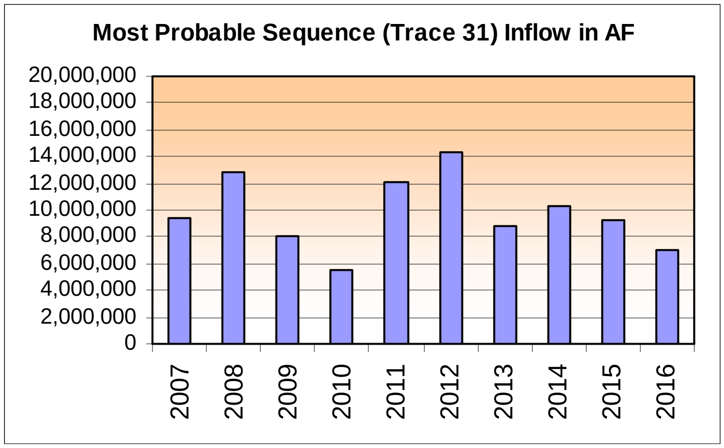

Figure A-2
Lake Powell Water Year Inflow for 2007 Through 2016 Under the Most Probable Sequence

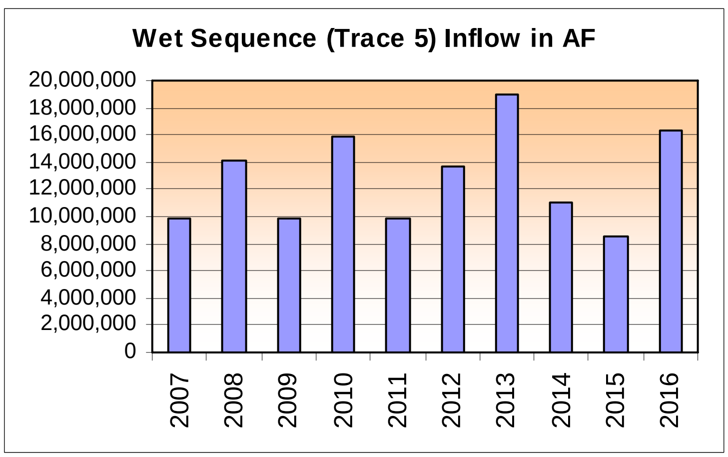

Figure A-3
Lake Powell Water Year Inflow for 2007 Through 2016 Under the Wet Sequence

Note that in all three sequences there is high degree of variability. The most probable sequence is a mix of average, above average, and below average inflow years. In the dry sequence, there are two years with above average inflow. In the wet sequence, 5 of the 10 years have average inflow, 4 have near average inflow, and one year has below average inflow.

After defining the three sequences, release data for Lake Powell for the 10-year period were extracted from CRSS output. The summation of these data for the three sequences, by water year, is displayed in Table A-2.

Table A-2
Lake Powell Water Year Release for 2007 Through 2016 Under the Dry, Most Probable, and Wet Sequences

Water Year Release	Dry Sequence	Most Probable Sequence	Wet Sequence
2007	8.23 maf	8.23 maf	8.23 maf
2008	8.23 maf	9.72 maf	11.43 maf
2009	8.23 maf	8.23 maf	8.89 maf
2010	8.23 maf	8.23 maf	13.23 maf
2011	8.23 maf	8.23 maf	9.59 maf
2012	8.23 maf	11.96 maf	11.37 maf
2013	8.23 maf	8.61 maf	14.11 maf
2014	8.23 maf	9.71 maf	10.74 maf
2015	8.23 maf	8.38 maf	8.72 maf
2016	8.23 maf	8.23 maf	14.96 maf

Under the dry sequence, there are no years in the next 10-year period where storage equalization releases would be required. Under the dry sequence, simulated releases from Lake Powell are 8.23 maf each year for the period 1907–1916.

Under the most probable sequence, inflow is sufficient enough that in half of the years storage equalization releases (releases greater than 8.23 maf) would be required. It is likely that over the next ten years, there will be a number of years with releases greater than 8.23 maf.

Under the wet sequence, releases greater than 8.23 maf would occur in all but the first year. Under this sequence, Lake Powell would fill in the years 2012, 2013, 2014, and 2016.

Monthly Release Volumes from Lake Powell

The assessment evaluates proposed changes in monthly release volumes in addition to proposed modifications to the Glen Canyon Operating Criteria (developed from the 1996 Glen Canyon Dam Operations EIS Record of Decision).

The monthly release volumes from CRSS for the dry, most probable, and wet sequences for the 10-year period 2007 through 2016 form the “base case” for this assessment.

The no action rule set in CRSS contains a default monthly release pattern for years when the annual target release is 8.23 maf. This pattern is shown in Table A-3 with monthly release volumes listed in thousand acre-feet (kaf).

Table A-3
CRSS (Base Case) Monthly Releases Under an 8.23 maf Water Year

Month	Base Case Monthly Release (kaf) (8.23 maf water years)
October	600
November	600
December	800
January	800
February	600
March	600
April	600
May	600
June	650
July	850
August	900
September	630

For Option A (and the variation of Option A), monthly releases are equivalent with the above table in an 8.23 maf release year. The proponents of Option A deferred to Reclamation to produce monthly release volumes. The emphasis of Option A (and its variation) is on modified powerplant operations within the month. The monthly releases for Option A (and the variation) are identical to the base case in this assessment not only in 8.23 maf release years, but for all years regardless of whether the operation is controlled by the minimum release objective or equalization.

The monthly release pattern for Options B and C, as mentioned earlier, is based on an 8.23 maf water year release. The monthly release patterns differ from the base case in Options B and C.[4] In addition, the monthly pattern in Option B changes from year to year. A challenge in the development of monthly releases for Options B and C was the patterning of monthly releases in years controlled by equalization, and to also assure that the total water year release is the same for all options for any given year.

In years when Glen Canyon's operation is controlled by equalization, post processing of the output data for Options B and C was performed to assure that the annual release did not deviate from the base case, and that the objective to equalize storage between Lakes Powell and Mead on September 30 was satisfied when Glen Canyon operations were controlled by equalization.

The CRSS model contains methods for distributing releases greater than 8.23 maf required for equalization. The CRSS mimics the actual operation of Lake Powell. In actual operations, inflow projections, Lake Powell storage, and upstream storage are factored to determine when to schedule equalization releases. In the CRSS model, a simulated forecast (which contains error and uncertainty terms reflecting historical forecast errors) is used in conjunction with projected

[4] The monthly release pattern for Options B and C are described elsewhere in this assessment.

operation of reservoirs above Lake Powell to forecast September 30 storage at Lake Powell. The CRSS model also projects September 30 storage at Lake Mead. Equalization releases, releases greater than 8.23 maf, are scheduled when Upper Basin Storage is greater than 602(a) storage and when Lake Powell storage would end up greater than storage in Lake Mead should the minimum objective release be maintained.

The CRSS model begins scheduling equalization releases as early as January. In actual operations, January is when the first water supply inflow forecast is disseminated by the National Weather Service. Similarly, in CRSS, January is the first month when a simulated inflow forecast is developed. In CRSS, equalization releases are scheduled when the simulated forecast in combination with projected storage at Lakes Powell and Mead shows that releases greater than 8.23 maf are required. CRSS determines the volume greater than 8.23 maf required for release and distributes this volume evenly across the months between the current month and September. For example, in January if the model determines that 900 kaf of equalization release is required (for a total water year release of 9.13 maf), an additional 100 kaf of water is scheduled in each of the nine months from January through September. In examining CRSS output, however, one never sees an even distribution of equalization across the months. That is because in the subsequent time step (the next month), the simulated inflow forecast changes (just as actual inflow forecasts change on a month-by-month basis). To follow up from the example before, one could potentially see a January that required 900 kaf of equalization release, but in the next model time step (February), the forecast could change requiring greater or lesser amounts of equalization release. The model would then adjust releases accordingly. The model output reflects uncertainty in water supply. This is consistent with actual operations where water supply forecasts are rarely static throughout the water year.

There was some discussion among the SPG as to how to pattern equalization releases in Options B and C. Proponents of these respective options discussed the benefit of scheduling equalization releases in the January through June time period, such that equalization releases in late summer and September were minimized. Such a qualitative adjustment is problematic for this assessment for a couple of reasons: (1) Inflow projections continue to shift in the late spring and summer months. Shifting equalization releases to the January through June time period while summer and September releases remain similar or equal to the 8.23 maf release monthly volume would result in not meeting the objective to equalize storage between Lakes Powell and Mead on September 30. In some years, Lake Powell would end up higher than Lake Mead with the reverse in others.[5] (2) CRSS scheduling for equalization releases does not optimize for the Glen Canyon Operating Criteria or power operations. There are times, for instance, when CRSS increases a June volume due to equalization. CRSS might schedule an extra 145 kaf to increase the monthly release from 650 to 795 kaf for the month. In actual operations, if the monthly volume was getting close to 800 kaf, some equalization release would be shifted from one month to another such that 800 kaf months (where the daily range of low to high flows increases from 6,000 cubic feet per second to 8,000 cubic feet per second) were achieved. If equalization releases were qualitatively adjusted in Options B and C, it follows that Option A equalization releases should also be adjusted from CRSS output.

[5] This is not likely an acceptable outcome given current diminished reservoir storage in Lake Powell and Lake Mead.

The resolution for handling equalization volumes in this assessment was to not deviate from the manner in which the CRSS model schedules equalization releases. For Option A, monthly releases are exactly as they are produced from CRSS. For Options B and C, a post processing method, “the CRSS Distribution Method,” was used to adjust monthly releases in equalization years. This method calculates the differential between the 8.23 maf monthly release and the CRSS produced equalization monthly release for the base case on a month-by-month basis. This differential for each month is then added to the 8.23 maf monthly release for Options B and C. In this way, the annual volumes remained the same for all options, and the monthly patterning of water for equalization is consistent across all of the options.

An example of the CRSS Distribution Method for year 2013 under the most probable sequence is shown in Table A-4. In this year, there is a small amount of equalization release required (a total of 382 kaf). Additionally in this example, CRSS keeps changing direction as to whether equalization is necessary as the model simulates on a month-by-month basis throughout the year.

Table A-4
Example of CRSS Distribution Method in 2013

WY 2013 Month	8.23 maf Base Case Rel (kaf)	CRSS Rel (kaf)	Delta	8.23 maf Opt B Rel (kaf)	Adjusted Option B Rel (kaf)	8.23 maf Option C Rel (kaf)	Adjusted Option C Rel (kaf)
Oct	600	600	0	615	615	500	500
Nov	600	600	0	595	595	650	650
Dec	800	800	0	615	615	800	800
Jan	800	983	183	615	798	800	983
Feb	600	698	98	555	653	675	773
Mar	600	571	-30	615	585	650	620
Apr	600	656	56	1101	1157	625	681
May	600	549	-51	861	810	625	574
Jun	650	595	-55	833	778	725	670
Jul	850	812	-37	615	578	825	788
Aug	900	1045	145	615	760	800	945
Sep	630	703	73	595	668	555	628
Total	8230	8612	382	8230	8612	8230	8612

Column “Delta” in the table is the difference between the 8.23 monthly pattern for the base case and CRSS output for the base case which includes adjustments for equalization. Note that some of the months have negative deltas. In the above example, equalization releases begin to be scheduled in January. In March, however, the model generates a lower inflow forecast whereby the model reverts to targeting an 8.23 maf release year. The only way to do this is to reduce releases below the 8.23 monthly pattern, because additional water has already been released in January and February.

The important point elucidated in the table is that monthly releases are adjusted in Options B and C to preserve the same uncertainty in forecasts as in the base case using the CRSS Distribution

Method. The volume in the "delta" column is added to the 8.23 monthly release in both Options B and C. This also preserves equal water year releases for all the options in all water years.

Figure A-4 shows monthly releases (for the most probable and dry sequence) for Option A. These monthly releases are derived directly from the CRSS model output and are also equivalent to the base case. Figures A-5 and A-6 depict monthly releases under Options B, and C. Monthly volumes in years requiring equalization were developed using the CRSS Distribution Method in Options B and C. Monthly releases for the dry sequence are also shown in Figures A-5 and A-6 to provide a reference for what releases would be in Option B and Option C under an 8.23 maf release year. Equalization releases are required in 2008, 2012, 2013, 2014, and 2015 under the most probable sequence. Releases in the following three figures are shown as average monthly flow in cubic feet per second (cfs). Note the varying patterns under which these equalization releases are made. The patterns reflect changing inflow forecasts within each of these years.

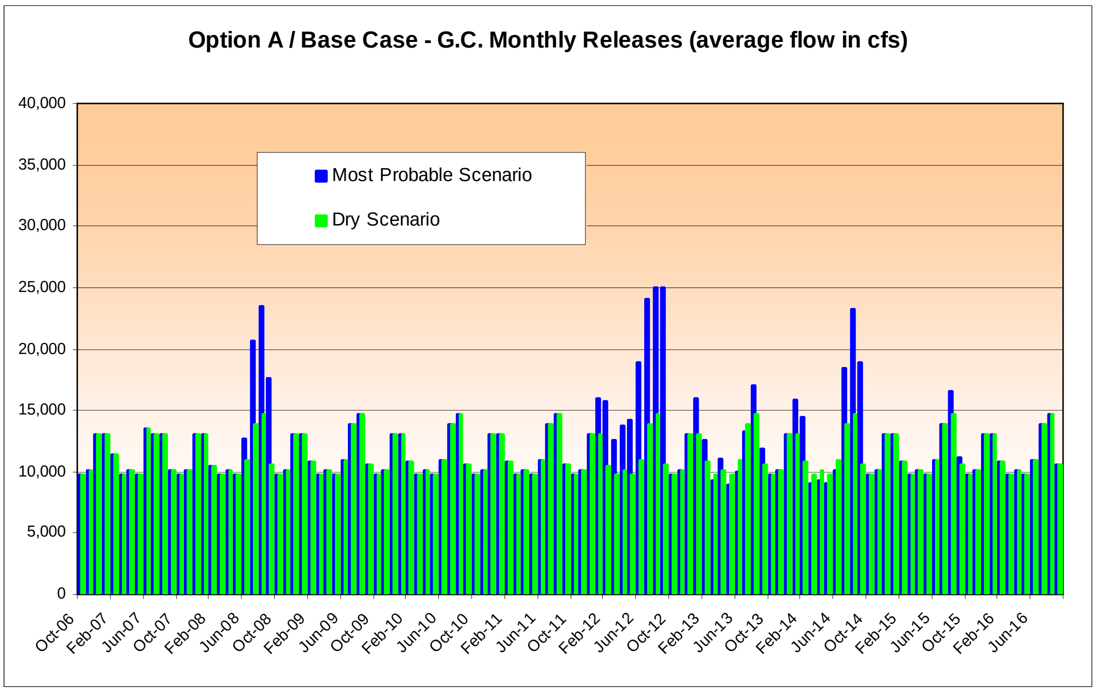

Figure A-4
Lake Powell Monthly Releases for the Dry and Most Probable Sequence for Option A

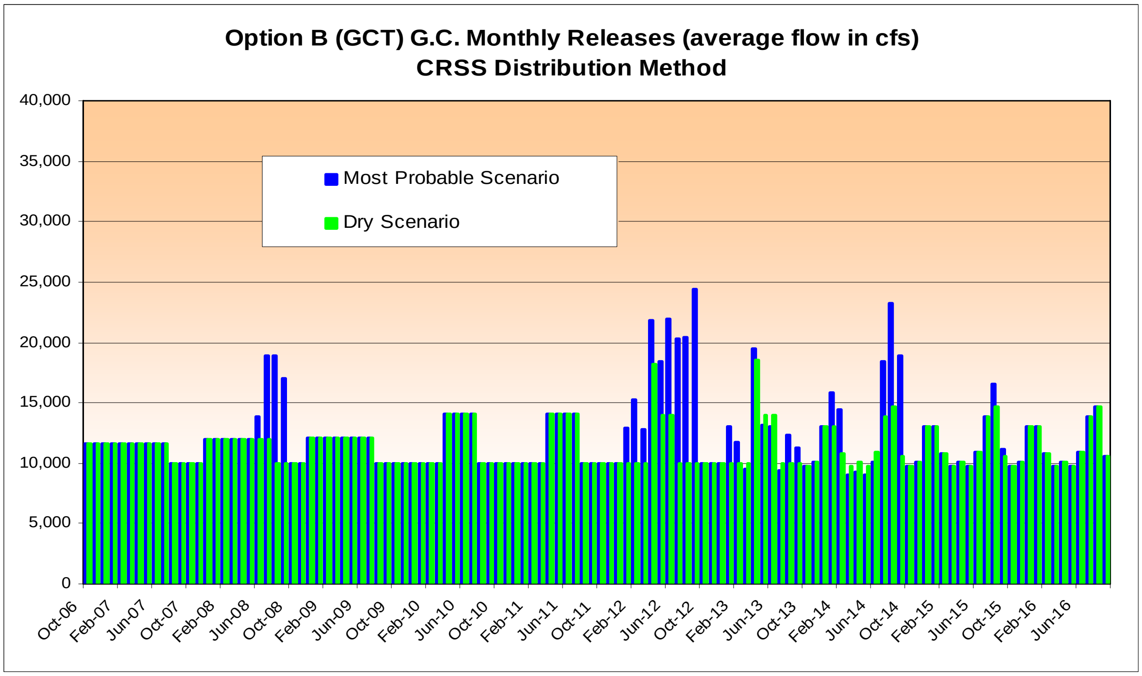

Figure A-5
Lake Powell Monthly Releases for the Dry and Most Probable Sequence for Option B Equalization Volumes Developed With the CRSS Distribution Method

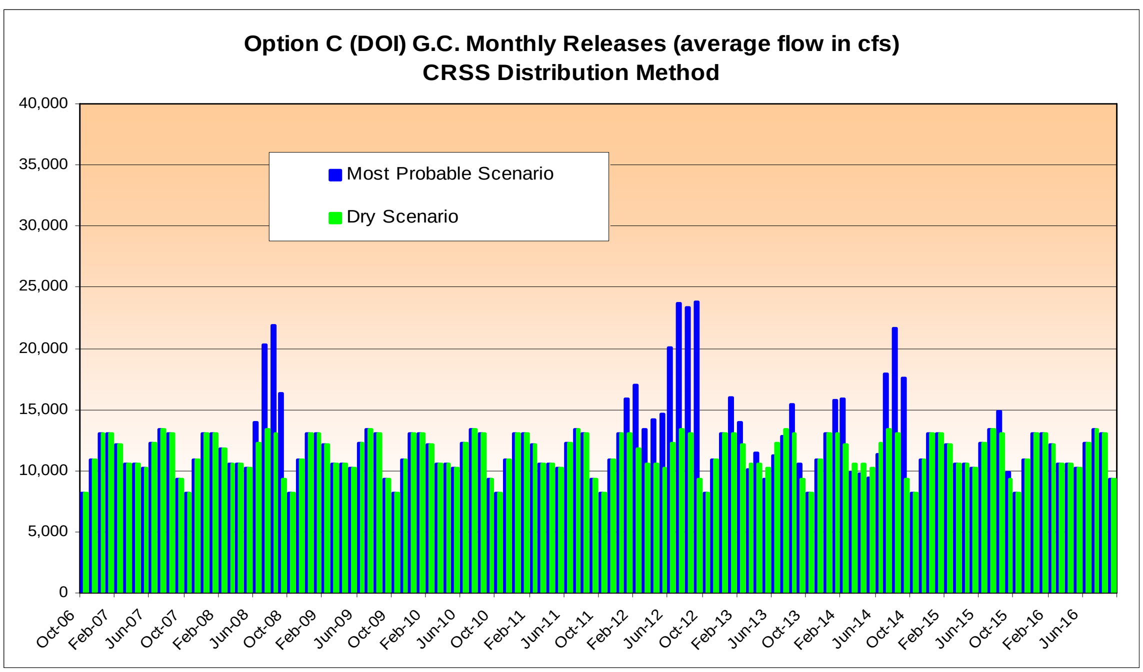

Figure A-6
Lake Powell Monthly Releases for the Dry and Most Probable Sequence for Option C Equalization Volumes Developed With the CRSS Distribution Method

It should also be noted that there will always be a difference between model simulations and actual operations. In actual operations, operational experience as well as other relevant factors not incorporated in the CRSS model are used. For instance, in the example of the simulation in 2013, shown in Table A-4 on page 8, releases were slightly below 600 kaf in three months (March, May, and June) under the base case. In actual practice, these release may have been maintained at 600 kaf. Actual equalization releases under an implementation of Options B or C would also likely have additional factors considered. For consistency in this assessment, the CRSS Distribution Method provides a valid method for comparing the various options.

Beach/Habitat Building Flows (BHBFs) Monthly Release Volumes from Lake Powell

A separate data set was developed to assess the effects of BHBFs (rather than use 10-year sequences for dry, most probable, and wet hydrologic conditions). Monthly volumes for BHBFs were developed for one year with two separate water year release volumes (an 8.23 maf release year and a 9.678 maf release year [an equalization year]). The year for analysis of the BHBFs was 2008.

Monthly volumes were developed for all three options for 2008 for three different BHBF events for both the 8.23 maf and 9.678 maf[6] release years. BHBFs were scheduled in either November, January, or March. An additional 200 kaf was added to the monthly release for months with BHBFs.

[6] The 9.678 maf release year was not an analogue. It was obtained by averaging the releases in the five years where there were equalization releases in the most probable sequence (years 2008, 2012, 2013, 2014, and 2015).

Table A-5 shows the monthly release distribution for a November BHBF for all three options under an 8.23 maf release year. For BHBFs in January and March, 200 kaf was added to January or March (instead of November) with the other monthly volumes remaining the same as listed in Table A-5.

Table A-5
BHBF Monthly Release Volumes in a 8.23 maf Year

WY 2008 Month	Option A 8.23 maf Release (kaf)	Option A change (kaf)	Option B 8.23 maf Release (kaf)	Option B change (kaf)	Option C 8.23 maf Release (kaf)	Option C change (kaf)
Oct	600	0	615	0	500	0
Nov	800	200	795	200	850	200
Dec	800	0	738	0	800	0
Jan	800	0	738	0	800	0
Feb	600	0	690	0	675	0
Mar	600	0	738	0	650	0
Apr	600	0	715	0	625	0
May	600	0	738	0	625	0
Jun	600	-50	715	0	600	-125
Jul	800	-50	738	0	800	-25
Aug	800	-100	515	-100	800	0
Sep	630	0	495	-100	505	-50
Total	8230	0	8230	0	8230	0

The monthly release distribution for a 9.678 maf release year with a November BHBF is shown in Table A-6. In the 9.678 maf release year, 50 kaf was taken out of the final four months of the water year (June through September) for all of the options. Distributions for January and March BHBFs were the same as shown above except that the added 200 kaf was added to January or March instead of November.

Table A-6
BHBF Monthly Release Volumes in a 9.678 maf Year

WY 2008 Month	Option A 9.678 maf Release (kaf)	Option A change (kaf)	Option B 9.678 maf Release (kaf)	Option B change (kaf)	Option C 9.678 maf Release (kaf)	Option C change (kaf)
Oct	600	0	615	0	500	0
Nov	800	200	795	200	850	200
Dec	800	0	738	0	800	0
Jan	906	0	844	0	906	0
Feb	721	0	811	0	796	0
Mar	619	0	757	0	669	0
Apr	645	0	760	0	670	0
May	635	0	773	0	660	0
Jun	695	-50	760	-50	770	-50
Jul	1058	-50	946	-50	1033	-50
Aug	1244	-50	959	-50	1144	-50
Sep	955	-50	920	-50	880	-50
Total	9678	0	9678	0	9678	0

Appendix B: Flow Variations

Summary of Hydrograph Parameters for Base and Options A, A Variation, B, and C – The following section summarizes basic differences in flows between the base case and the four experimental options, based on analysis of the 10-year hourly release hydrographs provided by Western Area Power Administration (WAPA). There are three sub-sections, one for each hydrologic scenario: minimum releases, most probable, and wet. For the minimum release hydrologic scenario all 10 years contain releases of 8.23 million acre-feet (MAF) annual water year volume; the most probable hydrology has 5 water years above 8.23 MAF and the wet hydrologic scenario has 9 water years above 8.23 MAF (see Fig. 1.1 below).

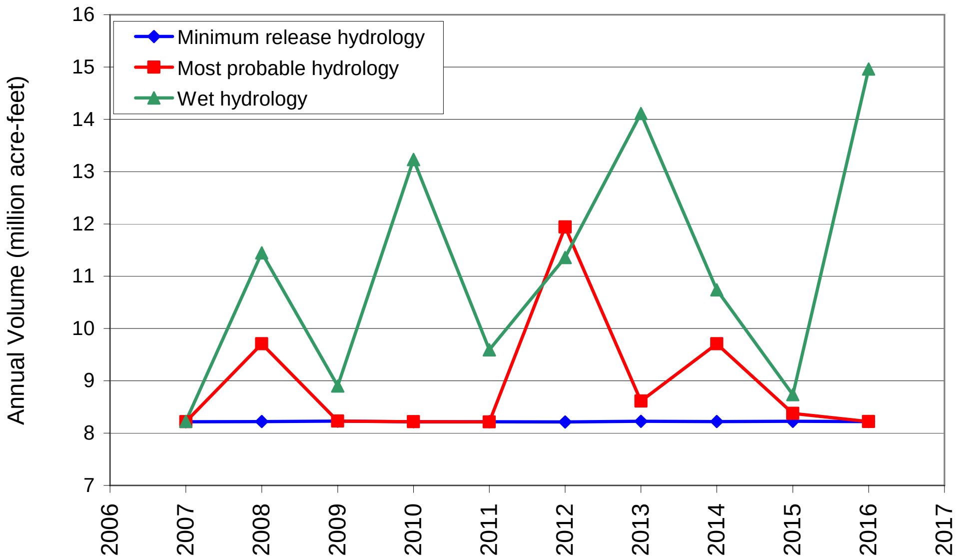

Figure 1.1 Annual water year release volumes for the three hydrologic scenarios.

Minimum Release Hydrology

Because the minimum release hydrology scenario contains the same annual release volume in every water year, the basic parameters can be easily summarized in a single table for each experimental option. To this end, Tables 1.2 – 1.6 contain the volume, minimum and maximum daily flows (weekday operations), daily range, and ramping rates for each month, for each experimental option. The basic differences between each option and the base, for 8.23 MAF water years, are summarized below.

Option A – Monthly volumes are unchanged from the base. In summer (Jul – Aug) and winter (Dec – Feb) seasons, the daily low flow is reduced and the daily peak flow is increased such that the daily range in flow is expanded. In Dec – Jan, the daily range is expanded from 8,000 cfs to 12,000 cfs, in Feb it is expanded from 6,000 cfs to 10,000 cfs, and in Jul – Aug it is expanded from 8,000 cfs to 10,000 cfs. In all other months, the daily low, peak, and range are identical to base values. The downramp rates are increased from 1,500 cfs/hr to 3,000 cfs/hr in all months; upramp rates are unchanged from base.

Option A Variation – This option is similar to Option A. Differences are as follows: 1) increased downramp rates (to 4,000 cfs/hr) in Nov – Mar, 2) expanded daily range (from 6,000 cfs to 8,000 cfs) in Oct, Nov, Mar, Jun, and Sep (expanded ranges not fully realized under minimum hydrology in Jun and Sep). Daily minimum and maximum flow are contained in Table 1.4.

Option B – Because this option is significantly different from options A, A Variation, and C in design, a table of monthly flow parameters strictly comparable to the other options cannot be developed, nor can the option be directly compared, month by month, to the base case. Option B consists of several blocks with variable levels of steady flows. The original plan was for seven years; to make it a 10-year plan, 3 years of ROD MLFF were added to the end of this option. Block 1, constituting the first 10 months starting in Oct 2006, consists of equalized monthly volumes of moderate fluctuating flows (700,000 acre-feet months, 4,000 cfs daily range). Block 2, encompassing the next 2 years, consists of 4 month stretches of steady flow (10,000 cfs) in late summer/fall (Aug – Nov) and 8 month stretches of moderate fluctuations the rest of the year. Block 3, encompassing the next 2 years, extends the steady flows to 8 months (Aug – Mar, also at 10,000 cfs) with 4 months of fluctuating flows with higher monthly volumes than the previous block (in order to maintain the same annual release volume). Block 4, encompassing the next 2 years, contains steady flows year-round with monthly volumes adjusted seasonally such that summer, fall, and winter (Jul – Mar) are the lowest volumes with increased volume in the spring. All fluctuating flow blocks employ ramping rates consistent with ROD MLFF. See Table 1.4 for details.

Option C – Monthly volumes are different from the base in 10 of 12 months (unchanged in only Dec – Jan). The volumes are lower in steady flow months (Sep – Oct) and summer (Jul – Aug) with the difference being made up with slightly higher volumes in Nov and Feb – Jun. Steady, low volume flows occur in Sep – Oct, and potentially in Aug based on triggering criteria in the last 5 years of the experiment. The daily low is reduced and daily peak increased in Dec – Feb such that the daily range is expanded from 8,000 cfs to 12,000 cfs in Dec – Jan and from 6,000 cfs to 10,000 cfs in Feb. In months where the volume has been increased, the daily low and peak are both increased while maintaining the same daily range as the base. The downramp rate is increased to 3,000 cfs/hr in 9 months (Nov – Jul) while remaining at 1,500 cfs/hr in Aug (Sep – Oct are steady flows). All fluctuating flow months retain the ROD MLFF upramp rates.

Table 1.2 Base (ROD MLFF) for minimum release hydrology water years

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/1500
Nov	600	6000	12000	6000	4000/1500
Dec	800	8500	16500	8000	4000/1500
Jan	800	8500	16500	8000	4000/1500
Feb	600	7000	13000	6000	4000/1500
Mar	600	6000	12000	6000	4000/1500
Apr	600	6500	12500	6000	4000/1500
May	600	6000	12000	6000	4000/1500
Jun	650	7500	13500	6000	4000/1500
Jul	850	9000	17000	8000	4000/1500
Aug	900	10000	18000	8000	4000/1500
Sep	630	7000	13000	6000	4000/1500

Table 1.3 Option A for minimum release hydrology water years

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/3000
Nov	600	6000	12000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	800	6000	18000	12000	4000/3000
Feb	600	5000	15000	10000	4000/3000
Mar	600	6000	12000	6000	4000/3000
Apr	600	6500	12500	6000	4000/3000
May	600	6000	12000	6000	4000/3000
Jun	650	7500	13500	6000	4000/3000
Jul	850	8000	18000	10000	4000/3000
Aug	900	9000	19000	10000	4000/3000
Sep	630	7000	13000	6000	4000/3000

Blue highlights indicate differences from base (ROD MLFF)

Table 1.4 Option A Variation for minimum release hydrology water years

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	5000	13000	8000	4000/3000
Nov	600	5000	13000	8000	4000/4000
Dec	800	5500	17500	12000	4000/4000
Jan	800	6000	18000	12000	4000/4000
Feb	600	5000	15000	10000	4000/4000
Mar	600	5000	13000	8000	4000/4000
Apr	600	6500	12500	6000	4000/3000
May	600	7000	12000	5000[1]	4000/3000
Jun	650	7000	14000	7000[2]	4000/3000
Jul	850	8000	18000	10000	4000/3000
Aug	900	9000	19000	10000	4000/3000
Sep	630	7000	13000	6000[2]	4000/3000

Blue highlights indicate differences from base (ROD MLFF)

[1] Maximum 6,000 cfs during wetter years

[2] Maximum 8,000 cfs during wetter years

Table 1.5 Option B for minimum release hydrologic scenario

	Months	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
1st block is 10 months of ROD/MLFF with equalized monthly volumes						
Block 1 (10 months) Oct 06 – Jul 07	all	700	8000	14000	6000	4000/1500
2nd block is two years with 4 months of steady, 8 months fluctuating each year						
Block 2 (2 years) Aug 07 – Jul 09	Aug – Nov	600	10000	10000	~ 0	~ 0
	Dec – Jul	730	9500	13500	4000	4000/1500
3rd block is two years with 8 months of steady, 4 months of fluctuating each year						
Block 3 (2 years) Aug 09 – Jul 11	Aug – Mar	600	10000	10000	~ 0	~ 0
	Apr – Jul	850	11500	15500	4000	4000/1500
4th block is two years of year-round steady flow, seasonally adjusted						
Block 4 (2 years, 2 mo) Aug 11 – Sep 13	Jul – Mar	600	10000	10000	~ 0	~ 0
	Apr	1090	18300	18300	~ 0	~ 0
	May	860	14000	14000	~ 0	~ 0
	Jun	830	14000	14000	~ 0	~ 0
5th block is three years of ROD/MLFF equivalent to Base						
Block 5 (3 years) Oct 13 – Sep 16	All years equivalent to Base scenario					

Table 1.6 Option C for minimum release hydrology water years

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	500	8100	8100	~ 0	~ 0
Nov	650	7000	13000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	800	6000	18000	12000	4000/3000
Feb	675	6000	16000	10000	4000/3000
Mar	650	7000	13000	6000	4000/3000
Apr	625	7000	13000	6000	4000/3000
May	625	6500	12500	6000	4000/3000
Jun	725	8500	14500	6000	4000/3000
Jul	825	9000	17000	8000	4000/3000
Aug (no trigger)	800	8500	16500	8000	4000/1500
Aug (trigger)	800	13100	13100	~ 0	~ 0
Sep	550	9300	9300	~ 0	~ 0

Blue highlights indicate differences from base (ROD MLFF)

Most Probable Hydrology

Annual water year release volumes exceed 8.23 MAF in 5 out of 10 years for the most probable hydrology. During these years, the monthly volumes and daily patterns become dependent on current lake levels (Powell and Mead, if equalization is needed) and forecasted inflow volumes to Lake Powell which begin to be available on January 1st of each year. The general pattern is for monthly volumes to begin to increase (compared to minimum releases) in January and to be greatest in the summer, though significant variation can occur depending on lake levels, forecasts, and measured Upper Basin runoff. This general pattern and variability are shown in Fig. 1.2.

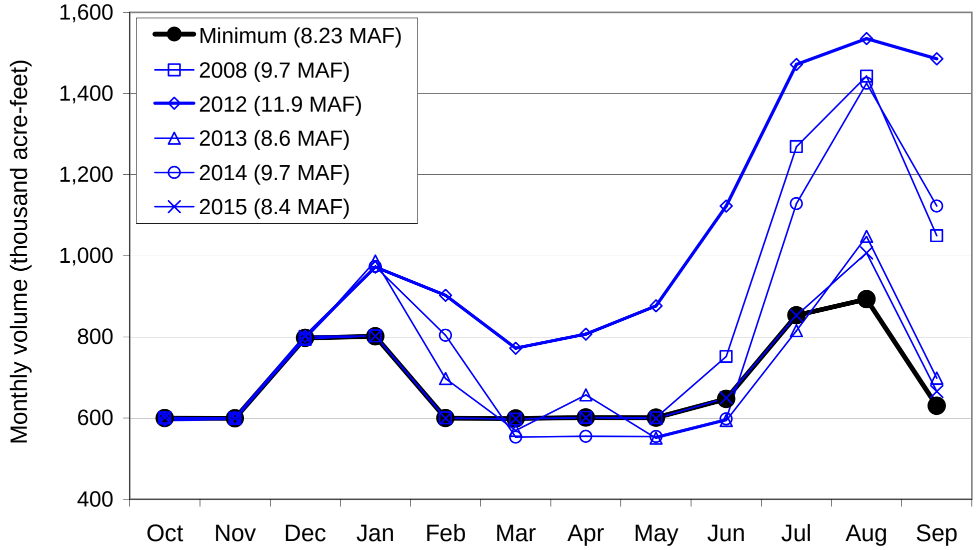

Figure 1.2 Monthly volume patterns (base) for a minimum release year and 5 years of most probable hydrology where annual water year volumes exceed 8.23 MAF.

In order to represent the range of release parameters for the most probable hydrology, tables similar to those for the minimum release hydrology were developed for water year 2012. This water year has the highest annual volume (11.9 MAF) as well as the highest volume in every month for the most probable hydrology. Tables 1.6 – 1.10 contain this information.

The pattern of change from the minimum hydrology for the base and options A, A Variaion, and C are very similar. Monthly volumes begin to increase when forecasts become available on January 1st (for all most probable years, volumes in Oct – Dec are equivalent to minimum release years). In some years, monthly volumes decrease in the spring to be equivalent to minimum years, while in other years (such as 2012), volumes remain elevated above minimum releases through the spring. Summer volumes are always greater than minimum releases for annual volumes greater than 8.23 MAF. In terms of daily release patterns, increased monthly volumes result in increased daily lows and peaks with the same ramping rates and daily range linked to the monthly volume (as for minimum release hydrology), until monthly volumes exceed about 1.5 MAF at which point releases become steady. This is illustrated in Tables 1.6 – 1.8 and 1.10 where increased volumes, lows, and peaks are seen in Jan – Jun along with increased daily ranges (from 6000 to 8000 cfs) in months when volumes are increased to greater than 0.8 MAF. In Jul – Sep, when monthly releases reach 1.5 MAF, steady flow releases of 25,000 cfs are implemented.

Option B is more difficult to summarize by selecting a single year because it contains 2-year blocks of different operations such that selecting a single year cannot represent the overall changes from the minimum release hydrology. For this option, all 10 years must be analyzed (excluding the last 3 years which are equivalent to the base). Table 1.8 contains the same summary information as Table 1.4 with additions detailing differences from minimum release hydrology. Block 1 remains unchanged because WY 2007 is an 8.23 MAF year. Block 2 (4 months steady, 8 months fluctuating) contains increased volume in Jun – Sep 2008; during these months, daily lows and peaks are increased with daily range and ramping rates maintained for fluctuating months. Block 3 (8 months steady, 4 months fluctuating) remains unchanged because water years 2009–11 are 8.23 MAF. Block 4 (all steady flows) contains increased volumes in 11 out of 24 months, mostly in WY 2012; when volumes are increased, the steady flow is simply increased to pass the required monthly volume.

Table 1.6 Base scenario (ROD MLFF) for most probable WY 2012 (11.9 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/1500
Nov	600	6000	12000	6000	4000/1500
Dec	800	8500	16500	8000	4000/1500
Jan	970	11500	19500	8000	4000/1500
Feb	900	11500	19500	8000	4000/1500
Mar	770	9000	15000	6000	4000/1500
Apr	810	9500	17500	8000	4000/1500
May	880	10000	18000	8000	4000/1500
Jun	1120	15000	23000	8000	4000/1500
Jul	1470	25000	25000	~ 0	~ 0
Aug	1540	25000	25000	~ 0	~ 0
Sep	1490	25000	25000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

Table 1.7 Option A for most probable WY 2012 (11.9 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/3000
Nov	600	6000	12000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	970	9000	21000	12000	4000/3000
Feb	900	10000	20000	10000	4000/3000
Mar	770	9000	15000	6000	4000/3000
Apr	810	9500	17500	8000	4000/3000
May	880	10000	18000	8000	4000/3000
Jun	1120	15000	23000	8000	4000/3000
Jul	1470	25000	25000	~ 0	~ 0
Aug	1540	25000	25000	~ 0	~ 0
Sep	1490	25000	25000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

Table 1.8 Option A Variation for most probable WY 2012 (11.9 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	5000	13000	8000	4000/3000
Nov	600	5000	13000	8000	4000/4000
Dec	800	5500	17500	12000	4000/4000
Jan	970	9000	21000	12000	4000/4000
Feb	900	10000	20000	10000	4000/4000
Mar	770	8000	16000	8000	4000/4000
Apr	810	9500	17500	8000	4000/3000
May	880	10000	18000	8000	4000/3000
Jun	1120	14500	22500	8000	4000/3000
Jul	1470	25000	25000	~ 0	~ 0
Aug	1540	25000	25000	~ 0	~ 0
Sep	1490	25000	25000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

Table 1.9 Option B for most probable hydrologic scenario

<table>
<tr><th></th><th>Months</th><th>Monthly volume (1000 ac-ft)</th><th>Daily Low Flow (cfs)</th><th>Daily Peak Flow (cfs)</th><th>Daily Range (cfs)</th><th>Upramp/ Downramp (cfs/hr)</th></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">1st block is 10 months of ROD/MLFF with equalized monthly volumes</td></tr>
<tr><td>Block 1 (10 months) Oct 06 – Jul 07</td><td>all</td><td>700</td><td>8000</td><td>14000</td><td>6000</td><td>4000/1500</td></tr>
<tr><td colspan="7"></td></tr>
<tr><td colspan="7">2nd block is two years with 4 months of steady, 8 months fluctuating each year</td></tr>
<tr><td rowspan="8">Block 2 (2 years) Aug 07 – Jul 09</td><td>Aug – Nov 07</td><td>600</td><td>10000</td><td>10000</td><td>~ 0</td><td>~ 0</td></tr>
<tr><td>Dec 07–May 08</td><td>730</td><td>9500</td><td>13500</td><td>4000</td><td>4000/1500</td></tr>
<tr><td>Jun 08</td><td>820</td><td>11500</td><td>15500</td><td>4000</td><td>4000/1500</td></tr>
<tr><td>Jul 08</td><td>1160</td><td>16500</td><td>20500</td><td>4000</td><td>4000/1500</td></tr>
<tr><td>Aug 08</td><td>1160</td><td>18800</td><td>18800</td><td>~ 0</td><td>~ 0</td></tr>
<tr><td>Sep 08</td><td>1010</td><td>17000</td><td>17000</td><td>~ 0</td><td>~ 0</td></tr>
<tr><td>Oct – Nov 08</td><td>600</td><td>10000</td><td>10000</td><td>~ 0</td><td>~ 0</td></tr>
<tr><td>Dec 08 – Jul 09</td><td>730</td><td>9500</td><td>13500</td><td>4000</td><td>4000/1500</td></tr>
</table>

3rd block is two years with 8 months of steady, 4 months of fluctuating each year						
Block 3 (2 years) Aug 09 – Jul 11	Aug – Mar	600	10000	10000	~ 0	~ 0
	Apr – Jul	850	11500	15500	4000	4000/1500
4th block is two years of year-round steady flow, seasonally adjusted						
Block 4 (2 years, 2 mo) Aug 11 – Sep 13	Jul – Dec 11	600	10000	10000	~ 0	~ 0
	Jan 12	790	13000	13000	~ 0	~ 0
	Feb 12	880	15300	15300	~ 0	~ 0
	Mar 12	780	12700	12700	~ 0	~ 0
	Apr 12	1290	22000	22000	~ 0	~ 0
	May 12	1130	18500	18500	~ 0	~ 0
	Jun 12	1300	22000	22000	~ 0	~ 0
	Jul 12	1240	20300	20300	~ 0	~ 0
	Aug 12	1250	20400	20400	~ 0	~ 0
	Sep 12	1450	24500	24500	~ 0	~ 0
	Oct – Dec 12	600	10000	10000	~ 0	~ 0
	Jan 13	800	13000	13000	~ 0	~ 0
	Feb – Mar 13	600	10000	10000	~ 0	~ 0
	Apr 13	1150	19500	19500	~ 0	~ 0
	May 13	860	14000	14000	~ 0	~ 0
	Jun 13	830	14000	14000	~ 0	~ 0
5th block is three years of ROD/MLFF equivalent to Base						
Block 5 (3 years) Oct 13 – Sep 16	All years equivalent to Base scenario					

Blue highlight indicates difference from minimum release hydrology scenario

Table 1.10 Option C for most probable WY 2012 (11.9 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	500	8100	8100	~ 0	~ 0
Nov	650	7000	13000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	970	9000	21000	12000	4000/3000
Feb	980	11500	21500	10000	4000/3000
Mar	820	9000	17000	8000	4000/3000
Apr	830	10000	18000	8000	4000/3000
May	900	10000	18000	8000	4000/3000
Jun	1200	16000	24000	8000	4000/3000
Jul	1440	25000	25000	~ 0	~ 0
Aug (no trigger)	1440	25000	25000	~ 0	~ 0
Aug (trigger)	1440	23000	23000	~ 0	~ 0
Sep	1400	24000	24000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

Wet Hydrology

Annual water year release volumes exceed 8.23 MAF in 9 out of 10 years for the wet hydrology. As with the most probable hydrology, monthly volumes and daily patterns become dependent on lake levels and forecasted inflow volumes during these years. There is even greater variability in monthly volume patterns for the wet hydrology, as shown in Fig. 1.3 below.

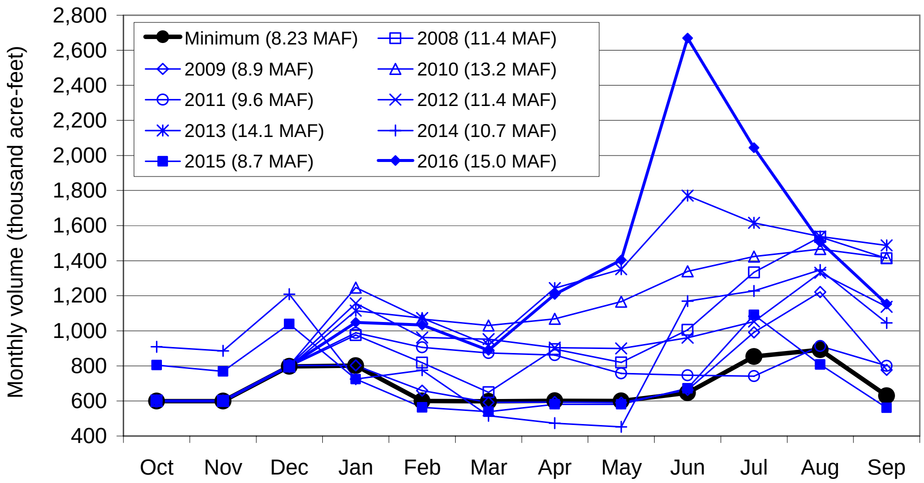

Figure 1.3 Monthly volume patterns (base) for a minimum release year and 9 years of wet hydrology where annual water year volumes exceed 8.23 MAF.

As for the most probable hydrology, tables have been developed for the highest volume water year (2016, 15.0 MAF) for the base and SPG options A, A Variation, and C. Tables 1.11 – 1.14 contain this information. The basic difference from minimum releases are the same as those detailed for WY 2012 of the most probable hydrology, except that summer volumes in wet WY 2016 are higher such that in Jun – Jul the releases are steady and at or above powerplant capacity (33,000 cfs). Another significant difference between wet and most probable hydrology is that wet monthly volumes in Oct – Dec of WYs 2014 and 2015 exceed minimum releases; volumes never exceed minimums in these months during most probable. These higher volume releases in Oct – Dec occur only during nearly full reservoir conditions in order to meet January 1 target of 3,684 feet (16 feet from full pool) at Lake Powell.

No similar table has been developed for option B wet hydrology, simply because of the sheer size of the table that would be required to convey all of the differences from the minimum release hydrology. Monthly volumes follow generally the same pattern as for the other options when annual volumes exceed 8.23 MAF. Because option B contains a prevalence of steady flows, most often when monthly volumes are increased the steady flow is simply increased accordingly to pass the required volume. During fluctuating months, daily lows and peaks are increased while maintaining ramping rates and daily ranges up to 1.5 MAF at which point steady flows ensue (same as other options). For the first 7 years of wet hydrology for this option, monthly volumes exceed the minimum releases in about 55% of months, typically in Jan – Sep.

Table 1.11 Base scenario (ROD MLFF) for wet WY 2016 (15.0 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/1500
Nov	600	6500	12500	6000	4000/1500
Dec	800	8500	16500	8000	4000/1500
Jan	1040	13000	21000	8000	4000/1500
Feb	1040	14000	22000	8000	4000/1500
Mar	890	10500	18500	8000	4000/1500
Apr	1210	16000	24000	8000	4000/1500
May	1400	21000	25000	4000	4000/1500
Jun	2670	45000	45000	~ 0	~ 0
Jul	2030	33000	25000	~ 0	~ 0
Aug	1510	25000	25000	~ 0	~ 0
Sep	1160	15500	23500	8000	4000/1500

Blue highlight indicates difference from 8.23 MAF years

Table 1.12 Option A for wet WY 2016 (15.0 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	6000	12000	6000	4000/3000
Nov	600	6000	12000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	1040	10000	22000	12000	4000/3000
Feb	1040	13000	23000	10000	4000/3000
Mar	900	10000	18000	8000	4000/3000
Apr	1210	16000	24000	8000	4000/3000
May	1400	21000	25000	4000	4000/3000
Jun	2670	45000	45000	~ 0	~ 0
Jul	2030	33000	33000	~ 0	~ 0
Aug	1510	25000	25000	~ 0	~ 0
Sep	1160	15000	23000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

Table 1.13 Option A Variation for wet WY 2016 (15.0 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	600	5000	13000	8000	4000/3000
Nov	600	5000	13000	8000	4000/4000
Dec	800	5500	17500	12000	4000/4000
Jan	1040	10000	22000	12000	4000/4000
Feb	1040	12500	22500	10000	4000/4000
Mar	900	10500	18500	8000	4000/4000
Apr	1210	16000	24000	8000	4000/3000
May	1400	21000	25000	4000	4000/3000
Jun	2670	45000	45000	~ 0	~ 0
Jul	2030	33000	33000	~ 0	~ 0
Aug	1510	25000	25000	~ 0	~ 0
Sep	1160	15000	23000	8000	4000/3000

Blue highlight indicates difference from 8.23 MAF years

Table 1.14 Option C for wet WY 2016 (15.0 MAF)

	Monthly volume (1000 ac-ft)	Daily Low Flow (cfs)	Daily Peak Flow (cfs)	Daily Range (cfs)	Upramp/ Downramp (cfs/hr)
Oct	500	8100	8100	~ 0	~ 0
Nov	650	7000	13000	6000	4000/3000
Dec	800	6000	18000	12000	4000/3000
Jan	1040	10000	22000	12000	4000/3000
Feb	1110	14000	24000	10000	4000/3000
Mar	950	11000	19000	8000	4000/3000
Apr	1240	16500	24500	8000	4000/3000
May	1500	25000	25000	~ 0	~ 0
Jun	2740	45000	45000	~ 0	~ 0
Jul	2020	33000	33000	~ 0	~ 0
Aug (no trigger)	1410	25000	25000	~ 0	~ 0
Aug (trigger)	1410	25000	25000	~ 0	~ 0
Sep	1080	18000	18000	~ 0	~ 0

Blue highlight indicates difference from 8.23 MAF years

APPENDIX C: Glen Canyon Dam Release Temperature Modeling

We used a reservoir hydrodynamic model to analyze the five SPG scenarios (BASE, A, A Variation, B and C) for Lake Powell. The calibrated model provided release water temperature for each of the scenarios. The model we used was U.S. Army Corps of Engineers' (USACE) CE-QUAL-W2 (W2; Cole and Wells 2000).

Background Information on the Model

The W2 model is a two dimensional, longitudinal/vertical hydrodynamic and water quality model. Because the model assumes lateral homogeneity, it was best suited for relatively long and narrow waterbodies like Lake Powell (Cole 2003). The water in the model was routed through a computational grid of cells that represent a waterbody. Each cell was a completely mixed reactor for each time step. Time steps vary from seconds to minutes depending on the volume of water to be routed in each step. Therefore, this type of modeling is very computer time consuming. The bathymetry file for Lake Powell is also extremely complex, which further increases the computation time for each run.
The Lake Powell W2 bathymetry had 9 branches, 90 segments, and 97 layers. All layers are 1.75 meters thick. The branches represent the following channels and/or bays (Figure 1):

- Main (Colorado River) channel
- Bullfrog Bay
- Escalante River channel
- San Juan River channel
- Rock Creek Bay
- Last Chance Bay
- Warm Creek Bay
- Navajo Canyon
- Wahweap Bay

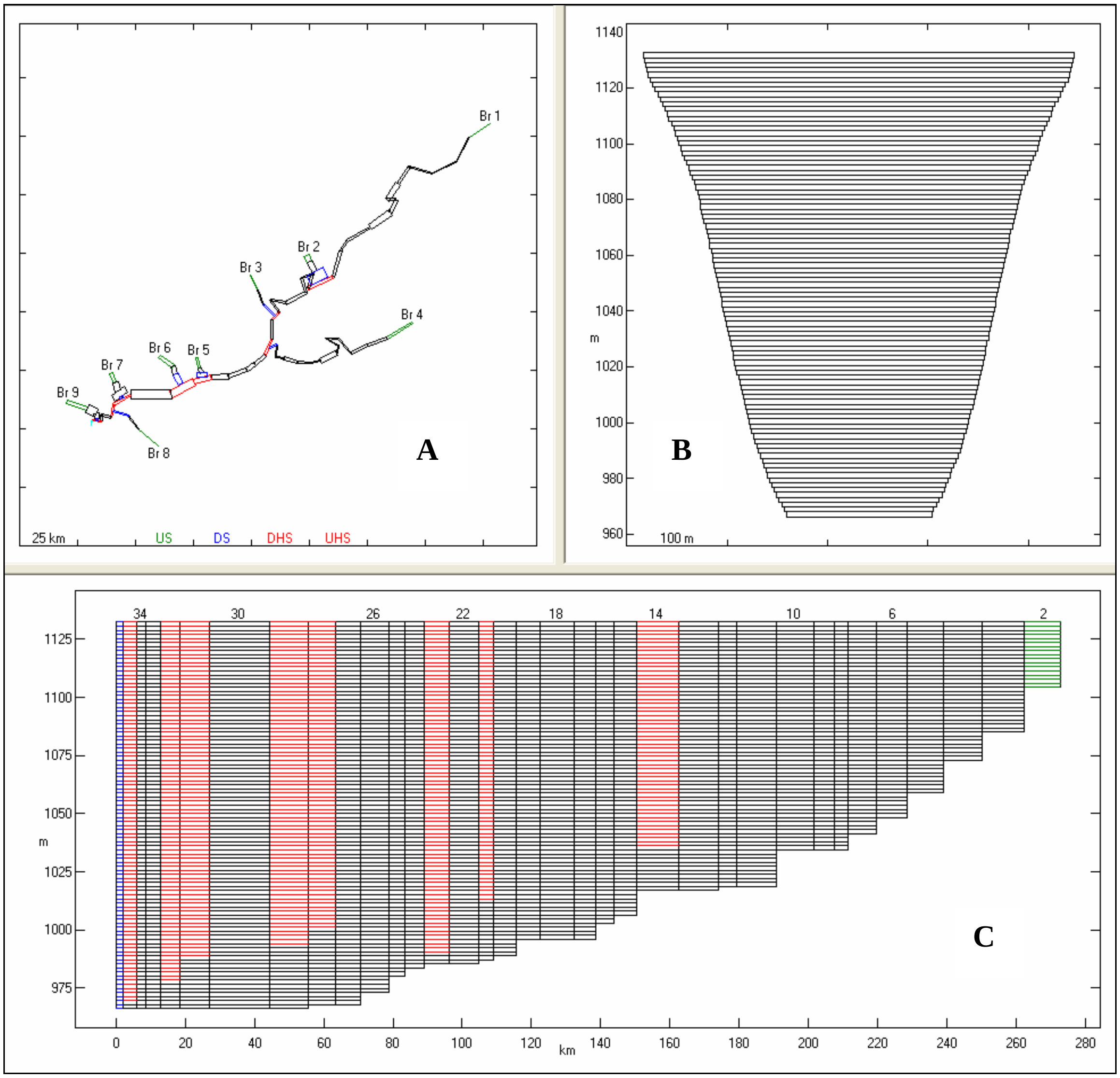

Figure C.1: Lake Powell Bathymetry: A) branches; B) cross section of a segment; and C) reservoir side profile.

Our model used historical meteorological, hydrological and physicochemical data from the period 1990–2005 for calibration. This was the only period that contained all empirical data required by the model, including hourly meteorology, river flows, and reservoir water temperatures. This period captures a wide range of reservoir elevations, from full pool to the lowest elevation since the filling of Lake Powell in 1980.

The model was calibrated to reservoir profiles and release temperatures over a16 year time period (1990–2005). The model reproduces most of the variables within error ranges of less than 5% over the entire reservoir and period. Figures C.2–C.6 illustrate model calibration of temperature profiles at different locations and time of year in the reservoir.

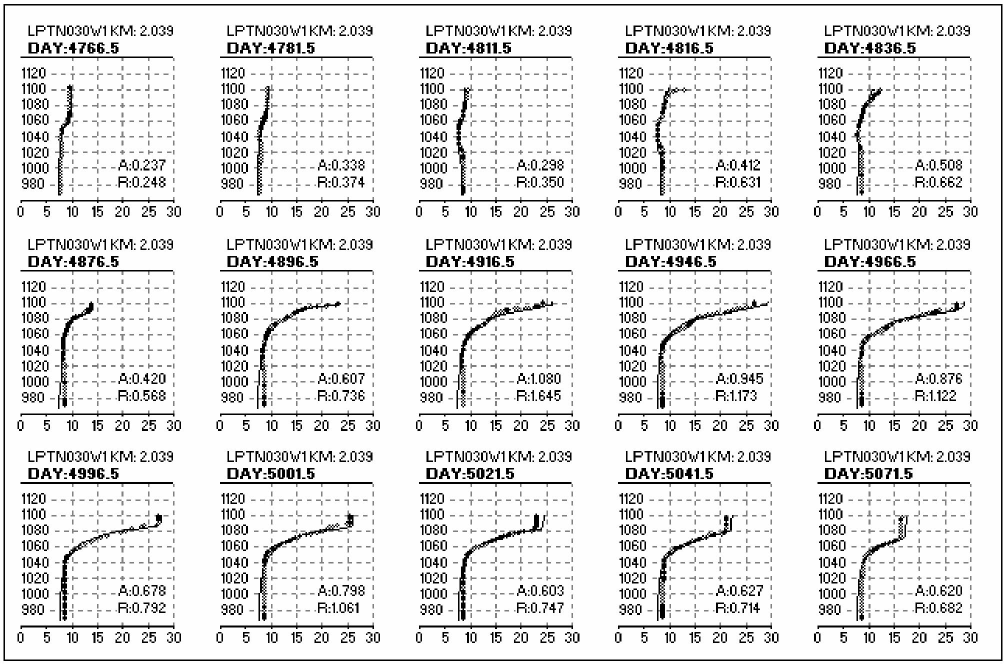

Figure C.2: Lake Powell, Wahweap 2003 Temperature Calibration Profiles

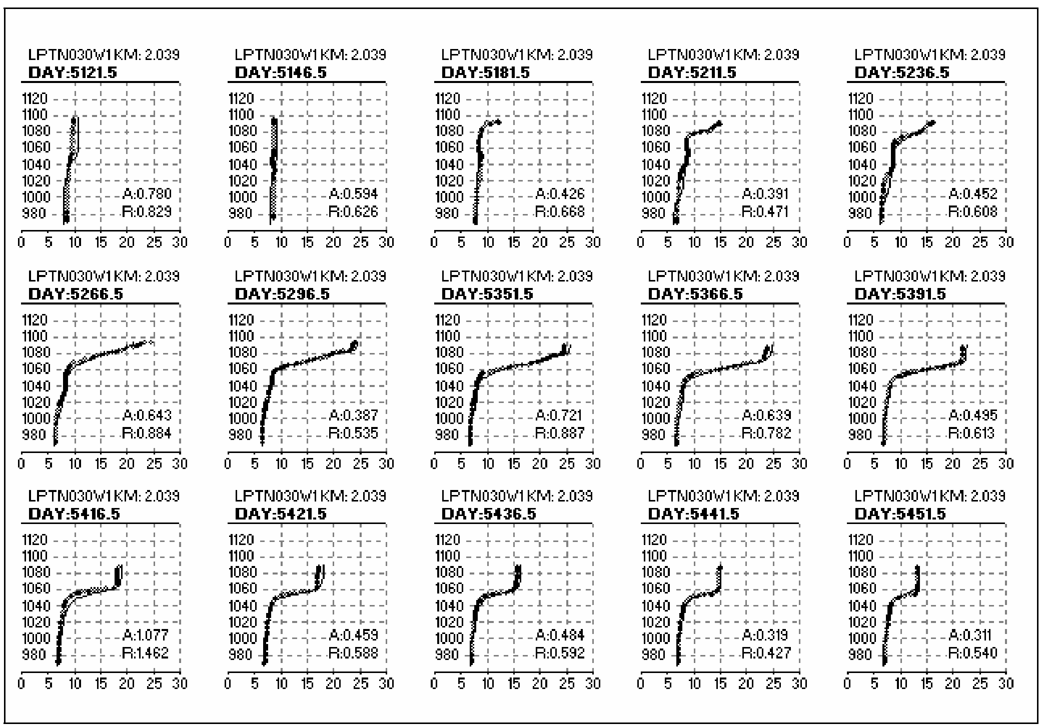

Figure C.3: Lake Powell, Wahweap 2004 Temperature Calibration Profiles

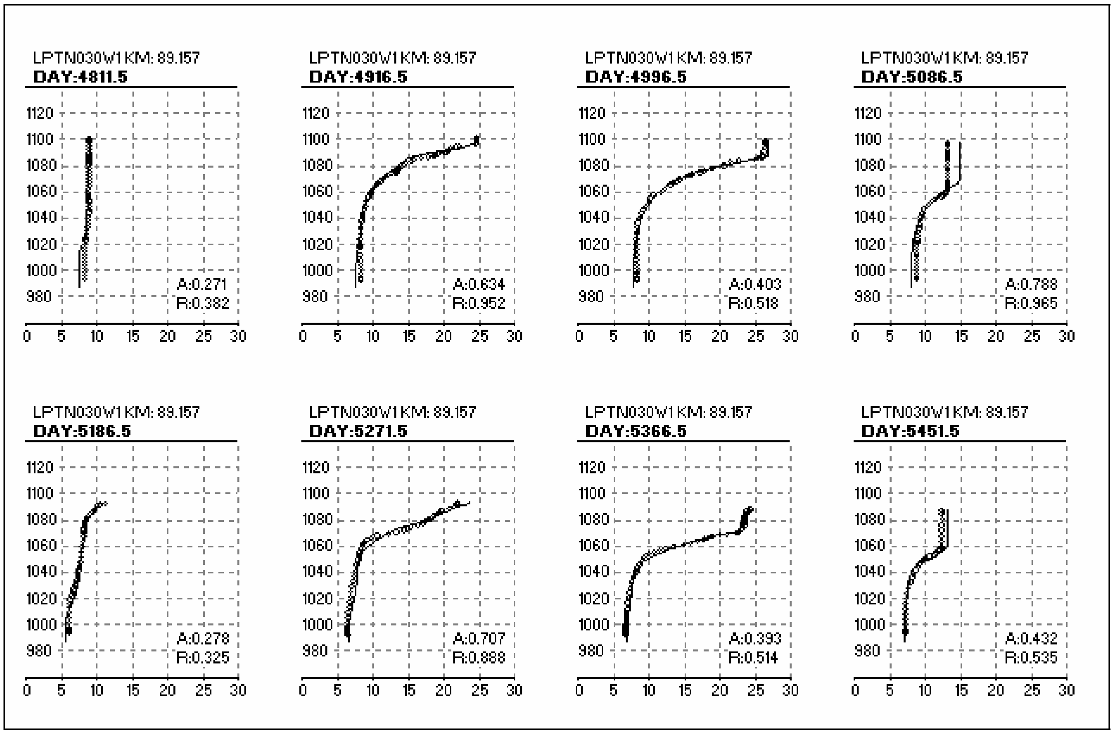

Figure C.4: Lake Powell, Oak Canyon 2003–2004 Temperature Calibration Profiles

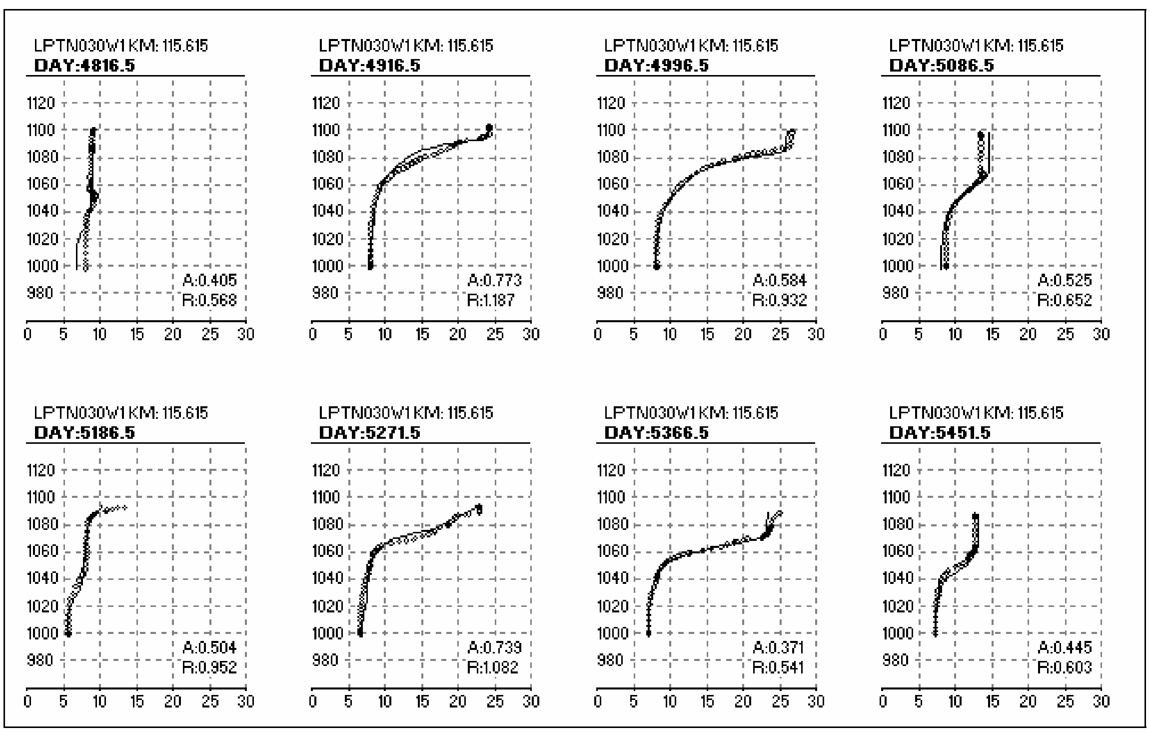

Figure C.5: Lake Powell, Escalante Confluence 2003–2004 Temperature Calibration Profiles

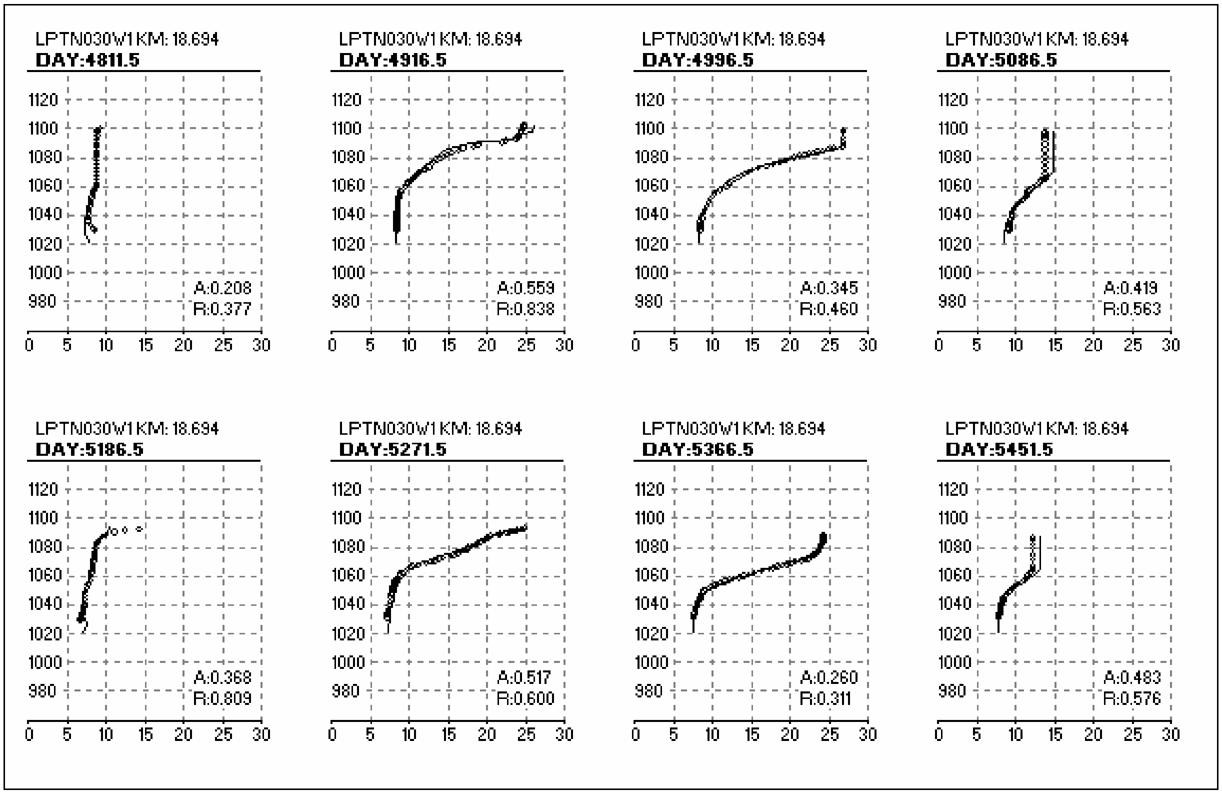

Figure C.6: Lake Powell, Cha Canyon 2003–2004 Temperature Calibration Profiles

The mean error of the calibrated release temperature was 0.4°C as shown on Figure C.7.

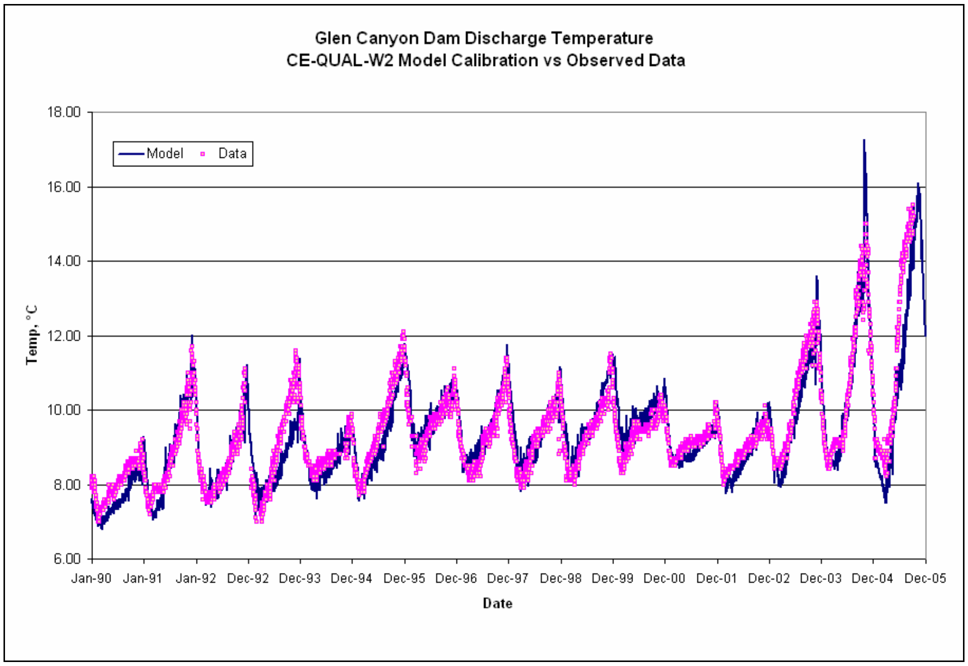

Figure C.7: Glen Canyon Dam Discharge Temperature Calibration

<u>SPG Model Scenario Assumptions</u>

We used this calibrated model to analyze the SPG scenarios with three hydrology traces (wet, most probable, dry) from the Colorado River Simulation System (CRSS) model. We matched historic meteorological data to go with the three CRSS hydrology traces and it was based on the inflow volume of each year. Therefore the inflow water temperatures into Lake Powell were the same as the year we selected the meteorological data.

We also assumed (1) the TCD would be operating 2 units out of a potential 8 units on a year-round basis, (2) the BASE scenario had no TCD operation, (3) the other four experimental options contained TCD operation in the last 5 years of the10- year period, (4) each of the 2 TCD had a capacity to release 4,000 cfs, (4) reservoir elevations within which the TCD could be active were between 3,700–3,520 ft , (5) a 30-ft submergence above each TCD intake was set to avoid surface vortex formation, as required for the protection of turbine runners, and (6) when reservoir elevations dropped below 3,520 ft, releases were made from the original penstock outlets at elevation 3,476 ft.

References

Cole, T., and S. Wells. 2000. CE-QUAL-W2: a two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.1. User Manual, Instruction Report EL-02-1 submitted to U.S. Army Corps of Engineers, Washington DC.

Cole, T., and S. Wells. 2003 (Revised). CE-QUAL-W2: a two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.1. User Manual, Instruction Report EL-02-1 submitted to U.S. Army Corps of Engineers, Washington DC.

Appendix D: Mainstem Temperature Modeling

A.1 INTRODUCTION

Water temperature is one of the most important drivers of biological productivity in the Colorado River ecosystem (CRE). Temperature influences all biological and chemical reactions and is one of the primary controls on the productivity of the aquatic food base and the success of native fishes within the CRE. Native fish species, including humpback chub, evolved in a seasonally warm and turbid riverine environment. The temperature regime of that environment has been drastically altered by the closure of Glen Canyon Dam (GCD).

The closure of GCD transformed a seasonally warm river into a consistently cold river owing to the hypolimnetic releases associated with the penstock withdrawal structures. Prior to dam closure, mean water temperature at Lees Ferry was 14°C, ranging from 0°C to 27°C. From 1973–2003, GCD release temperatures averaged 9.3°C, with fluctuations between 7°C and 12°C. Since 2003, GCD release temperatures have warmed considerably as a result of a substantial water level drop in Lake Powell. In July of 2005, mean daily release temperatures reached 13.6°C and a maximum release temperature of 16.3°C in October, 2005 (Vernieu and others, 2005). However, release temperatures in 2006 have trended towards colder releases similar to those of 2003 (Bill Vernieu, personal communication, 2006). Regardless of the impacts of future climate and hydrological conditions on GCD release temperatures, the temperature regime of the Colorado River below GCD will likely remain markedly different from predam patterns under the current operating schedule.

A.2 PURPOSE AND SCOPE

The objective of this experimental options assessment is to evaluate four long-term experimental flow options with respect to desired downstream water temperature regimes thought to be most beneficial to native biological resources, including native fish and the aquatic food base, identified in the GCDAMP ecosystem goals. For a summary of the experimental options refer to chapter 2 and appendix B.

We applied our recently developed mainstem water temperature model to simulate the fate of flow releases stipulated in the four experimental flow options. These simulations provide a quantitative comparison of the effects of variable flow regimes and release temperatures on the fate of the mainstem thermal environment, complementing the current state of knowledge. This appendix summarizes the calibration, validation and application of the unsteady transport model used in the mainstem temperature simulations.

A.3 METHODS

Mainstem water temperatures were simulated for BASE operations and each experimental option using a sequence of numerical models. First, monthly volumes were estimated for the 10-year period for BASE operations and all options using the BoR Colorado River Simulation System (CRSS) model (see appendix A for documentation). Hourly time series of dam releases were then generated by WAPA using CRSS monthly volumes as input into the GT-Max model (see appendix E for documentation). BoR then used these hourly flows to estimate GCD release temperatures using the CE-QUAL-W2 water quality model, including the operation of 2 units on a proposed Temperature Control Device (TCD) for WY 2012–16 for all four experimental options (BASE operations were not modeled) as described in section A.3.1 below. The downstream mainstem water temperature simulations were then conducted using the WAPA generated hourly flow releases and the BoR generated release temperatures as upstream boundary conditions for downstream temperature model (described in section A.3.2 below).

A.3.1 Lake Powell

Lake Powell hydrodynamic and water temperature modeling was conducted by BoR Salt Lake City staff. The methods and results are presented separately in appendix C.

A.3.2 Downstream from Glen Canyon Dam - Mainstem

An unsteady, one-dimensional water temperature model was developed for the 240-mile Colorado River (CR) mainstem reach from GCD (RM -15.6) to the Diamond Creek confluence (RM 226). The model employs the unsteady-flow model (UNSTEADY) of Wiele and Smith (1996) and Wiele and Griffin (1997) to simulate mainstem hydrodynamics and the enhanced Branched Lagrangian Transport Model (BLTM) of Jobson and Schoellhamer (1993) and Jobson (1997), to simulate water temperature dynamics. UNSTEADY is a reach-averaged model of diurnal discharge wave propagation developed specifically for the CR through the Grand Canyon (GC) and has been successfully utilized in a number of research applications in the GC. The BLTM model solves the one-dimensional advective dispersion equation by using a Lagrangian reference frame in which the computational nodes move with the flow. The BLTM model has found wide use throughout the U. S. Geological Survey (USGS) and elsewhere to simulate the fate and transport of conservative and non-conservative water quality constituents. Model development consisted of linking the flow and transport models and calibration and validation using data from the Grand Canyon Monitoring and Research Center mainstem temperature monitoring program.

A.3.2.1 Calibration and Validation

The model was calibrated and validated for two separate time periods (calibration - calendar year (CY) 2000; validation – CY 2005) at an hourly time step. CY 2000 was selected for calibration because it encompassed a wide range of discharge patterns (Low Summer Steady Flow experiment and peak discharges above 30,000 cfs) and also contained consistent water temperature records at the majority of the mainstem monitoring sites. CY 2005 was selected for validation because it had the highest GCD release temperatures ever recorded as well as alternating blocks of steady and fluctuating fall flows.

The data requirements to successfully run the UNSTEADY and BLTM models were as follows. Hourly measurements of discharge and release temperatures at GCD were used as the upstream boundary conditions. UNSTEADY-generated parameters at equally spaced computational nodes, including discharge, top width, and cross-sectional area, were used as hydrodynamic inputs into the BLTM model. Longitudinal dispersion coefficients derived by Graf (1995) using dye tracer methods were implemented at corresponding computational nodes. The BLTM model uses equilibrium temperatures to calculate the energy exchange between the atmosphere and the water surface. This approach utilized meteorological data from the Page, AZ cooperative weather station including daily maximum and minimum air temperature, the times of occurrence of these temperatures, and average daily wind speed to calculate equilibrium temperatures.

Hourly water temperature data from 6 mainstem sites was used to compare model predictions to observed temperatures. The model was then calibrated to these 6 sites by systematically adjusting the mass-transfer and free convection parameters within BLTM's wind function to minimize the root mean square error (RMSE) of the predictions. The model was further refined by adjusting the calculated equilibrium temperatures on a seasonal basis to provide a better fit to the observed data. The model was then validated for CY 2005 without further adjustment of the calibration parameters. Summary statistics are provided in table A.1 for both the calibration and validation periods at 6 river locations. The RMSEs for the calibration and validation time periods are comparable to each other, indicating the model is not overly sensitive to the calibration parameters, and typically less than 1ºC, increasing downstream as expected.

Table A.1. Error terms for predicted vs. observed water temperatures at 6 monitoring locations for 2000 and 2005. ME = mean error, MAE = mean absolute error, and RMSE = root mean square error.

Site	**2000 - Calibration**			**2005 - Validation**		
	ME (°C)	**MAE (°C)**	**RMSE (°C)**	**ME (°C)**	**MAE (°C)**	**RMSE (°C)**
RM 0	-0.02	0.25	0.32	-0.08	0.21	0.27
RM 30	0.16	0.25	0.33	-0.23	0.34	0.44
RM 61	0.24	0.38	0.48	-0.23	0.41	0.53
RM 87	0.53	0.60	0.73	-0.03	0.46	0.57
RM 166	0.70	0.84	0.98	0.07	0.59	0.72
RM 226	1.12	1.16	1.21	0.38	0.70	0.86

A.3.2.2 Applications, Results, and Discussion

Model simulations were performed for mainstem water temperatures over the 10-year period for each of the experimental options (including BASE operations) and hydrologic scenarios. BASE operations, four experimental options, and three hydrologic scenarios for each option resulted in 15 total simulations.

The effects of the temperature control device (TCD), 2 units out of 8 possible, which is a component of all experimental options (but not BASE operations), were evaluated by analyzing the first 5 and last 5 years of the simulation period separately, since the TCD comes online for all options halfway through the 10-year period. In this way, the experimental options can be compared to BASE operations (and each other) during these separate 5-year periods, but comparisons across the periods are not appropriate because of hydrologic and meteorological differences. We compare model simulation results for the first 5 years to evaluate differences between BASE operations and options (without a TCD), and use the last 5 years to evaluate the effects of the TCD.

Several metrics were computed to compare BASE operations and experimental options. For each 5-year period, we computed the average temperature and the percentage of time the temperatures exceed 16 ºC for 5 mainstem locations: at the dam and river miles 31, 65, 127, and 225 (termed Release, RM31, RM65, RM127, and RM225, respectively, in the plots below). The 16 ºC threshold was chosen because it is thought to have significance for mainstem native fish spawning (Hamman, 1982; Marsh, 1985). The locations were chosen to bracket the model domain (Release and RM225) and coincide with known congregations of humpback chub (RM31, RM65, and RM127).

The model simulation results are presented in a series of plots below. Each figure contains nine plots in a 3-by-3 matrix, with results from the first 5 years in the left column and the last 5 years in the right column. Results for minimum release hydrology (8.23 maf) are in the top row, most probable hydrology in the middle row, and wet hydrology in the bottom row. Figure A.1 shows average temperatures and figure A.2 shows the percentage of time the temperature exceeded 16ºC, for all five mainstem locations. Figures A.3 and A.4 contain the same information for a single site, RM65, broken down on a monthly basis in order to evaluate seasonal variability.

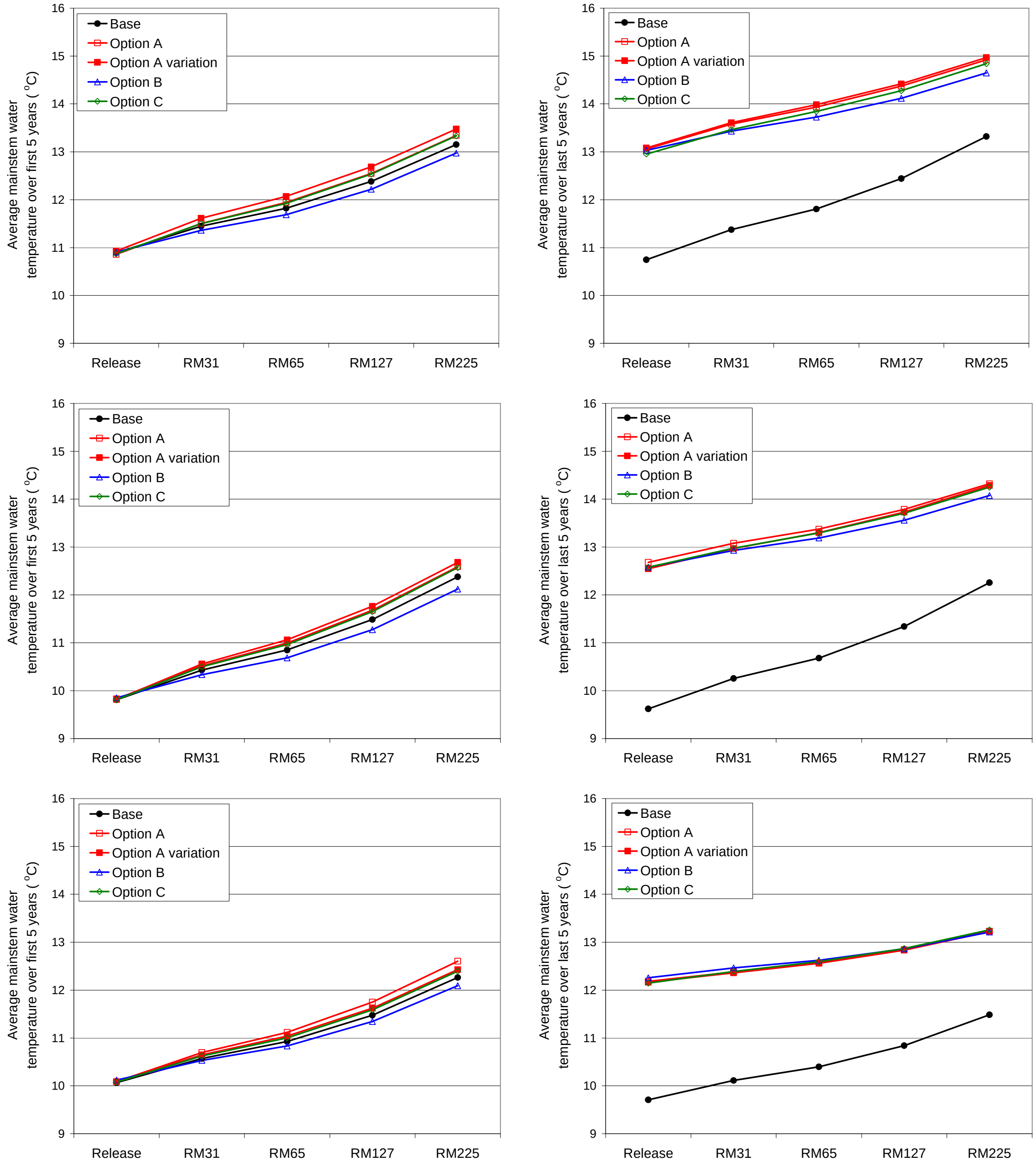

Figure A.1 Average mainstem water temperatures at 5 locations for the first 5 years (left column) and last 5 years (right column) of the simulation period for minimum release (top row), most probable (middle row), and wet (bottom row) hydrology.

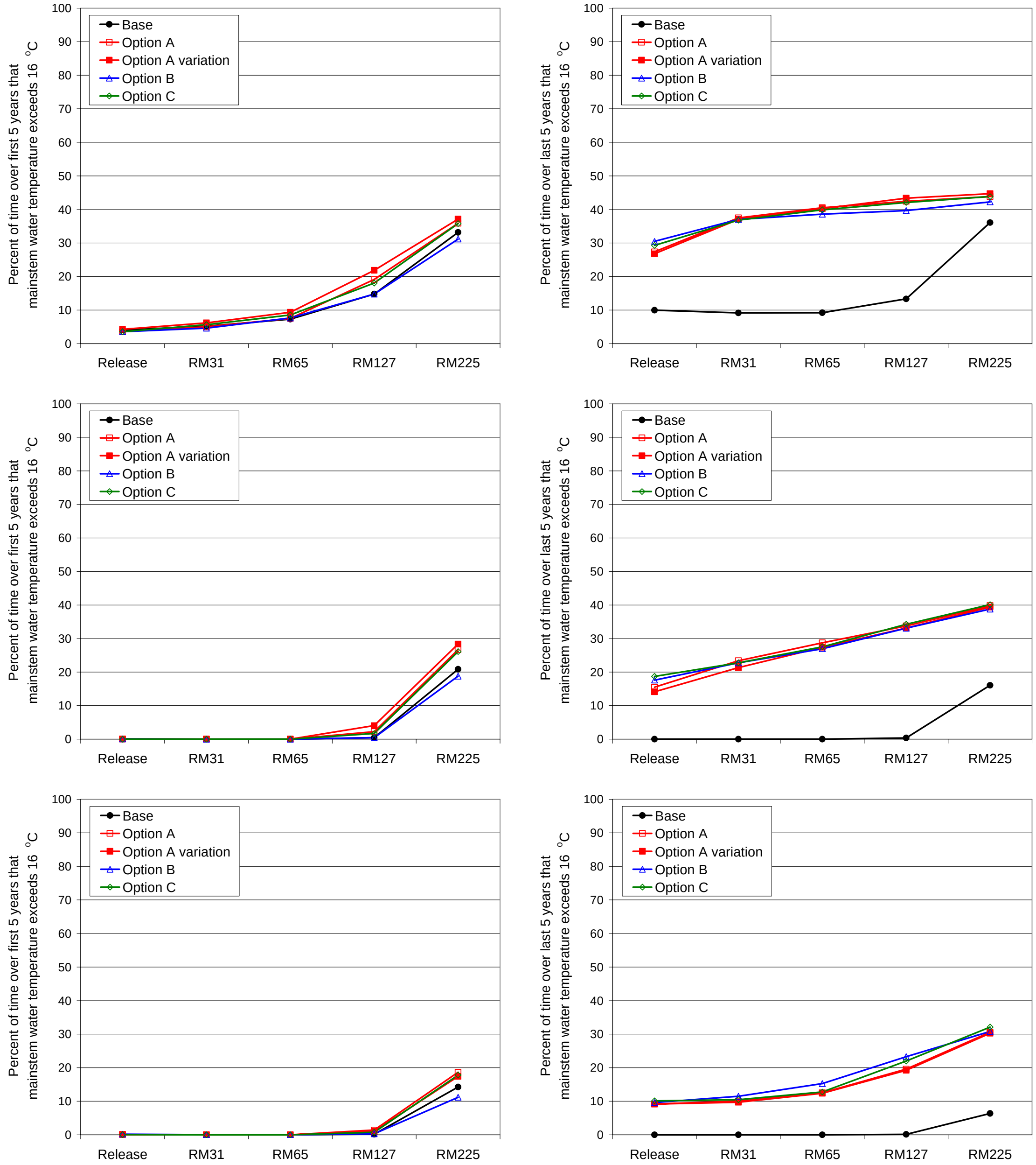

Figure A.2 Percentage of time mainstem water temperatures exceed 16 ºC at 5 locations for the first 5 years (left column) and last 5 years (right column) of the simulation period for minimum release (top row), most probable (middle row), and wet hydrology (bottom row).

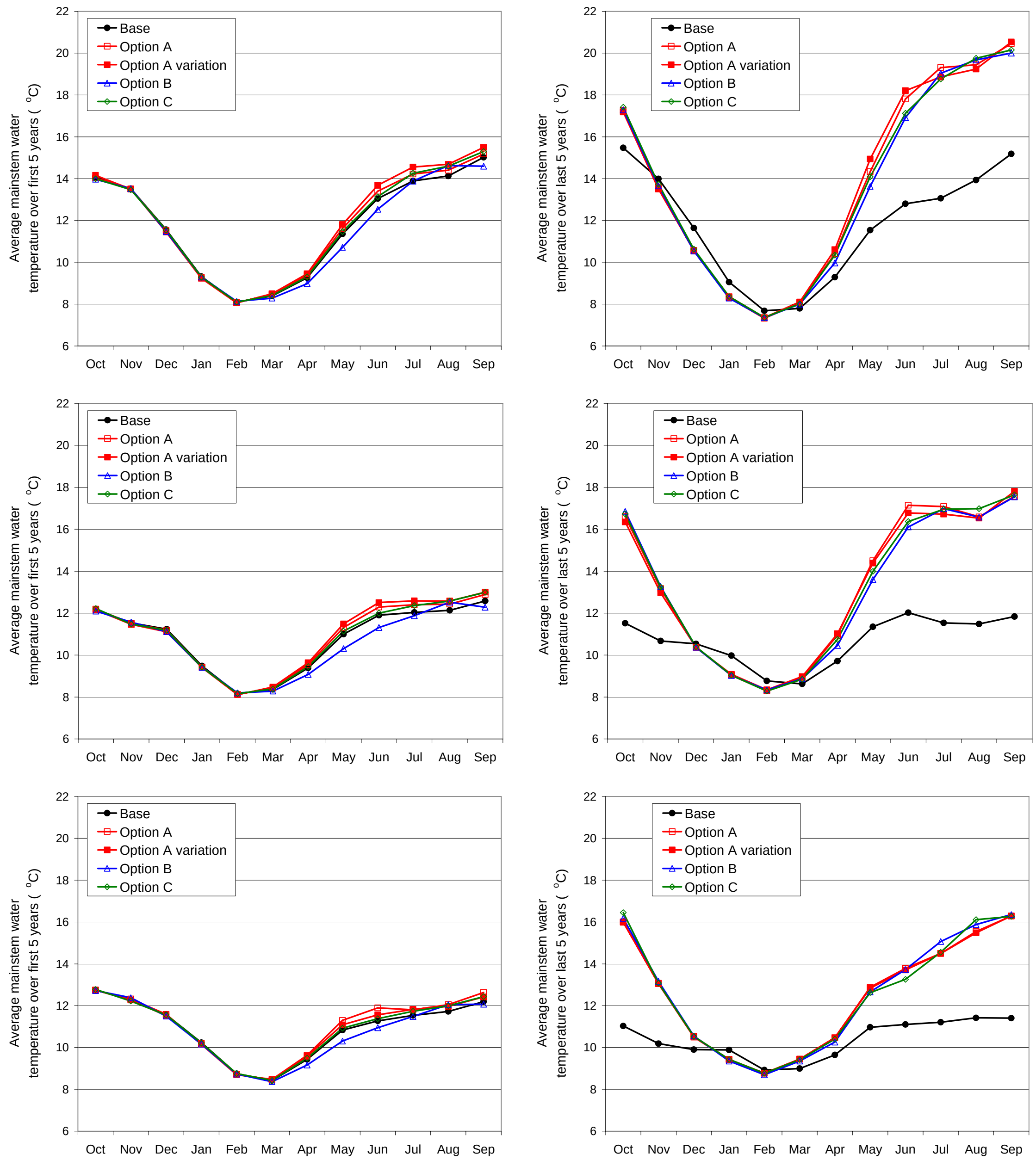

Figure A.3 Average mainstem water temperatures, by month, at RM65 for the first 5 years (left column) and last 5 years (right column) of the simulation period for minimum release (top row), most probable (middle row), and wet hydrology (bottom row).

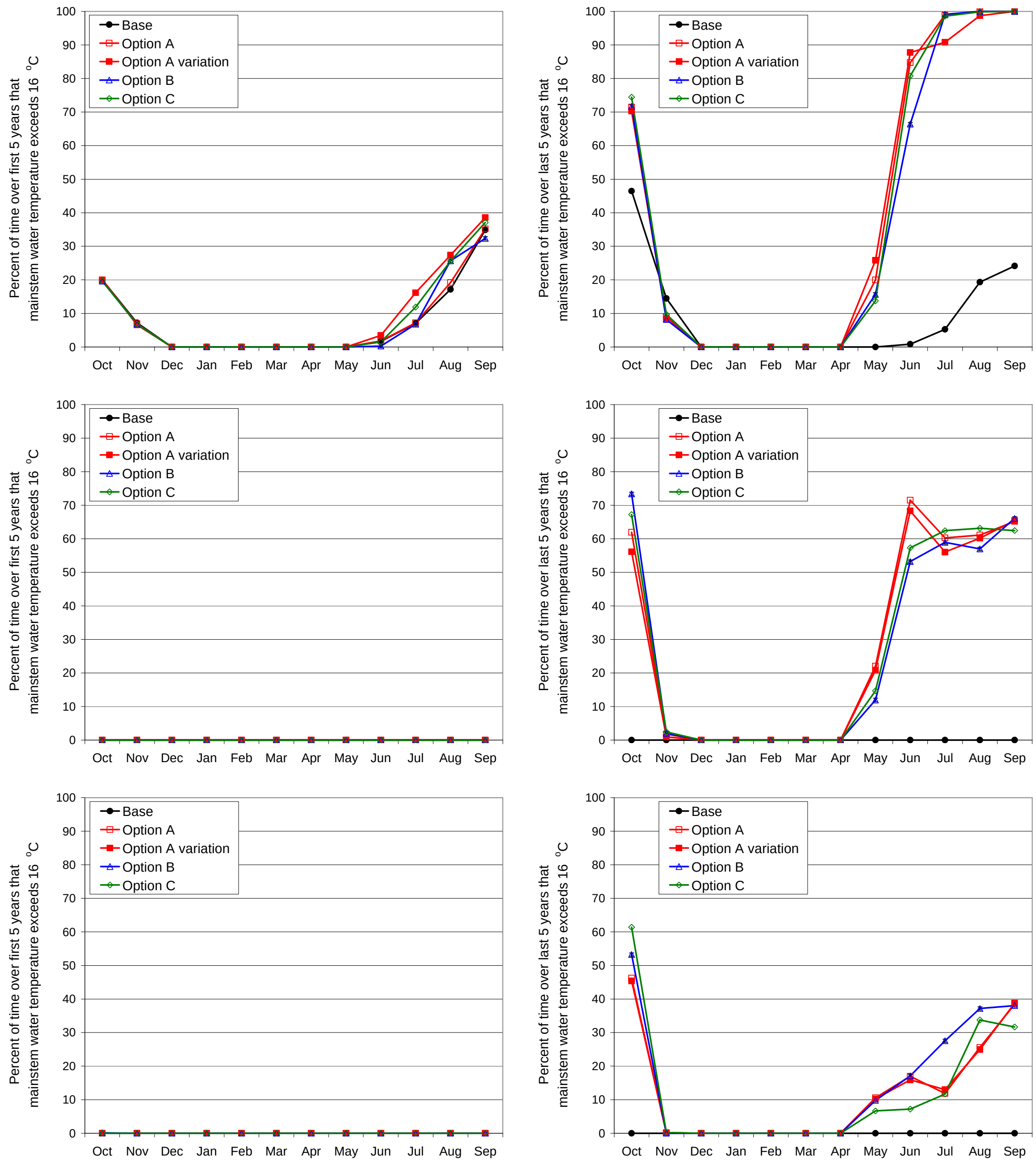

Figure A.4 Percentage of time mainstem water temperatures exceed 16ºC, by month, at RM65 for the first 5 years (left column) and last 5 years (right column) of the simulation period for minimum release (top row), most probable (middle row), and wet hydrology (bottom row).

Examination of the plots contained in figures A.1 – A.4 reveals that the 2-unit TCD and hydrologic conditions tend to have greater influences on mainstem water temperatures than the experimental options. In all of the plots, the simulated temperatures for the experimental options tend to group closely together; differences from BASE operations are apparent during the last 5 years (due to TCD); differences across the board for all options are apparent when the hydrology changes. These results do not come as a surprise given the dye studies of Graf (1995) who showed that steady and fluctuating flows of the same overall release volume result in nearly equivalent water velocities, which are a primary control on downstream mainstem temperatures because mean velocity determines the time available for water to warm (or cool) through surface heat exchange with the atmosphere. The results indicate that the differences between the options, in terms of monthly volumes, are not significant enough for the model to resolve the differences in water temperature, given the uncertainty in the calculations.

In order to evaluate the experimental options in comparison to the TCD and the hydrology, we computed the range in average water temperatures between the options for first 5 years (no TCD) and last 5 years (TCD) for the most probable hydrology, as well as the range in average water temperatures between the three hydrologic scenarios for the base case over all 10 years. The range is defined as the difference between the maximum average temperature and minimum average temperature. For example, if all options result in the exact same average temperature at a given location then the range is zero, or if all hydrologic scenarios result in the same average temperature then the range is zero. By performing these calculations, it's possible to isolate the effects of the experimental options (range over options, first 5 years), the effects of the TCD (range over options, last 5 years), and the effects of hydrology (range over hydrologic scenarios, base case, all 10 years). The results of these calculations, averaged over the three hydrologic scenarios, are presented in figure A.5.

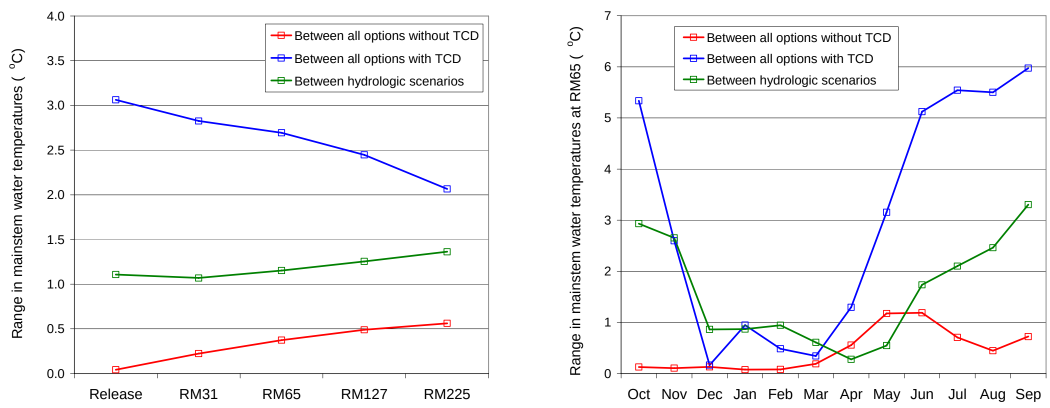

Figure A.5 Ranges in average mainstem water temperatures for 5 mainstem locations (left) and at RM65 (right). Red lines are the ranges between options (including BASE operations) for the first 5 years and thus show the maximum differences between the various options. Blue lines are the ranges between options for the last 5 years and thus show the average effect of the TCD. These ranges are both based on the most probable hydrology. Green lines are the ranges between the three hydrologic scenarios for BASE operations, over the entire 10 years (no TCD), and thus illustrate the effects of hydrology.

The results shown in figure A.5 provide a good summary of the model simulation results. First, focusing on the first 5 years where the TCD is not in operation (red lines), it is seen that the differences between the experimental options are, on average, less than 0.6 ºC at all 5 mainstem sites, and almost always less than 1ºC at RM65 for all months. Given the calibration results presented in section A.3.2.1, it must be concluded that differences between the experimental options are almost exclusively within the uncertainty of the model calculations. A potential exception to this conclusion is apparent in May and June, where the differences between options can exceed 1ºC at RM65 because of the high volume spring releases proposed in Option B which inhibit downstream warming during this time of year. Even these differences, however, are quite small in comparison to the range in temperatures realized through operation of the TCD (blue lines in figure A.5). For example, at RM65, the TCD leads to about 5 ºC of warming (over the base case) during the summer and fall months such that temperatures exceed 16ºC during these months nearly 100% of the time for the minimum release hydrologic scenario. Finally, figure A.5 also indicates that differences between the experimental options are typically less than differences between the hydrologic scenarios, which result from changes in release temperatures due to Lake Powell elevations and decreased downstream warming in summer due to high volume releases.

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APPENDIX E: Economic Analysis

Economic Analysis of Power System Impacts of Glen Canyon Dam Long-Term Experimental Options

October 27, 2006

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Prepared for the Grand Canyon Monitoring and Research Center

Abstract

This report is prepared for the Grand Canyon Monitoring and Research Center (GCMRC) to be included with other evaluations of four proposed GCD options on biological and physical resources. This report analyzes the economic impact of the four GCD options on electrical power production at Glen Canyon Dam (GCD). The GT Max model is used to simulate the operation of GCD. The model is respecified to include the GCD operating parameters for four options. The results are compared and an economic value is attributed to these results. The economic impact of the options over the ten-year study period is reported in net present value and levelized annual dollars.

Economic Analysis of Power System Impacts of Glen Canyon Dam Long-Term Experimental Proposals[1]

Introduction

The Glen Canyon Adaptive Management Work Group (AMWG) directed the Technical Work Group (TWG) to recommend options for a long-term plan for experimentation and improvement of downstream resources. The TWG and Grand Canyon Monitoring and Research Center (GCMRC) formed a Science Planning Group (SPG) to initiate this task. The SPG considered options for further consideration by the Technical Work Group (TWG) that include proposed releases from Glen Canyon Dam (GCD) and non-flow actions. This report will provide a cursory evaluation of the economic impact of these options from changes in GCD operations

This report is prepared for the Grand Canyon Monitoring and Research Center (GCMRC) to be included with other evaluations of the proposed GCD options on biological and physical resources. Taken together, the information from GCMRC will assist the TWG and AMWG in understanding, evaluating and developing recommendations related to the proposed options.

Purpose:

The purpose of this study is to identify the economic impacts on GCD's power generation from proposed long-term operational changes.

[1] Prepared by S. Clayton Palmer, Sam Loftin and Heather Patno. Western Area Power Administration, CRSP - MC

Economic Studies:

This report should be read as an economic analysis – the effect on the regional economy from a change in GCD operations. This requires that the authors estimate the change in resource use: the addition of generating resources that would have to be brought on line by those customers who have long-term firm electric service contracts from the Salt Lake Integrated Projects (SLCA/IP)[2], as a result of those options that decrease on-peak GCD electrical energy generation. For any option in which on-peak electrical energy is greater than the base scenario, the economic impact, or the change in resource use, is the postponement of construction of new generating capacity required to meet growing electrical demand.

Study Limitations

Given the time constraints imposed on this study, simplifying assumptions had to be made to reduce the time and effort necessary to provide an analysis. Notwithstanding the constraints, however, the authors believe the results are sufficient for the stated purposes. The simplifying assumptions are explained below. Other assumptions are described later in the document.

Simplifying Assumptions

- This analysis is limited to CRSP long-term firm electric service customers only. While other regional utilities buy and trade with customers who contract for CRSP resources, this analysis is simplified by assuming that those affected by changed operations at GCD are CRSP customers.

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[2] The federal hydroelectric resources that are marketed under the title SLCA/IP comprise the power resources of the Colorado River Storage Project. For this report, CRSP power resources will be used to refer to the electrical power of the SLCA/IP.

- The supply and demand for electrical capacity and energy are assumed to be roughly equal in the market within the Western U.S. region. This means that the utilities' reserve capacity margins are equal to or below the standard margins that are used for capacity expansion planning purposes.
- The analysis assumes that Western passes through impacts due to changed operations at GCD to its customers. As an example, if an option results in a decrease in GCD marketable capacity, Western expeditiously reduces its commitment of capacity to its CRSP customers in proportion to the reduction of GCD marketable capacity.
- With respect to the construction of new electrical generating capacity, if needed as a result of a proposed option, this construction takes place immediately and only to the extent required. This assumption can be considered reasonable if one considers that utilities who are planning new construction construct in "blocks" – building more than is immediately required. The utility hopes to sell that which is needed above native load to others at the average cost of the new facility. If a proposed option reduces GCD marketable capacity, the constructing utility will have to devote a larger portion of its new generation construction to meeting native load. Thus, construction and purchase plans are assumed to be altered in accordance with the impact on marketable capacity of a proposed option. In capacity cost calculations, on the advice of it's power customers, Western has assumed that new generation would be either simple-cycle or combined-cycle natural gas powerplants, with prices provided by customers that have recently constructed such generation.

In this regard, in order to improve the accuracy of the cost of capacity replacement, a capacity expansion model would have to be developed. Also, specific data would need to be gathered on CRSP customer demand growth and existing production facilities

- For options that result in an increase in marketable capacity, the generation and sales assumptions are immediately postponed in direct proportion to the change of marketable GCD capacity in response to impact of a proposed option.
- With respect to the value of electrical energy, the assumption is made that a proposed option which results in a reduction of on-peak energy means an increase in the production of off-peak energy, since water released through GCD is the same regardless of the pattern of release. In any event, the on-peak and off-peak electrical energy production is calculated under each option because on-peak generation is more valuable than off-peak.
- <u>Drop v. No Drop:</u> The operational constraints specified by the ROD provide some flexibility for Western's operation to meet its contractual obligations. One method that Western has used to increase the water available to generate electrical power during on-peak hours during weekdays is to reduce generation during the entire day on Sundays. By holding Saturday maximum generation to less than weekday maximum generation, Western can further decrease generation (down to ROD minimums, for example) during Sundays without violating the maximum-daily-change constraint. This is referred to by Western as "stepping down into Sunday" or as a Sunday "Drop". This type of operation depends on the relative difference between weekday and Sunday prices, as it may not make financial sense to increase off-peak purchases on Sunday in order to reduce on-peak

purchases during the week. The other type of operation is where Western maintains a nearly constant minimum off-peak generation during all days of the week, which we refer to as “no Sunday drop” operations. Since there are two rather different methods of operation, the analysis has been simplified by using only “no drop” operations in the baseline cases. References to the baseline through this document and in tables in the results section will be to the “no-drop” baseline.

- Emergency operation of GCD as allowed by the GCD ROD, the GCD operating criteria and the Interagency Agreement between Reclamation and Western will not be included[3]. We presumed that each scheduled GCD release and the consequential electrical energy generation is not altered “real time”.
- We assume that modifications to the operation of the powerplant at GCD translate into changed purchase and construction plans for SLCA/IP customers and that the new resource “mix” results in additional or lesser expense to the customer utility. Never the less, we make no attempt to analyze the possible reduction in electrical consumption that results from retail or end use customers through the price elasticity of demand. This is beyond the scope of this report.

The GT MAX Model

The GT MAX Model was developed by Argonne National Laboratory (ANL) under contract to the CRSP-MC’s Environmental and Resource Planning Division. The model is a computer simulation of weekly operations of all or part of the entire physical

[3] Cite MOU, Reclamation & Western

SLCA/IP, depending upon the user's preference. Various weeks may be put together to produce annual or seasonal data. The model identifies the solution that meets hourly demand requirements at minimum cost, subject to a list of restrictions imposed upon it. Restrictions include how much water is allowed through GCD over a defined period, flow requirements at Flaming Gorge powerplant, or a mandate that no power be sold on the spot market for less than an agreed-upon price.

GT MAX utilizes its objective function to maximize the value of water released through the turbines. GT Max minimizes the price paid for each hour of supplemental electrical generation available. Supplemental electrical generation is the generation above Western's contractual obligation. GTmax's objective function is:

$$\min \sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} X_{ij}$$

Where: X_{ij} is the purchase of the ith megawatt of supplemental electrical power during the jth hour.

P_{ij} is the price paid (or sales price) of electrical power of the ith megawatt in the jth hour.

Pursuit of the objective function is subject to a variety of constraints: 1) the water available for release through a given SLCA/IP powerplant during a week, 2) restrictions on the operation of a powerplant, 3) the technical capabilities of each powerplant, and 4) environmental limitations or targets that restrict the operation of the powerplants. The model minimizes the objective function subject to these constraints over a specified period of time. When actual historic input data are used, the GT MAX Model mimics real world SLCA/IP operations.

The GT MAX's projections do not precisely match actual powerplant operations because the computer model has nearly perfect information at all times while SLCA/IP operators do not. Operators are also constrained by other, non-modeled, physical constraints, i.e., power outages, scheduled maintenance, etc., while the GT MAX is not.

The user-supplied operating restrictions incorporated into the model include minimum and maximum flows, hourly and daily ramping constraints,[4] and minimum and maximum reservoir water elevations. The GT MAX Model simulates powerplant operations on an hourly time step over weekly periods. The model output contains 168 hourly data points of powerplant water release and generation.

Normally, GT MAX is run as a simulation model with all of the larger SLCA/IP units simultaneously. For this SPG options analysis, GCD was modeled in isolation. This is so the economic impacts of changing GCD operating parameters could be estimated in isolation. The GT MAX is capable of, and often does, modify hourly generation at one or more of the SLCA/IP powerplants in response to a change at one of the units. The output of the GT MAX is hourly generation values for all hours of a week for one week in each month.

Identification of Model Inputs that Constrain the GT Max Objective Function Common to All Cases

The GCMRC described the options in order for the authors [5] to accurately model the GCD options. This is the information we used to develop the operating parameters for

[4] Ramping refers to the increase or decrease in the volume of water flowing through an individual powerplant over a specified period of time.

each of the options. In order to produce detailed GCD release patterns, in some cases, more information was required than was provided by GCMRC. Additional information sometimes was requested from the sponsors. The sponsors, in most cases, participated in conference calls between GCMRC and the authors in order to accurately model the GCD options.

Input 1—Water Available for Release through a given SLCA/IP Powerplant throughout the Week

GT-Max utilizes a weekly volume release in acre feet (AF) from each powerplant. The weekly volume is calculated by equally distributing a monthly volume (AF) on a daily basis and then summing the days in a week. GT-Max then distributes volume hourly throughout the week to optimize energy from water released.

In order to begin the economic impact of the GCD options, as inputs to the GT Max model, annual release volumes were needed for each hydrological condition for each year modeled. In addition, a monthly distribution of this annual release volume was required for each year and each option. The annual release volumes and the monthly distribution of these volumes for the base scenario were provided by Reclamation. Reclamation developed this information using the CRSS model. An explanation of this model and the development of annual release data and monthly distributions for the current effort are included as Appendix 1 of this report[6].

The following table displays the GCD release as modeled by CRSS for three hydrologic sequences. These values are used for each of the proposed options. Additionally, the

[5] Draft Evaluation of GCD Options, GCMRC, June ___ 2006

monthly distributions in tabular and graphic format for each year and hydrological condition are included at the end of the report. Notice that there are 10-years of release data for each hydrological condition.

TABLE 1
Annual GCD Release for Three Hydrological Conditions

Water Year Release	Lower Decile (Dry Scenario)	Most Probable	Upper Decile (Wet Scenario)
2007	8.23 maf	8.23 maf	8.23 maf
2008	8.23 maf	9.72 maf	11.43 maf
2009	8.23 maf	8.23 maf	8.89 maf
2010	8.23 maf	8.23 maf	13.23 maf
2011	8.23 maf	8.23 maf	9.59 maf
2012	8.23 maf	11.96 maf	11.37 maf
2013	8.23 maf	8.61 maf	14.11 maf
2014	8.23 maf	9.71 maf	10.74 maf
2015	8.23 maf	8.38 maf	8.72 maf
2016	8.23 maf	8.23 maf	14.96 maf

Inputs 2—Restrictions on the Operation of a Powerplant

Water/Power Conversion Factor

Hydraulic head or the measurement of potential energy available to convert water to energy effects the amount of power produced with the water available. Each powerplant has a specific regression curve associated with it based on historical energy produced at different hydraulic heads. This water-to-power conversion ratio is imported into GT-Max and used to estimate energy production at current hydraulic head.

[6] *Development of Monthly Lake Powell Inflow and Release Sequences for the Assessment of Experimental Options* T. Ryan, USBR, October, 2006

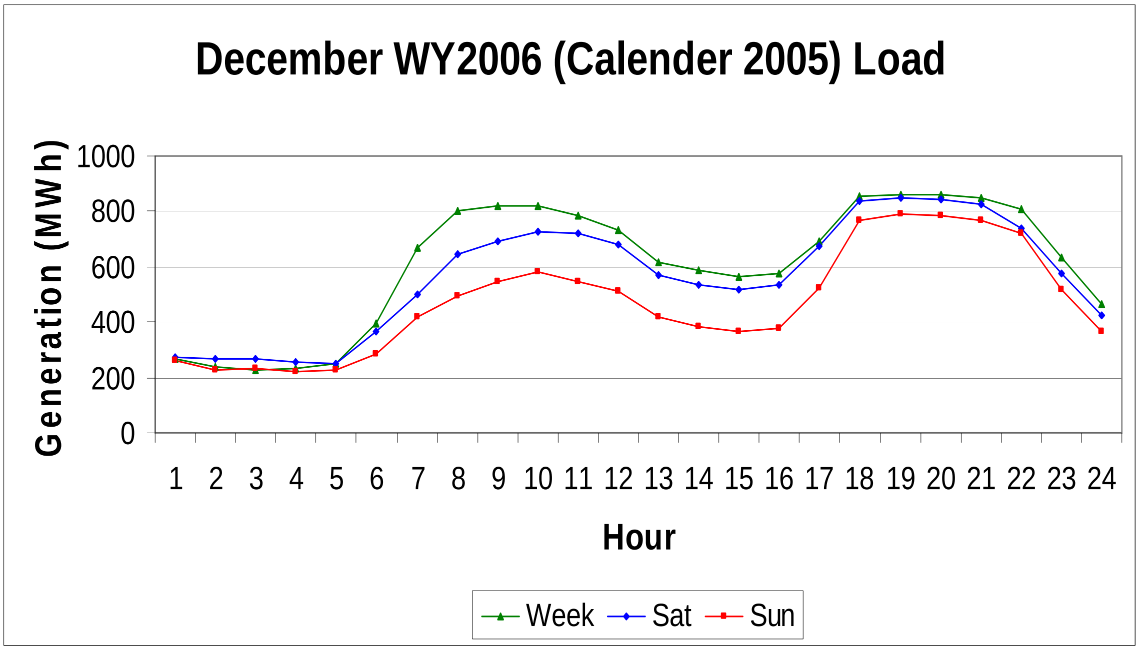
Hydraulic Head

Reclamation produces a 24-month study using its hydrologic model RiverWare. The 24-month study reports 12 months of actual power release, bypass release, end of month (EOM) storage capacity and fore bay (reservoir elevation), along with reporting the predicted values for the next 12 months. The reservoir elevation is used as a measure of hydraulic head. When operations are assumed that differ from the historical or predicted patterned release, the release volume is added or subtracted from the EOM storage and CRSS model runs correlate the new release pattern and storage to EOM reservoir elevations. The reservoir elevation ultimately agrees at the end of any year during the ten-year study period.

Development of CRSP Customer Demand/Load Data

Load calculations are estimated using the previous year's actual customer load scheduled with Western. The monthly load is broken down into Sunday/Holiday, Saturday and Weekday 24-hour load profiles that are then reconstructed into a new monthly profile for the month to be studied. The new monthly load schedule is revised to meet the maximum capacity and energy allocations and minimum capacity take of that new month. Energy allocations were reduced in 2004 in consultation with power customers in response to the drought conditions at that time. As part of that agreement to reduce allocations, they have been increasing to pre-specified levels each year since 2004 with the maximum level to be reached in WY2009 and held constant thereafter. In this analysis, these intermediate energy allocation levels were used in calculating the customer loads in WY2007 and 2008 with the maximum level being used in 2009 through 2016. Figure 1 is a graphical representation of CRSP customer load for three 24-hour periods. These data are taken from December, 2005 and are illustrative of the load data collected as GT MAX model input values.

Figure 1
Illustration of Daily SLCA/IP Customer Load Pattern



In addition to the input data, one needs to prepare the data for model use and specify how the GT MAX model will be used and how GT MAX output data will be aggregated in order to make appropriate comparisons. The latter is referred to as the post processing of the modeled data.

<u>Spot Market Prices</u>

A simple price pattern in the spot market node of the model input includes $2 on-peak and $1 off-peak. Sensitivity analysis of the spot market node showed that the objective function in the model responds only to incremental differences in prices. When actual prices were included in the model the resulting pattern did not differ from output produced when the simple price pattern was used. Sunday generation patterns as a result of the simple price pattern appear flatter than Western's normal representative schedule. Spot market transmission costs of $1 were added on Sunday and $0.01 on Saturday in order to reflect Western's schedule during those times. The resultant pattern on Sunday and Saturday did follow the demand schedule input, but at a reduced generation pattern compared with the weekday schedule.

Input 3—Technical Capabilities of Each Powerplant

Glen Canyon Dam

GCD has a powerplant with an operating capacity of 1,300 MW. The GCD is currently operated in conformance with the operating criteria established in February 24, 1997[7]. These criteria limit such operating parameters as the maximum release (under normal hydrological conditions), minimum release, the maximum change in release that can take place from one hour to the next (up ramps and down ramps) and the maximum total change in release in a 24-hour period. There are other requirements and limitations on the operation of the GCD described in these criteria and related documents that are not part of this modeling effort. Mostly, these relate to the operation of the GCD under emergency conditions.

Other Major CRSP Powerplants Included in the Base Scenario Modeling

The following are brief descriptions of the other CRSP powerplants and the assumptions used in the GT MAX modeling for all scenarios.

[7] Operating Criteria for Glen Canyon Dam In accordance with the Grand Canyon Protection Act of 1992, February 24, 1997.

- ❖ Flaming Gorge Dam contains a powerplant with a nameplate capacity of 150 MW. It is operated within operating criteria established in 1978 and in conformance with a biological opinion completed in 2005. For modeling purposes, the Flaming Gorge powerplant was assumed to operate under a steady flow operation. Monthly water volumes used for the 10 year study period were provided by Reclamation.

- ❖ Aspinall Units consists of three powerplants: Blue Mesa, Morrow Point and Crystal. Combined they total a nameplate capacity of 283 MW. Monthly water release data for these three powerplants over the ten year study period were provided by Reclamation. Operating parameters used for the modeling for this analysis are unrestricted for Blue Mesa and Morrow Point. For Crystal, we limited operation to a constant flow.

- ❖ Fontenelle Dam houses a powerplant that has a nameplate capacity of 11 MW. Monthly water release data was provided by Reclamation.

- ❖ The Collbran project consists of two powerplants called Upper and Lower Molina. Together they have a nameplate capacity of 12 MW. Monthly release data was provided by Reclamation. For modeling purposes, we assume that they operate at a constant rate during on-peak hours and have a zero release during off-peak hours.

Input 4—Environmental Limitations or Targets that Restrict the Operation of the Powerplants

Development of a Base Scenario:

The Base Scenario represents the current operation of GCD as required by the Record of Decision (ROD) of the GCD EIS and the subsequent GCD Operating Criteria adopted in February, 1997.

The ROD was the result of an extensive evaluation of the historic operation of GCD. Several analyses were completed and summarized in the GCD operations EIS – including an economic analysis. The economic analysis and an evaluation of methods were reported in three volumes[8].

Most importantly, this analysis is an attempt to add to the economic analysis completed and summarized in the GCD EIS. The current analysis is a much "slimmed down" approach. However, we attempt to estimate the opportunity cost, or economic impact of modified restrictions on the operating criteria at GCD[9]. The power system economic impact of the implementation of the Modified Low Fluctuating Flow (MLFF) in the EIS was estimated to be $44.2 million dollars in levelized, net present value (1991 $). The method used to estimate this figure as the economic impact was referred to as "Annual Economic Cost". The assumptions used by the authors in this report are, within the limited scope and effort of this analysis, an attempt to duplicate this method.

[8] U.S. Bureau of Reclamation, October, 1993 *Power System Impacts of Potential Changes in Glen Canyon Power Plant Operations*
____________, July, 1995, *Power System Impacts of Potential Changes in glen Canyon Power Plant Operations, Phase III, Final Report*
____________, February, 1990, *Evaluation of Methods to Estimate Power System Impacts of Potential Changes in Glen Canyon Powerplant Operations*

[9] In the above reports, the analysis that best corresponds to the analysis in this report is referred to as federal economic impacts

The MLFF and the national economic impact of $44.2 million annually is therefore the base scenario for this economic analysis. Therefore the impacts described in this report for each of the GCD options (whether positive or negative) would be in addition to the impact of the MLFF.

To be complete, the MLFF must be modeled under more than one hydrological condition since these conditions in the Colorado River basin are quite variable.

To develop a base scenario, the following input data is required:

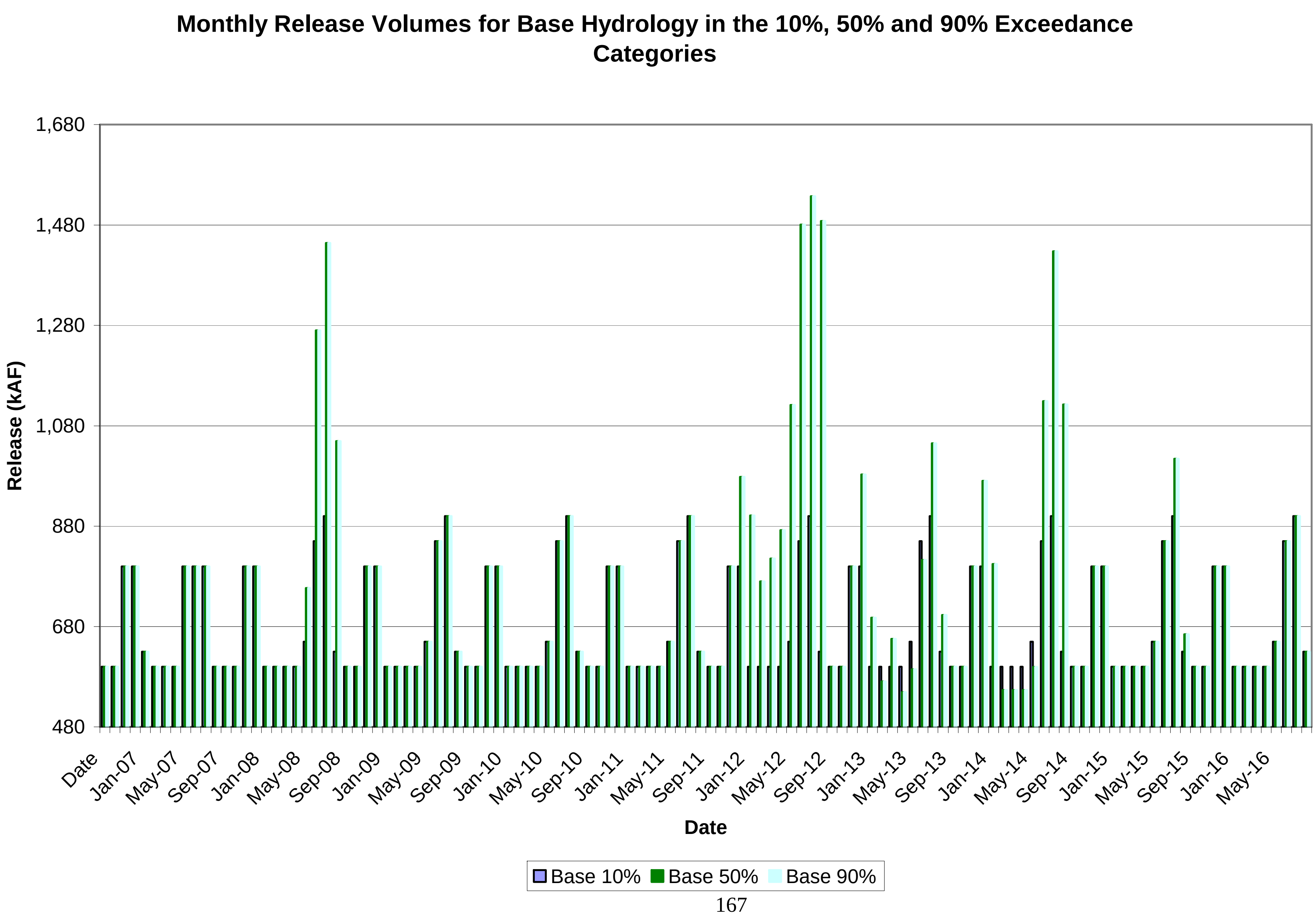
1. annual volumes of GCD release for the 10 year study period,

2. a distribution of monthly water volumes throughout the year,

3. properly described GCD operational constraints,

The annual release volumes, along with the monthly distributions were developed by Reclamation for every month of each ten-year hydrological period. This procedure is described in the GT Max modeling section and further detailed in Appendix 1. Monthly release volumes are consistent in all 8.23 million acre feet (maf) years. When equalization occurs and hydrological considerations necessitate releases greater than 8.23 maf, monthly release volumes differ (Figure 2).

Figure 2


Monthly Release Volumes for Base Hydrology in the 10%, 50% and 90% Exceedance Categories
1,680
1,480
1,280
1,080
880
680
480
Release (kAF)
Date
Jan-07
May-07
Sep-07
Jan-08
May-08
Sep-08
Jan-09
May-09
Sep-09
Jan-10
May-10
Sep-10
Jan-11
May-11
Sep-11
Jan-12
May-12
Sep-12
Jan-13
May-13
Sep-13
Jan-14
May-14
Sep-14
Jan-15
May-15
Sep-15
Jan-16
May-16
Date
Base 10%
Base 50%
Base 90%

The operating criteria for GCD complies with the ROD constraints (Table 2).

TABLE 2[10]

Glen Canyon Base Scenario Operational Constraints					
Month	Max Daily Change UP/DOWN	Min Release[¥]	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	ROD*	5	25	4	1.5
11	ROD*	5	25	4	1.5
12	ROD*	5	25	4	1.5
1	ROD*	5	25	4	1.5
2	ROD*	5	25	4	1.5
3	ROD*	5	25	4	1.5
4	ROD*	5	25	4	1.5
5	ROD*	5	25	4	1.5
6	ROD*	5	25	4	1.5
7	ROD*	5	25	4	1.5
8	ROD*	5	25	4	1.5
9	ROD*	5	25	4	1.5

*ROD constraints limit maximum daily change up and down to: 5,000 cfs/day if month < 600,000 AF; 6,000 cfs/day if month >= 600,000 AF and < 800,000 AF; 8,000 cfs/day if month >= 800,000 AF.

[¥]Minimum releases between 7 am and 7 pm are 8,000 cfs and drop to 5,000 cfs during all other hours. Minimum release constraints indicate minimum releases below 8,000 cfs.

Development of Alternatives

Four alternatives were presented for analysis. These four alternatives are: SPG A, A Variation, SPG B and SPG C. SPG A and A Variation (A') utilize base case monthly release patterns. SPG B and C requested monthly release patterns that differ from the MLFF. In all hydrological scenarios 8.23 maf years remain the same for the base case, SPG A and A Variation. SPG C alters the MLFF 8.23 maf pattern, but the monthly release pattern does retain the altered 8.23 maf pattern in all years. SPG B has a tiered option that requires water release volumes to change over a seven year period. Years in which hydrological inflows necessitate releases greater than 8.23 maf do not retain similar patterns. GCD equalization constraints drive monthly releases according to hydrological inflows. A comparison of SPG A, A', SPG B and SPG C in graph display appears below (Figures 3, 4, 5). Tabular representation of monthly releases is included as Attachment 1.

[10] Operation of Glen Canyon Dam, Final Environmental Impact Statement, March 1995, U.S. Department of Interior, Bureau of Reclamation

FIGURE 3 – Wet Case

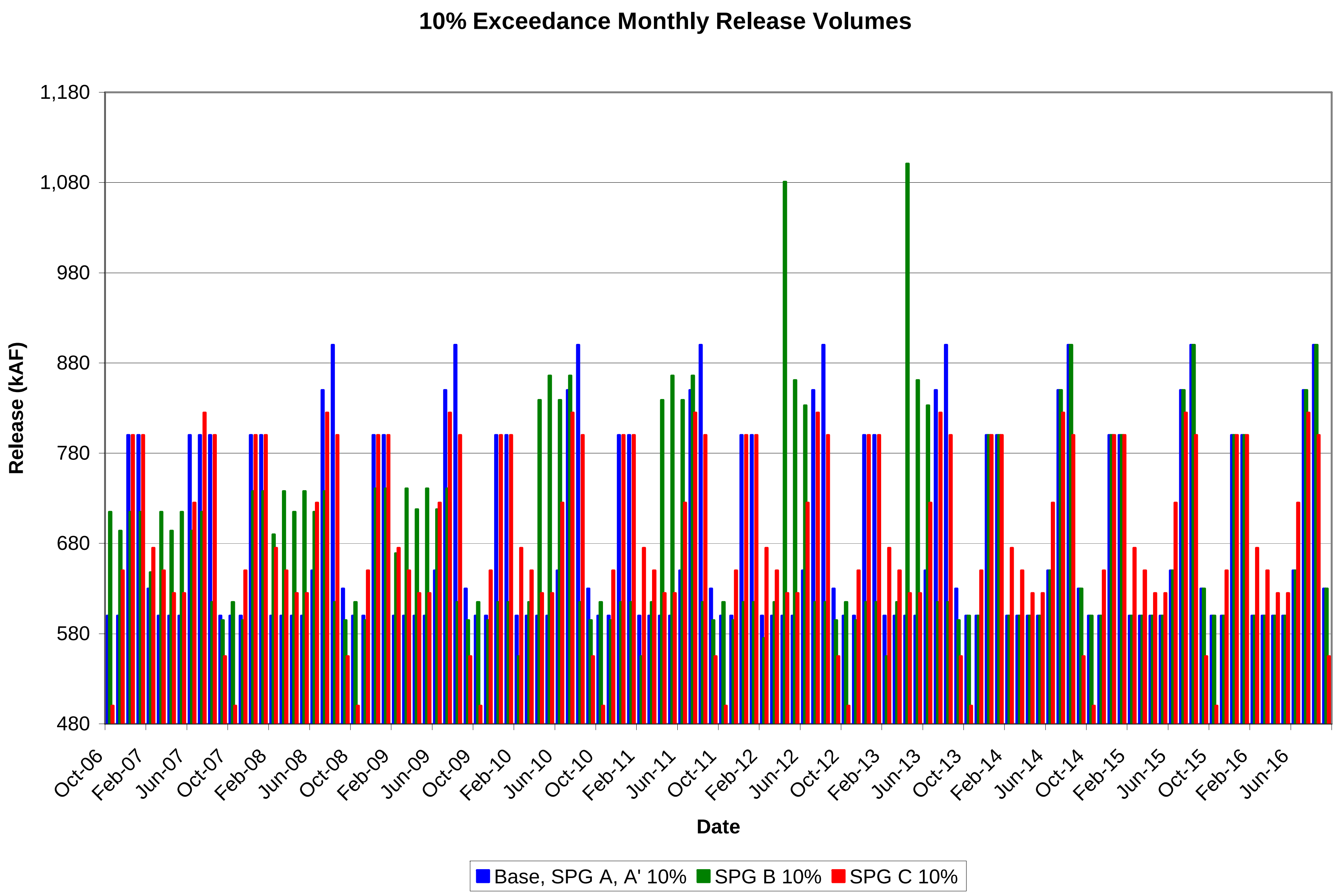


FIGURE 4 Most Probable Case

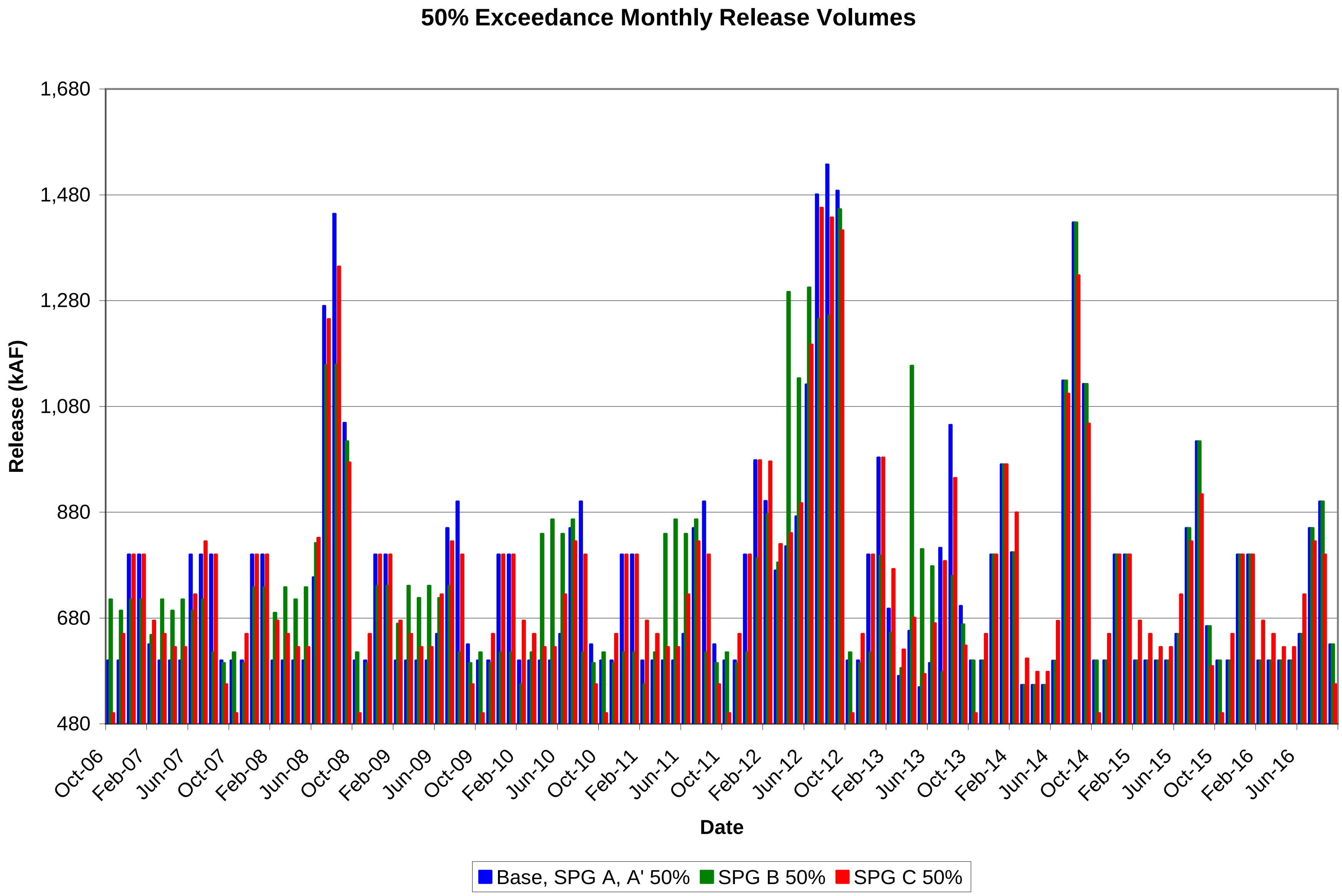
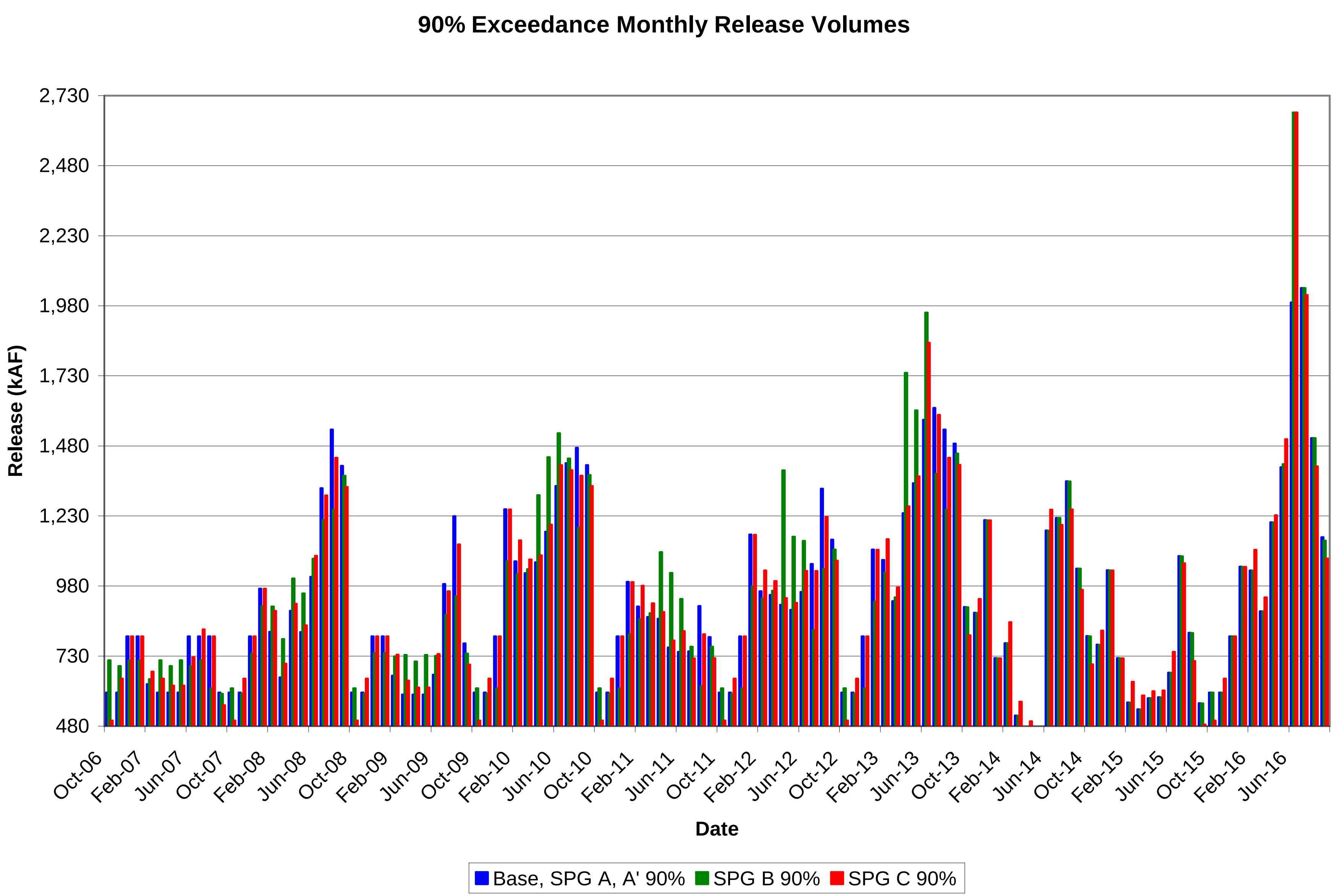


FIGURE 5 Dry Case



In order to understand the constraints that are used as inputs for the GT MAX model for each of the GCD options, the operational constraints for each of the options are included below as Table 3

TABLE 3

Glen Canyon SPG A Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release[¥]	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	ROD*	5	25	4	3
11	ROD*	5	25	4	3
12	12	5	25	4	3
1	12	5	25	4	3
2	10	5	25	4	3
3	ROD*	5	25	4	3
4	ROD*	5	25	4	3
5	ROD*	7	25	4	3
6	ROD*	7	25	4	3
7	10	7	25	4	3
8	10	7	25	4	3
9	ROD*	7	25	4	3

*ROD constraints limit maximum daily change up and down to: 5,000 cfs/day if month < 600,000 AF; 6,000 cfs/day if month >= 600,000 AF and < 800,000 AF; 8,000 cfs/day if month >= 800,000 AF.
[¥]Minimum releases between 7 am and 7 pm are 8,000 cfs and drop to 5,000 cfs during all other hours. Minimum release constraints indicate minimum releases below 8,000 cfs.

Glen Canyon SPG B Years 1-3 Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release[¥]	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	0.01	5	25	4	1.5
11	0.01	5	25	4	1.5
12	4	5	25	4	1.5
1	4	5	25	4	1.5
2	4	5	25	4	1.5
3	4	5	25	4	1.5
4	4	5	25	4	1.5
5	4	5	25	4	1.5
6	4	5	25	4	1.5
7	4	5	25	4	1.5
8	0.01	5	25	4	1.5
9	0.01	5	25	4	1.5

Glen Canyon SPG A Variation Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release[¥]	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	8	5	25	4	3
11	8	5	25	4	4
12	12	5	25	4	4
1	12	5	25	4	4
2	10	5	25	4	4
3	8	5	25	4	4
4	ROD*	5	25	4	3
5	ROD*	7	25	4	3

Glen Canyon SPG B Years 4 & 5 Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release[¥]	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	0.1	5	25	4	1.5
11	0.1	5	25	4	1.5
12	0.1	5	25	4	1.5
1	0.1	5	25	4	1.5
2	0.1	5	25	4	1.5
3	0.1	5	25	4	1.5
4	4	5	25	4	1.5
5	4	5	25	4	1.5

6	ROD*	7	25	4	3
7	10	7	25	4	3
8	10	7	25	4	3
9	ROD*	7	25	4	3

6	4	5	25	4	1.5
7	4	5	25	4	1.5
8	0.1	5	25	4	1.5
9	0.1	5	25	4	1.5

Glen Canyon SPG C Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release¥	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	0.01	5	25	4	1.5
11	ROD*	5	25	4	3
12	12	5	25	4	3
1	12	5	25	4	3
2	10	5	25	4	3
3	ROD*	5	25	4	3
4	ROD*	5	25	4	3
5	ROD*	7	25	4	3
6	ROD*	7	25	4	3
7	ROD*	7	25	4	3
8	ROD*	7	25	4	1.5
9	0.01	7	25	4	1.5

Glen Canyon SPG B Years 6 & 7 Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release¥	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	0.1	5	25	4	1.5
11	0.1	5	25	4	1.5
12	0.1	5	25	4	1.5
1	0.1	5	25	4	1.5
2	0.1	5	25	4	1.5
3	0.1	5	25	4	1.5
4	0.1	5	25	4	1.5
5	0.1	5	25	4	1.5
6	0.1	5	25	4	1.5
7	0.1	5	25	4	1.5
8	0.1	5	25	4	1.5
9	0.1	5	25	4	1.5

Glen Canyon SPG B Years 7-10 Operational Constraints

Month	Max Daily Change UP/DOWN	Min Release¥	Max Release	Hourly Up-ramp	Hourly Down-ramp
10	ROD*	5	25	4	1.5
11	ROD*	5	25	4	1.5
12	ROD*	5	25	4	1.5
1	ROD*	5	25	4	1.5
2	ROD*	5	25	4	1.5
3	ROD*	5	25	4	1.5
4	ROD*	5	25	4	1.5
5	ROD*	5	25	4	1.5
6	ROD*	5	25	4	1.5
7	ROD*	5	25	4	1.5
8	ROD*	5	25	4	1.5
9	ROD*	5	25	4	1.5

Post-Processing of GT MAX Modeled Output

As stated above, the GT MAX model output is a data set of a week (168 values) of hourly electrical generation, in megawatts, for the week modeled. One representative week is modeled for each month in a given year. A total of ten years are modeled. These ten years of data are the GT MAX outputs for each of three hydrological conditions. Due to the large amount of data generated, post-production of these data is necessary to formulate an understanding and a context.

Extending the weekly runs to the entire year

Each representative week of generation modeled by GT MAX is turned into a month of generation by replicating the typical week four times, plus a fractional portion of a week determined according on the particular month. This is done for all twelve months when exporting the GT MAX modeled outputs into a spreadsheet. The resulting spreadsheet contains hourly energy production for an entire year (8760 hours) of study for a particular hydrological condition and scenario. The entire study data base consists of a set of these spreadsheets comprising the ten year study period, for each scenario, and for the three hydrological conditions. For ease of modeling and post processing, in each of the ten future years studied the first day of the Water Year begins on a Sunday, thereby simplifying the task of keeping track of the weekdays, Saturdays, and Sundays for the 10 year study period.

For the base scenario, the data consists only of hourly generation amounts. No dollar values are applied.

Losses and Project Use

Hourly hydro generation was reduced by subtracting project use estimates and system losses to obtain the net hourly generation available to meet customer scheduled load. Project use loads were calculated using the same values that determine monthly AHP (available hydropower), and are based on recent energy schedules of those loads as recorded by the CRSP MC scheduling office. System losses were calculated at 7.81 percent of the hourly hydro generation, the same value as used in other modeling.

Load Following Capacity

In addition to the production of electrical energy, the GCD powerplant produces electrical generating capacity. Electrical energy and capacity are related but separate electrical products. Typically, wholesale buyers of electricity purchase two products: capacity and energy. These two products respectively represent the construction and operating costs of production.

For the base scenario, the difference between GCD minimum generation and maximum generation within a month was used to determine the amount of capacity for the month. For example, if the GT MAX minimum hourly GCD output for December, 2008 for the dry hydrological condition is 300 MW (Sunday at 5 AM) and the maximum hourly GCD output for this month is 650 MW (Wednesday at 4 PM), then the determination of GCD capacity for that month is 350 MW. This is the "load following" capacity of GCD in this month. The "load following" GCD capacity is calculated and compared to the "total capacity" of GCD because it better represents the contractual relationship between changes in the GCD operation and the resulting impact on CRSP customers.

Comparison of Options vs. Base Scenario

For each GCD option the GT MAX is run with all of the SLCA/IP powerplants included in the model run. GCD generation is then extracted and put into the base case spreadsheet. This is done so that the impact of the option being considered is calculated from only the changes at the GCD powerplant. The SCLA/IP powerplants retain base case generation values.

Once a spreadsheet is prepared that includes the GT MAX modeled output from GCD with the base scenario GT MAX output from the other CRSP units, the hourly CRSP generation numbers for the base scenario are compared to each hourly CRSP generation of an option. Each option is compared separately.

When an hourly electrical generation value for the base scenario is compared to the same hour for an option, the difference will either be positive or negative. A positive difference means that there is that much more electrical energy produced at GCD in that hour for that option as compared to the base scenario. A negative difference means the opposite.

The difference was then multiplied by an energy price to calculate an hourly cost of energy purchases from or sales to the spot market. Energy costs were summed for an entire month and added together to get a total cost or revenue per month.

The monthly load following capacity is averaged over a year. This “yearly average, load-following capacity” is the relevant capacity statistic and will be compared to the same statistic for each option in order to calculate the capacity impacts of the options.

Accounting for Impacts on Capacity among the GCD Options

In order to fully assess the economic impact on GCD electrical power production, the difference in marketable capacity between the baseline case and an option was calculated using a yearly average capacity value. Then, a capacity price was determined and the estimated change in marketable capacity was multiplied by the capacity price. This was then added to the estimate for economic impact of an option using energy prices alone. The total impact is then calculated.

Total of Estimated Loss/Gain

The total economic impact of an option, as compared to the baseline is the addition of the change in the purchases and sales and the change in marketable capacity. These are summed to get the total impact. A preferred way to look at this, however, is to represent a range of possible economic impacts with the purchase/sales change being the lower end of an economic impact for an option. The purchase/sales change added to the value of loss/gain in capacity represents the upper range of possible economic impact of an option as compared to the baseline.

Prior to describing the method of comparing the impact of the GCD options against the base scenario, it is worth noting those variables that are held constant between the base scenario and any of the GCD options. We attempt to keep all of the model inputs constant unless the values of these inputs are expressly changed by a GCD option. The following are held constant: SLCA/IP customer hourly demand, hourly purchase prices, the operating parameters of the other CRSP power units and capacity replacement cost.

As the results of our analysis are described below, it is worth reiterating that these impacts are scored against a baseline that is a regulated electrical power generator. That is, GCD is regulated through restrictions on operating parameters put in place in 1997.

Comparison Method

The hourly generation values are compared to the matching hourly values of the change case. The differences for each hour are the variables used to assess the impact of a GCD option. Therefore, only the differences (or the delta) are used. This way, a comparison of the base scenario with any of the four GCD options is a comparison of differences.

The database that results from this comparison is in hourly generation value differences. These hourly differences are multiplied by the avoided cost or replacement cost.

Selection of hourly avoided cost

For this economic analysis, the authors attempt to estimate the value of electrical generating resources that would need to be added to existing construction plans or that would be avoided. Whether constructed or avoided depends on the direction of the impact. These costs will be of two types: electrical energy and electrical capacity. As we stated at the outset of this paper, electrical energy and capacity are separate electrical products. Therefore, we identified energy prices and capacity prices separately.

Electrical Energy is Valued Hourly

Wholesale electrical market participants frequently make spot market trades on an hourly basis, sometimes referred to as hour- ahead or real time purchases. Hour-ahead energy prices increase and decrease each hour to track changes in generation and system load in a given area over a given time period. Hourly values therefore, better represents the opportunity cost of using electrical energy to serve the utility's native load as compared to a static price for defined on-peak and off-peak periods.

Pricing assumptions for electrical energy values were: futures prices for energy at the Palo Verde trading hub for October 2006 through September 2007 as reported by Prebon Energy in the July, 2006 time frame[11]. The on-peak and off-peak price was used for all purchases during a given month depending on the time of the purchase. Table 4 shows the spot market prices used.

[11] Prebon Energy of Jersey City, NJ provides power marketers, utilities, producers, risk managers and institutions with a single comprehensive source for price information and liquidity in a broad and expanding range of energy markets including, coal, natural gas, oil and power. See http://www.prebonenergy.com/index.aspx. Prebon is one of several entities Western has access to that report wholesale prices at western US trading hubs.

Table 4
Spot Market Prices

	Onpeak	Offpeak
October	$ 58.39	$ 48.33
November	$ 70.25	$ 58.14
December	$ 81.31	$ 67.29
January	$ 78.68	$ 65.11
February	$ 78.75	$ 65.17
March	$ 77.01	$ 63.73
April	$ 51.44	$ 42.57
May	$ 50.25	$ 41.59
June	$ 50.74	$ 41.99
July	$ 82.24	$ 68.06
August	$ 83.00	$ 68.69
September	$ 83.91	$ 69.44

Monthly on-peak and off-peak prices were translated into hourly energy prices by scaling them according customer demand. Figure 1 of this report shows a representation of SLCA/IP customer demand by hour for an illustrative day in December. Hourly customer demand information for each month was used as a surrogate for system load to create an index – each hour being scaled up or down in proportion to the load in that hour. The monthly future's price was modified according to this index so that the average of the hourly prices over the period was the same as the monthly futures price. Even though 2007 future's prices are used, these prices remain constant for the 10-year study period. They are not escalated to account for inflation - this is a "real" number analysis.

This method allows for the representation of hourly values. Historic hourly values are a matter of record, but we choose to construct hourly data on the value of electrical energy based on the market's best estimate of future prices. This avoids the problem that, in a volatile energy market, past conditions are often unrepresentative of future conditions, as well as avoiding the problem of missing or anomalous hourly historical values.

Using this set of hourly prices for a month, we multiplied the difference in electrical energy generation each hour by the hourly price to yield the dollar impact for that hour. We then summed the hourly "deltas" over the month. This was done for each month of the year and this process was repeated for each year of the ten-year study.

Results

Table 5 shows the electrical energy impact by year for each of the four options as compact to the base scenario. These are shown for each of the three hydrological conditions. A negative impact (as compared to the base case) is shown in red and in parentheses. Positive impacts are shown in black.

TABLE 5
Impact of GCD options on the value of energy production - compared with the base scenario
(Net of sales/purchases, 2006 $)

Dry Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	2,658,214	1,973,837	2,166,098	1,784,279	(638,044)	2,032,725	1,963,606	1,885,246	1,883,218	2,174,330
A Var	3,431,464	2,565,203	3,004,804	2,594,068	126,990	2,738,880	2,710,709	2,646,086	2,630,214	2,858,950
B	(5,306,724)	(10,047,447)	(9,223,666)	(13,640,087)	(15,334,711)	(18,243,064)	(18,179,461)	982,107	50,533	42,410
C	811,678	(693,130)	(260,768)	(895,798)	(2,048,943)	(408,833)	(405,699)	(961,595)	(903,068)	(698,255)
MP Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	870,781	440,492	2,274,493	2,163,843	2,588,848	1,892,990	2,367,489	430,699	2,474,325	2,181,922
A Var	1,618,909	1,309,967	3,119,687	2,952,387	3,275,465	2,794,987	3,567,623	1,266,560	3,365,766	2,996,435
B	(8,833,558)	(10,940,178)	(10,159,789)	(15,381,093)	(14,577,983)	(17,674,643)	(20,203,360)	(1,317,689)	(337,613)	44,575
C	(208,773)	(1,317,279)	(411,933)	(675,850)	755,772	(340,902)	(152,932)	(1,586,277)	(862,929)	(1,367,940)
Wet Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	2,098,646	1,880,026	2,486,511	1,519,587	2,862,172	2,285,072	2,960,105	2,099,602	2,247,485	1,979,330
A Var	2,186,059	2,487,221	3,308,227	1,866,228	3,365,282	2,167,203	2,788,933	2,838,941	3,419,277	2,395,987
B	(8,357,907)	(8,980,300)	(9,665,265)	(13,347,437)	(16,108,922)	(21,022,289)	(20,688,428)	37,310	29,413	(203,084)
C	$ 1,006,602	$ 1,212,620	$ (136,670)	$ (66,466)	$ (632,779)	$ (1,439,541)	$ 1,748,008	$ (755,747)	$ 388,022	$ 122,309

Table 6 is a 10-year average of the results from Table 5. The average impact of the four options is recorded in this table. Remember that these are impacts of electrical energy production only (capacity analysis will come later). It is also important to note that these data are the outcomes of a real analysis: there is no "inflation factor" used.

TABLE 6
Energy impacts, 10 Year Average

Dry Hydro	
Base Case	$0
A	$1,788,351
A Variation	$2,530,737
B	($8,890,011)
C	($646,441)

M P Hydro	
Base Case	$0
A	$1,768,588
A Variation	$2,626,779
B	($9,938,133)
C	($616,904)

Wet Hydro	
Base Case	$0
A	$2,241,854
A Variation	$2,682,336
B	($9,830,691)
C	$114,636

Capacity Impacts of the GCD Options

In addition to the generation of electrical energy, GCD also provides electrical capacity through contractual arrangements between Western Area Power Administration and the SLCA/IP customers.

In order to assess the impact of an option against the base scenario, we calculated load following capacity for an option in the same way that we performed this calculation for the base scenario. As the reader will recall from our description of the base scenario, we took the GCD minimum and maximum generation for each week (representing a month) from the GT MAX model output as a representation of the "load following" capacity for the month. The monthly data are averaged over a year to yield a yearly average. The relevant comparison is therefore between the base scenario 12-month average capacities for a year against the same calculation for a GCD option.

Table 7 records the "load following" capacity impacts, by year, of the GCD options as against the base scenario in megawatts. A GCD Option which results in a reduction in load-following capacity is shown in red and is parenthetical. A GCD option which results in an increase in load-following capacity as compared to the base scenario is shown in black.

Table 8 shows the dollar impact of the GCD options regarding load-following capacity. Table 6 is derived from the capacity impacts recorded in Table 5. The GCD capacity impacts are multiplied by the replacement cost for capacity. Again, Table 6 is a record of "differences" only; "deltas" when compared to the base scenario.

Determination of Capacity Values

For this analysis, capacity is valued at the replacement cost identified by some SLCA/IP customer utilities who have recently constructed facilities which provide load following capacity[12]. These customer data were collected in order to get information regarding the construction cost per megawatt of a recently built facility that provides electrical services similar to the GCD powerplant.

For Table 8, economic impacts are presented in 2006 dollars. Red numbers in parentheses are reductions in economic value. Black numbers are gains in economic value.

---

[12] SRP & TriState: capacity construction cost for a load following/peaking facility recently constructed in Arizona.

TABLE 7
Impact of GCD Options on Load Following Capacity – Compared to the Base Scenario (MW)

Dry Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	-	-	-	-	-	-	-	-	-	-
A	40	37	38	37	31	38	38	36	34	38
A Var	56	56	60	54	49	60	57	53	52	60
B	(57)	(126)	(130)	(155)	(154)	(214)	(201)	39	0	0
C	(6)	21	(4)	(1)	0	10	(4)	(3)	(3)	31

MP Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	-	-	-	-	-	-	-	-	-	-
A	44	48	34	41	33	23	38	40	47	43
A Var	60	71	57	62	55	43	66	57	76	66
B	(130)	(133)	(144)	(178)	(185)	(224)	(232)	8	(9)	(0)
C	0	42	(6)	(1)	(11)	80	(5)	(6)	2	37

Wet Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	-	-	-	-	-	-	-	-	-	-
A	33	29	36	30	20	36	63	42	48	29
A Var	33	43	41	2	27	49	54	24	48	97
B	(142)	(152)	(142)	(226)	(237)	(290)	(196)	0	0	0
C	(12)	55	(1)	(28)	(32)	14	63	(19)	12	73

TABLE 8
Load Following Capacity Dollar Difference Compared to the Base Case
(2006 $)

Dry Base

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
A	3,208,803	2,957,005	3,019,745	2,931,286	2,509,444	3,062,295	3,076,772	2,858,492	2,754,997	3,048,194
A Var	4,474,209	4,484,716	4,766,447	4,299,626	3,906,664	4,822,448	4,542,151	4,255,859	4,191,329	4,792,982
B	(4,549,786)	(10,079,619)	(10,371,797)	(12,384,994)	(12,303,554)	(17,108,416)	(16,108,811)	3,106,963	4,991	3,884
C	(447,024)	1,654,463	(291,390)	(52,670)	1,669	809,276	(353,303)	(207,096)	(208,080)	2,442,006

MP Base

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
A	3,541,658	3,833,383	2,750,002	3,243,249	2,604,754	1,847,852	3,024,815	3,174,341	3,795,985	3,401,708
A Var	4,813,007	5,705,233	4,549,188	4,929,035	4,406,651	3,424,000	5,271,135	4,541,949	6,089,531	5,317,202
B	(10,390,317)	(10,640,324)	(11,504,269)	(14,216,585)	(14,793,460)	(17,925,884)	(18,565,923)	658,126	(695,186)	(10,962)
C	39,334	3,383,465	(493,853)	(50,959)	(895,040)	6,366,806	(419,826)	(497,747)	191,862	2,975,164

Wet Base

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Base Case	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
A	2,625,337	2,318,695	2,845,591	2,381,462	1,636,459	2,910,560	5,070,309	3,389,525	3,853,127	2,311,332
A Var	2,625,337	3,420,095	3,298,432	216,404	2,198,121	3,911,060	4,357,609	1,923,895	3,846,814	7,745,403
B	(11,395,548)	(12,131,571)	(11,375,438)	(18,061,776)	(18,985,453)	(23,172,316)	(15,694,985)	2,458	2,458	1,862
C	(930,597)	4,402,511	(119,273)	(2,248,784)	(2,538,933)	1,091,040	5,079,772	(1,547,705)	990,854	5,826,253

Table 9, below, provides information regarding the 10-year average of capacity impacts for the four options as compared to the base scenario.

TABLE 9
Average Capacity Impact of Options

Dry Base		
	Average (MW)	**Average ($)**
Base Case	**-**	**$0**
A	**36.78**	**$2,942,703**
A Variation	**55.67**	**$4,453,643**
B	**(99.74)**	**($7,979,114)**
C	**4.185**	**$ 334,785**
MP Base		
	Average (MW)	**Average ($)**
Base Case	**0.00**	**$0**
A	**39.02**	**$3,121,775**
A Variation	**61.31**	**$4,904,693**
B	**(122.61)**	**($9,808,478)**
C	**13.249**	**$ 1,059,921**
Wet Base		
	Average (MW)	**Average ($)**
Base Case	**0.00**	**$0**
A	**36.68**	**$2,934,240**
A Variation	**41.93**	**$3,354,317**
B	**(138.51)**	**($11,081,031)**
C	**12.506**	**$ 1,000,514**

In order to calculate the total economic impact of the GCD options, the energy and capacity impacts are summed together.

Table 10
Total Economic Impact of Options Compared to Base Scenario
(2006 $)

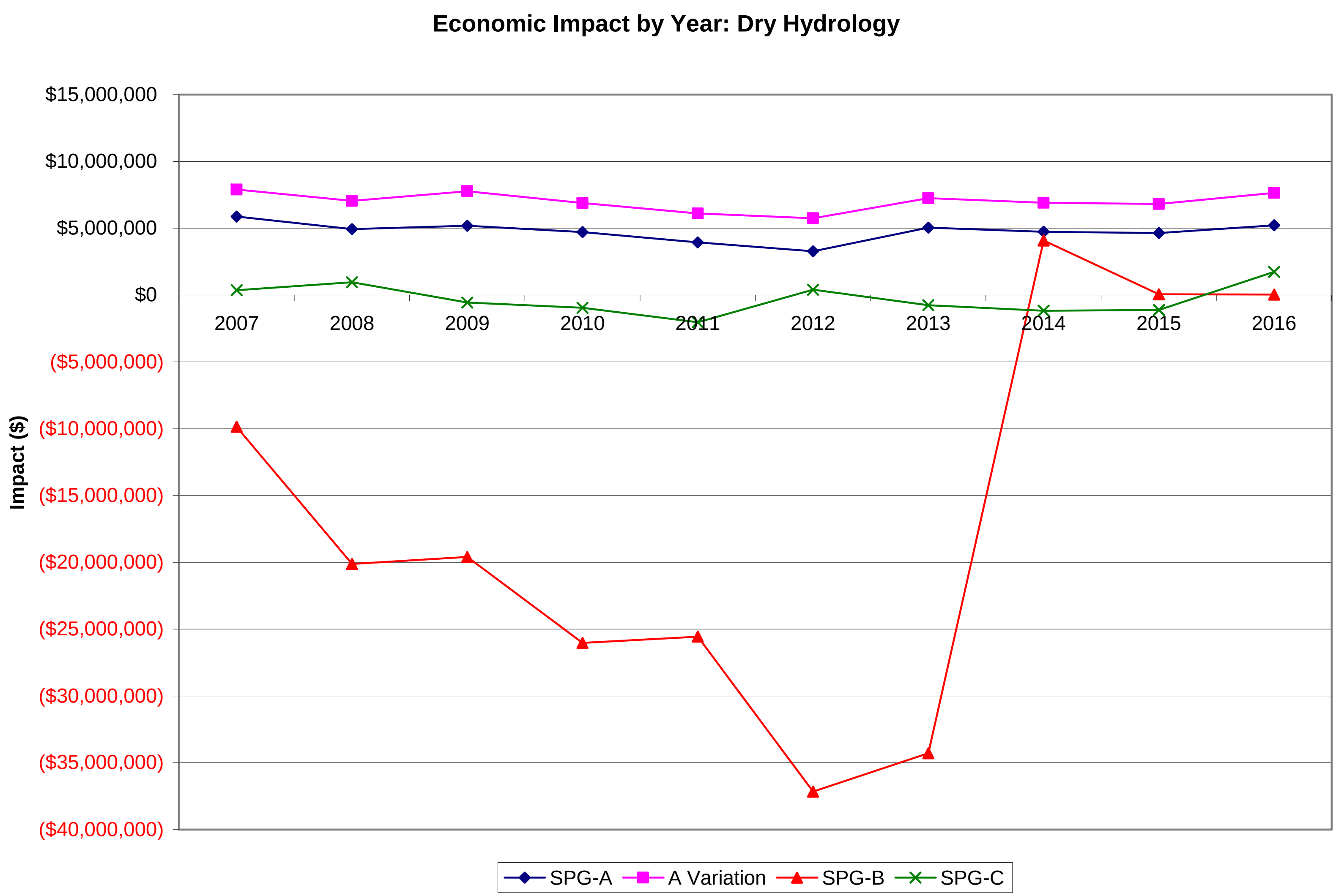
Dry Hydro	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	5,867,016	4,930,842	5,185,843	4,715,565	1,871,401	5,095,020	5,040,379	4,743,738	4,638,214	5,222,524
A Var	7,905,672	7,049,919	7,771,251	6,893,694	4,033,654	7,561,328	7,252,860	6,901,945	6,821,543	7,651,932
B	(9,856,510)	(20,127,066)	(19,595,463)	(26,025,082)	(27,638,265)	(35,351,480)	(34,288,272)	4,089,069	55,523	46,294
C	364,655	961,333	(552,158)	(948,469)	(2,047,274)	400,443	(759,002)	(1,168,691)	(1,111,148)	1,743,750

MP Hydro	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	4,412,439	4,273,875	5,024,495	5,407,091	5,193,603	3,740,842	5,392,305	3,605,041	6,270,310	5,583,630
A Var	6,431,916	7,015,201	7,668,875	7,881,422	7,682,115	6,218,986	8,838,758	5,808,509	9,455,297	8,313,637
B	(19,223,875)	(21,580,502)	(21,664,058)	(29,597,678)	(29,371,442)	(35,600,528)	(38,769,283)	(659,563)	(1,032,800)	33,613
C	(169,439)	2,066,186	(905,786)	(726,809)	(139,268)	6,025,904	(572,758)	(2,084,024)	(671,067)	1,607,225

Wet Hydro	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Base Case	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
A	4,723,983	4,198,721	5,332,102	3,901,050	4,498,631	5,195,632	8,030,414	5,489,128	6,100,611	4,290,662
A Var	4,811,396	5,907,316	6,606,659	2,082,631	5,563,403	6,078,264	7,146,542	4,762,836	7,266,092	10,141,391
B	(19,753,455)	(21,111,871)	(21,040,704)	(31,409,213)	(35,094,375)	(44,194,605)	($36,383,413)	39,768	31,872	(201,221)
C	76,006	5,615,131	(255,943)	(2,315,250)	(3,171,712)	(348,501)	6,827,780	(2,303,451)	1,378,876	5,948,562

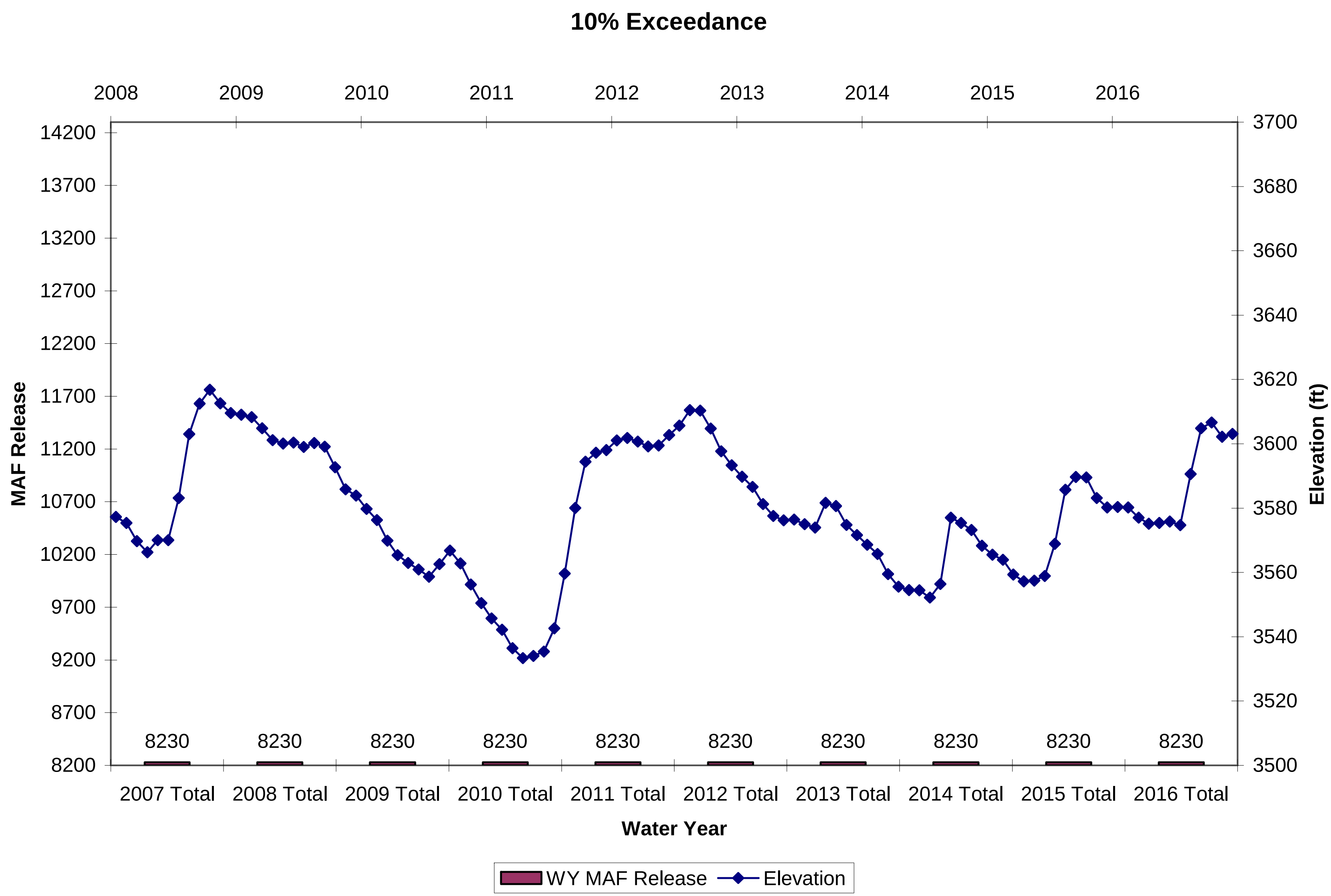
An evaluation of the economic impact apart from the issue of hydraulic head indicates that option “A Variation” lies consistently above “A” indicating its increased economic value (Figure 6) Options “A Variation” and “A” consistently lie above the base scenario, indicating that they provide added economic benefits in terms of electrical power production. GCD option “C” vacillates between a positive and negative impact. If no August trigger is applied to option “C” then the impact for the option is strongly tied to hydrology and hydraulic head as compared to the base case. GCD option “B” reduces economic benefit and lies significantly below the other options in most years. However, in years 2014 – 2016, GCD option “B” returns to “ROD” operations.

FIGURE 6



Economic Impact by Year: Dry Hydrology
Impact ($)
$15,000,000
$10,000,000
$5,000,000
$0
($5,000,000)
($10,000,000)
($15,000,000)
($20,000,000)
($25,000,000)
($30,000,000)
($35,000,000)
($40,000,000)
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
SPG-A
A Variation
SPG-B
SPG-C

FIGURE 7



10% Exceedance
2008
2009
2010
2011
2012
2013
2014
2015
2016
14200
13700
13200
12700
12200
11700
11200
10700
10200
9700
9200
8700
8200
MAF Release
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3500
Elevation (ft)
8230
8230
8230
8230
8230
8230
8230
8230
8230
8230
2007 Total
2008 Total
2009 Total
2010 Total
2011 Total
2012 Total
2013 Total
2014 Total
2015 Total
2016 Total
Water Year
WY MAF Release
Elevation

A comparison of the graphical representation of the total economic impact by year for the four GCD options in the dry hydrological (10% exceedance) category against the elevation and water release illustrates the impact of hydraulic head on turbine efficiency. In the dry hydrological condition all releases are 8.23 maf. However, between 2010 and 2012 the reservoir elevation magnitude reaches 40 feet in difference between years. This impacts both total energy and capacity differences. A comparison between the graphs shows the magnitude of the total economic impact corresponding with the elevation curve (Figures 6 and 7 above). Further analysis shows the impact of hydraulic head on capacity (Figures 8 and 9). The hourly hydrograph produced in the base case for the month of November in years 2011 and 2012 releases the same amount of water and is scheduled nearly the same way. The hydrograph for 2011 decreases releases on Sunday (Figure 8). Although the water released is the same, the generation produced from the water does not compare (Figure 9).

FIGURE 8*

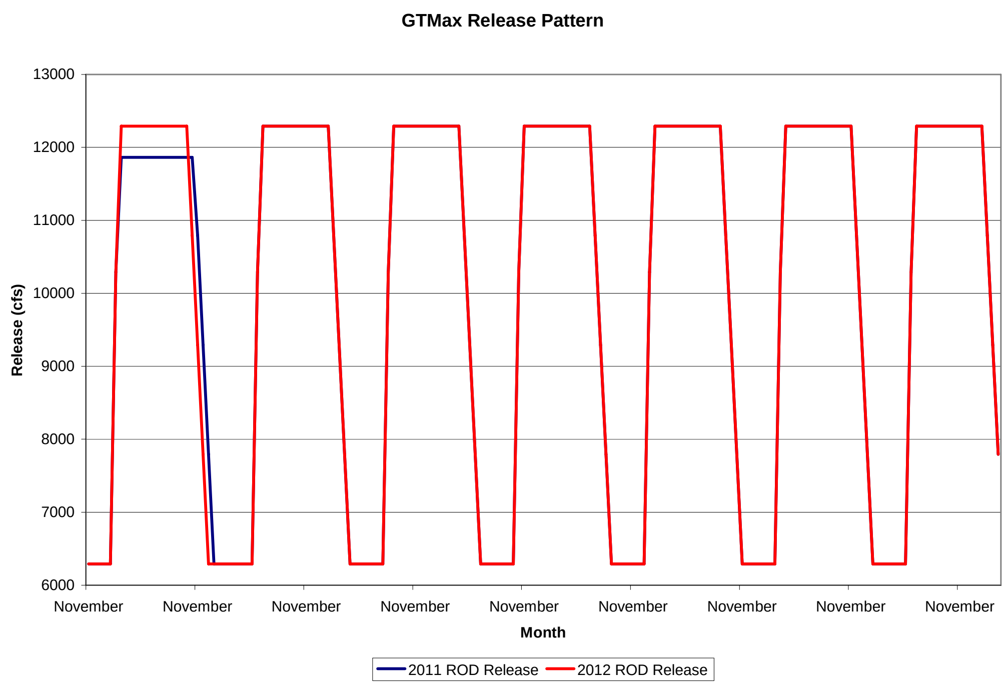
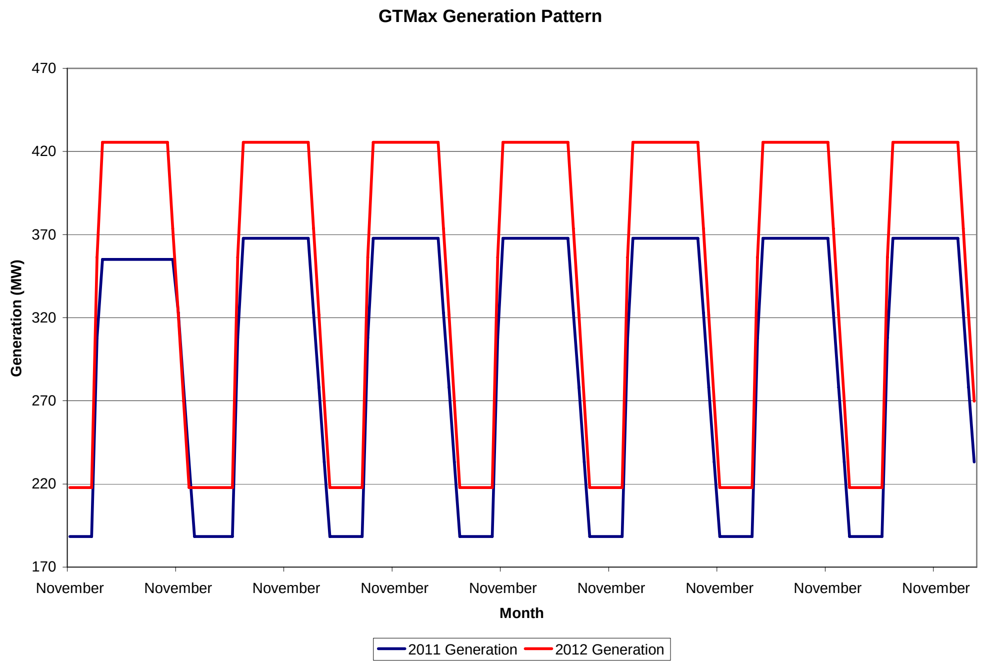


FIGURE 9**



A visual analysis of the most probable condition shows that the total economic impact for all scenarios in 2012 tend to converge toward each other (Figure 10 below). This can be explained by both the large annual water release in order to equalize in that year and the increased reservoir elevation in 2012 (Figure 11). Years in which large quantities of water volume are released converge together. Once monthly volumes necessitate the evacuation of water above the maximum ROD constraint of 25,000 cfs, all scenarios release water without fluctuation consistently throughout the day at the level required to evacuate the monthly volume. At that point operational constraints between the options no longer appear because all scenarios releases high-volume, flat flows on a consistent basis. The phenomena appears again with wet hydrological scenarios (Figures 12 and 13).

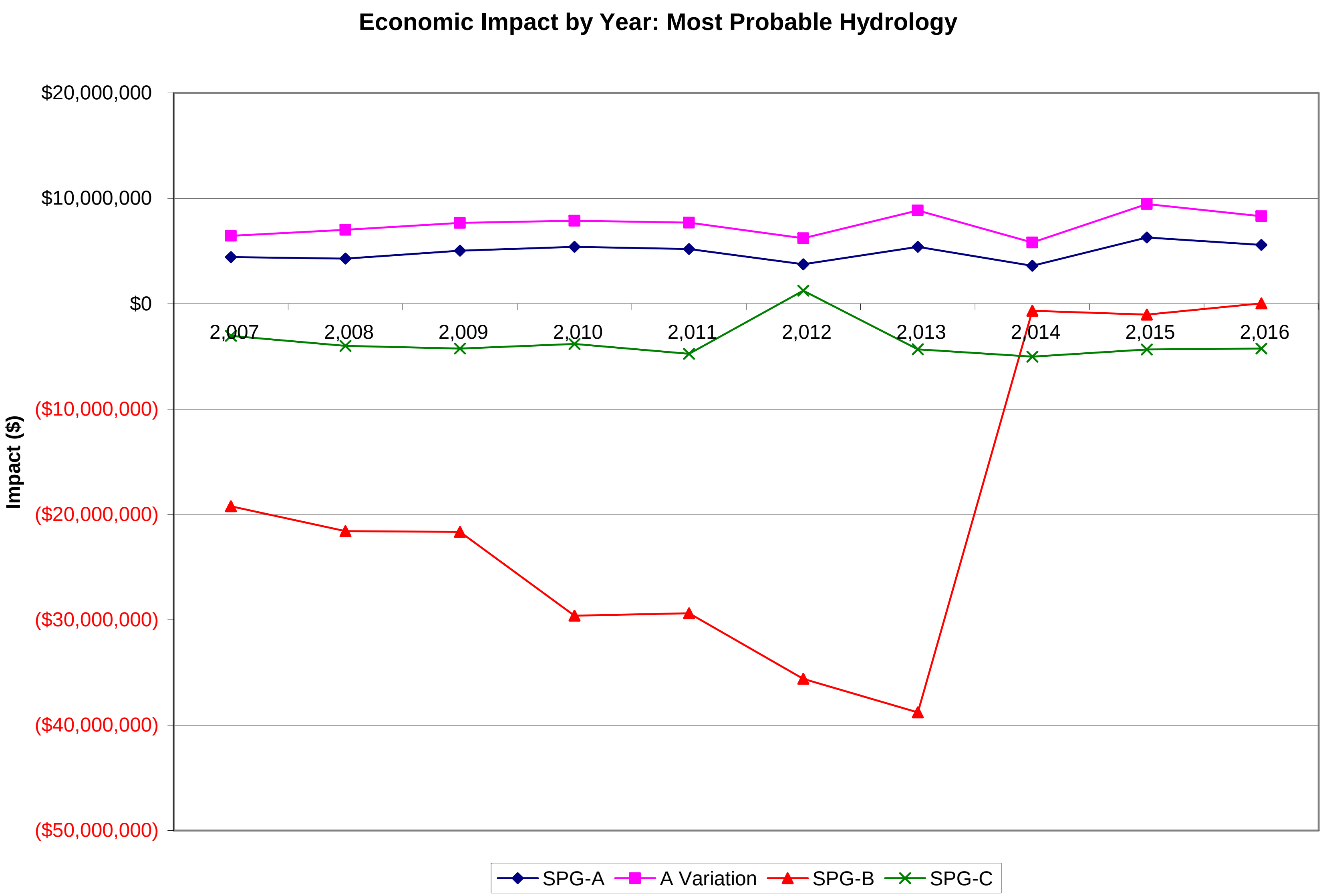
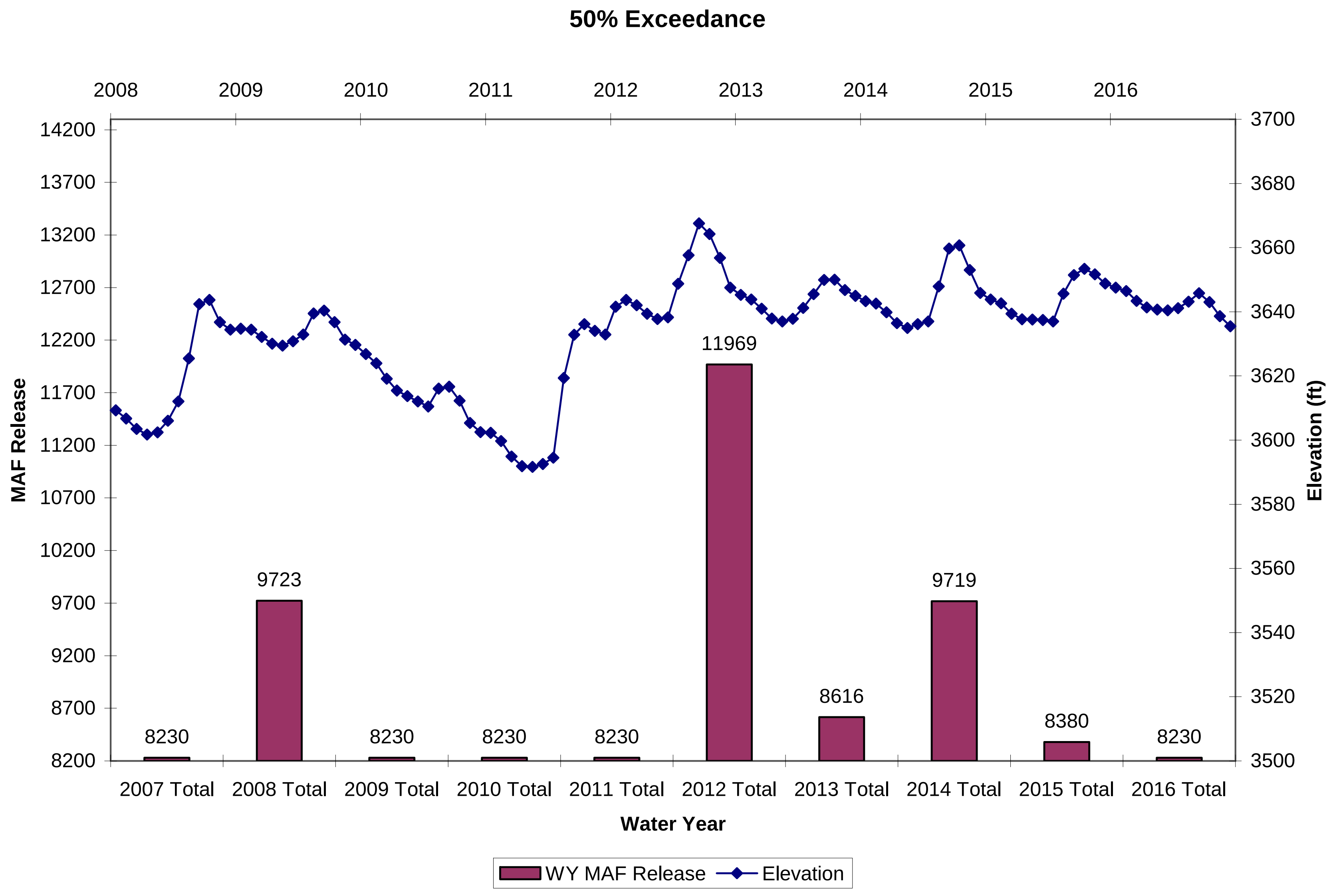

Economic Impact by Year: Most Probable Hydrology
$20,000,000
$10,000,000
$0
($10,000,000)
($20,000,000)
($30,000,000)
($40,000,000)
($50,000,000)
Impact ($)
2,007
2,008
2,009
2,010
2,011
2,012
2,013
2,014
2,015
2,016
SPG-A
A Variation
SPG-B
SPG-C

Figure 10

FIGURE 11



50% Exceedance
2008
2009
2010
2011
2012
2013
2014
2015
2016
14200
13700
13200
12700
12200
11700
11200
10700
10200
9700
9200
8700
8200
MAF Release
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3500
Elevation (ft)
8230
9723
8230
8230
8230
11969
8616
9719
8380
8230
2007 Total
2008 Total
2009 Total
2010 Total
2011 Total
2012 Total
2013 Total
2014 Total
2015 Total
2016 Total
Water Year
WY MAF Release
Elevation

FIGURE 12

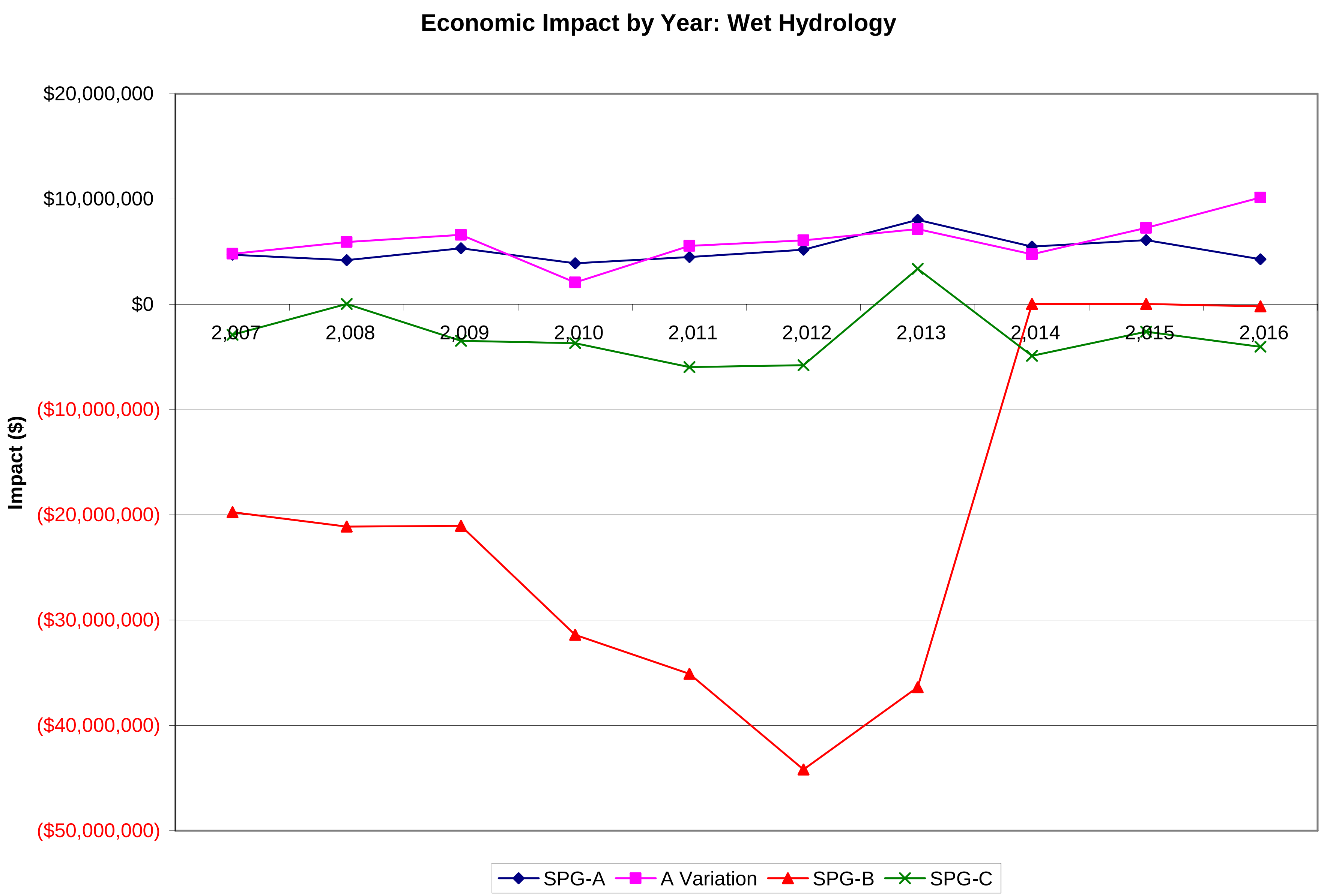
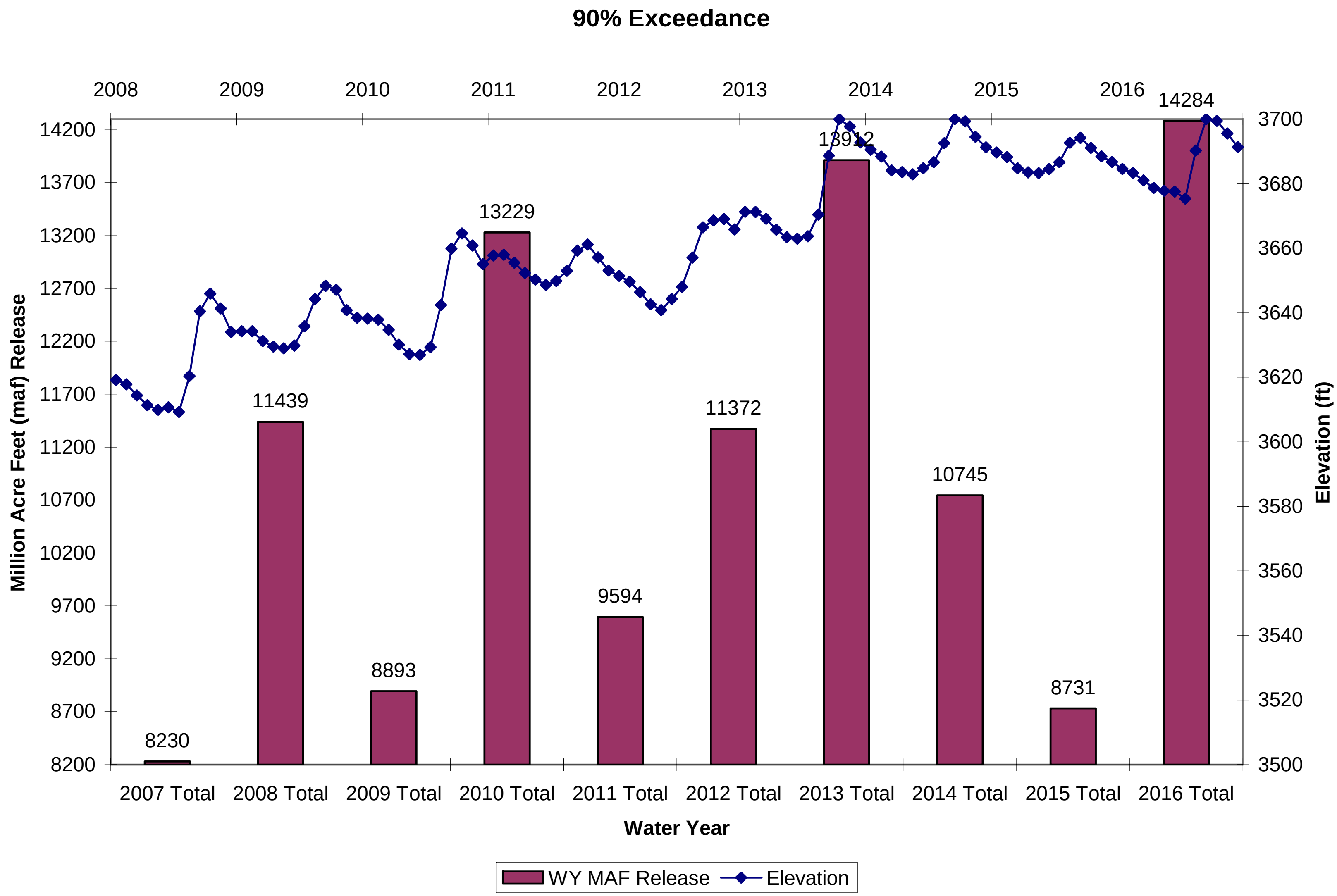

Economic Impact by Year: Wet Hydrology
$20,000,000
$10,000,000
$0
($10,000,000)
($20,000,000)
($30,000,000)
($40,000,000)
($50,000,000)
Impact ($)
2,007
2,008
2,009
2,010
2,011
2,012
2,013
2,014
2,015
2,016
SPG-A
A Variation
SPG-B
SPG-C

FIGURE 13



90% Exceedance
2008
2009
2010
2011
2012
2013
2014
2015
2016
14200
13700
13200
12700
12200
11700
11200
10700
10200
9700
9200
8700
8200
3700
3680
3660
3640
3620
3600
3580
3560
3540
3520
3500
Million Acre Feet (maf) Release
Elevation (ft)
8230
11439
8893
13229
9594
11372
13912
10745
8731
14284
2007 Total
2008 Total
2009 Total
2010 Total
2011 Total
2012 Total
2013 Total
2014 Total
2015 Total
2016 Total
Water Year
WY MAF Release
Elevation

10-Year Average Calculations

The analysis presented in Table 8 and in Figure 2 are the estimated economic impacts by year for the four options relative to the base scenario. Note that GCD Option B is the only option in which operational criteria is modified from one year to the next. The other options have differing impacts in each year of a hydrological condition because the water release targets change from one year to the next – even within a hydrological condition. From these yearly data, these summary statistics are calculated: 10-year average, net present value, annualized (levelized) net present value and expected values. Table 11 records the 10-year average of each of the four options by hydrological condition.

TABLE 11
Total Economic Impact – 10 Year Average
(2006 $)

Dry Hydro	
Base Case	$ -
A	$4,731,054
A Variation	$6,984,380
B	($24,697,448)
C	($311,656)

Most Probable Hydro	
Base Case	$ -
A	$4,890,363
A Variation	$7,531,472
B	($27,972,481)
C	$443,016

Wet Hydro	
Base Case	$ -
A	$5,176,093
A Variation	$6,036,653
B	($29,855,377)
C	$1,145,150

The Net Present Value of GCD Options

The conversion of annual dollar values over period of study to a lump sum present worth or present value is a standard calculation. It is a standard method for evaluating competing long-term projects when applied to capital budgeting. In the present case, the net present value of the GCD options over the ten year study period is calculated. The methods used here are in accord with the economic analysis guidelines followed by federal agencies; specifically, Western Area Power Administration[13]. The net present values of each option are recorded in Table 12 by hydrological condition.

The present analysis is "inflation free". That is, no attempt has been made to adjust the costs or prices used in future years of the study period by inflation rates. Therefore, this analysis presents dollar values in real terms[14].

The discount rate used for the net present value calculations is the discount rate published by the U.S. Office of Management and Budget (OMB) for the use of federal agencies undertaking real dollar analysis during the year 2006[15]. The discount rate specified by OMB is 2.7 %. This rate is consistent with other contemporary recommendations for a real discount rate[16].

As shown in Table 12, the economic impact of the various GCD options varies by hydrological condition – even within an alternative. However, a consistent pattern emerges. Options A and A Variation consistently provide economic benefit over the range of hydrological conditions. A Variation delivers about a $20 million dollar benefit above Option A in the dry and most probable hydrological cases but are almost identical in the wet case. Option C carries a negative economic impact over the three hydrological conditions. Option B also carries a negative economic impact over the three hydrological conditions and the impact is between four and six times higher in magnitude than Option C.

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[13] Economic Analysis Guidelines, Western Area Power Administration, September, 1987, Golden, Colorado

[14] Real numbers - such as real wages, real interest rates, or nominal gross domestic product - are corrected for the effects of inflation. The nominal value is measured in the currency unit at that date.

[15] Office of Management and Budget (OMB), FRN, January, 2006

[16] Internet reference: real discount rates are between 1.8% and 2.5%.

TABLE 12
Net Present Value (2006 $)
(d = 2.7, n = 10)

DRY Hydrology		
Base case	$ -	
A		$41,060,893
A Variation		$60,553,426
B		($149,556,188)
C		($2,659,034)
Most Probable		
Base case	$ -	
A		$42,180,802
A Variation		$64,939,986
B		($175,327,485)
C		$3,862,269
WET		
Base case	$ -	
A		$44,562,271
A Variation		$51,572,570
B		($185,582,611)
C		$9,454,159

Expected Value of the GCD Options

Since the hydrological conditions have a known probability, one can calculate the expected value of the economic impact of the GCD options. Expected value is a standard statistical method of describing the central tendency of a set of occurrences outcomes or events. The calculation is completed by multiplying each outcome by its probability of occurrence.

Reclamation's hydrological conditions were developed through modeling efforts that provide information on the probability of occurrence. The “WET” condition is the “upper decile” of a set of numbers generated by the RiverWare model. The “DRY” condition is the “lower decile” of this same set of numbers. Therefore, these two conditions occur with a probability of 0.10. This leaves the “most probable” hydrological condition: the median value of the numbers generated by the RiverWare model, with a probability of occurrence of 0.80.

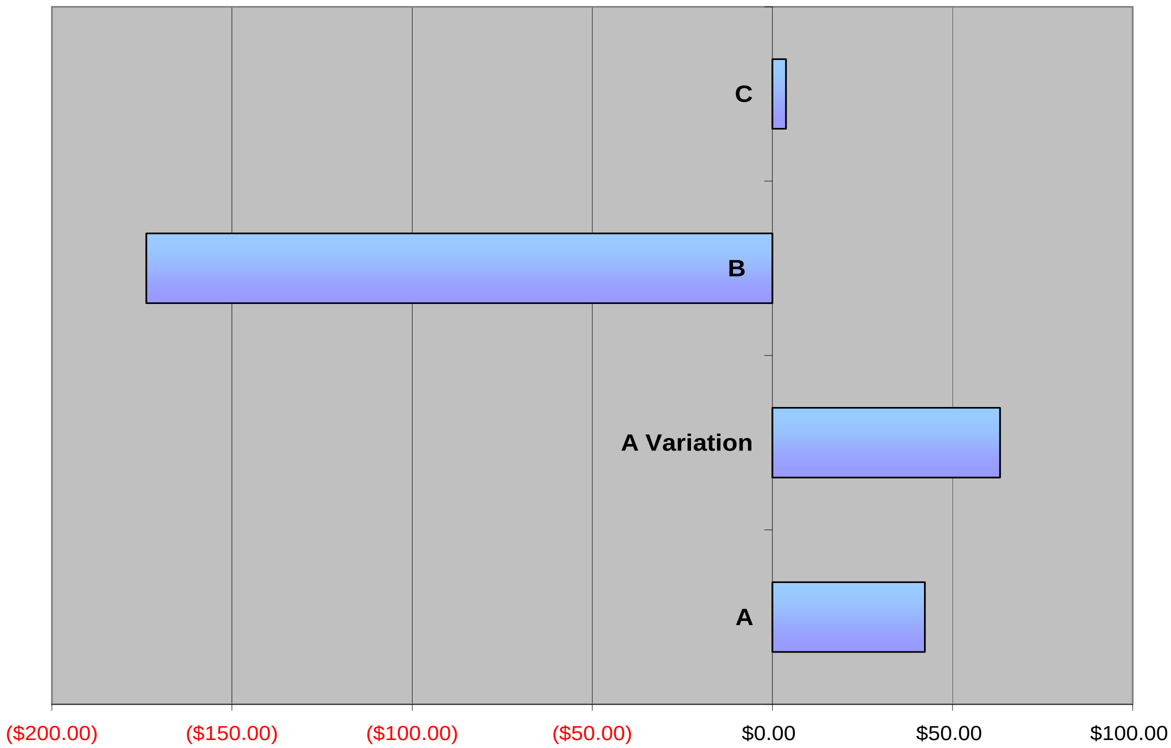
Table 13 reports the expected value calculations for the four GCD options. The numbers reported in Table 13 are the expected value of the net present value of economic impacts of the four GDC options. These numbers are summary statistics in that they present a “lump sum” economic impact of the four GCD options, where the impacts are further “weighted” by the probability of occurrence. Table 13 therefore represents “the bottom line” regarding the impacts in this report.

TABLE 13
Expected Value of
Net Present Value
(2006 $)
(Calculated from Table 12)

Base case	$ -
A	$42,306,958
A Variation	$63,164,588
B	($173,775,868)
C	$3,769,328

Figure 14 provides a visual representation of the data from Table 13. In Figure 14, the center line represents the base scenario. The economic impact of the four GCD options is represented by bars that stem in either a negative or positive way from the base scenario.

FIGURE 14
Net Present Value, Total Economic Impact
(millions of 2006 $)



Previous Studies Using this Method:

Similar modeling methods have been used by the authors and others in the past to estimate the economic impact of proposed changes in CRSP unit operations. An evaluation of the Low Steady Summer Flow (LSSF) experiment conducted in the spring and summer of 2000 used a similar modeling process[17]. Also, an evaluation of the 1992 biological opinion (BO) on the operation of Flaming Gorge Dam was completed to establish cost share amounts for the long-term funding of the Upper Colorado Endangered Fish Recovery Program (UC-RIP)[18].

[17] Palmer, S.C. and C. Burbidge, 2004, "*Financial Effect on Western and its Customers of the Low Summer Steady Flow Experiment at Glen Canyon Dam*", 2004, Grand Canyon Monitoring and Research Center, USGS publication

[18] Palmer, S.C., and T. LaRue, "*The Financial Impacts to Western and Its Customers of the 1992 Biological Opinion on the Operation of Flaming Gorge Dam*", 1999, prepared in support of proposed Federal long-term funding legislation for the Upper Colorado and San Juan recovery implementation programs.

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Additional Related Economic Analyses

1. Annualized Present Value

Another standard method of presenting net present value information is to levelize the lump sum net present value data into annualized information. Table 14 reports the results of these calculations. In this table, the data are presented by hydrological category. As with previous tables, negative economic impacts are in red, economic benefits are in black. These levelized values are probably more useful for GCD options A, A Variation and C. This is because the annualization of a net present value number for Option B tends to mask the progressive nature of this option. Option B progresses over seven years toward a greater number of months of restricted GCD operation and then ends with three years in which the GCD operation is unchanged from the Record of Decision.

Table 14
Annualized Present Value of GCD Options
($2006)

DRY	
Base case	
A	**$4,740,182**
A Variation	**$6,990,453**
B	**($17,265,176)**
C	**($306,966)**
Most Probable	
Base case	
A	**$4,869,467**
A Variation	**$7,496,850**
B	**($20,240,285)**
C	**$445,871**
WET	
Base case	
A	**$5,144,391**
A Variation	**$5,953,679**
B	**($21,424,165)**
C	**$1,091,414**

Expected Value of Annualized Net Present Value

As with the net present value information (Table 12), the expected value of the annualized data is calculated. These calculations are presented in Table 15. Again, the weighting is in accord with the probabilities articulated by Reclamation – upper and lower deciles for the wet and dry, the remainder for the most probable case.

Table 15
Expected Value of
Annualized Net Present Value
($2006)
(Calculated from Table 14)

Base Case	$ -
A	$4,884,031
A Variation	$7,291,893
B	($20,061,163)
C	$435,142

2. BHBF CASES

All of the GCD Options include Beach/Habitat Building Flows (BHBF) as GCD experimentation. The Grand Canyon Monitoring and Research Center (GCMRC), has not prepared a science plan for the further evaluation of BHBFs. Therefore, the GCMRC determined that the economic evaluation of BHBFs would be modeled separately.

Western and Reclamation prepared a base scenario under the most probable hydrological condition for a single illustrative year. This base-case year is one in which the GCD release is 9.7 million acre feet (maf). This number is the average of all most probable years that are above the minimum release amount of 8.23 maf. Western and Reclamation prepared a monthly distribution of this release for each of the four options.

It was necessary to create a base scenario for each of the options so that the economic impact of the BHBF experiment would not be tainted by the change from the MLFF to the option. In other words a base scenario needed to be prepared for Option B so that the economic impact of a BHBF within Option B would not also include the effect of moving from the Option B flows back to the MLFF operations. The same was needed for Option C.

The monthly GCD release volumes for each of the four options where used as input values to the GT MAX model to produce hourly generation values for a base scenario for each option.

The second step was to redistribute the base scenario water volumes over the year to those monthly water volumes that would accommodate a BHBF for each of the four GCD options. These new monthly water volumes were then used as inputs in the GT MAX model to produce hourly generation values. The base scenario hourly generation values were then compared to the change case hourly generation values for each option.

Once the generation differences between the base cases and the change cases were calculated, the differences were multiplied by the relevant electrical power prices. These prices are the same as those used elsewhere in this analysis. They are hourly values and intended to represent the opportunity costs of adding or reducing GCD electrical power production for each hour.

Tables 16, 17, and 18 report the results, by month of the economic impact of the inclusion of a BHBF for each option. Red numbers indicate months in which the economic impact of GCD electrical production is reduced. Black numbers indicate months of economic benefit. The totals for this illustrative year are also included. There is not a significant difference in the economic impact of a BHBF among the options – once the impact of an option is held constant, the BHBF has roughly the same impact in every option.

These tables report three time periods for each option; a fall BHBF, a winter BHBF and a Spring BHBF. These are reflective of the fact the GCMRC is currently pursuing further scientific information to indicate the best timing for BHBF. Currently, these three time periods are being considered. They are **not** additive: a BHBF within an option is presumed to occur **once** in a year – timing not yet determined.

If a BHBF is assumed in a particular year for a particular option, the economic impact of the BHBF for each of options would be **added** to economic impact of the option in the year in which a BHBF is conducted.

Table 16
Option A:
BHBF CASES

Most Probable Hydrological Conditions

Option A BHBF Cases: Net Purchase/Sales Compared to Base Case

	January	March	November
October	$0	$0	$0
November	$0	$0	$2,380,384
December	$0	$0	($102,143)
January	$2,272,793	$0	($115,635)
February	($88,246)	$0	($87,745)
March	($75,151)	$2,546,367	($75,151)
April	($49,709)	($49,709)	($49,709)
May	($44,406)	($44,693)	($44,406)
June	($999,581)	($999,581)	($999,295)
July	($1,589,279)	($1,589,279)	($1,589,279)
August	($1,491,067)	($1,491,067)	($1,491,067)
September	($1,588,250)	($1,588,250)	($1,588,250)
Total	**($3,652,897)**	**($3,216,212)**	**($3,762,297)**

Table 17
Option B:
BHBF CASES
BHBF Cases: Net Purchase/Sales Compared to Base Case
(2006 $)

	January	March	November
October	$291	$291	$291
November	($4,879)	($4,879)	$2,590,652
December	($5,236)	($5,236)	($96,373)
January	$2,657,987	($8,019)	($110,577)
February	($101,750)	($5,930)	($101,750)
March	($92,713)	$2,597,127	($92,713)
April	($62,264)	($62,264)	($61,954)
May	($57,795)	($57,795)	($57,795)
June	($1,001,405)	($1,001,707)	($1,001,405)
July	($1,612,868)	($1,613,475)	($1,612,868)
August	($1,594,559)	($1,595,162)	($1,594,559)
September	($1,590,302)	($1,590,302)	($1,589,710)
Total	**($3,465,494)**	**($3,347,351)**	**($3,728,762)**

Table 18
Option C:
BHBF CASES
BHBF Cases: Net Purchase/Sales Compared to Base Case

	January	March	November
October	$218	$218	$218
November	($5,164)	($5,164)	$2,273,350
December	($7,471)	($7,471)	($109,024)
January	$2,267,243	($8,944)	($123,940)
February	($103,150)	($5,991)	($103,150)
March	($85,946)	$3,084,946	($85,558)
April	($54,919)	($55,183)	($54,919)
May	($50,123)	($50,123)	($50,123)
June	($1,173,504)	($1,173,504)	($1,173,201)
July	($1,619,439)	($1,619,439)	($1,618,780)
August	($1,598,815)	($1,598,815)	($1,598,815)
September	($1,589,589)	($1,589,589)	($1,589,589)
Total	**($4,020,657)**	**($3,029,058)**	**($4,233,530)**

3. GCD Option C: "No August Triggers" Included in the GT MAX Model

GCD Option C includes "August triggers". The idea is that, related to the flushing of larval and/or juvenile humpback chub into the main stem of the Colorado River in the Grand Canyon as a result of monsoonal activity, the flows from GCD would be steadied. The criteria for an August trigger have not been established. This presents a modeling dilemma; because of the uncertainty regarding whether to model August with or without these triggers. In order to assess the economic impact of GCD Option C and to deal with the uncertainty of triggers that remain undetermined, the GCMRC and the Option C proponents requested that another set of model runs and analyses be conducted in which GCD Option C includes "August "triggers". This means that the operating criteria for the month of August is that the target volume of water will be released as a steady flow.

The economic analysis presented in the previous tables did not include August triggers for any of the Augusts for GCD Option C. To the degree that GCD Option C has Augusts that "trigger" and others that don't, the economic analysis presented above is an understatement of the economic impacts of GCD Option C. One can bracket the possible economic impact of GCD Option C by comparing the "with August trigger" and the "without August trigger" analysis. The "without trigger" would be the smallest estimated economic impact for GCD Option C. The "with trigger" would be the greatest estimated economic impact for GCD Option C.

The following tables: Tables 19, 20, 21 & 22 present the economic impact of GCD Option C where this option is modeled an analyzed with August triggers. Table 19 presents the total economic impact by year and by hydrological condition for GCD Option C with no August triggers. Table 20 reports the 10 year average of economic impacts of GCD Option C with August triggers. Table 21 reports the net present value of GCD Option C without August triggers by hydrological condition in 2006 dollars. Table 22 is the net present value weighted by the probability of hydrological events: the expected value of the impact of Option C with August triggers.

The results of the reanalysis of GCD Option C are illustrative. The impact of GCD Option C *with* August triggers is significantly different from the effect of Option C without August triggers.

TABLE 19
Option C: With August Triggers – by Year
(2006 $)

Dry Hydro	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
w/ Trigger	($2,381,420)	($4,385,635)	($3,593,263)	($3,450,375)	($4,857,877)	($5,512,370)	($3,807,788)	($3,950,937)	($4,013,214)	($4,088,227)
MP Hydro	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
w/ Trigger	($3,046,051)	($4,003,605)	($4,262,862)	($3,825,038)	($4,747,643)	$1,228,826	($4,326,318)	($5,021,793)	($4,356,183)	($4,247,632)
Wet Hydro	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
w/ Trigger	($2,903,652)	$29,897	($3,467,358)	($3,695,538)	($5,968,443)	($5,784,044)	$3,372,967	($4,885,763)	($2,590,906)	($4,035,499)

TABLE 20
Option C: With August Triggers – Total Economic Impact – 10 Year Average
(2006 $)

Dry Hydrology	
w/ Trigger	**($4,004,111)**
Most Probable Hydrology	
w/ Trigger	**($3,660,830)**
Wet Hydrology	
w/ Trigger	**($2,992,834)**

TABLE 21
Option C: With August Triggers
Net Present Value
(2006 $)

Dry Hydrology	
C: w/ Trigger	**($34,752,282)**
Most Probable Hydrology	
C: w/ Trigger	**($31,573,597)**
Wet Hydrology	
C: w/ Trigger	**($25,754,612)**

TABLE 22
Option C: With August Triggers
Expected Value of Net Present Value
(2006 $)

C: w/ August T	**($31,309,567)**