PROPOSED ALTERNATIVE FOR THE LONG-TERM EXPERIMENTAL AND MANAGEMENT PLAN FOR FLOW AND NON-FLOW ACTIONS RELATED TO THE OPERATION OF GLEN CANYON DAM

A Resource Targeted Condition-Dependent Strategy

DRAFT – July 2, 2012

Prepared By:

The document was prepared by the seven Colorado River Basin States and the Upper Colorado River Commission representatives. They have developed this alternative for analysis and consideration as part of the Department of Interior's preparation of a Long-Term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS).

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EXECUTIVE SUMMARY

The seven Colorado River Basin States and the Upper Colorado River Commission representatives (collectively referred to as the Basin States) have developed this alternative for analysis and consideration as part of the Department of Interior's preparation of a Long-Term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS). This Alternative meets the purpose and need of the LTEMP EIS by identifying dam operations, management actions, and experimental options that will provide a framework for adaptively managing Glen Canyon Dam over the next 15 to 20 years, consistent with the Grand Canyon Protection Act (GCPA), the Law of the River, and other provisions of applicable Federal law. This alternative incorporates and uses scientific information developed since the 1996 Record of Decision to better inform Department of the Interior decisions on dam operations and other management and experimental actions. This alternative is designed to enable the Secretary to continue to meet statutory responsibilities for protecting and improving Glen Canyon National Recreation Area and Grand Canyon National Park resources and values for future generations, conserving ESA-listed and other native species, and protecting Indian Tribal interests, while meeting his water delivery obligations pursuant to the Colorado River Compact and the Law of the River and generating hydroelectric power.

This alternative is entitled "A Resource Targeted Condition-Dependent Strategy" because it implements management actions to benefit key resources and uses experiments and research to further develop future management actions that are based on variable resource conditions. It balances learning with improvement of other key resources of interest as identified in the "Desired Future Conditions for key resources of the Grand Canyon" as adopted by the Adaptive Management Work Group (AMWG) of the Glen Canyon Dam Adaptive Management Program (AMP). This alternative addresses the full range of possible future hydrologic conditions and can be implemented consistent with the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operation of Lake Powell and Lake Mead (Interim Guidelines; Reclamation 2007). It also recognizes the provisions of the High-Flow Experimental Protocol and Non-Native Fish Control EAs and FONSIs, as part of the experimental design.

A group of scientists, with expertise in important Grand Canyon resource areas, was consulted in order to incorporate the best available science in this alternative. Both flow and non-flow actions were developed based on the latest science in order to improve conditions for humpback chub, conserve sediment for beaches and habitat, enhance the aquatic food base, support the trout fishery in Lees Ferry, mitigate adverse impacts to important cultural resources, and benefit hydropower production and recreation uses in Grand Canyon. The alternative includes an experimental science design using decision trees to describe experimental triggers based on resource conditions. Ultimately, these experimental treatments are expected to inform future actions to benefit key resources in Grand Canyon.

The alternative utilizes an adaptive management framework for flow and non-flow actions, including monitoring, that focus on the following areas:

1. Science Framework – This alternative employs a robust science design intended to test the efficacy of a range of treatments or experiments over a wide range of environmental conditions. It is imperative that we develop management actions that are resilient against environmental perturbations. It uses decision trees to consider condition-dependent actions aimed at benefitting key resources (humpback chub and sediment for beaches and habitat). The goal of the experimental design is to establish with some confidence, the causal relationships that will inform future actions.
2. Humpback Chub Recovery – The Grand Canyon population of the humpback chub has grown in numbers over several years of operations under the Modified Low Fluctuating Flow (MLFF) operational regime. The number of adult humpback chub has nearly doubled to about 9,000 adults since its low point in 2000. Continuation of the improved status of this endangered population is critical, and warrants a conservative approach to future operational modifications to continue this recovery.
3. Sediment for Beaches and Habitat – Under the store and release option for conducting High Flow Experiments (HFE), lower flows with less fluctuations are proposed from August through October, months during which the Paria River floods are most likely to deliver sediment into the Colorado River mainstream. Lower dam releases with less fluctuation would retain sediment in the mainstem which may increase the likelihood of an HFE. Under sediment enriched conditions (Paria River inputs), load following flows would be curtailed until an HFE is conducted in November. This sediment retention flow regime is intended to retain sediment inputs to maximize the benefits of an HFE.
4. Trout Fishery Management – Trout management flows will be tested to enhance the trout fishery at Lees Ferry and limit emigration of trout downstream to the Little Colorado River (LCR) where they could prey on endangered humpback chub or compete with them for limited food resources. The intent is to establish a high quality trout fishery in Lees Ferry reach that does not limit the recovery of humpback chub. Some limited mechanical removal will be tested in the Lees Ferry reach as well.
5. Cultural Resources – The alternative can be implemented consistent with the obligations that exist under the GCPA, National Historic Preservation Act, and the Memorandum of Agreement for recent actions of importance to the tribes.
6. Hydropower – Sediment research has shown that the current downramp rate is not an important factor in sediment loss from the system and thus the restriction on the hourly down ramp rate is unnecessary for sediment conservation. Also, current fish research has shown there is little concern for stranding of native fish within this range of down ramps. Hourly down ramp rates would increase from 1,500 cfs to 2,500 cfs with appropriate monitoring.

The Grand Canyon ecosystem is comprised of a dam with generally clear, cold releases, and high levels of photosynthetic production with a transition downstream to a more turbid but cool-water river. This is a dramatically different ecosystem than that of the historic pre-dam conditions. In summary, this alternative does not try to turn back the clock. Instead, the strategy builds on past successes to determine how to sustain the gains in resource conditions that have already been achieved (e.g., sand, humpback chub, and trout). The alternative focuses on key questions in an experimental design that minimizes confounding effects. It also acknowledges that certain actions, such as HFEs are a proven tool warranting ongoing structured experimentation and may need only minor modifications related to trigger criteria and duration, and close monitoring specifically targeted at the risk of accelerated sand loss in downstream reaches. The population of humpback chub has doubled and the recruitment has tripled over the last decade, likely due to mainstem rearing increases unrelated to sand management.

The major management uncertainties currently are related to how to maintain this gain in humpback chub abundance in the face of cold-water regime periods and predation by non-native fish, especially trout. Experimentation and monitoring needs to focus on trout both as a resource and threat to native fish, in particular how to mitigate positive effects of high flows, steady flows, and HFEs on trout recruitment with the risk of negative effects on native fish and trout growth. The quickest way to learn how to manage trout with flow treatments will be by using experimental policy tests conducted as single year tests spread widely over time and well-replicated, rather than 3-year block tests as used in the past. Other initiatives (e.g. humpback chub translocations to other tributaries, vegetation management) will involve local-scale experimentation with relatively low cost and risk. While one-year policy tests are attractive in terms of statistical replication and comparison, it is recognized that some actions may have cumulative effects that will not be detected by short treatments. Thus, the option is left open to apply certain treatments (particularly trout management flows) that are likely to have such cumulative effects over longer treatment periods (2-3 yr) in the second half of the 20-year planning period.

The alternative supports the adaptive management approach and AMP. It includes the creation of AMP technical teams which would be administered by the AMP and membership determined by the AMWG. These teams would provide a technical and policy review before decisions are made by DOI on actions like HFEs and Trout Management Flows. These teams would include membership by the Basin States and by other stakeholders of the AMP.

This alternative represents a compilation of flow and non-flow experiments and treatments integrated with a base dam operation built on past success. The elements of this alternative are related and interdependent and removing or replacing one or more of these elements without full consideration of the entire alternative and experimental design would likely diminish its management and experimental value.

RESOURCE TARGETED CONDITION-DEPENDENT STRATEGY

A Detailed Description

This alternative provides an adaptive management framework that meets the purpose and need of the LTEMP EIS as described in 76 Fed. Reg 39435 (July 6, 2011) and 76 Fed. Reg 64104 (Oct. 17, 2011). It is a resource targeted approach that implements management actions designed to meet resource goals (Appendix A) and benefit key resources using condition-dependent decision trees. It further develops information to inform the Department of the Interior's decisions regarding future operations of Glen Canyon Dam (see Table 1 for an overview of actions). A well balanced alternative is critical not only to the Colorado River ecosystem in Grand Canyon but also to the preservation of stable water supplies for the Colorado River Basin and a renewable source of energy in the form of hydropower. This alternative meets the purpose of the LTEMP by balancing resource improvement with learning, and:

- Focuses on the recovery of humpback chub and then, without harming recovery, addresses other important resources such as sediment for recreational beaches and native fish habitat, the rainbow trout fishery at Lees Ferry, and the aquatic food base.
- Uses an experimental design to evaluate effectiveness of treatments, including focused short-term scientific experiments to assess the efficacy of specific actions within the Colorado River ecosystem.
- Uses a condition-dependent framework, with decision trees, to evaluate treatments and move to management actions.

This alternative is a set of base dam operations and flow and non-flow experiments that are not severable from each other. The elements of this alternative are related and interdependent and removing or replacing one or more of these elements without full consideration of the entire alternative and experimental design would likely diminish its management and experimental value.

The alternative supports the adaptive management approach and AMP. It includes the creation of AMP technical teams which would be administered by the AMP and membership determined by the AMWG. These teams would provide a technical and policy review before decisions are made by DOI on actions like HFEs and Trout Management Flows. These teams would include membership by the Basin States and by other stakeholders of the AMP.

Science Design

The science design of this alternative was developed and evaluated with the assistance of a Science Panel and Experimental Design Advisors (Appendix B). The science design emphasizes the importance of demonstrating repeatability of treatment responses (i.e., replication of treatments). The goal is to obtain data and information that enables us to answer the management questions with as little uncertainty as possible. Although past research and management actions have helped reduce the range and impact of possible threats, the relative significance of each potential impact remains uncertain because multiple ecological, biological, and physical habitat changes have occurred. Haynes *et al.* (2012) advocate the need to include experimental management that is actively adaptive with adequate randomized controlled trials. The apparent trout response to the spring 2008 HFE is an excellent example of why this is needed. High rainbow trout recruitment and good growth occurred in 2009-10 following that HFE, and it was proposed that the HFE had stimulated trout production such that it and future HFEs might lead to negative effects on native fish through increases in trout predation and competition. What makes the response hypothesis credible is that Korman's trout recruitment reconstruction (Figure 4) showed a similar response after the spring 1996 HFE (Korman *et al.* In Review). Nevertheless, there was no apparent response to the fall 2004 HFE, indicating need for further replication to remove all doubt about the response hypothesis and to test for the possibility of combining HFEs with trout management flows (as occurred in 2004-5 but not 1997 and 2009). However, the story is more complicated because it is likely that the trout population was already increasing in 2007-8 before the 2008 HFE (Figure 4), perhaps in response to increases in flow and the level of Lake Powell, potentially in part as a function of nutrient concentrations passing through the dam.

The two driving critical science questions addressed by this alternative are:

> *How can a nonnative trout fishery in Glen Canyon coexist with the recovery of humpback chub in Marble and Grand Canyons?*
>
> *What is the appropriate rehabilitation strategy and goal for physical habitat of the Colorado River, given the limited supply of fine sediment, and the characteristics of the large-scale flow regime?*

The science design employs 3 tiers of treatment (see Table 1):

1. Primary: Core experiments with high management importance, where repeatable results are the focus instead of new knowledge gains, use block design
2. Secondary: Experimental actions intended to increase knowledge or management activities that are unlikely to confound primary results
3. High uncertainty/Risk: Experiments with high risk of confounding primary experiments, risk to key resources or uncertainty with implementation.

Any serious consideration of an adaptive management framework for the operation of Glen Canyon Dam over the next 20 years must account for key natural variables (far right column Table 1; stochastic factors), such as dam release temperatures, Paria River sediment inputs, release volumes, trout abundances at the LCR, and the potential for aquatic invasions. Any treatments tested during this next experimentation phase in Grand Canyon must be resilient to these and other natural variables in order to be a successful candidate for a management action. Recent Colorado River Simulation System (CRSS) modeling predictions suggest that Lake Powell elevations will be quite variable over the next 20 years, with a high likelihood of periods of both warm and cold release temperatures (Figures 5a-b). This is likely to provide an experimental baseline of cold and warm regimes downstream from the dam. In order to describe some of this variability Tables 2a-c were developed to display three potential scenarios based on (a) likelihood of warm and cold dam releases, (b) a probabilistic implementation of HFEs (store and release and rapid response), (c) a

2x2 factorial science design of trout management flow treatments and HFEs, and (d) other condition-dependent actions.

Despite the unpredictability of the natural (stochastic) variables, this alternative has been structured using decision rules to take advantage of those changing conditions. Based on the three scenarios (Tables 2a-c) over 20 years, a good mix of treatments (HFEs, trout management flows, mechanical removal) under warm and cold conditions is achievable. Tables 2a-c results in about 2-3 replicates (HFEs and trout management flow treatments) for warm and cold dam releases over the next 20 years. Although these scenarios are perfectly reasonable to occur we know from experience that the need for contingency planning is necessary to ensure some minimum level of treatment for critical combinations. There will likely be at least one, or more likely two or three periods of low Lake Powell elevation levels and an associated warming of dam releases (Figure 5). At a minimum, the trout/native fish treatments need to occur under both warm and cold river conditions. These contingency rules for the various treatments must ensure opportunistic response to changes in thermal regimes. Further, 2012 and 2013 represent a critical period in the treatment sequence, since these will likely bring first low then high trout abundance at the LCR under cold water conditions; thus these years represent a critical opportunity to observe humpback chub population response (i.e., juvenile survival in the mainstem) to high and low densities of trout during coldwater conditions.

The factorial experimental design requires that treatments be applied in 1-year blocks spread widely over the planning period. But there has been considerable debate among Grand Canyon scientists about the dangers of using such short treatment periods. Some treatments, particularly trout management flows, may have strong cumulative effects (when applied several years in a row as routine management practices if initial tests appear promising). For example, several years of reduced trout recruitment may result in growth and foodbase improvements that are not evident when only one year class is experimentally reduced, and juvenile humpback chub rearing in the mainstem are likely to remain there for more than one year so as to be exposed to cumulative survival and growth impacts of any treatment that persistently alters temperature or predation risk. In order to assess key cumulative effects on trout and humpback chub, it is expected that the experimental treatment periods for at least trout management flows may need to be extended to 2-3 years in the second decade of the planning period. The use of such extended treatment periods will weaken the experimental design from a statistical perspective (fewer replicates than initially hoped, fewer treatment combinations tested), but it may be necessary to evaluate cumulative effects at some point during this period.

Intervening Base Flow Regime

This alternative includes management actions and experiments that conform collectively to the Law of the River and specifically the Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Interim Guidelines; U.S. Department of the Interior 2007) will guide monthly target volumes. Release targets from Glen Canyon Dam are required to conform to a set of laws that govern water storage in Lake Powell and Lake Mead. Release volumes from Glen Canyon Dam are beyond the control of Reclamation managers and are a natural variable (stochastic variable) which must be anticipated. While Lake Powell is a large storage reservoir, annual release volumes are ultimately determined by hydrological conditions in the Upper Colorado River Basin.

For this alternative (about 20 years), the following intervening base flow regime would be implemented. Both flow and non-flow experiments, including high-flow experimental releases (HFEs), would be applied on an annual basis to address critical uncertainties using a factorial design (Table 1, Tables 2a-c). There are two key reasons why this intervening base flow regime is proposed for Glen Canyon Dam operations:

- The flow regime is similar to the MLFF flow regime under which the Grand Canyon population of the humpback chub has grown significantly since 2000, nearly doubling in size and expanding in the mainstem outside of the LCR. (Martel unpublished presentation to TWG May 2012 on ASMR results; U.S. Fish and Wildlife Service 2002).
- The MLFF flow regime has been in place for about 15 years. In that time, significant scientific information has revealed many positive aspects to a flow regime with fluctuations. A continuation of a fluctuating operating regime will allow further scientific exploration and analysis of experimental treatments while maintaining a flow pattern that is very similar to what has been in place for over 15 years. This allows for maximum focus on the evaluation of new treatments. Adding another flow regime to test would substantially increase the time to adequately evaluate the differences between treatments and could potentially be a confounding element that could limit interpretation of other important treatments.

The proposed alternative consists of an intervening base flow regime that is built on knowledge gained from operations under MLFF (table describing this flow is presented below). This alternative is designed to perform over a range of annual release volumes which may be expected to occur in the next 20 years. Illustrative hydrographs are provided in Appendix C to illustrate a year that anticipates targeted monthly volumes, sediment retention flows, an HFE, and trout management flows within the context of a base flow.

Intervening Base Flow Regime [1]

Month[(a)]	Minimum Release (cfs)[(b)]	Maximum Release (cfs) [(c)]	Hourly Up-ramp (cfs/hr)	Hourly Down-ramp (cfs/hr) [(d)]	Maximum Daily Change Proportional to Monthly Release [(d)]
Oct	5,000/8,000	25,000	4,000	2,500	100:1
Nov	5,000/8,000	25,000	4,000	2,500	100:1
Dec	5,000/8,000	25,000	4,000	2,500	100:1.2
Jan	5,000/8,000	25,000	4,000	2,500	100:1.2
Feb	5,000/8,000	25,000	4,000	2,500	100:1.2
Mar	5,000/8,000	25,000	4,000	2,500	100:1
Apr	5,000/8,000	25,000	4,000	2,500	100:1
May	5,000/8,000	25,000	4,000	2,500	100:1
Jun	5,000/8,000	25,000	4,000	2,500	100:1.2
Jul	5,000/8,000	25,000	4,000	2,500	100:1.2
Aug	5,000/8,000	25,000	4,000	2,500	100:1.2
Sep	5,000/8,000	25,000	4,000	2,500	100:1

[(a)] While not shown, monthly releases for August, September, and October will be targeted as low-volume release months to minimize sediment transport.

[(b)]Minimum releases between 7 am and 7 pm are 8,000 cubic feet per second (cfs) and drop to 5,000 cfs during all other hours (no change from previous operations).

[(c)]Maximum Release relates to conditions in which normal load-following operations are being followed. There are times in which water release amounts are driven by wet hydrological conditions or the need to deliver water to the Lake Mead in accord with the Interim Guidelines which will require a release that exceeds this amount.

[(d)] During trout management flow treatments downramp rate limitations are relaxed for short periods to allow for adequate treatments which require faster downramp rates.

[(e)]Maximum daily change: While the monthly release is scheduled in acre feet, the maximum daily change is in cubic feet per second (cfs). Therefore the monthly volume will be proportional to the maximum daily change. (Monthly volume: Maximum daily change = 100:1 or 100:1.2). Further analysis needs to be conducted to develop and understand if proportions will be applicable all release levels, specifically high volume releases.

Operational Considerations

Under the Interim Guidelines (Reclamation 2007), targeted annual volumes can vary significantly between years. Releases from Glen Canyon Dam can be as little as 7.0 million acre feet (maf) and up to or in excess of 18.6 maf (e.g., April 2012 CRSS results). During the runoff season, the volume of water forecasted to flow into Lake Powell changes month by month. An example of the unpredictability of the forecast was during the 1983 water year. The May 11 forecast for the inflow into Lake Powell for April through July was 13.4 maf. However, by June 7, the forecasted inflow increased to 21.7 maf. This represented a 38% increase in the forecasted inflow just 2 months before the end of the runoff season. The actual inflow into Lake Powell in WY 1983 was 20.8 maf.

This emphasizes the variability of the water release scenarios and the difficulty in predicting the release volume. Therefore, because of the legal requirements and the inability to

[1] It is worth noting that achieving the minimum release requires 5,768,000 af of an 8.23 maf release. If Reclamation operated at the maximum release year-round, that would require 18.1 MAF.

control or accurately predict hydrological conditions this alternative will treat the annual release volume of Glen Canyon Dam as an exogenous variable. Further, it is likely that the annual volume will be highly variable over the course of the 20 year implementation of this alternative.

Lower Monthly Water Volumes to Retain Sediment (Targeted Approach)[2]

Monthly releases for August, September, and October (next water year) will be targeted as lower-volume release months to minimize sediment transport which is primarily affected by monthly release volume. Paria River floods are most likely to occur in these months. These lower volume releases would retain more sediment than previous operations with higher release volumes in these months. The benefit of retained sediment would likely increase (a) the frequency of triggering an HFE, and (b) the magnitude and duration of an HFE (Reclamation 2011a; see Figure 1). Other monthly volumes would be set based on the Interim Guidelines (Reclamation 2007) and hydrological conditions. In some hydrologic conditions the Interim Guidelines would dominate monthly release targets. The volatility of the forecast and the lateness of the runoff period within the water year will sometimes require significantly larger volumes of water to be released during the period in which Paria River inputs occur. Under these conditions, the “targeted” approach will have to be curtailed in favor of compliance with the Law of the River, including allocation, appropriation, development and exportation of the waters of the Colorado River basin as implemented through the 2007 Interim Guidelines. Figure 1 is an illustration of the criteria used for decisions related to dam operations for sediment retention.

Targeted lower monthly volumes for sediment retention from August-October may also benefit native fish and other resources similar to the test proposed immediately below. The primary mechanisms for aquatic resource effects would be through increasing warming (especially of nearshore areas) and habitat stabilization (aquatic food base) due to the reduced fluctuations. Under years with sediment input (see below), these low volume months may have no load following fluctuations resulting in similar conditions to the 2000 Low Summer Steady Flow test (Ralston 2011).

Sediment Retention Flows: condition-dependent curtailment of “load following”

If there is substantial Paria River sediment input during the accounting period (July-October) as defined by the HFE Protocol (Reclamation 2011a), load following flows would be curtailed during August, September, and October depending on when the input(s) occurred. These “flat” flows would serve to retain the maximum amount of sediment during this period with the release volume planned for those months. Flows would not be held to one constant flow rate, however as daily fluctuations would be made in order to respond to changing hydrology and to meet release requirements from the 2007 Interim Guidelines. Sediment retention flows would

[2] A Note on Monthly Volumes The Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007) will guide monthly target volumes and total annual release volume. “Targeted” monthly release volumes for August through October for the purpose of sediment retention, will have to be adjusted as necessary to conform to the Colorado River Basin Project Act and Long-Term Operating Criteria as currently implemented through the 2007 Interim Guidelines.

only be triggered if Paria River sediment inputs were of a magnitude to trigger one of the 13 HFE types (Figure 1 here; see page 32 of Reclamation 2011a). Under the 2007 Interim Guidelines, it may be difficult in some years to implement sediment retention flows and meet release targets. Thresholds for triggering retention flows could be considered based on an analysis of their effectiveness, cost, and release goals. It might not be cost-effective to implement flat flows from August-October under minimal sediment inputs. Sediment inputs could be modeled, and an optimum threshold could be determined based on a specified criteria.

If the inputs are considered insufficient to trigger an HFE, then a return to load-following flows would be implemented based on the monthly releases to date and the available water needed to meet release requirements (off-ramp). The primary mechanisms for aquatic resource effects would be through increasing warming (especially of nearshore areas) and habitat stabilization (aquatic food base).

“Maximum Daily Change” Operational Criteria as a Proportion of Monthly Volume

Under MLFF operations, the maximum daily change allowed is a function of the monthly release volume (see table on page 10), which, in turn, is a function of hydrology and annual release requirements. There are two threshold release volumes that set the amount of load following that can occur over a day. In months with an anticipated release volume of 800,000 acre feet (af) or more, the maximum daily change is 8,000 cfs; for months with an anticipated release volume above 600,000 af, but below 800,000 af, the maximum daily change is 6,000 cfs; and for months with an anticipated release volume below 600,000 af, the maximum daily change is restricted to 5,000 cfs. This alternative would alter the daily change limits to be a simpler rule utilizing a proportion of the anticipated monthly volume.

- For the months of October, November, March, April, May and September, the maximum daily change allowed would be proportional to the anticipated targeted volume for release that month. The ratio of monthly volume to maximum daily change would be 100:1.

- For the months of December through February and for June through August, the maximum daily change allowed would be proportional to the anticipated targeted volume for release that month. The ratio of monthly volume to maximum daily change would be 100:1.2.

This is a minor change from the previous tiers used under MLFF. The proportional change is similar to what is used in the tiers under MLFF.

Under the proportional approach described in this alternative, Reclamation would have more flexibility to meet water deliveries with a wider range of release options. The added flexibility in peak power months, plus higher downramp rates, will allow Reclamation to modify releases to better conform to electrical value and changes in electrical demand over the course of the day.

Note that under “sediment retention flows” discussed above, the months of August, September and October would have no load-following flows when a sediment input occurs at the Paria River (as described above based on a condition-dependent trigger). Further analysis needs to be conducted to develop and understand if proportions will be applicable all release levels, specifically high volume releases.

Downramp Rate

The 1,500 cfs downramp rate constraint was originally based on the hypothesis that excess pore-water pressures during rapid drawdown causes bank instability and contributes to a greater tendency for sand bar erosion. Research by Budhu and Gobin (1994) using field data from Grand Canyon that were collected during June 1991, when the downramp rates exceeded 2,500 cfs/hr, indicated that the side-slopes of the sand bars will erode back to an angle of 11 to 14 degrees under fluctuating flow conditions, but further erosion due to the fluctuating flows does not occur. A more recent laboratory study by Alvarez and Schmeeckle (2012) demonstrated that erosion rates (per diurnal cycle) did not depend on ramp rates, but instead on sandbar steepness. Therefore, steep sandbar faces would be likely to erode rapidly, by mass failure and seepage erosion, compared to shallower more stable slopes in the absence of other erosion processes, regardless of dam discharge ramp rates. They concluded that sediment loss is more likely to be controlled by peak discharge rates and duration (overall amount of flow), than it is by ramping rates (Alvarez and Schmeeckle 2012).

Thus, the hourly downramp rate in this alternative would increase year-round from 1,500 cfs/hr to 2,500 cfs/hr (Appendix C, Figure C-3). The change from 1,500 cfs/hr to 2,500 cfs/hr will allow a greater degree of operational flexibility needed to follow reductions in electrical demand. At the end of the day, electrical demand decreases at a rate that exceeds 1,500 cfs/hr. The increase to 2,500 cfs/hr allows for the operation of Glen Canyon Dam to better conform to these reductions in schedules. Operations under the new downramp rate would likely result in more time spent at higher flows, although this is likely to be a very small change in operation. More advanced modeling of flow scenarios would be needed to understand the implications on total sediment export.

Non-Flow Management Activities

Adaptive Management Program

This alternative is designed to learn by doing in a structured, fairly predictable manner through a set of defined actions, predefined experiments, and decision points that take into account unpredictable events, such as very low or very high hydrological conditions, lower reservoir elevations and warm releases, and sudden increases in predators of humpback chub. The success of the alternative will be an improved understanding of the management of Glen Canyon Dam with the use of the knowledge gained. Ultimately, this information will enable the Secretary to continue to meet statutory responsibilities for protecting and improving Glen Canyon National Recreation Area and Grand Canyon National Park resources and values for future generations, conserving ESA-listed and other native species, and protecting Native American Tribal interests, while meeting water delivery obligations and generating hydroelectric power.

The alternative provides a framework for continuing to adaptively manage Glen Canyon Dam and the downstream resources. The alternative advocates the use of, and is dependent on the use of stakeholder groups composed of both policy and technical groups (i.e., TWG and AMWG). This alternative employs a condition-dependent process whereby decisions need to be made according to an agreed-upon set of rules. This alternative provides decision trees that will help to guide more specific and explicit criteria for implementation of actions and experiments as agreed to by the stakeholders. As part of the adaptive management process and decision structure, it will be necessary to establish structured AMP technical teams. The technical teams would be created and administered through the AMP, and include membership from the Basin States and other AMP stakeholders. These teams would be consulted (see Figure 1) during decision making about the various adaptive management actions envisioned in this plan (e.g., decisions to implement an HFE or Trout Management Flows). These teams would provide a technical and policy review and would be composed of members appointed by their AMWG representatives (could include TWG members or other technical staff).

Core Monitoring Program and Monitoring for Treatment Effects

This alternative advocates, and in fact, emphasizes the need for continued monitoring and research similar to past efforts (GCMRC 2012) and implementation of a core monitoring program. Additionally there is a continuing need to maintain monitoring programs that have the capacity to detect and respond to changed conditions from both experimental treatments and uncontrolled variables identified in Table 1. Hence it is critical to maintain existing elements of the proposed GCMRC core monitoring program, and to add some key elements to that program based on recent experience with short-term monitoring aimed at evaluating specific experimental treatments. Elements that should be considered for core include:

- Rainbow trout early life stage survival studies (RTELSS) that consist of monthly shoreline sampling using slow electrofishing and mark-recapture methods provides detailed (monthly, spatial) data on abundance, habitat use, and early survival rates of rainbow trout in the Lees Ferry reach.
- The Natal Origins project, initiated in the fall of 2011, addresses a number of questions related to the Lees Ferry trout fishery and emigration of trout to the LCR inflow reach. The project provides relatively precise estimates of abundance in the Lees Ferry reach, at two locations in Marble Canyon, and just upstream and downstream of the LCR. It also provides direct estimates of emigration rates from Lees Ferry to Marble Canyon, and within Marble Canyon and the LCR inflow reach. It provides accurate estimates of growth which are paired with direct estimates of food availability (measured on the same trips and locations), which will improve our ability to understand factors that control the size of trout in the Lees Ferry fishery.
- Monitoring of mainstem abundance, growth and survival of juvenile humpback chub near the LCR confluence, using protocols developed for the nearshore ecology (NSE) program now the juvenile chub monitoring(JCM) program. Using a combination of slow electrofishing, hoop netting, and mark-recapture methods; in combination with Little Colorado River hoop netting LCRHN, allows estimation of mainstem rearing contribution to humpback chub recruitment to the LCR population.
- Application of NSE sampling protocols in short reaches just downstream from tributaries that are receiving humpback chub translocations and in other downstream aggregations. This is a necessary part of evaluating the translocation strategy as a means to establish additional humpback chub spawning and rearing populations outside of the LCR reach.

- The development of a systematic monitoring program to assess juvenile humpback chub distribution in the mainstem in an approximately 20-km reach of river from just upstream of the LCR to Hance Rapid. This will allow for mapping of the distribution of juvenile humpback chub in mainstem habitats as a response metric to varying mainstem river conditions (e.g., temperature, trout abundance, etc.).
- Annual netting (hoop, trammel) in the mainstem from Lees Ferry to Diamond Creek provides PIT tag capture-recapture and relative abundance (catch per effort) for native fishes, mainly suckers and downstream humpback chub aggregations that likely consist mainly of downstream dispersers from LCR spawning (this program has not been maintained consistently over the years). New methods are being tested to better evaluate population size and to avoid risks to the population from incidental mortalities associated with increases sampling effort.
- Estimation of sand storage across a large number of cross-section transects (older USGS transect sites plus enough more to characterize storage in all major eddy structures).
- Use of drift monitoring as the primary sampling method for the aquatic food base, so as to assess long-term changes in the abundance of invertebrates actually available for consumption by fish (and by riparian species like swallows and bats). Drift monitoring complements benthos sampling for a more complete assessment of the invertebrate community. Benthos sampling is labor intensive and there is a substantial delay and cost in processing, but used discretely together with drift sampling, these provide a valuable and comprehensive survey of the invertebrate community.
- Use of continuous dissolved oxygen (DO) recorders at several sites (dam, Lees Ferry, LCR, Bright Angel, Diamond, middle Granite Gorge) to track changes in aquatic ecosystem production and respiration, especially in relation to changes in total flow and effective aquatic habitat area, and also in relation to actions like HFE that are thought to stimulate production.
- Annual electrofishing in the Lees Ferry reach, providing overall abundance and size structure information on age 1+ rainbow trout.
- System-wide electrofishing at a large number of stations downstream of Lees ferry, providing density and size composition information on age 1+ rainbow and brown trout and on densities and spatial distributions of key warm water species in the mainstem (juvenile humpback chub, suckers, carp, catfish). This sampling could be combined with other projects.
- Spring and fall hoop netting in the LCR provides density and PIT tag based recruitment and abundance estimates for the main humpback chub and sucker subpopulation spawning in the LCR.

In addition, there is a critical need for testing new methodologies for monitoring status and expansion of populations of existing warm-water non-native species (carp, bullhead and channel catfish, sunfish and bass) as well as new warm and cold-water invaders. Existing methods (e.g., netting, electrofishing) does not work well for many of these species to determine population size or even presence-absence information. Technologies that should be tested include Didson cameras (high resolution acoustic cameras) and side-scan sonar. Electrofishing protocols should be developed specifically for warm-water fishes. Further, the PIT tagging program should be extended to tag all large-bodied warm water fishes captured, including carp, channel catfish, striped and smallmouth bass, and larger bullheads. Existing programs for monitoring high-stage sand storage and camping areas should be expanded to provide more detailed mapping and monitoring of changes in storage and area, particularly above the 40,000 cfs stage where there will not be direct sand deposition due to HFEs. It is as yet unclear whether aeolian transport of sand deposits to higher elevations after HFEs is having an impact in terms of sustaining the higher-level deposits. Funding should be considered to provide resources to test novel monitoring approaches, but not at the expense of the core resource monitoring programs currently in place that have led to our substantial learning related to humpback chub and sand resources.

Cultural Resource Considerations

- Clearly identify the actions necessary to complete Reclamation's obligations under the National Historic Preservation Act (Section 106) within the geographic area between Glen Canyon Dam and Lake Mead.
- Identify a cultural program in response to the requirements of the Grand Canyon Protection Act.
- Incorporate traditional knowledge of the tribes into the monitoring program and the decision making process.

Grand Canyon Humpback Chub Recovery Implementation Program

This alternative includes an endorsement of a Grand Canyon Recovery Implementation Program (RIP) for humpback chub subject to a commitment of federal funding for the entire Program. A Grand Canyon RIP could be used to fully implement the Humpback Chub Comprehensive Management Plan (adopted by the AMWG in August 2009) and to implement other management actions aimed at the recovery of humpback chub in the Lower Basin Recovery Unit. The RIP should design and implement a Hazardous Materials Plan for the LCR at Cameron Bridge. The RIP should also develop a humpback chub stocking plan as a contingency. This activity would evaluate the efficacy and need for augmenting (stocking) humpback chub in Grand Canyon and developing an appropriate plan under limited situations. Stocking humpback chub on top of an existing wild population should be viewed as an absolute last resort under dire circumstances.

Flow Actions and Experiments

If a RIP for humpback chub is established, many of these actions and experiments could be transferred to that recovery program.

Trout Management Flows: Experimentation and Management

The rainbow trout fishery at Lees Ferry is a valued and popular recreational fishery that has been the focus of a series of extensive monitoring projects by state and federal agencies since shortly after the closure of Glen Canyon Dam. High, steady releases from Glen Canyon Dam during the spring and summer of 2011 appear to have contributed to a recruitment event that was many times higher than recruitment estimates between 2003-2010, including the 2008 year class which responded positively to the 2008 HFE (Korman and Melis 2011, Korman *et al.* 2011, Korman *et al.* In Review). Although this recruitment event may sound like a positive change for the Lees Ferry fishery, monitoring by the AGFD and the GCMRC from 1991-2009 has shown that the fishery is becoming increasingly dominated by smaller, sub-catchable trout and the catch of larger, trophy sized trout is becoming relatively rare. This monitoring has also shown that as the number of smaller trout increases, the condition index of larger trout decreases (Makinster *et al.* 2010) and emigration increases (Korman *et al.* In Review).

This treatment would evaluate potential methods for using releases from Glen Canyon Dam to reduce the excessive production of age-0 rainbow trout in order to improve the quality of the Lees Ferry trout fishery and potentially help conserve humpback chub and other native fishes. This strategy has two potential benefits; (1) flow manipulations in Lees Ferry are likely to be much less expensive and intrusive than large-scale mechanical removal efforts downstream, and (2) trying to manage LCR reach trout densities without reducing the productivity up stream will be difficult to overcome during highly productive time periods (e.g., trout response to 2008 HFE and response to 2011 high steady flows). The goal is to develop a management action based on condition-dependent criteria using decision trees (Figures 1 and 2). Key metrics for a high quality trout fishery would also need to be developed, such as targets for adult and juvenile numbers, individual fish condition, age-0 numbers, and information and value determined through the CREEL survey (AGFD). Trout management flows could be used to help attain these goals with other management tools employed by AGFD and the NPS. Trout management flow treatments should address the following questions:

- Evaluate the potential for utilizing changes in downramp rates to strand or displace juvenile trout and reduce recruitment,
- Evaluate different types and magnitudes of trout stranding flows,
- Determine if flow and non-flow actions at Lees Ferry would be effective in improving the Lees Ferry trout fishery.

Trout management flows have been tested at various times in the last decade, and before that during the GCES experimental flows. Recently, trout management flows were tested from 2003-2005 (Korman *et al.* 2011) with daily dam release fluctuations from 5,000–20,000 cfs during the period January 1–March 31, in order to test the effects of redd mortality on recruitment. Results have shown that high density-dependent survival at later life stages (Korman *et al.* 2010) appears to offset mortality in early life stages; i.e., increased egg and fry mortality did not lead to reductions in overall recruitment due to increases in survival of rainbow trout at later life stages (Korman *et al.* 2011). However, hydro-peaking has been shown to have an effect on early life stages of trout, which has led to numerous proposed flow options for testing releases on trout (Korman and Compana 2009, Korman and Melis 2011).

Further research is needed to establish the effectiveness of various treatments and to establish decision criteria which would be used later to implement management actions (see trout management decision trees Figure 2). Trout management flows will be tested in a 2x2 factorial design with HFEs over a 20-year period in order to evaluate their potential effectiveness in manipulating trout recruitment levels in the Lees Ferry reach (Tables 2a-c) over a variety of environmental conditions. The goal is to develop management tools that are robust to a range of natural and human caused conditions. It is unclear whether experimentation under the scenarios described in Tables 2a-c would be sufficient in developing a successful management strategy within a shorter time (e.g., 10 years). It is likely that substantial progress would be made in developing this decision tree with explicit condition-dependent criteria, but it is unlikely that experimentation would evolve rapidly to a management-only scenario where all information is known during the 20-year timeframe envisioned by the EIS.

To separate effects of HFEs and trout management flows, the following factorial design will be used for experimentation on an annual basis (see Tables 2a-c):

Fall HFE (Yes or No)	Trout Management Flow Tests (Yes or No)
No HFE	No trout management flows (2-3 replicates each warm and cold releases).
No HFE	Test trout management flows (2-3 replicates each warm and cold), to test management flows alone.
Yes HFE	No trout management flows (2-3 replicates each warm and cold), to test HFEs alone
Yes HFE	Test trout management flows (2-3 replicates each warm and cold), to test both in the same year

Two sub-options under this activity will be considered. First, evaluate a forward titration approach (described below) beginning with moderate treatments. This would limit the effect on the trout population and would minimize impacts to the aquatic food base. However, it might also have too small of an effect and the response may be undetectable or unclear. Second, evaluate a reverse titration approach. This strategy would implement much more robust actions to affect trout recruitment in order to establish easily observable results. In successive treatments evaluate more moderate treatments through a reverse titration (described further below).

Nested within the titration experimental framework, at least four flow scenarios would need to be evaluated: (1) age-0 stranding and displacement flows from May-June, (2) age-0 stranding and displacement flows from July-August, (3) age-0 stranding and displacement flows without moving to high flows (e.g., 20,000 cfs) prior to dropping to a minimum, and (4) apply flow reductions only at night to the above scenarios with the objective of reducing food base impacts from desiccation.

Flow scenarios 1 and 2 (age-0 stranding and displacement flows) will consist of 3 days at steady 20,000 cfs followed by a rapid drop (unrestricted down ramp rate) to 5,000 or 8,000 cfs to be held for 6 hrs during daylight hours (6 am – noon). Three such cycles would be conducted over the month. A 3-day flow cycle would be followed by 7 days of normal flows, and this 3-7 day pattern would be repeated 3 times over the month. This option would include tests of this method in May-June; and then in July-August if sediment retention flows were not in effect.

Flow scenario (3) will test whether it is necessary to attract trout to higher elevations (e.g., steady 20,000 cfs) before having a rapid drop. Trout generally reside at the normal minimum flow (Korman and Compana 2009). Thus, they may be susceptible to a rapid drop in flow without having to raise flows for an extended period before hand. Very high flows (as in previous treatments) would involve flooding shorelines above the varial zone with no developed invertebrate community. Rainbow trout juveniles may not respond quickly enough due to the lack of food in these areas. Thus, treatment (3) would stabilize flows near the normal minimum (within the varial zone), and would then apply a rapid downramp below the minimum.

Flow scenario (4) will apply flow reductions only at night. This would likely reduce the impacts of trout management flows on the food base by avoiding desiccation during the day.

In a forward titration approach (approach where small incremental changes are made at the start of the experiment), flows would first be implemented in May only. Hatch date analysis will allow comparisons of early survival rates for fish exposed to management flows (1st half of spawn) to those that were not exposed (2nd half of spawn). Estimates of age-0 abundance in fall (November) can be compared to abundance in non-management flow years (data are available from 2004 to present) to determine how effective the regime was on reducing recruitment to the adult population (recruitment is defined here as abundance of age-0 trout in fall). The frequency and duration of management flows could be increased depending on the results (hatch date analysis, fall abundance) and the target age-0 fall abundance. Target age-0 fall abundance can be computed given a target size for the adult population and estimates of mortality rates determined from the Natal Origins project. Nested within this treatment are the 4 flow scenarios described above.

In a reverse titration approach (approach where large incremental changes are made at the start of the experiment), flows would be implemented in May and June (and possibly in July and August depending upon sediment inputs). Estimates of age-0 abundance in fall (November) can be compared to abundance in non-management flow years (data are available from 2004 to present). The severity, frequency, or duration of management flows will be decreased depending on the results (hatch date analysis, fall abundance) and the target age-0 fall abundance. The flows would be similar to above, but may involve more treatments depending on conditions. This option would include additional tests of this method in July-August if sediment retention flows were not in effect. Nested within this treatment are the 4 flow scenarios described above.

When the next period of low annual releases (8.23 maf) like the 2002-2006 period does arrive, one option would be to avoid trout management flows severe enough to potentially suppress the food base (as was the case in 2003-2005), so as to test whether just low, warm flows are sufficient to result in reduced trout recruitment. This contingent policy option would involve abandoning the planned titration and potentially moving treatments around in Tables 2a-c to accommodate years with no treatment with these temperature conditions.

There is also the potential that longer treatment periods may be necessary to assess cumulative effects. This is discussed above under experimental design and is re-iterated here. In order to assess key cumulative effects on trout and humpback chub, it is expected that the experimental treatment periods for at least trout management flows may need to be extended to 2-3 years in the second decade of the planning period. The use of such extended treatment periods will weaken the experimental design from a statistical perspective (fewer replicates than initially hoped, fewer treatment combinations tested), but it may be necessary to evaluate cumulative effects at some point during this period.

Store-and-Release Fall HFE

Fall HFEs would be conducted according to the HFE EA protocol (Reclamation 2011a), with sediment retention flows from August – October (see above) when triggered by significant Paria River sediment inputs using a decision tree (Figure 1). The HFEs will be triggered by a condition-dependent rule based on 13 levels of high flow events determined by the amount of sediment coming into the river (Paria River inputs), the amount estimated to be retained at the time of the flow event (modeling intervening flows), and the flood volume and duration which would maximize beach building and balance imports with exports. Fall HFEs have a probability of being triggered of about 0.61 in any year based on the protocol developed by Reclamation (2011a). A random number generator was used to develop a series of scenarios based on the annual likelihood of having a significant sediment input large enough to trigger an HFE (Tables 2a-c). This results in frequency of about 12-13 fall HFEs over a 20-year time period. Because the sequences in Tables 2a-c represent only one of many possible sequences that will be controlled by annual climatic and operational conditions, Mussetter (pers. comm.) used Monte Carlo simulation with the same assumptions to test the likely variability of the flow sequences from those represented in Tables 2a-c. Mussetter's more sophisticated analysis using 1,000 model runs confirmed that most likely number of HFE's per 20 year period is in the range of 12 to 13 (about 35% probability), and there is a 95% probability that the number of HFE's will be between 9 and 18.

Curtailment of HFEs will be possible if adverse effects to primary resources are identified (e.g., decline in humpback chub related to HFEs). These HFEs will occur in blocks of 3 with a rapid response HFE occurring every fourth cycle (e.g., 3 store and release then 1 rapid response, see Tables 2a-c). Aquatic food base monitoring is critical to ensure that repeat-HFEs don't result in movement to less desirable food base states (ecosystem shifts) that may not be reversible (Robinson and Uehlinger 2008).

Rapid-Response Fall HFE

Rapid response HFEs were discussed by Reclamation (2011a) as a potential alternative to store and release HFEs to be tested as part of the actions considered in that EA. Lucchitta and Leopold (1999) first considered the possibility of a rapid response test in relation to an LCR input. In this alternative, rapid response HFEs will be tested in a block design with store and release HFEs (above; see Tables 2a-c for three scenarios) aimed at maximizing benefits from Paria River inputs.

Release of an HFE from the dam will be timed to coincide with a Paria River flood using a sediment decision tree (Figure 1). A rapid-response HFE would take immediate advantage of sediment delivered by a Paria River flood, potentially conserving more silt and clay inputs, and other organic matter that may provide ecological benefits to native plants and provide nutrients to backwaters. Matching the HFE release to the Paria River flood may also require less water to be released from the dam for the experiment. Sediment retention flows (above) would not be necessary because flows would be occurring at the same time. Multiple rapid-response HFEs could be released within the same fall time period depending upon the frequency of significant Paria River inputs (Kimbrel 2012). For example, a significant input might occur in August and a rapid-response HFE might be triggered. This could occur again a few weeks later, and if it meets the requirements for size of input another rapid-response would be triggered. This is different than the store-and-release fall HFE that would occur no more than once per year. Long-term effects are expected to be similar to store-and-release fall HFEs, thus minimizing confounding effects. Short-term effects might include different beach building and storage relationships, substantially higher fine sediment (silt and clay) storage in beaches, and might change the stability of the beaches (variety of sediment size classes could increase stability of sandbars to erosion).

Store-and-Release Spring HFE

Spring HFEs conducted in 1996 and 2008 created strong year classes of rainbow trout at Lees Ferry (Korman *et al.* 2010, Korman *et al.* 2011, Korman and Melis 2011). High trout abundance and emigration from the Lees Ferry reach are believed to negatively affect humpback chub through predation and competition (Yard *et al.* 2011). Reclamation (2011a) identified a temporary deferral of spring HFEs through 2014 as a mitigation element to reduce risk and improve protection for listed native fish in their FONSI. Under this proposed alternative, store-and-release spring HFEs would be deferred during experimentation with fall HFEs and trout management flows (roughly the first 10 years) in order to develop successful methods to mitigate trout impacts and ensure the continued recovery of humpback chub (Tables 2a-c). Spring HFEs could be implemented under condition-dependent criteria which may be developed during the first 10-20 years (Figure 1). Spring HFEs have a likelihood of about 0.47 (Reclamation 2011a) which results in about 3-5 events over a 10 year period based on the three scenarios developed (Tables 2a-c). Spring HFEs will have most likely key on the sediment retention flows for a Spring HFE. Here are the considerations: (1) spring HFE most likely to key on sediment delivery from the Little Colorado River (LCR) into the Grand Canyon; e.g., below the LCR. Since it is further downstream from Glen Canyon Dam and the relationship of flow to channel form and retention in Grand Canyon is not well known for Marble Canyon the need for sediment retention flow is less certain. It is nevertheless possible for a spring Paria River flow, in which case, sediment retention flow and a spring HFE could benefit Marble Canyon. Spring HFEs will have additional negative impacts to power production and it is unknown at this time whether sediment retention flows should be conducted prior to Spring HFEs. Additional analysis will be necessary if and when Spring HFEs are implemented to determine the impacts to hydropower and the appropriateness of sediment retention flows prior to these HFES.

Aquatic Food Base Experiments

This alternative would develop a monitoring and research program using the current program and recent Peer Evaluation Panel (PEP) review as a starting point and using in-river and laboratory based experiments to determine what could be done in Grand Canyon to increase the diversity of taxa. This program would work with other research programs from other systems that could be used to compare conditions (e.g., below Flaming Gorge, Cataract Canyon) and evaluate factors leading to more or less diversity. This program would use existing research to evaluate the role of temperature and flow patterns on resource conditions, and develop experiments which could eventually be implemented in Grand Canyon with reasonable certainty of success. Research is also needed to understand the relationship of tributaries to mainstem food availability, and to describe the food base in the LCR (the primary humpback chub rearing area) and how foodbase diversity and availability may relate to humpback chub recovery. Small-scale in-river experiments, laboratory experiments, and evaluation of surrogate river reaches will likely be the most effective and cost-saving approach for evaluating food base, given that a series of flow experiments that may be needed to evaluate the food base could be substantial and costly.

Transitional Flows Between Seasons

The transition in flow volume from one month to the next can be a substantial change in the rate of water released from the dam. Low volume months, such as a 600,000 af month, can be followed by a month that exceeds 900,000 af. These large transitions may have a negative impact on food base productivity. This alternative includes a stepped transition between months where substantial differences in the amount of water releases occur. The decision rules for transition flows need to be developed to take into account the transition size which would trigger these flows, and the amount of time necessary to provide suitable transition to minimize impacts to the food base. Current food base research is equivocal on whether there are measureable food base impacts under previous operations, so this component of the alternative is considered an experimental treatment and is evaluated for effectiveness.

Naturally-Warmed Releases

In years of low reservoir elevation (below about 3625’), the effect of warm temperatures on aquatic invertebrates and algae (i.e., food base) and native fish growth and survival may be tested. Recent CRSS modeling suggests warm periods during the next 20 years based on correlations between reservoir elevations and temperatures (Figure 5a-b), and should be considered in the experimental design as a likely factor in all scenarios (Table 2a-c). Contingency rules will be established that guide changes to the experimental design to capitalize on warm or cold releases in order to maximize learning as conditions provide opportunities.

Condition-Dependent Steady Flow Experiment

One of the more uncertain and controversial aspects of Glen Canyon Dam operations is the proposal to move toward more steady flows to benefit native fish and for sediment conservation. There have been only two extended periods of steady releases from Glen Canyon Dam, and the effects of these on canyon resources have been mixed and inconclusive (Ralston 2011). These are: (1) Low Summer Steady Flow (LSSF) of 8,000 cfs from June 1 to September 4, 2000, and (2) Fall Steady Flows (FSF) during September and October, 2008-2012 based on available volumes. Investigations of the LSSF did not show significant changes in fish populations, growth rates, or survival (Trammell *et al.* 2002) and results were confounded by a 4-day release of 30,000 cfs in September. Although sediment supply was low in 2000, the LSSF did effectively retain the little sediment that was supplied by tributaries, and the subsequent 4-day high release caused modest increases in the area of mid-elevation sandbars (Schmidt *et al.* 2007). Responses by other resources, including the aquatic food base, riparian vegetation, and the trout fishery were also mixed and inconclusive (Ralston 2011). The FSF of 2008-2012 were implemented primarily to evaluate warming of nearshore habitats to benefit native fish, especially humpback chub. Preliminary results of nearshore ecology studies (Pine and Finch unpublished results) show reduced growth and no significant difference in survival of juvenile humpback chub during the

FSF compared to other flow. These studies also suggest that juvenile humpback chub are found in a wide range of habitat types along complex shorelines where they can adjust position with changing flows.

As described above, it would be risky to drastically alter the flow regime in which humpback chub are recovering and could possibly reverse the increases of the last decade. Furthermore, adding a significant new treatment to the experimental design would require a longer experimental plan to evaluate its effects along with other treatments (i.e., trout management flows and fall HFEs). We also recognize the probability of near-future low reservoir elevations and warm dam releases, such as during 2004-2011, during which there will be an opportunity to evaluate the benefits of warm releases to downstream resources, including native fish, humpback chub, and the aquatic food base. Given the mixed and inconclusive results of prior steady flow tests, we have incorporated the opportunity to evaluate the experimental need for a steady flow test into this alternative on a condition-dependent scenario. If this alternative produces temperature variability in the first ten to fifteen years, a steady flow test would not be evaluated. However, if there is a need to evaluate a warm water regime and reservoir elevations have not been variable enough to collect the necessary data, then this alternative proposes the evaluation of a steady flow test aimed at achieving warmer temperatures. Such evaluation would not occur in the first ten years of the implementation of this alternative. If the evaluation is warranted, implementation shall be conditioned upon the status of the humpback chub and other critical resources. The States and other stakeholders shall be formally consulted during any such evaluation. If, however, hydrologic conditions are likely in the near future (before the end of the twenty year period), then such an evaluation would not be warranted. Further rationale for not implementing other steady flow tests is provided in detail in Appendix D – Treatments Considered and Not Included.

Non-Flow Actions and Experiments

<u>Condition-Dependent Mechanical Removal of Trout at the LCR and Humpback Chub Natural Mortality Research</u>

This treatment proposes to evaluate the relationship between trout abundance and juvenile humpback chub survival. The primary treatment is mechanical removal of trout in the LCR reach using a condition-dependent decision-tree that has a substantial learning objective (Figure 2, right panel). It is expected (see Tables 2a-c) that temperatures will go through a number of warm and cold cycles (natural variation) over the next 20 years. This warming uncertainty is incorporated into the experimental design with HFEs and trout management flows (see below) – thus it should be possible to evaluate the effects of trout on humpback chub in the mainstem under a variety of environmental conditions. The condition-dependent trigger for removal will be sensitive enough to avoid prolonged negative effects on the adult humpback chub population. The research and monitoring program will continue to emphasize investigations of critical relationships (e.g., importance of mainstem juvenile rearing, natal origins of adult fish). It also must determine if trout abundance at the LCR can, under various conditions, reduce juvenile humpback chub survival in the mainstem, and if those reduced survival rates ultimately lead to a meaningful reduction in recruitment to the LCR spawning population. Research programs such as the Juvenile Chub Monitoring (JCM) program are essential and information from that program as well as the LCR monitoring program is displayed in Figure 6.

An individual-based model for population viability analysis of humpback chub in Grand Canyon (unpublished) was used to help determine the following proposed triggers for this treatment. Based on these model runs, it is estimated that loss of substantial proportions of juvenile humpback chub in the mainstem during a 3-5 year period would not pose a substantial risk of extinction to the humpback chub population. The following criteria would be used as a trigger to implement mechanical removal of trout in the LCR Reach (RM 56.3-65.7):

- Annual survival of juvenile (age-0 and age-1) humpback chub declines to a point at which a lowered level of recruitment is likely to affect the population trajectory and result in a measurable decline of adults. Juvenile survival will be monitored with the NSE study (e.g., JCM) and the determination of recruitment will be made with a stock-recruitment model; **or**
- The abundance of trout (rainbow trout and brown trout) exceeds the level seen in 2003 of about 6,900 in the 9.4-mi reach of the Colorado River (RM 56.3-65.7); **or**
- If the humpback chub population drops by 1,000 adults during the same time period that the abundance of trout (rainbow trout and brown trout) exceeds 690 (which is 10% of the level seen in 2003 of about 6,900 in the 9.4-mi reach of the Colorado River).

For the long-term recovery of humpback chub, it is critical to understand some key components of natural mortality that will likely influence the viability of this population. Although trout can impact humpback chub in the mainstem, it is unclear under what scenarios (high trout/low humpback chub, high trout/warm water, etc.) that these factors are important to recruitment and ultimately to adult trends (i.e., population level effects). All fish are subject to natural mortality factors including predation by other species (and themselves), parasites and diseases, thermal shock, starvation, and downstream displacement – all of which can influence recruitment. Sometimes predation can rise to the level that it has a population-level impact, while other times recruitment exceeds natural mortality to result in an increasing population. There are many factors that affect natural mortality of humpback chub; the question is, whether they pose a threat to recovery, and under what scenarios those threats are likely to interact? The actions proposed here are designed to better understand these relationships so a reasonable long-term management program can be implemented.

The effect of trout abundance on mainstem juvenile survival rates could be evaluated based on 3 or 4 annual replicates of survival rates measured under high trout abundance, which is likely to occur in the next few years owing to the current very high trout abundance in Glen and Upper Marble Canyons. The effect of trout abundance on the estimated recruitment to the LCR humpback chub population (using ASMR) cannot be measured until about 2-4 years after the treatment (high trout abundance) begins. Results from humpback chub juvenile survival rates would be available annually and would be a fairly sensitive indicator of juvenile status in the mainstem. A precipitous decline in those survival rates (see Figure 6; specified decline amount over some time period) and adult population decline (using ASMR) would be used to trigger LCR trout removals, regardless of whether direct linkages were made with the research program (off-ramp). Thus, this approach could result in some short-term negative effects on humpback chub, and if these effects were observed would trigger LCR reach trout removals based on the criteria. Information gained from this approach would be invaluable to the long-term management of the species, to ensure recovery by informing managers on the necessary nonnative conditions needed to maintain a robust humpback chub population in Grand Canyon.

This alternative will not include a test of the trout removal curtain in the Paria River to Badger Rapid (PBR) reach as described by Reclamation (2011b; nonnative fish control). The rationale is provided in detail in Appendix D – Treatments Considered and Not Included.

Lees Ferry Mechanical Trout Management

Rainbow trout juvenile (age-0) removal (by electrofishing) will be tested in the fall in the Lees Ferry reach, as a way to reduce juvenile density and to potentially improve trout growth and reduce dispersal rate downstream (emigration), without any risk of impacting the food base through flow reductions. Reliable estimates of age-0 abundance are available each fall from Natal Origins project (based on reach-wide mark-recapture sampling) and it is fairly certain that removals could be calibrated to have a desired effect and resulting target population size. Similar to Trout Management Flows, it is uncertain whether such reductions will increase growth in the adult population or reduce downstream migration. Initial analyses indicate that it would take a large and expensive effort to reduce abundance in a big recruitment year, but it could be effective in a moderate recruitment year. In a moderate year, 40 days of removal effort (2 electro-fishing boats) could reduce the population by 80%. In a big recruitment year twice as much effort (80 days, requiring 3 months of near continuous fishing effort) would only reduce the population by about 30%. If Trout Management Flows are not successful in meeting trout recruitment goals, or if flows have a substantial negative food base impact, then mechanical removal efforts could be implemented in years of moderate recruitment events as an alternative approach.

Removal of Trout from Bright Angel Creek

The primary source of brown trout to the LCR reach is the Bright Angel Creek and associated inflow area of the mainstem. Removal of trout from Bright Angel Creek and the mainstem would likely reduce predation on juvenile humpback chub in the LCR reach by brown trout, and also make Bright Angel available for translocations of humpback chub (similar to Shinumo and Havasu creeks; Valdez 2000). The establishment of another tributary population of humpback chub and the associated mainstem aggregation (redundancy) would greatly reduce the threat to the population from an LCR-related catastrophe.

Translocate Humpback Chub to Tributaries – Establish Robust Aggregations

Efforts would continue to translocate humpback chub to tributaries in the Grand Canyon, including Shinumo, Havasu, and Bright Angel creeks, above Chute Falls in the LCR, and to evaluate other locations possibly including the Paria River. The establishment of tributary populations of humpback chub and the likely growth of the associated mainstem aggregations would greatly reduce the threat to the population from an LCR related catastrophe. Although some spawning is likely to occur, it will be difficult to establish other self-sustaining populations outside of the LCR spawning complex. Thus, continued long-term translocations, perhaps on a rotational basis based on young of the year availability in the LCR, would likely be necessary. However, this would provide multiple in-river redundant populations to the LCR spawning complex which could be used to re-populate the LCR if there was a catastrophe within the LCR. It is possible that these other tributary related aggregations could have a low risk of extinction and given new estimates of growth and adult survival (higher survival rates for adults), we would expect these aggregations to be persistent and contribute to population recovery goals (i.e., demographic recovery goals). Seasonally warmed tributaries could also provide suitable temperature conditions for spawning on cobble/gravel bar in inflow areas. Warming under projected scenarios (Figure 5 and Tables 2a-c), could increase growth of individuals possibly reducing predation risk and increasing the likelihood of these individuals contributing to the overall Grand Canyon humpback chub population.

Humpback Chub Refuge System

This action establishes a humpback chub refuge population of 1,000 individuals in an off-site hatchery facility (e.g., Dexter, Bubbling Pond). This activity is already underway and will provide a safeguard against future catastrophic loss by maintaining sufficient numbers of fish to produce a broodstock and augment any depleted population, as well as maintaining the genetic diversity of the humpback chub in the Grand Canyon.

Riparian Vegetation Control

Recreational beaches in critical areas that are adequately sized for camping and recreation can have substantial reductions in useable space because of vegetation encroachment (GCMRC knowledge assessment 2012). This action would identify critical beaches and allow for managers to remove the associated vegetation through either flow and/or non-flow actions to determine if more useable camping space can be created and maintained.

Control of Nonnative Warmwater Fish

Managers and scientists have expressed concern that populations of nonnative fishes adapted to warm water, most of which are already present in Grand Canyon (e.g., channel catfish, *Ictalurus punctatus;* common carp, *Cyprinus carpio;* fathead minnow, *Pimephales promelas;* red shiner, *Cyprinella lutrensis*; and plains killifish, *Fundulus zebrinus*), may increase at the expense of native fishes under warmer water conditions. Additionally there is significant concern over the increased risk of establishment of species present within the Colorado River basin, but not found in Grand Canyon such as smallmouth and largemouth bass which are highly piscivorous and have high potential for restructuring the extant fish community in Grand Canyon. All experimental options support continued research of this threat and implementation of control measures as needed with concomitant monitoring of the native fishes, especially humpback chub.

Turbidity to Control Trout

The SDM workshop (Runge *et al.* 2011) identified turbidity as a high performing alternative for nonnative fish control by limiting the effectiveness of sight-feeding by trout. Investigate the possibility of using a pump-back system in the Paria River drainage to increase the turbidity in the mainstem. The first step would be a feasibility study looking at options, limitations, and cost-benefit. The study should consider to the possibility of installing a pumping system at Lees Ferry to transport a small amount of water up into the Paria River drainage to increase turbidity for a few weeks in the mainstem to disadvantage rainbow trout. If feasible and reasonable to consider implementation of such a proposal, NEPA analysis should be considered for a potential turbidity experiment. Other options such as Trout Management Flows should be fully considered before a turbidity system is fully tested.

Synthesis

It is important that this alternative address the key resource considerations such that at the end of the 15-20 year period, the major uncertainties, as understood today, in the Grand Canyon ecosystem have been addressed. This alternative would be implemented in two phases. Phase I (approximately the first 10 years) would implement a series of experiments that would provide the information and criteria necessary to implement certain management actions or additional experiments to be implemented under Phase II (approximately second 10 years based on conditions). This approach is consistent with the purpose and need of the EIS and with the principles of adaptive management. The two key questions identified will (1) provide a better understanding of the linkage between the recreational trout fishery and recovery of the humpback chub, and (2) define an appropriate strategy for rehabilitating a sand-limited physical environment.

This alternative would test different trout management flows in the Lees Ferry reach to determine the manner of flow releases that best helps to develop a high quality trout fishery and also minimizes downstream emigration to reaches inhabited by humpback chub. The appropriate level of mechanical removal of trout would be implemented following the outcome of these flow experiments, with off-ramps to ensure the continued recovery of humpback chub. The results of these experiments would provide the information necessary to construct criteria that would trigger future actions (e.g., trout management flows, HFEs, mechanical fish removal) and would provide information for establishing and maintaining a high quality trout fishery. It may also inform humpback chub population levels to continue to meet requirements of the ESA.

Phase I of this alternative also proposes to better define the relationship of tributary sediment input and the use of dam releases to rebuild and maintain sandbars used for recreation and as important habitat for wildlife and fish. Based on the availability of sediment, a store-and-release fall HFE would be tested in three year blocks (not necessarily consecutive years based on availability of sediment and hydrology). These HFEs would be used to evaluate the effect on the Lees Ferry trout fishery, the food base, sediment supply, and beach area and volume. A rapid-response fall HFE would occur after three store-and-release fall HFEs, and would provide the contrast for evaluating the efficacy of the two types of HFEs for building sandbars that benefit recreation and native fish habitat.

Monitoring the effects of these experiments on key resources will be important for interpreting results and establishing cause-effect relationships. This alternative identifies the areas of resource monitoring that may be covered by core monitoring and additional effects monitoring that may be necessary for distinguishing the more subtle experiment-related effects.

PREVIOUS LEARNING AND ASSUMPTIONS

A substantial amount of knowledge has been gained from numerous experiments and monitoring of canyon resources (e.g., Gloss et al. 2005; Melis 2011; Colorado River Knowledge Assessment Workshops, October 18-19, 2011 and February 1, 2012). The GCMRC has produced and compiled a substantial library on the resources of the Colorado River downstream of Glen Canyon Dam and in Lake Powell; http://www.gcmrc.gov/gcmrc.aspx. In order to make the best possible use of the large amount of available scientific information, this alternative development process consulted with scientists knowledgeable and experienced with these resources. The following is a summary of lessons learned from experiments and a discussion of paradigm shift, or the way in which knowledge gains through adaptive management has reshaped our thinking about the Grand Canyon Ecosystem and dam operations (see also Appendix E).

Experimentation in Grand Canyon: Lessons Learned

From 1996 to 2012, five types of experimental actions were implemented (Figure 3a), including:

1. Six scheduled high releases from Glen Canyon Dam designed primarily to conserve sand and sediment (BHBF=beach-habitat building flow; HMF=high managed flow; HFE=high flow experiment):
   - 1996 BHBF, 45,000 cfs for 7 days, March 26–April 2, 1996.
   - 1997 HMF, 31,000 cfs for 72 hours, November 5–7, 1997.
   - 2000 HMF, 31,000 cfs for 72 hours, May 2–4, 2000.
   - 2000 HMF, 31,000 cfs for 72 hours, September 4–6, 2000.
   - 2004 HFE, 41,000 cfs for 60 hours, November 21–23, 2004.
   - 2008 HFE, 41,500 cfs for 60 hours, March 5–7, 2008.
2. Low steady summer flow: constant dam releases of 8,000 cfs, June 1–September 4, 2000, designed primarily to evaluate warming of nearshore habitat occupied by humpback chub, and preceded and followed by 4-day releases of 30,000 cfs, each in early May and September, 2000, designed to evaluate displacement of small-bodied nonnative fish.
3. Nonnative fish management flows: daily dam release fluctuations of 5,000–20,000 cfs during the period January 1–March 31, each in 2003–2005, designed to control survival of trout eggs and fry in the Lees Ferry reach.
4. Nonnative fish mechanical removal: removal using electrofishing of primarily rainbow trout and brown trout (*Salmo trutta*) from 2003–2006 and in 2009 from a 9-mile reach of the Colorado River in the vicinity of the LCR confluence, designed to evaluate the efficacy of removing predators on the humpback chub population.
5. Fall steady flows: steady releases from Glen Canyon Dam of between 8,000–15,500 cfs, depending on the year, each September and October from 2008–2012, intended to evaluate effects of nearshore habitat stability on young humpback chub.

In addition to the five types of experimental actions described above, the river downstream of the dam was also being variously affected by dam releases volumes and temperatures, caused primarily by changes in the water level of Lake Powell as a consequence of a regional drought starting in the late 1990s. This led to:

- Lower lake volumes and lower dam releases from 2000 to 2010, and
- Historically warmer dam releases particularly in late summer and early fall of 2004–2011 when maximum average daily temperature reached 58°F (14.5°C) on October 6, 2004 and 60°F (15.7°C) on October 14, 2005; prior maximum was about 54°F (12°C).

An overview of these experimental actions is shown in Figures 3a-d, concurrent with river flows and temperature, as well as abundances of rainbow trout and adult humpback chub from 1989 to 2012, to illustrate the challenges of implementing experiments in the Colorado River downstream of Glen Canyon Dam. Concurrent experiments and fish numbers may indicate associations, but these have not been confirmed as cause-effect relationships. The following is a brief description of the rainbow trout and adult humpback chub abundances and possible associations with experimental actions and ongoing river flows and temperatures; greater detail of these events and apparent relationships are described in the 2012 EA for the High Flow Experimental Protocol.

Adult humpback chub in the vicinity of the LCR and rainbow trout in the Lees Ferry reach have been quantitatively monitored starting in 1989 and 1991, respectively. The rainbow trout population in the Lees Ferry reach increased by about 10% annually from 1993 to 1997, remained high until 2001, then declined dramatically by about 20% annually from 2001 to 2007, followed by a sharp increase in numbers in 2008 (Figure 3d). A marked 66% increase in catch rate from 1996 to 1997 was attributed to the spring 1996 HFE and the effect of high velocity water on cleansing spawning beds and stimulating food production for young trout. Conversely, the decline in trout abundance from 2001 to 2007 was system-wide and was attributed to several factors including:

- Increased daily fluctuations during 2003-2005 that led to alternating short-term inundation and desiccation of spawning beds and food production areas;
- Increased water temperatures associated with low reservoir elevations that led to high trout metabolic demands coupled with periodic oxygen deficiencies, and a static or declining food base consisting largely of the New Zealand mudsnail which cannot be digested by trout;
- The November 2004 HFE that caused low apparent survival of rainbow trout and a 30% decline in catch rate, and possibly set back winter-time food production;
- Nonnative fish management flows in January-March of 2003-2005, which reduced survival of eggs and young; and
- A program of mechanical removal in the vicinity of the LCR that reduced numbers of trout by 90% during 2003–2006, but reported a return of trout numbers by 2009.

After 2007, there was a dramatic 200% increase in rainbow trout catch rate from 2008 to 2009 that is attributed to increased survival and growth of young trout following the March 2008

HFE and the cleansing effect of that high release on spawning beds and the food base; this was a similar but more dramatic effect than with the spring 1996 HFE. The trout population in Lees Ferry has remained high since 2008 and increased with high dam releases in 2011, apparently because of a greater availability of spawning beds and substrate for food production with higher flows. From a food web perspective, we learned that although the spring 2008 HFE increased aquatic food production at Lees Ferry, a concurrent increase in production was not seen at downstream locations (i.e., LCR, Diamond Creek; Rosi-Marshall et al. 2010). Also, food base was not monitored for the fall 2004 HFE and the effect on aquatic production is unknown.

Modeling of trends in catch rates of rainbow trout from Glen Canyon Dam to the LCR indicated higher levels of recruitment in Glen Canyon result in greater emigration of rainbow trout from Glen to Marble Canyon (Korman *et al.* In Review). The inverse relationship between adult humpback chub numbers and trout catch rates shown in Figure 3d suggests predation or competition effects. However, other poorly understood factors and/or relationships could be contributing to this pattern of humpback chub abundance. Population estimates of adult humpback chub (age 4+) showed a decline in numbers of individuals from 1989 to 2000, followed by an increase of about 50% to an estimated 7,650 adults in 2008 and preliminarily to 8,912 in 2011. Declining and low numbers of adult humpback chub apparently corresponded with increasing or high numbers of rainbow trout during 1997-2001, and increasing numbers of adult humpback chub apparently corresponded with decreasing or low numbers of rainbow trout. However, the increase in age 4+ humpback chub was due to increased survival of young humpback chub and recruitment that occurred before 1999 and probably began as early as 1996, at a time when trout numbers were highest. The increase in humpback chub recruitment began at least 4 and as many as 9 years prior to implementation of nonnative fish management flows, mechanical removal of nonnative fish, warmer dam releases, the 2000 low steady summer flow experiment, and the 2004 HFE. Furthermore, it is unclear if the increase in humpback chub is attributable to conditions in the mainstem or to conditions in the LCR, the major spawning tributary of the humpback chub in Grand Canyon that is unaffected by dam operations.

The pattern of key resources in the river downstream of the dam and the manner in which prior experiments have been conducted and our ability to monitor and discern their effects is instructive in designing future dam operations and experiments. It is unwise to implement multiple simultaneous or overlapping experiments whose effects may be confounded by other actions or unforeseen natural events. In designing and implementing experiments, it is important to focus on those actions that are most likely to have the greatest benefit to a desired resource and are implemented in a manner that does not affect other experiments. It is also important to acknowledge that a key resource, humpback chub, was evidently experiencing successful survival and recruitment under MLFF established through the 1996 Record of Decision (U.S. Department of the Interior 1996) and prior to implementation of a number of experiments designed to benefit this key resource. This is not to say that these experiments were needless or ineffective. In fact, the lesson learned is that focused, well-designed experiments can help identify actions that can be incorporated into dam operations that help to offset detrimental effects of these operations and benefit key resources.

Paradigm Shift

Documented patterns in key resources in the last 10-15 years and findings from experiments have prompted a paradigm shift in thinking about how to best manage Glen Canyon Dam to benefit downstream resources. The MLFF alternative was implemented by the 1996 ROD because it would reduce daily flow fluctuations, provide scheduled high releases of short duration (i.e., beach/habitat-building flows) to rebuild high elevation sandbars, deposit nutrients, restore backwater channels, and provide some of the dynamics of a natural system, while allowing limited flexibility for power operations. For the first 5 years after MLFF was implemented, a key resource—the humpback chub—apparently continued to decline in abundance and experiments like the low steady summer flow of 2000 continued to evaluate the effect of fluctuating flows against stable flows on the recovery of humpback chub. In the meantime, adult population estimates of humpback chub revealed that there must have been successful reproduction prior to 1999 and as early as 1996, indicating that conditions appeared suitable for the species under MLFF. Preliminary results from a more recent investigation of nearshore ecology contrasting MLFF with stable September-October, 2008-2012, flows show no difference in survival and reduced growth of juvenile humpback chub (Pine and Finch unpublished data).

These findings indicate that reproduction, recruitment, survival, and growth of humpback chub occurred within the range of MLFF flows sufficient to increase numbers of adults by 50% from 2001 to 2008. However, other monitoring programs and experiments show that under MLFF food base may be limited; cold downstream temperatures continue to prevent mainstem reproduction; and reduced fluctuations enable natural reproduction and increased numbers of rainbow trout that result in greater predation and competition on young humpback chub. Identifying and isolating these variables allows for either specific management actions or experiments targeted at a better understanding of these issues.

Another aspect of this paradigm shift is the role of high releases for rebuilding high elevation sandbars and the collateral effect of HFEs. The spring 1996 BHBF revealed that a release of 45,000 cfs for 7 days was not a necessary duration for sandbar building, and subsequent HFEs in 2004 and 2008 were effective with releases of 41,000 cfs for only 60 hours. Yet, periodic releases allowed for intervening erosion of sediment, and it was determined that high releases are more effective when specifically scheduled to coincide with delivery of sediment from the Paria River (September-October) and the LCR (January-March). A refinement of this approach is a rapid response high release to a sediment-enriched flood from the Paria River that could effectively conserve a greater amount of sediment.

The spring 1996 BHBF and 2008 HFE, while designed to conserve sediment, also increased production and survival of young rainbow trout at Lees Ferry and escapement to downstream areas where they prey on and compete with young humpback chub. The effect of this predation and competition on the humpback chub population is not fully understood, but has warranted offsetting actions to regulate the numbers of rainbow trout at Lees Ferry. These actions would reduce downstream escapement and predation of humpback chub, but could also improve the quality of the trout fishery with fewer, larger, and better conditioned fish.

An investigation of a selective withdrawal structure on Glen Canyon Dam was a common element of the 1995 EIS and an element of the RPA of the 1995 Biological Opinion and would provide warmer water releases and allow for mainstem spawning of native fish. Interest and support for a selective withdrawal structure have waned following a series of workshops, an EA, and a risk assessment showing that the cost of such a structure may not justify the uncertain benefits to native fish that could be offset by expanded nonnative fish populations and possible effects to the food base.

Evaluating the environmental impact of Glen Canyon Dam operations is an opportunity to reevaluate what has been learned from prior actions and refine the operation in a manner that better protects downstream resources. The 1996 ROD (p. G-11), identified the goal of the preferred alternative was "not to maximize benefits for the most resources, but rather to find an alternative dam operating plan that would permit recovery and long-term sustainability of downstream resources while limiting hydropower capability and flexibility only to the extent necessary to achieve recovery and long-term sustainability" (U.S. Department of the Interior 1996). In a similar approach, the alternative developed herein is not likely to maximize benefits to most resources (see Schmidt *et al.* 1998), but should permit recovery and long-term sustainability of most downstream resources.

SCIENCE DESIGN

Walters *et al.* (2011) felt the most pressing adaptive management need in the Grand Canyon is to understand the linkage between HFEs and trout that may have negative impacts on native fishes. This has also been the discussion at TWG and AMWG meetings and in discussions with GCMRC. They also stressed a need to devise experimental plans that recognize need for feedback (contingent) response to unpredictable future conditions in terms of tributary sand inputs and changes in fish recruitment due to factors other than management actions.

This science design approach recognizes that the essence of adaptive management is not about resolving scientific uncertainty in general, but rather resolving uncertainty about the impacts of specific policy choices that would lead to different decisions being made (Walters *et al.* 2011). Unlike the pure toggle-on toggle-off approach of the typical block experimental design, this alternative is based on a hierarchy of treatment applications based on resource need (targeted), block design for key experiments with confounding results, and a series of condition-dependent actions.

The goal is to develop a science design and research program that will ensure that data and information obtained enables us to answer management questions with as little uncertainty as possible. In order to be successful with an adaptive management program, the science design chosen must consist of a set of actions and experiments that specify:

- The resources goals to be achieved (Appendix A),
- Be able to identify when these targets are achieved within a specified level of certainty,
- Indication when targets are not being met, and
- An altered path forward to achieve resource goals (off-ramps).

The construction and operation of Glen Canyon Dam and a variety of other interrelated factors have contributed to the status of humpback chub and the loss of sediment in Grand Canyon. Although actions have been taken to reduce negative impacts, they have not had the desired effects in all cases. Humpback chub numbers declined during the 1990s, leveled off in the early 2000s, and then began increasing at about 5% per year for the last decade. However, there is great uncertainty about the causative factors both for the decline and the recent recovery. The stabilization and recovery in adult population numbers and recruitment is correlated with a suite of recent management actions (e.g., nonnative fish removal, warm water temperatures, trout management flows, high flow equalization releases). To date, monitoring hasn't been effective in teasing out many of these potential cause-effect relationships in the Colorado River Ecosystem (CRE). Hence, there is a need for an experimental/adaptive management approach that directly considers the use of information gained through scientific exploration in order to achieve key resources objectives, definitively answer critical questions, and reduce uncertainty around management actions.

Although past research and management actions have helped reduce the range and impact of possible threats, the relative significance of each potential impact remains uncertain because multiple ecological, biological, and physical habitat changes have occurred. This makes it difficult to choose among competing hypotheses and difficult to know where exactly to focus management efforts for maximum benefit and minimal cost. In an ideal world, specific measures would be identified and implemented based on a series of complementary research investigations designed to definitively identify the proximate causes and specific mechanisms of impact. Unfortunately, today there are numerous examples of species in danger of extinction with multiple causes and great uncertainty in how to recover them (e.g., Pacific salmon, Puget Sound orca, Steller sea lion, and Kootenai River white sturgeon).

This alternative is driven by two experimental actions: (a) fall store-and-release HFEs, and (b) rainbow trout management actions (both flow and non-flow) that address the two principal uncertainties regarding sediment and humpback chub/trout relationship. Other treatments will follow in a nested hierarchy based on decision criteria. These will be more opportunistic based on the types of environmental variables that exist in any one year. The science design employs 3 tiers of treatment:

1. Primary: Core experiments with high management importance, results are preferred over knowledge gain, use block design.
2. Secondary: Experimental actions intended to increase knowledge or management activities that are unlikely to confound primary results
3. High Uncertainty/Risk: Experiments with high risk of confounding primary experiments, risk to key resources, or uncertainty with implementation

Overlaid on any experimental design is going to be the significant impacts of natural variation. Key variables that are likely to impact this study design are:

1. Paria River sediment inputs (seasonal)
2. Warm water (likely under lower hydrology and low lake levels)
3. Cold water (likely under higher hydrology and higher lake levels)
4. Annual release volume requirements
5. High trout numbers at the LCR (greater than the densities in 2000)
6. Low trout numbers LCR (less than the densities in 2000)
7. Aquatic invasions (unknown species, but something is likely to be established)

In the past, these types of unplanned “treatments” have provided a backdrop of long term habitat variability that has made it difficult to interpret apparent responses to experimental treatments. We can expect these types of changes to occur through the time period of this EIS in the Grand Canyon’s Colorado River ecosystem. In particular, it is likely that tamarisk will continue to be impacted by the tamarisk beetle with substantial effects to the riparian system over the next decade, with potentially large impacts on terrestrial components of the food base available to aquatic organisms and on stability of some shoreline environments. It is also quite likely that the current period of high flows will be followed by another extended drought, long and severe enough to cause at least one more period of high river temperatures within the next two decades (Walters *et al.* 2011).

Scientific Treatments

In planning for future experimental treatments as part of the GCDAMP, it is important to learn from past experience about what policy treatments deserve further field testing, and how to carry out such treatments so as to better control for effects of ongoing, uncontrolled system change and effects of interaction between treatments. The best way to provide such control is to (1) plan for adequate replication of treatments, so as to see what responses are measurable despite changes in background conditions, and (2) use a planned treatment pattern over time that avoids, as much as possible, combinations of treatments whose effects cannot be distinguished from each other except when there is a need to deliberately test for interaction effects (such as use of trout management flows after HFEs to immediately reduce food base response to the HFEs). In addition, it is important to plan for innovative treatments that offer promise for better performance.

Previous GCMRC proposals for long term experimental management (GCMRC 2006) have recommended a fixed treatment schedule over time, with interspersion and replication of policy tests in patterns that would minimize confounding of effects of different treatments applied at the same times while allowing for estimation of combined effects for a few key treatments when deliberately combined in a “factorial” experimental design. While such a fixed treatment schedule might be scientifically preferable, it ignores the authorized purposes of the dam and the limitations placed on research and the need in ongoing management for contingent or feedback application of treatments, including the unpredictable disruptive effect of stochastic events. Sediment researchers have resolved that HFEs should only be conducted when (contingent on, in feedback response to) tributary floods provide sand inputs worth trying to save (Rubin *et al.* 2002, Wright *et al.* 2008). Costly mechanical removal and other trout management measures should be carried out only when potentially dangerous (for native fish) trout recruitments become evident; there is no point in applying such treatments when trout densities are already low.

In the theory of adaptive management, the term “dual effects of control” is used to describe the potential conflict between applying treatments in a scientifically most informative pattern (i.e. fixed schedule over time) versus need to respond immediately as conditions change even if that response makes it difficult or impossible to determine the marginal effect of each treatment. Formal optimization methods have been used to examine this information versus management performance trade-off problem for simple harvest management cases, and it has been found that the best strategy is likely to be a compromise that produces some clear treatment response data but not at the expense of incurring dangerous risks by ignoring data that imply need for immediate remedial treatments. In short, pressing need for feedback response typically trumps need for clear scientific response measurement. In the three scenarios developed for this alternative (Tables 2a-c) we examine treatment scenarios based on both block design approaches and condition-dependent decision trees. The objective is to develop a treatment design that is responsive to changing conditions while providing best possible scientific contrast and replication within the constraints imposed by the need for feedback response and resource results.

All scenarios shown in Tables 2a-c were developed by assuming that HFEs will be a leading cause of changes in sand storage and productivity of the rainbow trout population, and that change in the trout abundance will then be transmitted downstream into negative impacts on native fishes if mitigation measures (seasonal flow treatments, mechanical removal) are not employed. This assumption is certainly justifiable considering observed changes in rainbow trout recruitment following the 1996 and 2008 HFEs, and native fish responses following the mechanical removal experiment. The 2011 knowledge assessment workshop participants recognized the possibility of much larger negative effects of trout management flows (especially following HFEs) than were considered in the SDM workshop. The SDM participants did not have access to ecosystem modeling (Ecosim) results suggesting that trout management flows may have had very large negative effects on trout abundance and size (Walters *et al.* 2011).

Monitoring for Decision Criteria

The ongoing Juvenile Chub Monitoring (JCM; formerly the Nearshore Ecology project) and rainbow trout juvenile sampling (RTELSS) programs should be considered for inclusion as part of the core monitoring program. These programs provide critical early information about the immediate success or failure of several key management options, ranging from impact of flow management on rainbow trout recruitment to impact of trout on juvenile humpback chub survival in the Colorado River mainstem. Without these programs, we will be less able to tease apart the effects of multiple management actions taking place at the same times, since we will have only basic information about cumulative trends in resource response. Serious consideration should be given for expanding the JCM work to downstream locations in lieu of full implementation of traditional mainstem trout sampling.

In previous sections we outline the substantial learning that has taken place since the last EIS and the paradigm shifts that have happened. Most notably, we highlight that fluctuating flows seem to have no deleterious effect on the recovery of humpback chub. MLFF has sustained a robust population trajectory for humpback chub over the last decade, and therefore at a minimum, must not be impeding recovery. Thus, we propose that movement from the regime that has resulted in a recovering endangered species should be done in a measured and extremely careful manner which is based on discrete experiments with clear “off-ramps” that allow ending the experiments early if conditions deteriorate for humpback chub or other key resources.

Decision trees have been developed for sediment and trout management and are attached as Figures 1 and 2. These describe the beginnings of a rationale for the conditions necessary to undertake experiments and when to stop them. Replication will be an important component of any experiment. Just because we observe an effect one time, does not mean we can adequately predict that in the future. We must have a focused scientific approach that is centered on testing and collecting information that is important in answering critical management questions. We also believe that it is important to test and evaluate a few things well rather than attempt to simultaneously or continuously implement tests with a high risk for confounding effects.

Based on past magnitudes of apparent fish recruitment responses to treatments like non-native fish removal and HFEs, we believe that the current monitoring effort will be adequate to detect effects of the magnitudes that are likely to occur under the proposed alternative. We can expect treatment effects of order doubling or halving from historical average abundances to be detectable, not small effects like 20% increases or decreases. Such small effects would not likely be measurable even with substantial increases in fish monitoring effort. We certainly will see large enough changes in fish recruitments to be clearly detectable; the issue will not be detection of change, but rather whether it will be possible to explain the changes in view of possible confounding (multiple possible causes) effects of uncontrolled variation (Walters *et al.* 2011).

Discussion of Other Resources

This alternative identifies four key resources, including humpback chub, sediment, recreational trout fishery, and aquatic food base. We recognize the need to discuss other resources and how this alternative and the monitoring program will consider them further. The following list of resources is taken from the HFE Protocol EA (Reclamation 2011a). This alternative description did not perform a NEPA-level analysis of impacts on canyon resources, given that this alternative will be evaluated as part of the formal LTEMP EIS process.

Physical Resources

- Water and Dam Releases—water and dam releases are an integral part of this alternative.
- Water Quality—this alternative was not designed to specifically test or evaluate aspects of water quality, although it is acknowledged that some elements of the alternative may affect water quality, such as withdrawals from Lake Powell.
- Sediment—sediment is an integral part of this alternative.

Biological Resources

- Vegetation—this alternative was not designed to specifically test or evaluate aspects of vegetation, although it is likely to be affected, especially in riparian areas, by elements of this alternative, such as HFEs; this alternative included a non-flow experiment of riparian vegetation control to make camping beaches more available.
- Terrestrial Invertebrates and Herptofauna—this alternative was not designed to specifically test or evaluate aspects of terrestrial invertebrates and herptofauna, although certain flows like HFEs may affect these organisms.
- Aquatic Food Base—the aquatic food base is an integral part of this alternative.
- Other Native Fish (flannelmouth sucker, bluehead sucker, speckled dace, razorback sucker)—although these native fish species are not specifically identified for evaluation, tests designed to benefit humpback chub (e.g., trout management flows that reduce trout abundance) may also benefit other native fish species and these can be evaluated through the same monitoring programs that evaluate responses by humpback chub (e.g., NSE).
- Warmwater Nonnative Fish—warmwater nonnative fish are monitored annually with core monitoring programs that are used to monitor humpback chub and other native fishes. This alternative supports continued research of this threat and implementation of control measures as needed with concomitant monitoring of the native fishes, especially humpback chub.
- Southwestern Willow Flycatcher—this alternative was not designed to specifically test or evaluate aspects of the willow flycatcher, but core monitoring will continue to follow the status and trend of this species.
- Other Birds (peregrine falcon, bald eagle, California condor)—this alternative was not designed to specifically test or evaluate aspects of other bird species, but core monitoring will continue to follow the status and trend of these species.

- Mammals—this alternative was not designed to specifically test or evaluate aspects of mammal populations, although certain flows like HFEs may affect small mammals in riparian communities. Core monitoring may help address some but not all of these issues.

Cultural Resources

- Historic Properties—dam releases, particularly HFEs have potential to protect historic properties by reinforcing sand beaches that help to offset effects of erosion around these properties.
- Sacred Sites—The area of the LCR is a sacred area for Native Americans. This alternative proposes to more fully evaluate the relationship of trout abundance and juvenile humpback chub survival that will better inform any decision to mechanically remove trout from the vicinity of the LCR.

Socio-Economic Resources

- Hydropower—hydropower is an important consideration of this alternative.
- Recreation (angling, boating)—Continued dam operation similar to MLFF will provide continued certainty to anglers and boaters (rafters) needing to have reliable access to certain areas of the canyon.

LITERATURE CITED

Alvarez, L.V. and M.W. Schmeeckle. 2012. Erosion of river sandbars by diurnal stage fluctuations in the Colorado River in the Marble and Grand Canyons: Full-Scale laboratory experiments. River Research and Applications, DOI: 10.1002/rra.2576, 16 pp.

Budhu, M and R. Gobin. 1994. Instability of sandbars in Grand Canyon. ASCE J Hydr Engineering, Vol 120, No 8, pp 919-933.

GCMRC. 2006. Assessment of the estimated effects of four experimental options on resources below Glen Canyon Dam. Draft Report. U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center.

GCMRC. 2012. FY 2013-14 draft budget and workplan (TWG) June 2012.

Gloss, S.P., J.E. Lovich, and T.S. Melis, eds. 2005. The state of the Colorado River ecosystem in Grand Canyon: U.S. Geological Survey Circular 1282, 220 p. (Also available at http://pubs.usgs.gov/circ/1282/.).

Haynes, L., O. Service, B. Goldacre, D. Torgerson. 2012. Test, learn, adapt: developing public policy with randomised controlled trials. Cabinet Office. Behavioral Insights Team. Available: http://www.cabinetoffice.gov.uk/sites/default/files/resources/TLA-1906126.pdf

Kimbrel, S. 2012. Determining large flood events on the Paria River for a rapid response alternative High Flow Experiment. U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center Denver, Colorado. Technical Report No. SRH-2012-08. 25 pgs.

Korman, J., and S.E. Campana. 2009. Effects of hydropeaking on nearshore habitat use and growth of age-0 rainbow trout in a large regulated river: Transactions of the American Fisheries Society, v. 138, no. 1.

Korman, J., M. Kaplinski, and T.S. Melis. 2010. Effects of high-flow experiments from Glen Canyon Dam on abundance, growth, and survival rates of early life stages of rainbow trout in the Lees Ferry reach of the Colorado River: U.S. Geological Survey Open- File Report 2010–1034. 31 p.

Korman, J., M. Kaplinski, and T.S. Melis. 2011. Effects of fluctuating flows and a controlled flood on incubation success and early survival rates and growth of age-0 rainbow trout in a large regulated river. Transactions of the American Fisheries Society 140:487-505.

Korman, J., and Melis, T.S., 2011, The effects of Glen Canyon Dam operations on early life stages of rainbow trout in the Colorado River: U.S. Geological Survey Fact Sheet 2011-3002, 4 p.

Korman, J., S.J.D. Martell, C.J. Walters, A.S. Makinster, L.G. Coggins, M.D. Yard, and W.R. Persons. In Review. Estimating recruitment dynamics and movement of rainbow trout in the Colorado River in Grand Canyon using an integrated assessment model. Submitted to Can. J. Fish. Aquat. Sci.

Lucchitta I., and L.B. Leopold. 1999. Floods and sandbars in the Grand Canyon. GSA Today, Vol. 9, No. 4, pgs 1-7.

Makinster, A.S., L.A. Avery, and W.R. Persons. 2010. Status of the Lees ferry rainbow trout fishery: U.S. Geological Survey Open File Report 2010-1195.

Melis, T.S., ed., 2011, Effects of three high-flow experiments on the Colorado River ecosystem downstream from Glen Canyon Dam, Arizona: U.S. Geological Survey Circular 1366, 147 p.

Ralston, B.E. 2011. Summary report of responses of key resources to the 2000 Low Steady Summer Flow Experiment, along the Colorado River downstream from Glen Canyon Dam, Arizona. USGS Open-File Report 2011–1220.

Reclamation. 2007. Environmental Impact Statement—Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. Bureau of Reclamation, Upper and Lower Colorado Region, October

Reclamation. 2011a. Environmental Assessment—Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020. Bureau of Reclamation, Upper Colorado Region, December 30.

Reclamation. 2011b. Environmental Assessment—Non-Native Fish Control Downstream from Glen Canyon Dam. Bureau of Reclamation, Upper Colorado Region, December 30.

Robinson, C.T., and U. Uehlinger. 2008. Experimental floods cause ecosystem regime shift in a regulated river. Ecological Applications, 18(2), 2008, pp. 511–526.

Rosi-Marshall, E.J., T.A. Kennedy, D.W. Kincaid, W.F. Cross, H.A.W. Kelly, K.A. Behn, T. White, R.O. Hall, and C.V. Baxter. 2010. Short-term effects of the 2008 high-flow experiment on macroinvertebrates in Colorado River below Glen Canyon Dam, Arizona: U.S. Geological Survey Open-File Report 2010–1031, 28 p. (Also available at http://pubs.usgs.gov/of/2010/1031/.)

Rubin, DM, D.J. Topping, J.C. Schmidt, J. Hazel, M. Kaplinski, and T.S. Melis. 2002. Recent sediment studies refute Glen Canyon Dam hypothesis: EOS, June, 2002.

Runge, M. C., E. Bean, D.R. Smith, and K. Sonja. 2011. Non-native fish control below Glen Canyon Dam—Report from a structured decision-making project. U.S. Geological Survey Open-File Report 2011–1012.

Schmidt, J.C., R.H. Webb, R.A. Valdez, G.R. Marzolf, and L.E. Stevens. 1998. Science and values in river restoration in the Grand Canyon. BioScience 48(9): 735-747.

Schmidt, J.C., D.J. Topping, D.M. Rubin, J.E. Hazel, Jr., M. Kaplinski, S.M. Wiele, and S.A. Goeking. 2007. Streamflow and sediment data collected to determine the effects of low summer steady flows and habitat maintenance flows in 2000 on the Colorado River between Lees Ferry and Bright Angel Creek, Arizona: U.S. Geological Survey Open-File Report 2007–1268, 79 p.

Trammell, M., R.A. Valdez, S.W. Carothers, and R. Ryel. 2002. Effects of a low steady summer flow experiment on native fishes of the Colorado River in Grand Canyon—final report: Flagstaff, Ariz., SWCA, Inc. Environmental Consultants, submitted to U.S. Geological Survey, Grand Canyon Monitoring and Research Center, cooperative agreement no. 99–FC–40–2260, 77 p. [Available upon request by contacting the Center Director, U.S. Geological Survey, Southwest Biological Science Center, 2255 N. Gemini Drive, Flagstaff, Ariz. 86001.]

U.S. Department of the Interior. 1996. Record of Decision. Operation of Glen Canyon Dam—Final Environmental Impact Statement, Colorado River Storage Project, Coconino County, Arizona: Salt Lake City, Utah, Bureau of Reclamation, Upper Colorado Regional Office, 337 p., accessed November 18, 2010, at http://www.usbr.gov/uc/library/envdocs/eis/gc/pdfs/Cov-con/cov-con.pdf.

U.S. Department of the Interior (Interior). 2007. Record of Decision, Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead. December.

U.S. Fish and Wildlife Service. 2002. Humpback chub (*Gila cypha*) Recovery Goals: amendment and supplement to the Colorado Squawfish Recovery Plan. U.S. Fish and Wildlife Service, Mountain-Prairie Region (6), Denver, Colorado.

Valdez, R.A., S.W. Carothers, M.E. Douglas, M. Douglas, R.J. Ryel, K.R. Bestgen, and D.L. Wegner. 2000. Research and implementation plan for establishing a second population of humpback chub in Grand Canyon. Report to the Grand Canyon Monitoring and Research Center. U.S. Department of the Interior. Flagstaff, Arizona 86001.

Walters, C.J., J. Korman, and T.S. Melis. 2011. Ten-year plans for experimental policy tests in the Glen Canyon Dam Adaptive Management Program—overview of issues and options with results from a GCMRC knowledge assessment II expert workshop, June 1-3, 2011. Draft report.

Wright, S.A., J.C. Schmidt, D.J. Topping. 2008b. Is there enough sand? Evaluating the fate of Grand Canyon sandbars. GSA Today 18(8):4-10.

Yard, M.D., L.G. Coggins Jr., C.V. Baxter, G.E. Bennett, and J. Korman. 2011. Trout piscivory in the Colorado River, Grand Canyon: effects of turbidity, temperature, and fish prey availability. Transactions of the American Fisheries Society, 140:2, 471 – 486.

FIGURES

Figure 1. Decision Tree for fall HFEs including rapid-response testing. Under the proposed block design, 3 store and release HFEs would be implemented and the 4th would be a rapid response test. This block design would continue over the 20 years of the LTEMP. Decisions about intervening base flows, the ability to implement sediment retention flows, and targeted monthly volumes for sediment conservation would all be predicated on the ability to meet release requirements under the Interim Guidelines (Reclamation 2007).

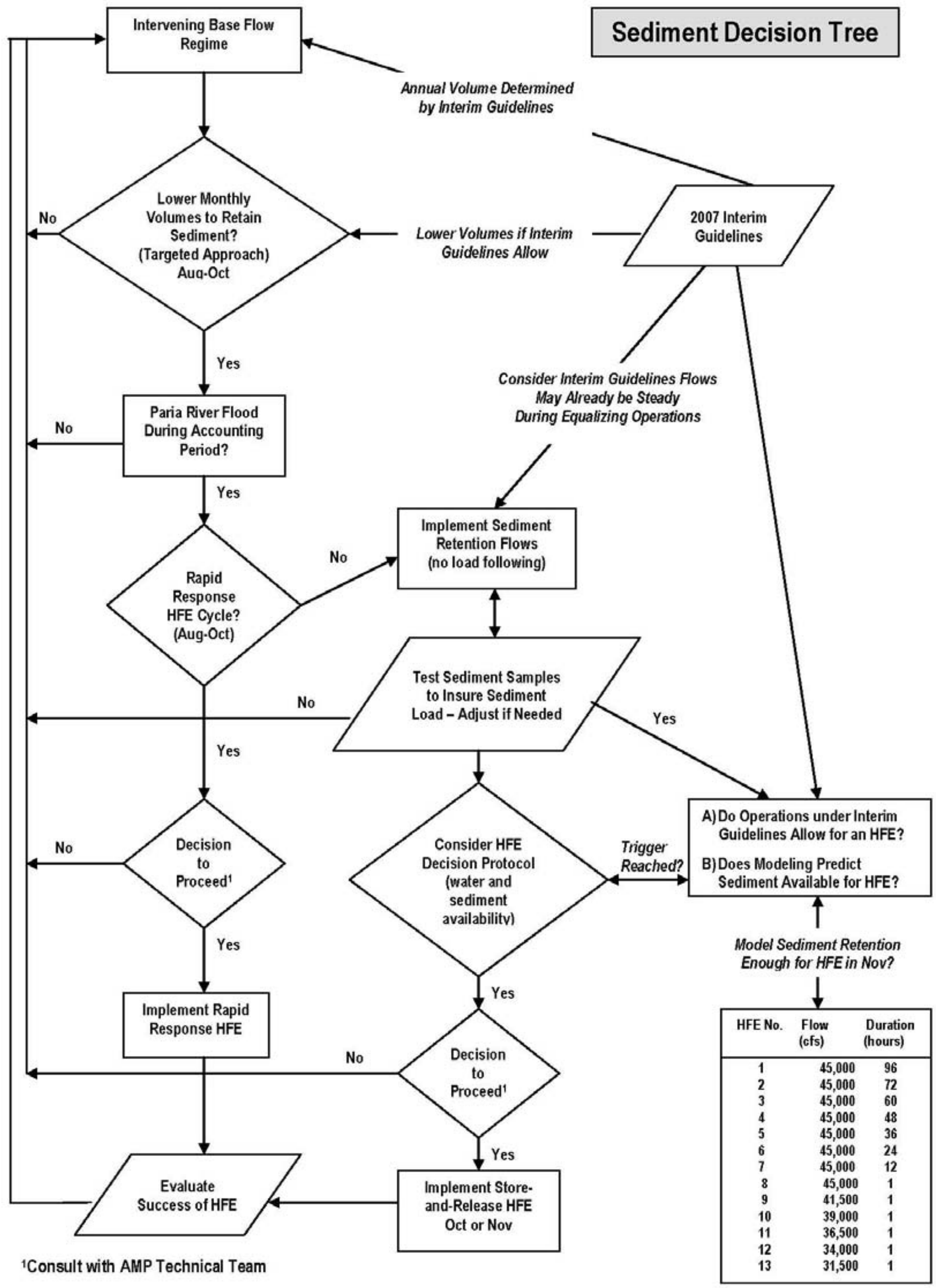
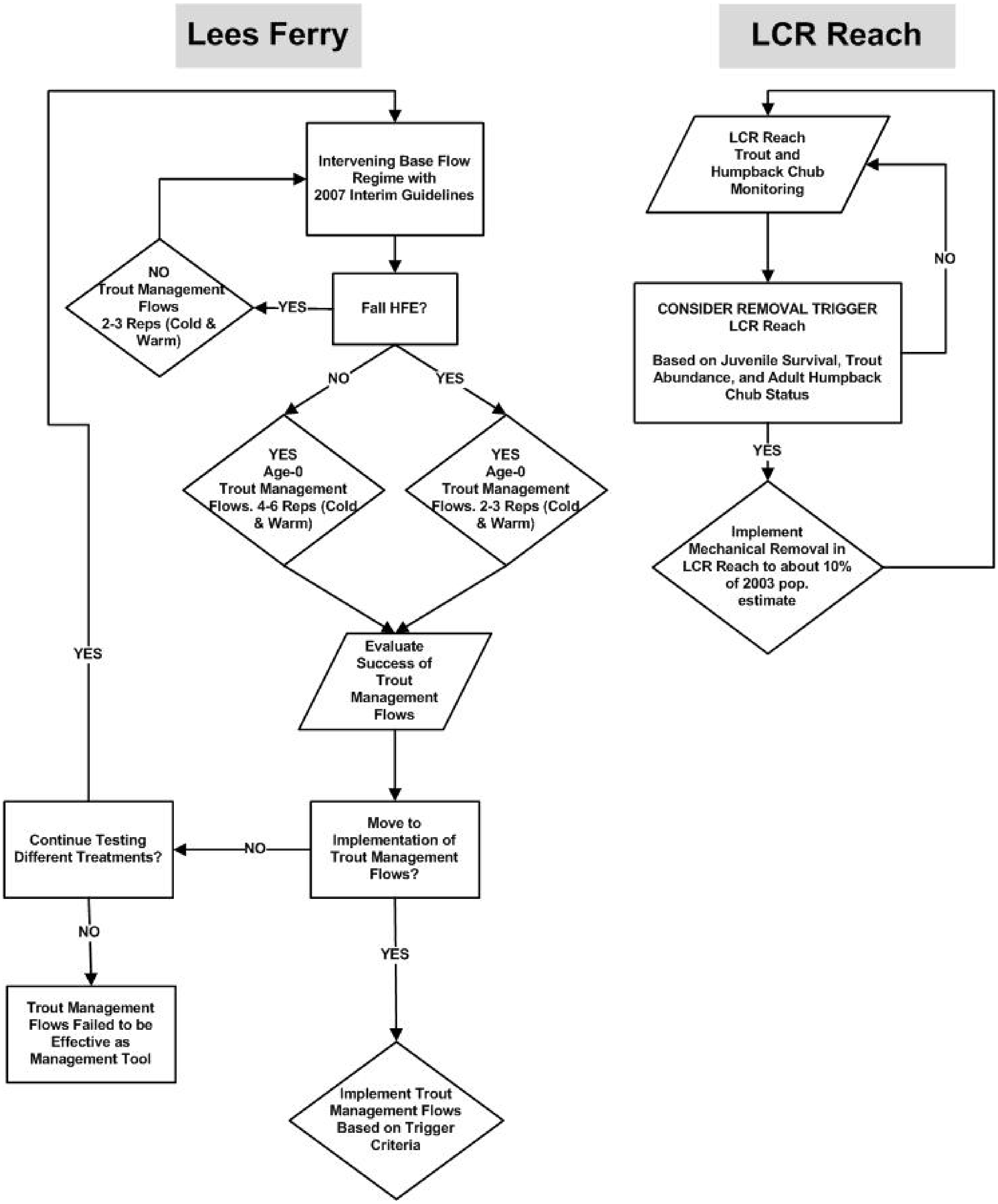


Figure 2. Decision tree for trout management flow treatments. The LCR reach trout removal trigger would continue throughout the entire period.



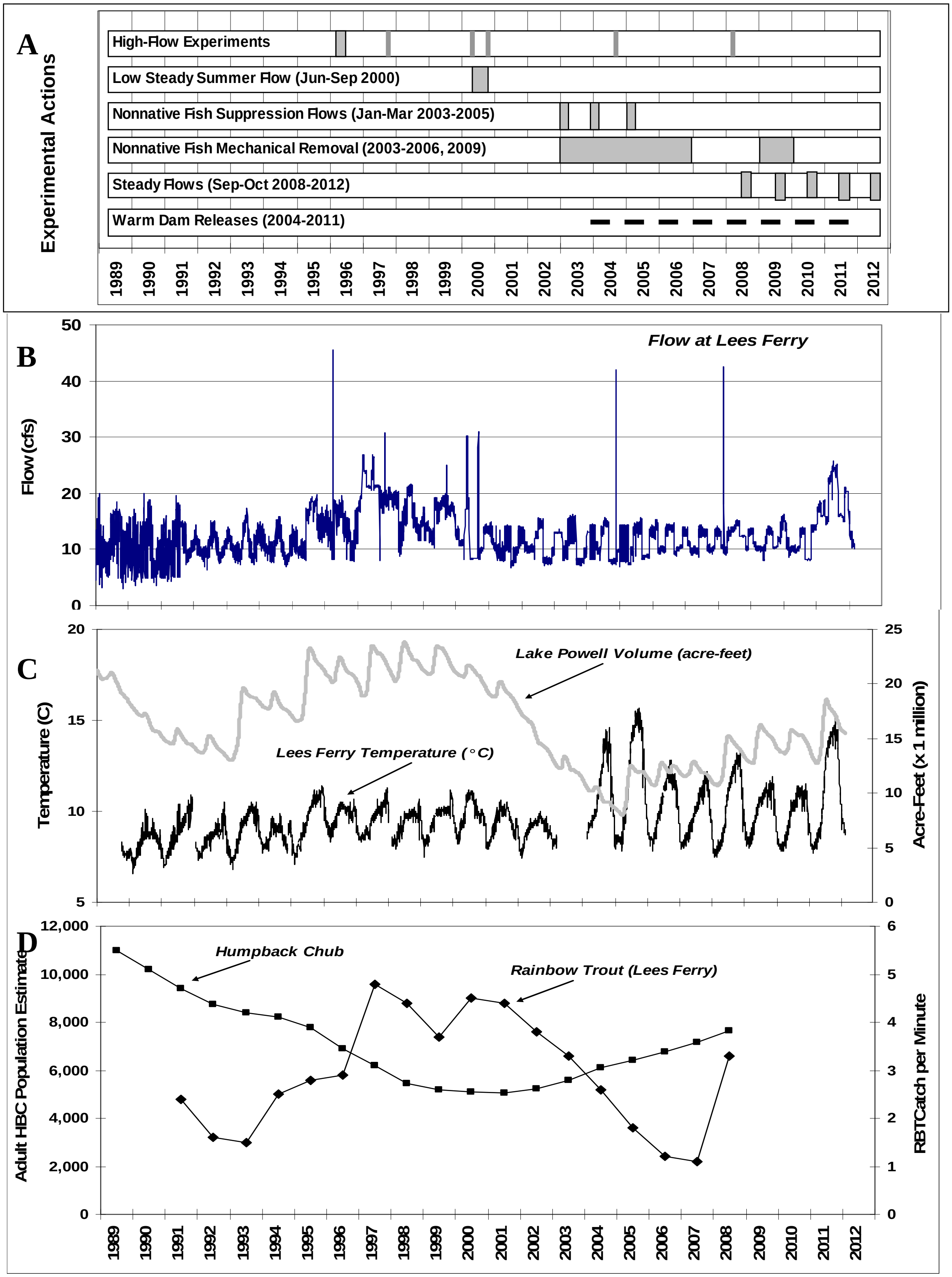


Figure 3. (A) Experimental actions for 1989 – 2012, (B) flow of the Colorado River at Lees Ferry in thousand cfs (kcfs), (C) volume of Lake Powell and water temperature at Lees Ferry, and (D) abundances of humpback chub and rainbow trout.

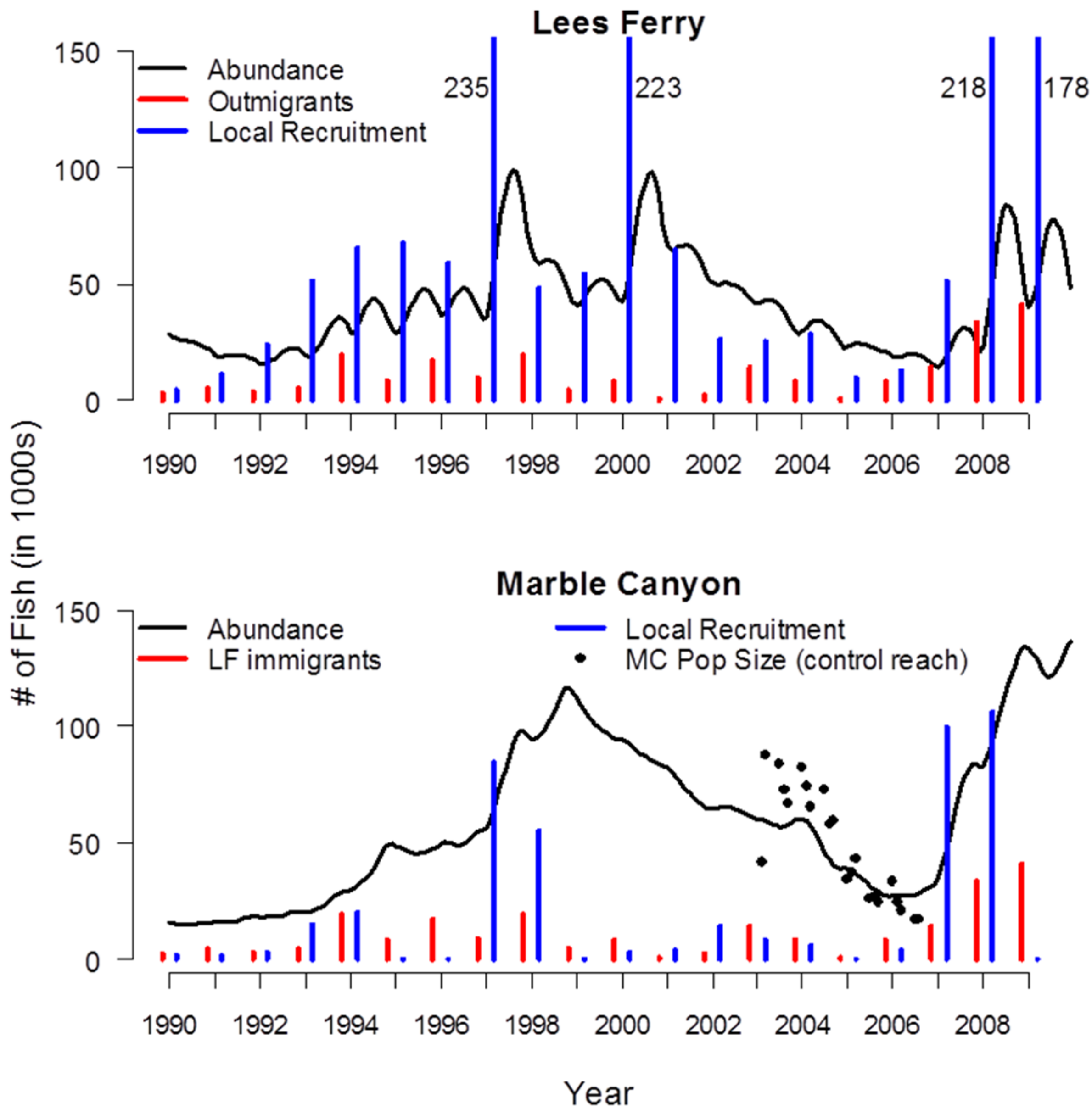


Figure 4. Rainbow trout recruitment in Lees Ferry and Marble Canyon as back calculated, modeling results (Korman unpublished figure based on data from Korman *et al.* In Review).

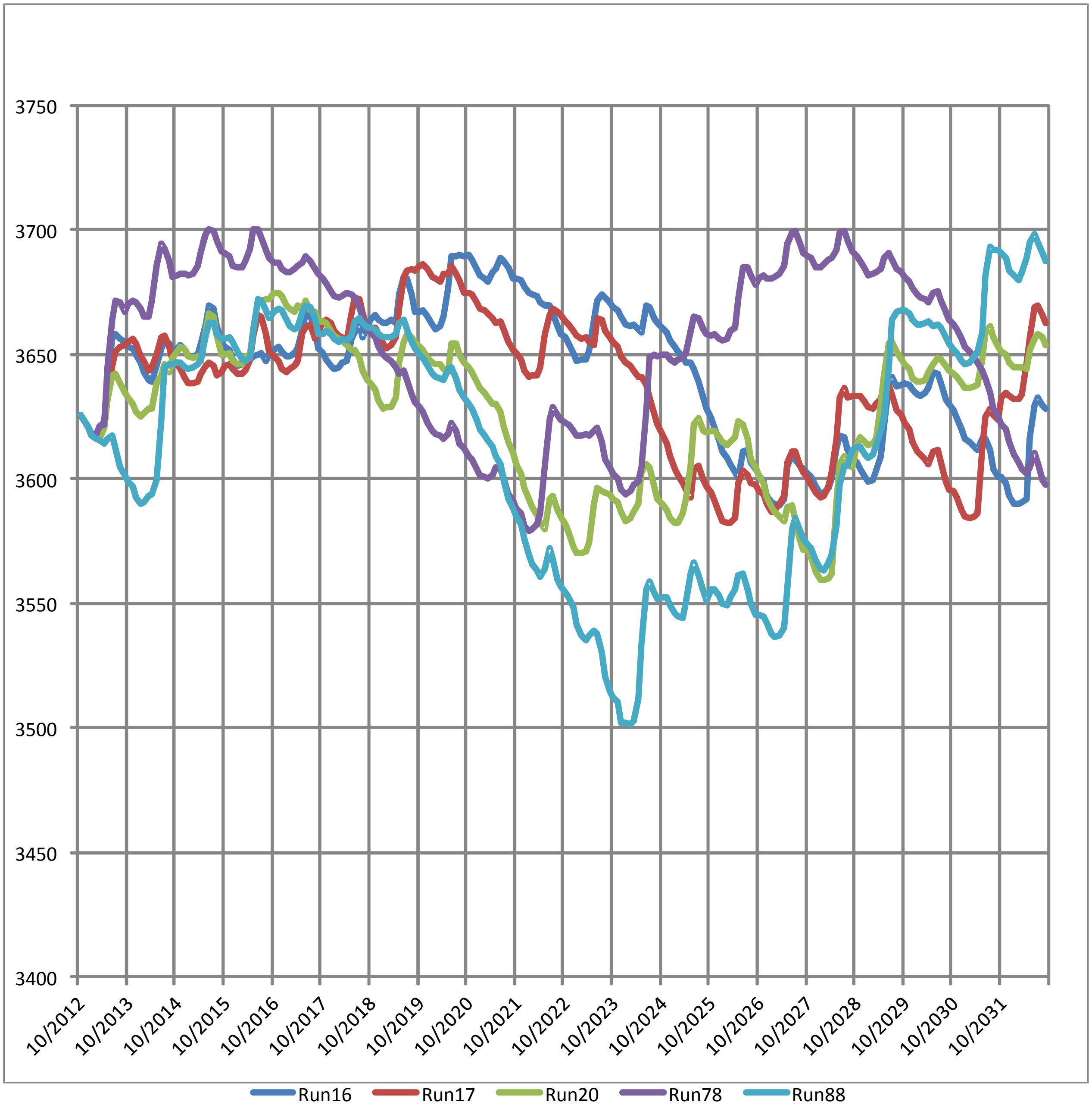


Figure 5a. Five CRSS traces for projected Lake Powell elevations for the next 20 years chosen to be representative of the median condition (Melis unpublished data based on CRSS runs by Reclamation, April 2012; Lake Powell surface elevation in feet on y-axis and date on x-axis). Glen Canyon Dam outflows warm substantially when reservoir elevations drop below about 3625' for at least two months. These traces were used in Tables 2a-c as an example of a potential temperature scenario.

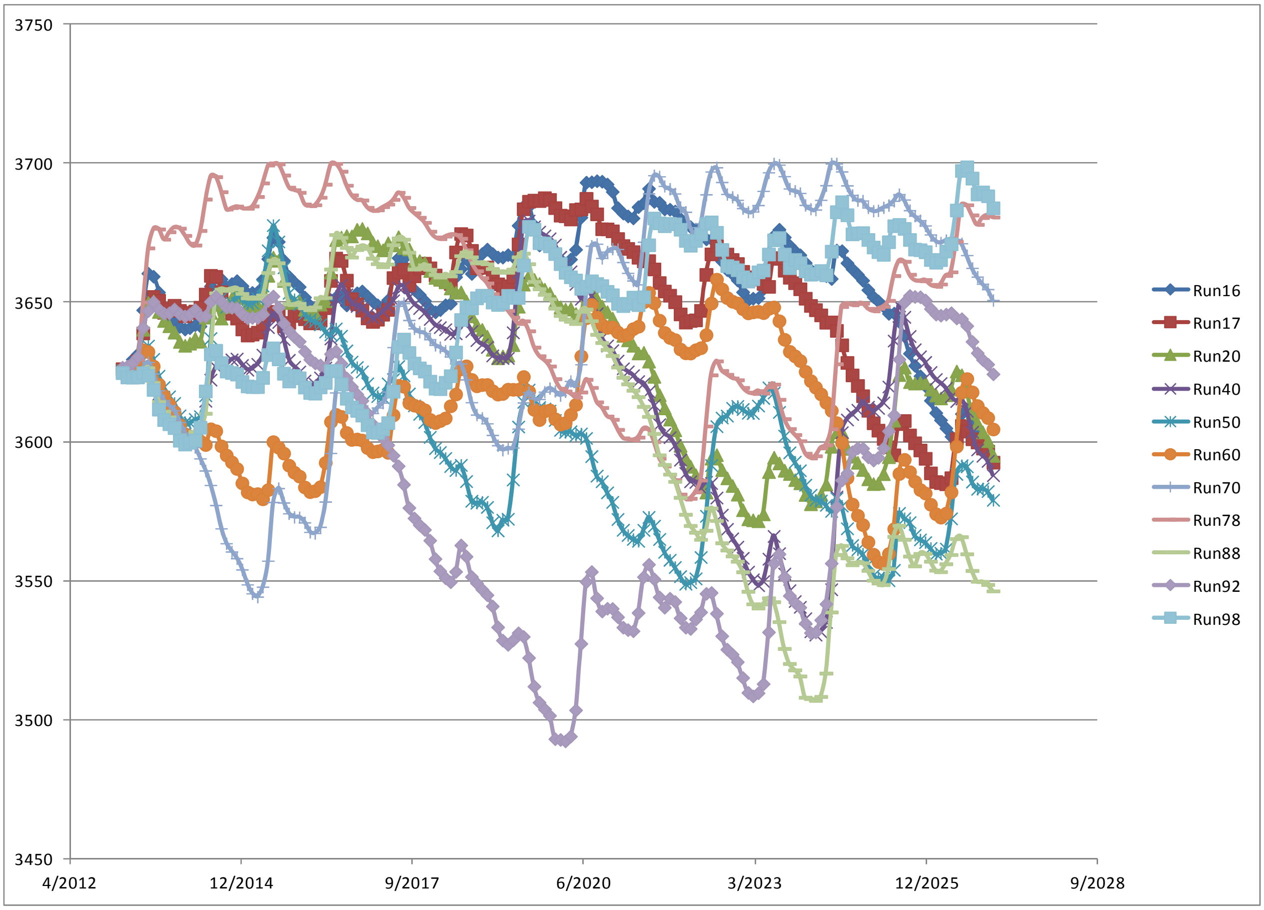


Figure 5b. Eleven CRSS traces for Lake Powell elevations for the next 20 years which reflect the greater level of variability over this time period and the potential for lower lake levels in the near future (Reclamation CRSS results April 2012, unpublished data; Lake Powell surface elevation in feet on y-axis and date on x-axis). It demonstrates the likelihood of having numerous warm and cold release conditions over the next 20 years based on correlations between lake elevations and warming (unpublished data).

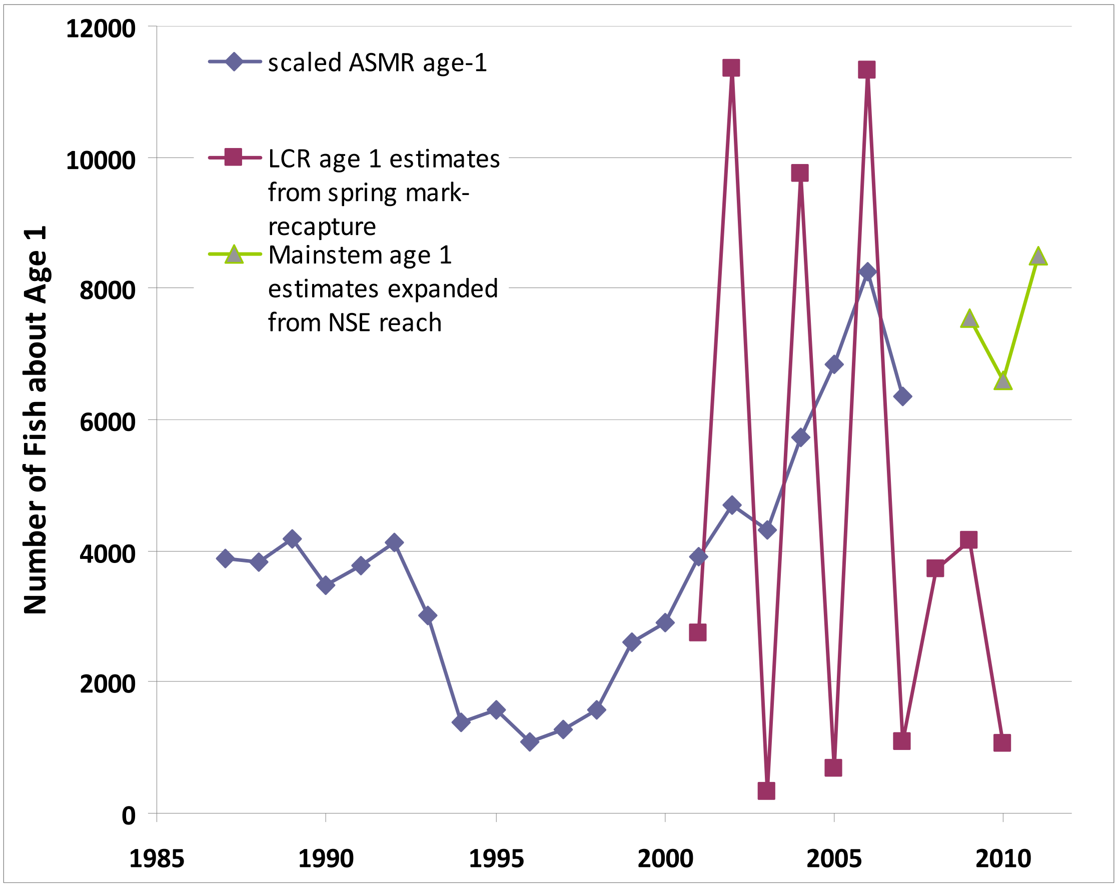


Figure 6. Numbers of humpback chub around age 1, estimated for the whole LCR population using ASMR, and separately for the two main rearing area components: LCR rearing numbers from mark-recapture, and mainstem numbers from NSE sampling. Strong measured fluctuations in age-1 abundance in the LCR are not reflected in fluctuations in abundance of age-2 and older fish, indicating probable strong density-dependent mortality of the strong age 1-year-classes and hence severe limits on LCR rearing. Note that the two area components add to greater than the ASMR total; this is likely due to double counting of fish that rear and were observed in both habitats. Note also that strong measured fluctuations in age 1 abundance in the LCR are not reflected in fluctuations in abundance of age 2 and older fish, indicating probable strong density dependent mortality of the strong age 1 year-classes and hence severe limits on LCR rearing (unpublished data from B. Pine and C. Walters, June 26, 2012).

TABLES

Table 1. Glen Canyon Dam base actions, experiments, and natural variables considered in the proposed action for experimental design. Note: the columns on this table are independent and there is no relationship among columns within a given row.

Intervening Base Flow Regime	Primary Experiments	Secondary Experiments	High Uncertainty/Risk	Natural Variables (stochastic factors)
Downramp rates (2,500 cfs)	Store and release fall HFE (3 in a row)	Removal of brown trout from Bright Angel Creek	Low summer warming flow if no natural warming occurs	Paria River sediment inputs
Targeted monthly volumes for sediment (Aug-Oct)	Rapid response fall HFE (every 4th fall HFE; multiple tests could occur in a year)	Translocate humpback chub to Bright Angel, Havasu, Chute, and Shinumo		Warm or cold dam releases (Lake Powell elevation)
Condition-dependent sediment retention flows (Aug-Oct)	Store and release spring HFE (after trout management developed)	Riparian vegetation control		Large annual volume (> 8.23 maf)
				Minimum release volume (8.23 maf)
				Less than minimum volume (e.g.,, 7.0 maf)
Maximum daily change as a percentage of monthly volume	Trout management flows (2x2 factorial design)	Control of warmwater nonnative fish		“High” trout abundance in the LCR reach (e.g., greater than 6,900 adults)
				“Low” trout abundance in the LCR reach (e.g., much less than 6,900 adults)
	Lees Ferry fall trout mechanical removal	Humpback chub refuge population		Aquatic invasions (e.g., invertebrates, fish, etc)
	LCR mechanical trout removal (condition-dependent)	Aquatic food base monitoring and research (including evaluating transitional flows between months)		

Experiment Descriptions:

Primary: Core experiments with high management importance, use factorial science design.

Secondary: Experimental actions intended to increase knowledge or management activities that are unlikely to confound primary results.

High Uncertainty/Risk: Experiments with high risk of confounding primary experiments, risk to key resources, or uncertainty with implementation.

Key Natural Variables: Stochastic parameters which will influence the performance of the draft alternative and must be modeled to determine performance. It is likely that some of these factors will be more probable over the next 20 years then they were over the last 20 years (e.g., minimum release volume 8.23 maf, warm dam releases).

Table 2a. Scenario 1. A series of three scenarios showing the combination of block-design approaches which would be implemented. Based on the likelihood of a fall HFE (probability of .61 in any one year), and the potential for spring store and release HFEs (probability of .47 in any one year). Store and release fall HFEs are separated in blocks with rapid response HFE testing (3 store and release and then 1 rapid response). Sediment retention flows are implemented any year a fall store-and-release HFE is triggered. Warm and cold periods are provided as a possible scenario based on CRSS predictions over the next 20 years, represents a possible scenario. A "0/1" denotes a resource-dependent action triggered by condition, so it could be either off (0) or on (1).

Random Number Fall HFE	Probability met Fall HFE? (0.61)	Year	Temps Warm-1 Cold-0	Store and Release Fall HFE (.61)	Sediment Retention Flows	Rapid-Response Fall HFE (.61)	Trout Management Flows	LCR Mechanical Trout Removal	Extirpation of trout from BA	Translocate HBC	Riparian Vegetation Control	Control Nonnative Fish	Store-and-Release Spring HFE (0.47)	Random Number Spring HFE
0.768	0	1	1	0	0	0	0	0/1	1	0/1	0/1	0/1	--	--
0.645	0	2	1	0	0	0	1	0/1	1	0/1	0/1	0/1	--	--
0.431	1	3	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.604	1	4	0	1	1	0	3	0/1	1	0/1	0/1	0/1	--	--
0.967	0	5	0	0	0	0	0	0/1	1	0/1	0/1	0/1	--	--
0.176	1	6	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.657	0	7	0	0	0	0	1	0/1	0/1	0/1	0/1	0/1	--	--
0.529	1	8	0	0	0	1	3	0/1	0/1	0/1	0/1	0/1	--	--
0.308	1	9	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	--	--
0.252	1	10	1	1	1	0	3	0/1	0/1	0/1	0/1	0/1	--	--
0.037	1	11	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.663
0.675	0	12	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	0	0.892
0.697	0	13	1	0	0	0	1	0/1	0/1	0/1	0/1	0/1	0	0.686
0.030	1	14	1	0	0	1	3	0/1	0/1	0/1	0/1	0/1	1	0.198
0.358	1	15	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.787
0.027	1	16	1	1	1	0	3	0/1	0/1	0/1	0/1	0/1	0	0.532
0.571	1	17	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	1	0.015
0.636	0	18	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	0	0.591
0.034	1	19	0	0	0	1	3	0/1	0/1	0/1	0/1	0/1	1	0.265
0.363	1	20	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.717
	*rapid response cycle								*0/1 denotes action triggered by condition-dependent criteria					

Table 2a. Scenario 1, continued, description of actions and their timing for all scenarios.

Components	Criteria
Temperatures	0 = Cold (Lake Powell elevation above 3625'), based on CRSS traces 1 = Warm (Lake Powell drops below 3625' for two months), based on CRSS traces
Store and Release Fall HFE	0 = Would not occur 1 = Would occur at probability of 0.61
Sediment Retention Flows	1 = Would occur in all years following Paria River flood except for rapid response years
Rapid-Response Fall HFE	0 = Not implemented 1 = Implemented after 3 store-and-release fall HFEs, based on probability of 0.61
Trout Management Flows	0 = No Fall HFE year, no trout management flows (2-3 replicates warm and cold) 1 = No Fall HFE year, yes trout management flows (2-3 replicates warm and cold, test flows alone, Phase I) 2 = Fall HFE year, no trout management flows (2-3 replicates warm and cold, test effects of fall HFEs alone, Phase I) 3 = Fall HFE, yes trout management flows (2-3 replicates warm and cold, test flows with HFEs, Phase I)
LCR Mechanical Trout Removal	0 = unlikely to trigger removals during the first 5 years of testing 1 = Implemented if triggered, after 5 years of testing of high trout densities in LCR reach to achieve target abundance
Extirpation of Trout From BA	1 = Implemented in all years until target trout abundance is reached, assume first 6 years are needed annually
Translocate HBC	0/1 = Implemented in all years as necessary to achieve translocation goal
Riparian Vegetation Control	0/1 = Implemented in all years as necessary and feasible to meet goals
Control Warmwater Nonnative Fish	0/1 = Implemented as necessary, based on core monitoring of fish populations, look every year
Store-and-Release Spring HFE	0 = Not implemented, envisioned not implemented for first 10 years then based on probability 1 = Implemented after Phase I of trout management flow development methods (year 11 starts Phase II) based on probability .47

Table 2b. Scenario 2.

Random Number Fall HFE	Probability met Fall HFE? (0.61)	Year	Temps Warm-1 Cold-0	Store and Release Fall HFE (.61)	Sediment Retention Flows	Rapid-Response Fall HFE (.61)	Trout Management Flows	LCR Mechanical Trout Removal	Extirpation of trout from BA	Translocate HBC	Riparian Vegetation Control	Control Nonnative Fish	Store-and-Release Spring HFE (0.47)	Random Number Spring HFE
0.961	0	1	1	0	0	0	0	0/1	1	0/1	0/1	0/1	--	--
0.778	0	2	1	0	0	0	1	0/1	1	0/1	0/1	0/1	--	--
0.571	1	3	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.207	1	4	0	1	1	0	3	0/1	1	0/1	0/1	0/1	--	--
0.564	1	5	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.187	1	6	0	0	0	1	3	0/1	1	0/1	0/1	0/1	--	--
0.455	1	7	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	--	--
0.761	0	8	0	0	0	0	0	0/1	0/1	0/1	0/1	0/1	--	--
0.274	1	9	0	1	1	0	3	0/1	0/1	0/1	0/1	0/1	--	--
0.985	0	10	1	0	0	0	1	0/1	0/1	0/1	0/1	0/1	--	--
0.763	0	11	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	1	0.177
0.260	1	12	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.823
0.639	0	13	1	0	0	0	1	0/1	0/1	0/1	0/1	0/1	0	0.959
0.052	1	14	1	0	0	1	3	0/1	0/1	0/1	0/1	0/1	1	0.371
0.393	1	15	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	1	0.253
0.234	1	16	1	1	1	0	3	0/1	0/1	0/1	0/1	0/1	1	0.274
0.384	1	17	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.988
0.866	0	18	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	0	0.619
0.428	1	19	0	0	0	1	3	0/1	0/1	0/1	0/1	0/1	1	0.062
0.340	1	20	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.902
	*rapid response cycle								*0/1 denotes action triggered by condition-dependent criteria					

Table 2c. Scenario 3.

Random Number Fall HFE	Probability met Fall HFE? (0.61)	Year	Temps Warm-1 Cold-0	Store and Release Fall HFE (.61)	Sediment Retention Flows	Rapid-Response Fall HFE (.61)	Trout Management Flows	LCR Mechanical Trout Removal	Extirpation of trout from BA	Translocate HBC	Riparian Vegetation Control	Control Nonnative Fish	Store-and-Release Spring HFE (0.47)	Random Number Spring HFE
0.022	1	1	1	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.511	1	2	1	1	1	0	3	0/1	1	0/1	0/1	0/1	--	--
0.548	1	3	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.176	1	4	0	0	0	1	3	0/1	1	0/1	0/1	0/1	--	--
0.245	1	5	0	1	1	0	2	0/1	1	0/1	0/1	0/1	--	--
0.544	1	6	0	1	1	0	3	0/1	1	0/1	0/1	0/1	--	--
0.722	0	7	0	0	0	0	0	0/1	0/1	0/1	0/1	0/1	--	--
0.663	0	8	0	0	0	0	1	0/1	0/1	0/1	0/1	0/1	--	--
0.388	1	9	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	--	--
0.809	0	10	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	--	--
0.361	1	11	1	0	0	1	3	0/1	0/1	0/1	0/1	0/1	1	0.210
0.921	0	12	1	0	0	0	1	0/1	0/1	0/1	0/1	0/1	0	0.731
0.262	1	13	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	1	0.222
0.515	1	14	1	1	1	0	3	0/1	0/1	0/1	0/1	0/1	1	0.438
0.934	0	15	1	0	0	0	0	0/1	0/1	0/1	0/1	0/1	0	0.617
0.398	1	16	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.777
0.159	1	17	1	0	0	1	3	0/1	0/1	0/1	0/1	0/1	0	0.910
0.087	1	18	1	1	1	0	2	0/1	0/1	0/1	0/1	0/1	0	0.690
0.477	1	19	0	1	1	0	3	0/1	0/1	0/1	0/1	0/1	0	0.696
0.041	1	20	0	1	1	0	2	0/1	0/1	0/1	0/1	0/1	1	0.443
	*rapid response cycle								*0/1 denotes action triggered by condition-dependent criteria					

APPENDIX A -- RESOURCE GOALS AND DFCs

The AMWG in March 2012 approved a series of Desired Future Conditions (DFCs) for the GCDAMP. The goals for this alternative are drawn from those DFCs, which are organized in four subject areas:

1. Colorado River Ecosystem,
2. Power,
3. Cultural Resources, and
4. Recreation

However, this alternative focuses our limited resources on the four key resource areas which are similar to the DOI priorities provided to the AMP by the Secretary's Designee (March 31, 2011 memorandum).

Humpback Chub Recovery

Recovery of the humpback chub population in Grand Canyon is a primary goal of the GCDAMP and consequently should be considered the primary target for the LTEMP. From the DFCs:

- Achieve humpback chub recovery in accord with the Endangered Species Act (ESA), the humpback chub comprehensive management plan, and with the assistance of collaborators within and external to the AMP.
- A self-sustaining humpback chub population in its natural range in the CRE.
- An ecologically appropriate habitat for humpback chub in the mainstem.
- Spawning habitat for humpback chub in the lower Little Colorado River (LCR).
- Establish additional spawning habitat and spawning aggregations within the CRE, where feasible.
- Adequate survival of young-of-year or juvenile humpback chub that enter the mainstem to maintain reproductive potential of the population and achieve population sizes consistent with the recovery goals.

Sediment for Beaches and Habitat

Sediment is necessary to build recreational beaches and may be important habitat for native fish as well as other needs described below. From the DFCs, high elevation open riparian sediment deposits along the Colorado River in sufficient volume, area, and distribution so as to provide habitat to sustain native biota and desired ecosystem processes, including:

- Nearshore habitats for native fish
- Marsh and riparian habitat for fish (food chain maintenance)
- Cultural resource preservation
- Maintenance of camping beaches, numerous, and distributed throughout the canyon.

Aquatic Food Base for Biological Goals

A healthy aquatic food base is a necessary component of a fully functioning ecosystem. Recent learning has highlighted the importance and complexity of the aquatic food base and the need to further understand the relationships between fish and food base:

- The aquatic food base will sustainably support viable populations of desired species at all trophic levels.
- Ensure that an adequate, diverse, productive aquatic food base exists for fish and other aquatic and terrestrial species that depend on those food resources.

Lees Ferry Rainbow Trout Fishery

It is highly desirable to develop and maintain a high quality rainbow trout fishery in Glen Canyon National Recreation Area (GCNRA) that does not adversely affect the native aquatic community in Grand Canyon National Park (GCNP):

- A high-quality sustainable recreational trout fishery in the river corridor in GCNRA, while minimizing emigration of non-native fishes.
- Operate Glen Canyon Dam to achieve the greatest benefit to the trout fishery in GCNRA without causing excessive detriment to other resources.
- Minimize emigration of non-native fish from the Lees Ferry reach in Glen Canyon National Recreation Area to downstream locations.
- Minimize emigration of non-native warm water fish to the mainstem Colorado River.

APPENDIX B – CONTRIBUTIONS BY SCIENTISTS

The development and evaluation of this alternative was done with the assistance of scientists with specific resource expertise and experience in the Grand Canyon. A panel of scientists was convened starting in late February 2012 and components of the alternative and the experimental design were developed through a series of meetings and conference calls among the scientists, the Basin States' Representatives, and a writing team. This alternative was written by a team with contributions from the scientists.

The following is a list of people primarily responsible for writing the document:

- Richard A. Valdez, Ph.D. (SWCA; Logan, UT)
- Shane Capron, M.S. (Western Area Power Administration (Western))
- Clayton Palmer, M.A. (Western)
- Craig Ellsworth, (Western)
- Jerry Wilhite, (Western)

The role of the scientists was to:

1. Consider how existing science should be considered in recommendations for Glen Canyon Dam operations over the next 10–15 years.
2. Consider how existing science informs possible non-flow management actions in the Grand Canyon.
3. Consider what important hypotheses require further experimentation, analysis or laboratory work, such that they would be incorporated into an action or experiment in the next 10–15 years.
4. Review existing draft of Desired Future Conditions in order to understand the stakeholder goals.

The following scientists were selected for the Science Panel because of their specific areas of expertise that aligned with the four key resource areas:

- Colden Baxter, Ph.D. (Idaho State Univ.; Pocatello, ID) – aquatic food base.
- Josh Korman, Ph.D. (Ecometrics; Vancouver, BC) – trout.
- Bill Pine, Ph.D., assisted by Colton Finch (Univ. of Florida; Gainesville, FL) – juvenile humpback chub.
- Robert A. Mussetter, Ph.D., PE (Tetra Tech; Ft. Collins, CO) – sediment.

- Richard A. Valdez, Ph.D., Science Panel Chair (SWCA; Logan, UT) – adult humpback chub.

The following Science Advisors were also asked to participate in a workshop with the Science Panel, the Basin States' Representatives, and the writing team to evaluate the alternative and particularly the experimental design:

- Carl Walters, Ph.D. (Univ. of British Columbia, Vancouver, BC).
- Duncan Patten, Ph.D. (Montana State Univ., Bozeman, MT).
- Richard Marzolf, Ph.D. (retired, U.S. Geological Survey, Reston, VA).

APPENDIX C – ILLUSTRATIVE HYDROGRAPHS

The following figures show elements of an illustrative hydrograph for a base year that includes: Targeted Monthly Volumes, Sediment Retention Flows and Trout Management Flows within the context of a Base Flow.

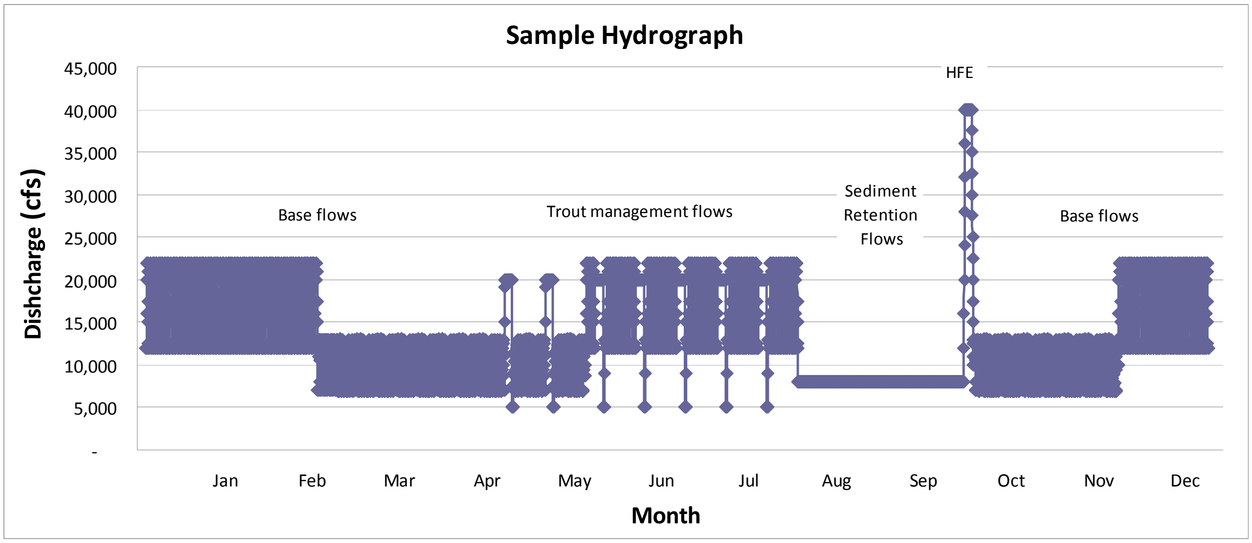


Figure C-1. Annual hydrograph illustrating a base flow that includes higher volume months, lower volume months, targeted monthly volumes (sediment conservation) in August through October, an HFE in November and Trout Management Flow experiments from May through July. This is an illustration of a year four of Table 2a. The remaining figures will illustrate the various components of this year.

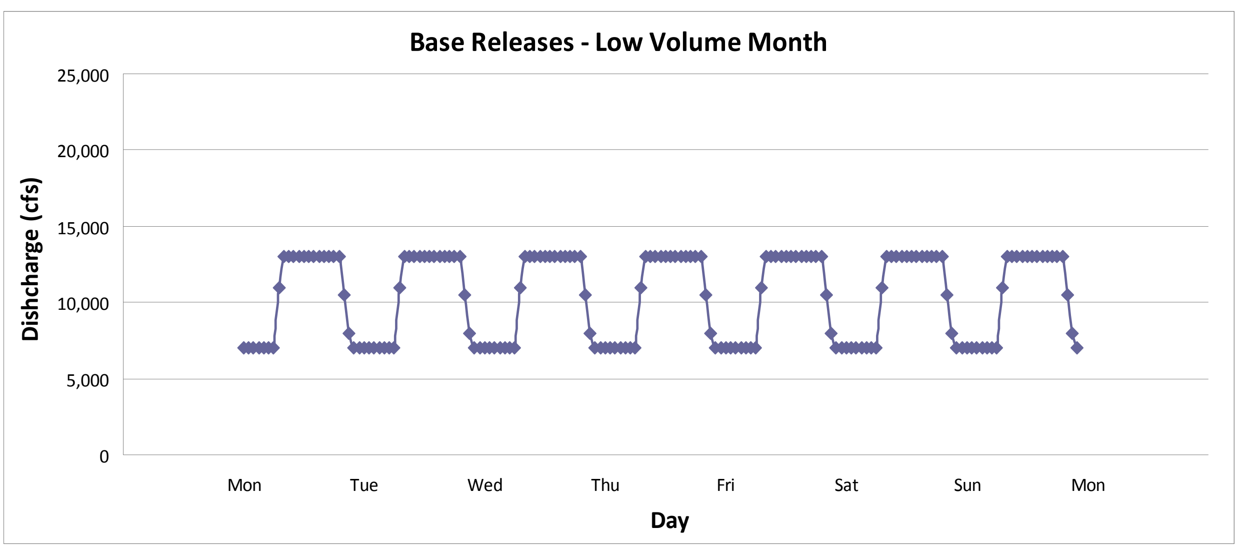


Figure C-2. Illustration of a week of the base flow in a low volume month. Low volume months are more likely to occur in the shoulder (power) months of October, November, March, April, May and September. Load following flows dominate with a daily pattern similar to MLFF.

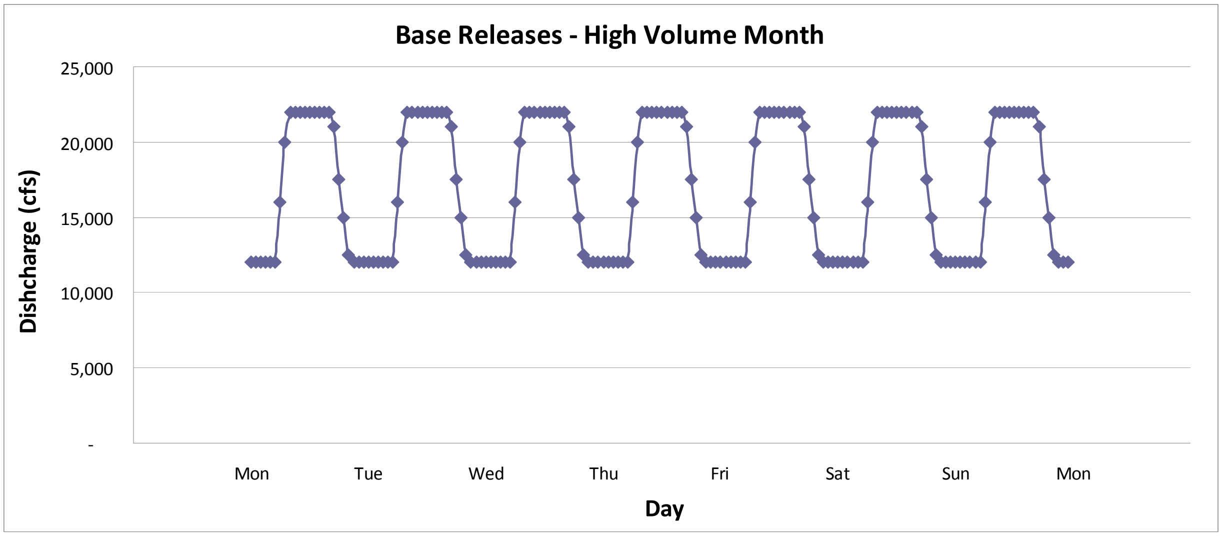


Figure C-3. Illustration of a week of a base flow in a higher volume month. These months are more likely in the peak power months of December, January, February, June, July and August. The daily pattern includes load following with a downramp rate of 2,500 cfs. The maximum daily change for load following is proportional to the monthly volume (in cfs).

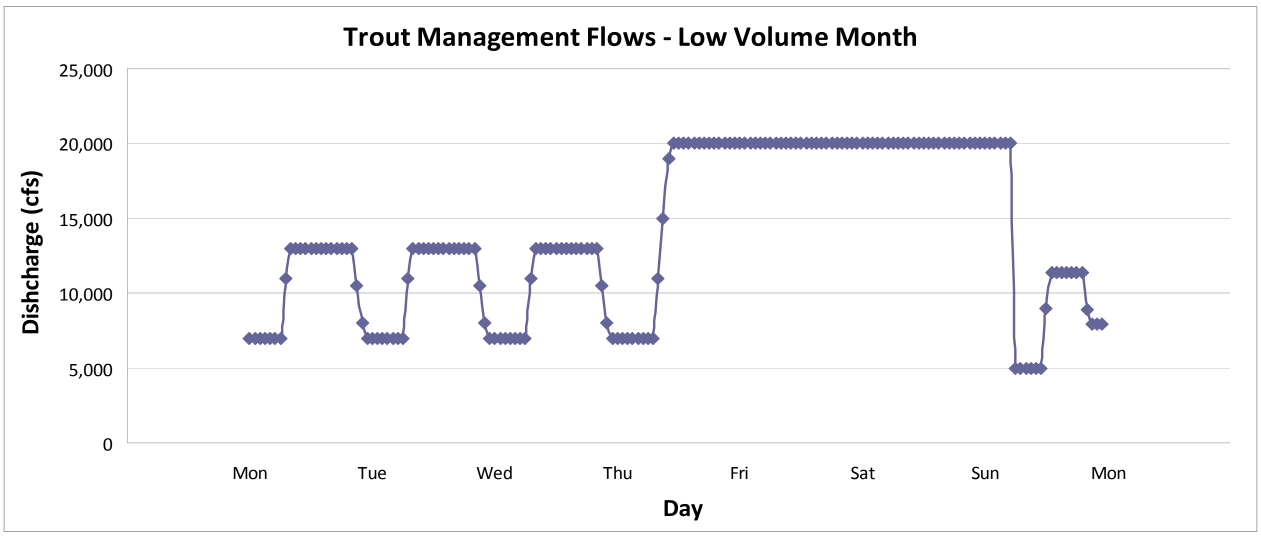


Figure C-4. Illustration of the concept a Trout Management Flow experiment. The one illustrated in this graph is a stranding flow experiment in a low volume month. The specifics of this experiment would need to be determined and tested. In this illustration, water release is brought up to 20,000 cfs for three days and then rapidly ramped down to 5,000 cfs. The intervening base flow regime is returned to between treatments.

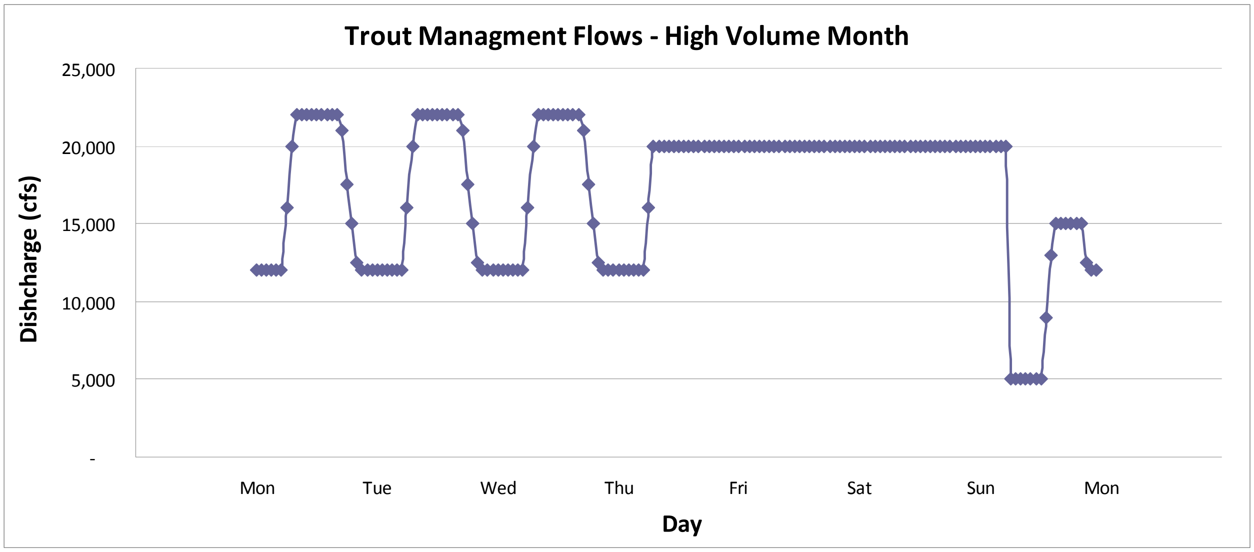


Figure C-5. Illustration of a Trout Management Flow experiment with a stranding flow in a high volume month. The stranding flow, as in a low volume months a 20,000 cfs constraint flow for three days, followed by a ramp down to 5,000 cfs.

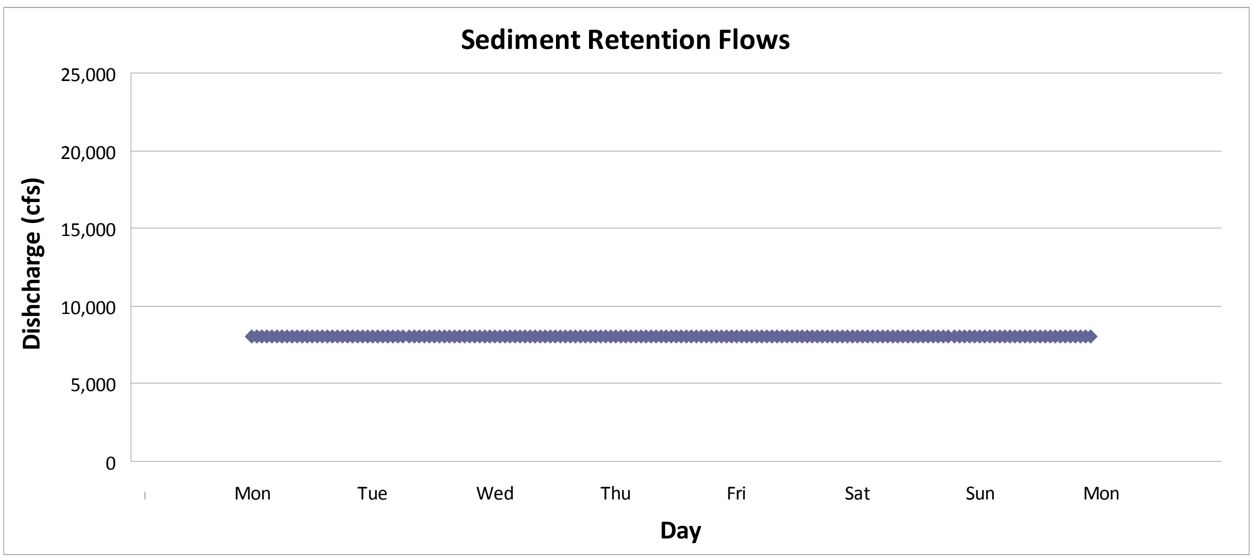


Figure C-6. Illustration of the "sediment retention flows" in a targeted monthly volume month. This would occur if there had been a significant, sediment-ladened flow at the Paria River. The actual steady release may not be at exactly this magnitude of release. The release also wouldn't be entirely without fluctuations due to operational changes, however load-following would be curtailed.

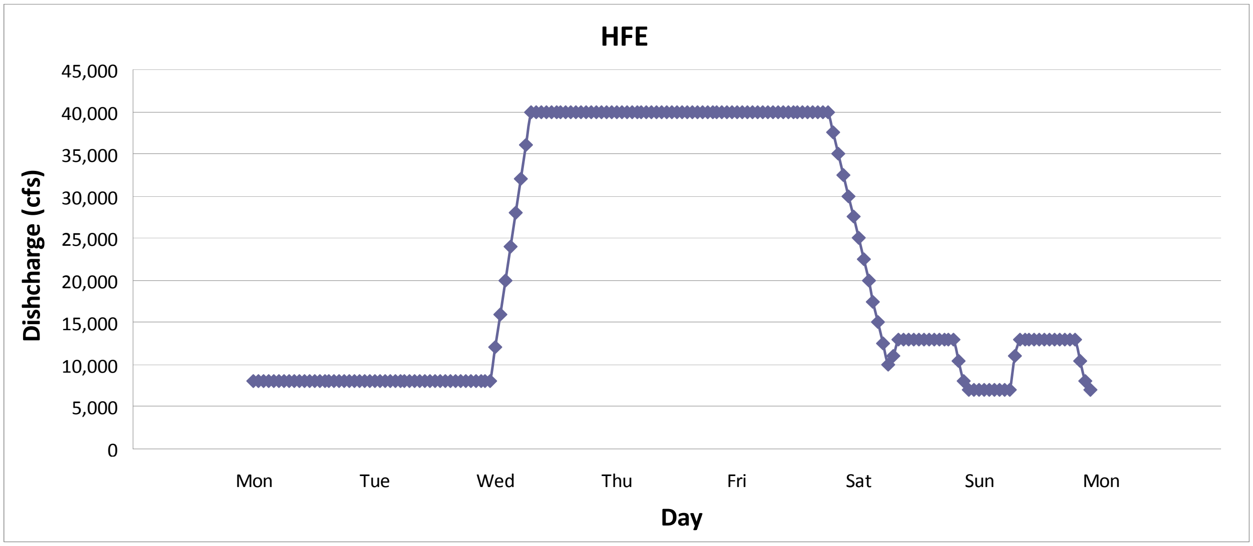


Figure C-7. A graphical illustration of an HFE. This particular HFE is 96 hours long during its peak. Operations preceding the HFE are depicted as sediment conservation flows and normal operations for a low volume month (October) begin at the conclusion of the HFE.

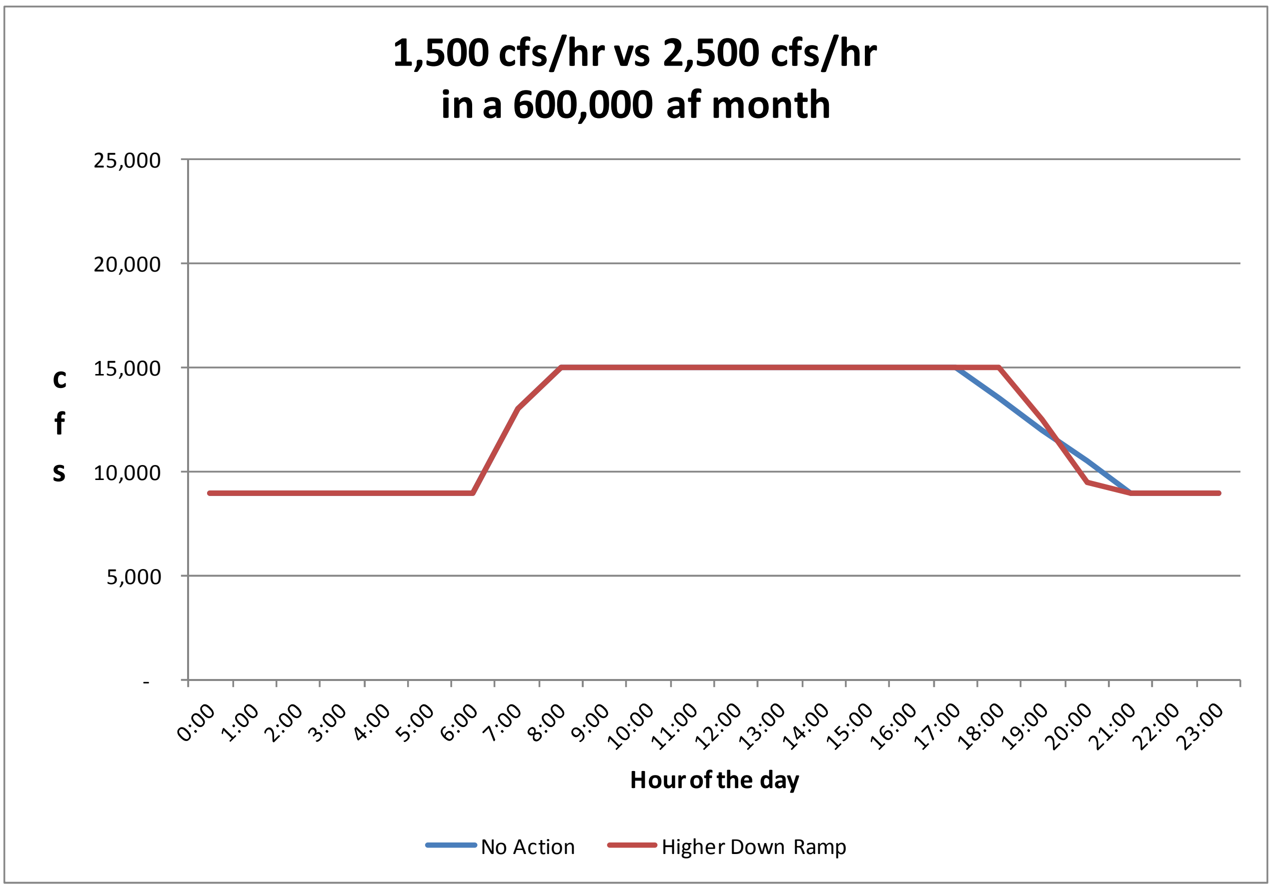


Figure C-8. Comparison of a 1,500 cfs/hr downramp rate with a 2,500 cfs/hr in a 600,000 af month.

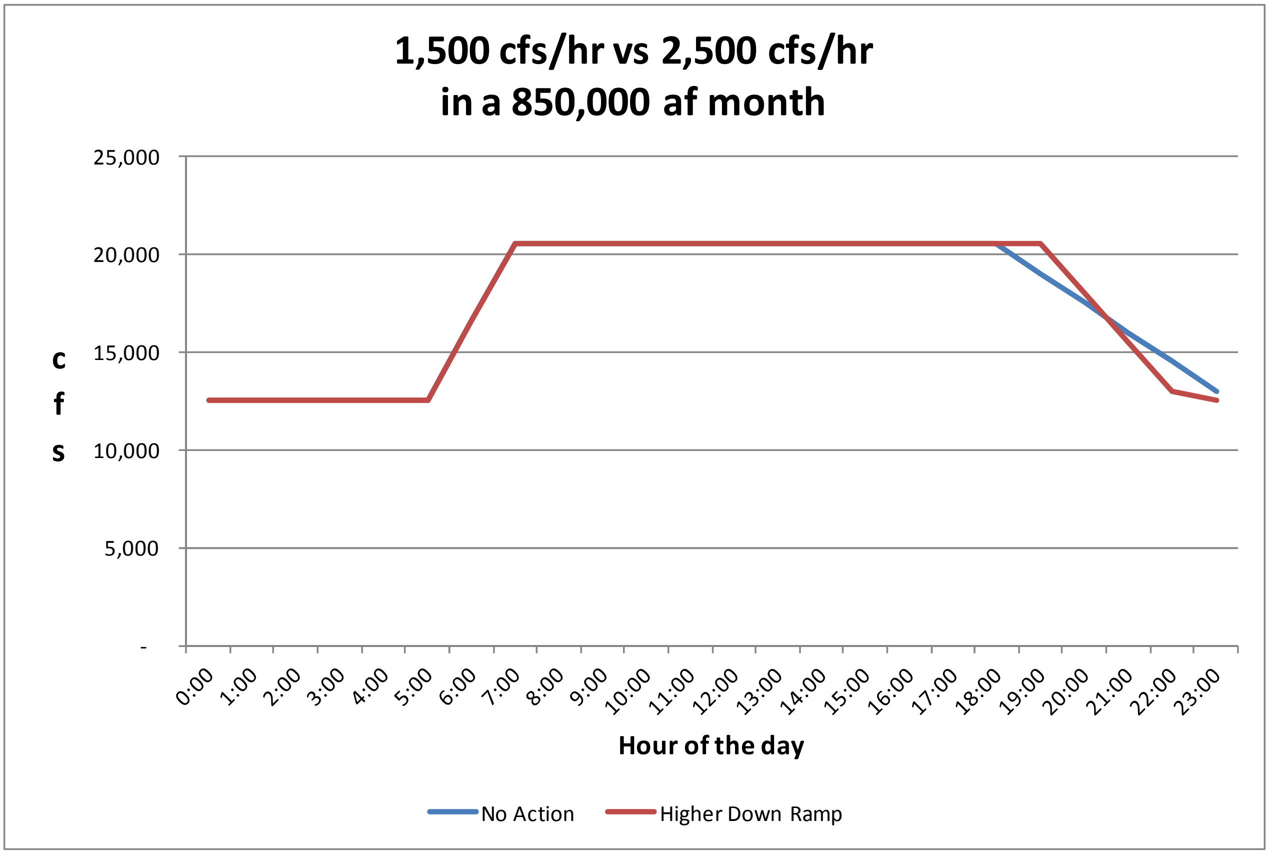


Figure C-9. Comparison of a 1,500 cfs/hr downramp rate with a 2,500 cfs/hr in a 850,000 af month.

APPENDIX D – TREATMENTS CONSIDERED AND NOT INCLUDED

The following treatments, as described below, were considered and not included in the alternative:

- Load-Following Flows.
- Paria-to-Badger Mechanical Removal.
- Other Steady Flow Experiments (one was included in the alternative).
- Sediment Augmentation Pipeline.
- Temperature Control Device.
- Generators on the River Outlet Works (bypass valves).

These treatments and those included in the alternative were evaluated in part with the following models:

- Core-Response Model developed for the structured decision-making project (Runge *et al.* 2011).
- Trout Escapement and Predation Model (Coggins and Korman, unpublished).
- An individual-based model for population viability analysis of humpback chub in Grand Canyon, used for cropping recommendations for young humpback chub in the Little Colorado River (Pine *et al.* 2011).

Load-Following Flows

Load-following flows are relatively unconstrained seasonal and diurnal variations in water releases from Glen Canyon Dam designed to maximize hydropower production. Load-following flows were a prominent feature of dam operations prior to the 1991 Interim Operations and the 1995 EIS that implemented modified low-fluctuating flows (MLFF). The load-following flows were characterized by large changes in daily releases that varied as much as 30,500 cfs/day; i.e., 1,000 cfs to 31,500 cfs in a 24-hr period (Reclamation 1995). These fluctuations caused the river to change by up to 13 ft and often included two peaks and two troughs in a 24-hr cycle.

This treatment was considered but not included in the experimental design because of the wide range of detrimental effects on canyon resources documented for load-following flows in Reclamation (1995, 1998):

- Wide range of flow conditions made running rapids difficult for white-water rafting;
- Wide range of flow conditions made access and use of camping beaches difficult;
- Highly variable flow conditions made access to fishing areas difficult for trout anglers;

- Highly variable flow resulted in low trout reproduction, survival, and growth; and
- Highly variable flow resulted in variable aquatic food base production.

Paria-to-Badger Mechanical Removal

The numbers of rainbow trout in the Lees Ferry reach are expected to increase as an unintended consequence of high-flow experiments (Reclamation 2011). An increase in the population could result in greater downstream dispersal of trout into reaches of the Colorado River that are occupied critical habitat of humpback chub (about 70-80 miles from Glen Canyon Dam). Competition and predation by rainbow trout and brown trout have been identified as a substantial source of mortality for juvenile humpback chub (Yard *et al.* 2011) that may reduce recruitment and possibly the overall size of the humpback chub population (Coggins 2008).

Mechanical removal of trout from the Colorado River has been shown to be effective at reducing abundance of trout in areas occupied by humpback chub (Coggins 2008). Because most of the rainbow trout that prey on humpback chub originate in the Lees Ferry reach, a strategy to intercept the downstream movement of trout was identified for the Paria-to-Badger reach (PBR) (Runge *et al.* 2010). This strategy involves mechanically removing trout from the Colorado River in an 8-mile reach immediately downstream of Lees Ferry, between the Paria River (RM 0) and Badger Creek (RM 8). This strategy was described in a Supplement to the 2011 Biological Assessments for HFEs and Non-Native Fish Control (Reclamation 2011a, 2011b).

In that supplement, the efficacy of the PBR was evaluated with a Trout Escapement and Predation Model (Coggins and Korman, unpublished) that considers the numbers of age-0 trout emigrating downstream from Lees Ferry, the monthly numbers of age-0 trout emigrating downstream through Marble Canyon together with specified numbers already in the main channel, and the effect on the humpback chub population using an age-structured stock recruitment model.

The model shows that if trout abundance is high in the mainstem through Marble Canyon, maintaining a humpback chub population of >6,000 adults with a probability >0.60 will require more than 10 PBR removal trips per year, and could also require more than 6 LCR removal trips per year (Reclamation 2011b). At higher Marble Canyon trout abundances (i.e., over 45,000 trout), it would be necessary to implement removal in both the PBR and LCR reaches. Trout abundance indices for the Lees Ferry reach for 2008-2009 show a similar abundance level to 2003 when Coggins (2008) reported the highest estimated abundance of 10,571 rainbow trout for the 8.1-mi "control reach." This equates to about 81,000 fish for the 62-mi Marble Canyon reach, assuming a uniform distribution of trout. At this higher Marble Canyon trout abundance, 10 monthly PBR removal trips and 6 monthly LCR removal trips would be necessary to maintain the humpback chub population above 6,000 adults at a probability of 0.60.

Given the high level of effort required for PBR (i.e., more than 10 trips/year) and the uncertainty as to whether it would work even with significant LCR mechanical removal trips, this treatment was considered but not included in the experimental design and a recommendation was made to investigate the efficacy of managing the Lees Ferry trout population with a combination of Trout Management Flows and other actions nearer the source of the fishery.

Steady Flow Experiments

Four types of steady flows were considered and not included in the alternative:

- Existing Monthly Volume Steady Flows;
- Seasonally-Adjusted Steady Flows;
- Year-Around Steady Flows; and
- Low Steady Summer Flows.

The first three types of steady flows identified above were also considered in the 1995 EIS (Reclamation 1995), and the fourth (low steady summer flows) was implemented in summer of 2000 (Ralston 2011). The first three types are illustrated in Figure D-1 taken from the 1995 EIS.

These steady flows were considered but not included in the alternative because of the potentially damaging effects to the following:

- Extended periods of steady flows (low or high) will result in high reproductive success and survival of trout in the Lees Ferry reach that leads to density dependent competition for available resources, poor condition of fish, and may promote migration to downstream areas (Korman *et al.* 2010, 2011). This dispersal is currently being assessed in the Natal Origins project.
- Rainbow trout that migrate downstream from Lee's Ferry may prey upon and compete with juvenile humpback chub in the LCR reach. These pressures potentially reduce juvenile humpback chub survival and ultimately recruitment (Yard *et al.* 2011).
- Extended periods of steady flow increases water clarity which is likely advantageous to sight feeders such as trout that prey on juvenile humpback chub (Yard *et al.* 2011).
- Extended periods of steady flow can cause senescence of the aquatic food base and result in long-term reduction of primary and secondary production (Blinn and Cole 1991).
- Extended periods of steady flow will stabilize shoreline habitats used by native and nonnative fish; the Nearshore Ecology Study has shown that growth and survival of native fishes is not significantly greater under stable flows than under fluctuating flows (Pine and Finch 2011).
- Prolonged periods of steady flow are not reasonably possible given the changes in dam operations necessitated by changing runoff conditions.

The following is a description of each of the four steady flows types.

<u>Existing Monthly Volume Steady Flows</u>

An existing monthly volume steady flow would provide steady flow on a monthly basis while continuing to maintain flexible monthly release volumes to avoid spills and maintain conservation storage. The range of flows for this type of release over an annual basis would be increasingly narrow in years of low hydrology (i.e., low release years; Figure D-1). In moderate to high release years, the hydrograph would take on a multiple block appearance with month-to-month transitions. Highest releases would occur in May-July during high release years, but may not occur in this period during moderate and low release years.

Seasonally-Adjusted Steady Flow (SASF)

A seasonally-adjusted steady flow would release water at a constant rate within defined seasons. The SASF treatment would provide steady flows on a 1- to 3-month basis, providing seasonal variations throughout the year. The highest releases would occur in May and June, with relatively low releases from August through December. Releases within each month would be steady and would have to equal or exceed the monthly minimums. Any additional water in excess of the minimum annual release volume would be distributed equally among the 12 months, subject to the established maximum. If forecasts changed, the volume of water to be released during the remainder of the year would be recomputed monthly based on updated forecasts, and the constant rate of release would be adjusted accordingly.

Year-Around Steady Flows

A year-round steady flow would eliminate fluctuating flows, both daily and seasonal. The minimum flow would be determined from the mean monthly release but would correspond generally to the minimum annual release volume of 8.23 maf, which is about 11,400 cfs. The minimum release requirement would be relaxed to avoid spills during high storage or inaccurate forecast situations. The monthly volume would be approximately the annual volume divided by 12, except when response to forecast changes would be required. If forecasts changed, the volume of water to be released during the remainder of the year would be recomputed monthly based on updated forecasts, and the constant rate of release would be adjusted accordingly. The ability to maintain a constant rate of release for the entire year would depend on the accuracy of streamflow forecasts and the amount of space remaining in Lake Powell.

Low Steady Summer Flows

A low steady summer flow is included in the alternative as described in the body of the document as a contingency action if future Lake Powell releases do not warm as expected (Figure 5).

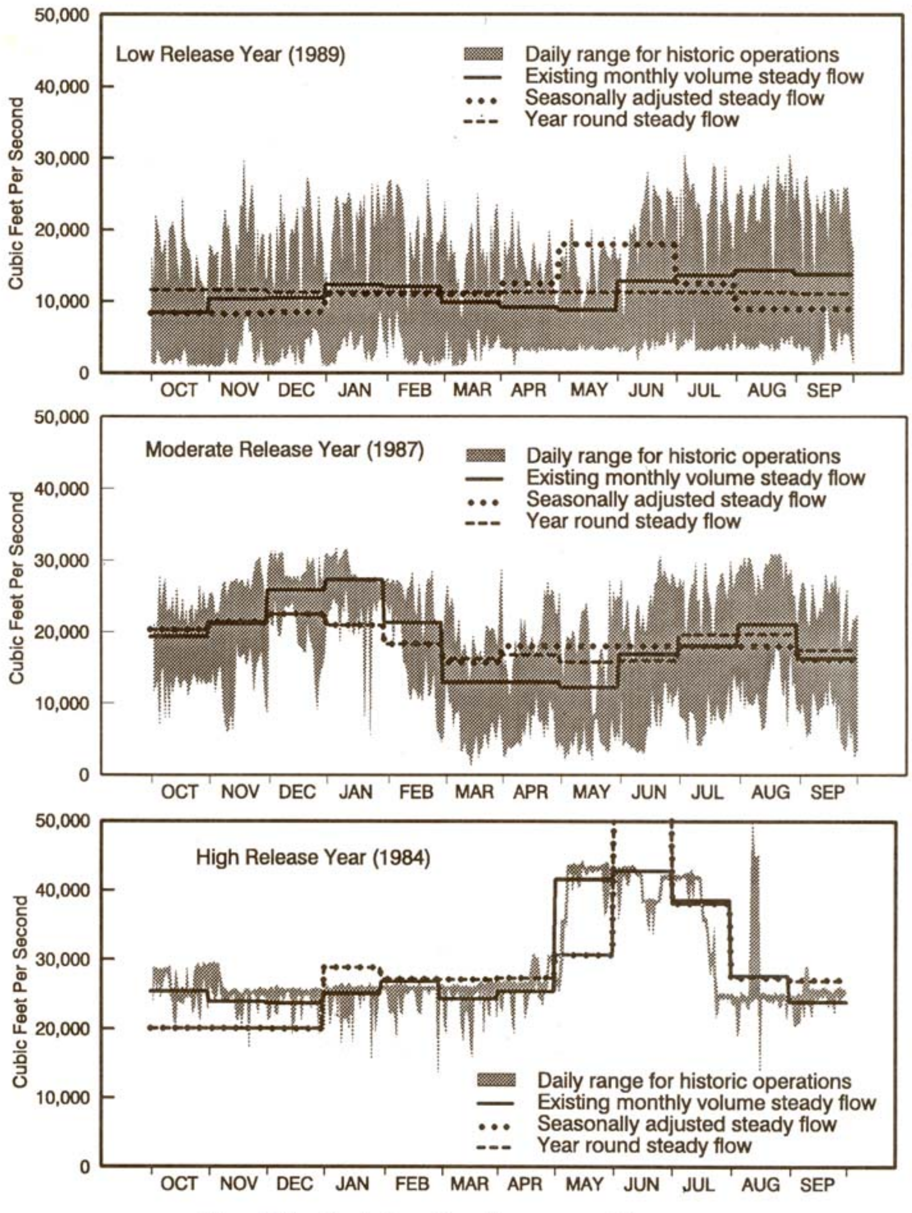


Figure D-1. Steady flows compared to No Action for low, moderate, and high release years. From 1995 EIS (Reclamation 1995).

Sediment Augmentation

Before Glen Canyon Dam, the Colorado River delivered about 60 million tons of sand per year past Lees Ferry (Topping *et al.* 2000). The completion of the dam in 1963 retained all of this sediment in Lake Powell and only small tributaries downstream from the dam now deliver smaller amounts of sediment to the Colorado River. Reduction of sediment has depleted the channel and sandbars of sand and organic matter, reduced the amount of turbidity in the water, and altered aquatic productivity processes. Sediment is an important component of the Grand Canyon Ecosystem, but providing it to the Colorado River downstream of Glen Canyon Dam is logically challenging and could be very costly.

Sediment augmentation was discussed in the 1995 EIS for the Operation of Glen Canyon Dam as a requirement to maintain a sediment balance for the Run-of-the River Alternative. A slurry pipeline was identified as the most feasible method of transporting sediment through Lake Powell to below Glen Canyon Dam. The cost of building a slurry pipeline was estimated at $400,000 per mile. For a completed pipeline from the river deltas of the San Juan, Dirty Devil, or mainstem Colorado River (Cataract Canyon) to Glen Canyon Dam, costs were estimated at $50, $80, and $85 million, respectively and operational costs were estimated at $10 million per year. A sediment augmentation system would likely take at least 15 to 20 years to implement. This timeframe included necessary research and data collection, NEPA compliance, design, Federal permitting, Congressional authorization, land purchase/easements, implementing mitigation procedures, and construction. Other means of sediment transport (barging and trucking) was identified as being less feasible and more expensive than a slurry pipeline.

In 2007, Reclamation developed a technical review of sediment augmentation alternatives (Randle *et al.* 2007). Alternatives were evaluated with respect to sediment sources, delivery locations, collection and conveyance methods, and sand storage areas. The objective for sediment augmentation below Glen Canyon Dam was identified to maintain a total sediment load of 4.8 million tons per year below Lees Ferry. Of this, an estimated 3.8 million tons of silt and clay were needed annually from May through December to meet the minimum suspended-sediment concentration to reduce predation on native and endangered fish and 1 million tons of sand were needed below Lees Ferry prior to each beach/habitat-building flow to maintain beaches and sediment-related habitats. A summary list of each component of the sediment augmentation system developed by Reclamation, and the alternatives considered in the review, are presented below in Table D-1 and a similar table can be found on page 7 of Randle *et al.* (2007). In this table, the alternative components that were considered technically feasible, and considered in some detail, are listed in a bold font. Alternative components that may be technically feasible, but were not considered in detail because they were judged to be excessively expensive, are listed in a normal font. Other alternative components that were considered to be technically or logistically infeasible are presented with gray shading.

Table D-1. Sediment augmentation alternatives assessed by Randle *et al*. (2007).

Sediment Sources-→	• Colorado River near Hite, UT (170 mi) • Dirty Devil River (160 mi) • San Juan River (120 mi) • Escalante River (99 mi) • **Navajo Canyon (33 mi)**		Lake Mead	Terrestrial Site Wahweap Bay Paria River
Sediment Delivery Locations-→	**Directly below Glen Canyon Dam**	**Near Lees Ferry**	Ferry Swale Canyon Water Holes Canyon	Paria River
Sediment Collection Methods-→	**Clamshell dredge**	Hydraulic dredge	Other dredges	
Sediment Conveyance Methods and alignments from Navajo Canyon-→	**Slurry pipeline submerged within Lake Powell to Antelope Point then overland to below Glen Canyon Dam**		Barge transport across Lake Powell to Antelope Point then truck transport to either below Glen Canyon Dam or Lees Ferry	
	Slurry pipeline submerged within Lake Powell to Antelope Point then overland to Lees Ferry		Slurry pipeline overland from Navajo Canyon to either below Glen Canyon Dam or Lees Ferry	
Sand Storage Areas-→	**Colorado River Plateau below Glen Canyon Dam**		**Terrestrial site near Lees Ferry**	

Five sediment deposits were identified within Lake Powell that contain enough sediment to support a sediment augmentation program to meet the objectives identified above (Navajo Canyon, Escalante River delta, San Juan River delta, Dirty Devil River delta, Colorado River delta near Hite). Although the annual sedimentation rates in Navajo Canyon are probably not be large enough to sustain a sediment augmentation program for the Grand Canyon indefinitely, Navajo Canyon was identified as the best sediment source due to the existing sedimentation volume, the future rate of sedimentation, and its close proximity to Lees Ferry. Sediment augmentation from Navajo Canyon at levels needed to meet objectives to benefit native and endangered fish and enhance beaches would likely sustain a sediment augmentation program for 10-20 years. The extraction of sediment resources in Navajo Canyon could be extended to 30-40 years if inputs from the Paria River are included to partially meet the sediment input objective of 4.8 million tons/year (Table D-2).

Table D-2. Sediment augmentation objectives for below Glen Canyon Dam with mean annual sediment inputs from the Paria River and amount of sediment used by Randle et al. (2007) in their analysis of sediment augmentation from Navajo Canyon.

	Objective (millions of tons)	Mean annual Paria River inputs (millions of tons)	Analysis for Sediment Augmentation in Randle *et al.* 2007 (millions of tons)	Difference between sediment objective and Paria River inputs (millions of tons)
Fine sediment	3.8	1.7	3.8	2.1
Sand	1.0	1.7	1.0	0
Total	4.8	3.3	4.8	2.1 (fine sediment)

A clamshell style dredge was selected as the preferred extraction method due to its increased effectiveness of excavating at the depths found in Navajo Canyon. Two dredges would be used to collect sediment; one to collect fine sediments from the downstream reaches of the canyon and one to collect sand and other courser sediments in the upstream reaches where the lake intersects the delta. The upstream dredge would operate year-round whereas the downstream dredge would only operate from May through December. The two dredges would be operated 24 hours a day during their period of operation. To meet transport objectives, 4,000 tons of sand would be dredged per day over a 250 workday year and 6,000 tons of fine sediments would be dredged per day over a 166 workday year.

A high-density polyethylene (HDPE) sediment slurry pipeline was found to be the only viable method for conveying the large quantities of sediment from Lake Powell to the Colorado River below Glen Canyon Dam. With adequate particulate suspension, HDPE pipe has an extremely high resistance to abrasion from slurries. The service life of a HDPE sediment slurry pipeline is expected to exceed 20 years.

The proposed pipeline alignments included a submerged pipeline with floating pump stations on Lake Powell that would exit the lake at Antelope Point. The pipeline would then travel overland to either below Glen Canyon Dam or to Lees Ferry. The pipeline alignment, if constructed to Lees Ferry, would likely follow the existing right-of-way for U.S. Highway 89. The pipeline alignment, if constructed to below Glen Canyon Dam, would drop down through an inclined shaft drilled from the rim down to the river near RM-12. Silt and clay would be released continuously during the conveyance period from May through December at either site. Sand would also be released continuously if delivered below Glen Canyon Dam but would be stockpiled on shore if delivered to Lees Ferry until just before a scheduled HFE. If Lees Ferry was selected as the sediment delivery point, sand would be stockpiled and stored on the south shore (river left) side of the river on the bluff opposite from the Paria River confluence and Cathedral Wash until the next HFE. If below Glen Canyon Dam was selected as the sediment delivery point, sand would be deposited in the river below the dam and stored in the river channel until the next HFE. The low gradient and deep pools between Glen Canyon Dam and Lees Ferry are expected to be sufficient to store the sand inputs from below Glen Canyon Dam until a beach-building flow is released. Sediment delivery near Lees Ferry would avoid many of the impacts on the trout fishery and foodbase in the Glen Canyon reach, but because of the increased distance would cost more than sediment delivery below Glen Canyon Dam. A delivery point in the Paria River was eliminated because there would be no means of transporting the augmented sediments to the

Colorado River in a timeframe that would meet management objectives and because of the Wilderness status for the river canyon.

Appraisal cost estimates (January 2006 dollars) were prepared for the five sediment augmentation alternatives. A summary comparison of these cost estimates are presented in Table D-3. Additional detail for these cost estimates are presented in Randle et al. (2007). These appraisal-level costs estimates do not directly include any costs for the purchase of land or right-of-way for pipelines or pump stations. Also, the estimates do not include any costs associated with traffic control or traffic disruption during construction activities. These cost estimates do include operating costs for the dredge system and power for the pump stations. Maintenance and replacement costs for pumps and motors are included, but not for any other items.

Table D-3. Summary comparison of appraisal cost estimates for five sediment augmentation alternatives.

Alternative	Project Capital Cost (Jan. 2006)	Annual Operating Cost (Jan. 2006)
Sand and Silt-Clay Slurry Pipelines from Navajo Canyon to below Glen Canyon Dam	$220 million	$6.6 million/yr
Sand and Silt-Clay Slurry Pipelines from Navajo Canyon to Lees Ferry	$430 million	$17 million/yr
Sand Pipelines from Navajo Canyon to below Glen Canyon Dam and Silt-Clay Slurry Pipelines from Navajo Canyon to Lees Ferry	$380 million	$11 million/yr
Silt-Clay Slurry Pipelines from Navajo Canyon to Lees Ferry (No sand slurry pipelines)	$300 million	$7.9 million/yr
Silt-Clay Slurry Pipelines from Navajo Canyon to below Glen Canyon Dam (No sand slurry pipelines)	$140 million	$3.6 million/yr

Because the sediment resources at Navajo Canyon are comparatively small (36 million m3) and unlikely to be capable of sustaining a sediment augmentation program indefinitely, it would be considered the short-term experiment to evaluate the effects of sediment augmentation on resources downstream of Glen Canyon Dam. If results are positive and it is deemed necessary to incorporate sediment augmentation as a long-term management action, the pipeline could be extended upstream to the much larger delta on the San Juan River (350 million m3) located another 87 miles upstream from Navajo Canyon. Recent cost estimates for this action have not been performed yet. Sediment augmentation from above Glen Canyon Dam was removed from further consideration in this alternative due to the desire of the Basin States to see if sediment related resources could first be improved with more effective utilization of the new HFE protocol presented by Reclamation in 2011.

Temperature Control Device

A temperature control device (TCD) on Glen Canyon Dam would provide the flexibility to modify the temperature of water released downstream of the dam (within limitations). A TCD could be used to warm releases during moderate to high elevations of Lake Powell or to cool releases during low reservoir elevations. Other dams have been modified to release desired temperatures, including Flaming Gorge Dam, Shasta Dam, and Hungry Horse Dam. The purpose for warm water releases is to provide more seasonal temperature variability of the Colorado River downstream from Glen Canyon Dam and specifically to:

- Increase the diversity, abundance, and biomass of invertebrates that form the aquatic food base.
- Provide for mainstem spawning of native fishes, including the endangered humpback chub.
- Improve the growth rate of native fish and reduce their time of susceptibility to predation.

Additionally, a TCD could be used during low reservoir elevation and warm releases to cool the water temperature and avert or reverse an undesirable effect, such as the increase or expansion of an invasive aquatic species.

The possible adverse effects of a TCD include:

- Increase and expansion of undesirable fish species that could compete with and prey on native fishes.
- Invasion of new aquatic species previously excluded by cool water temperatures.
- Reduction or elimination of aquatic invertebrate species adapted to either a relatively uniform water temperature (univoltine species) or a seasonally variable temperature (multivoltine species), but unable to adjust to periods of both regimes.
- Increased incidence of infection and infestation of harmful parasites and diseases, including those that afflict the Lees Ferry trout fishery and downstream native fish species (e.g., whirling disease, tapeworms, anchor worms), as well as those that might affect human recreational users such as rafters and anglers.

The following is a history of the TCD for Glen Canyon Dam:

- 1978: The U.S. Fish and Wildlife Service (Service) in the first Biological Opinion on Operation of Glen Canyon Dam concluded that the construction and operation of Glen Canyon Dam jeopardized the continued existence of the humpback chub by reducing water temperature and changing the aquatic system (U.S. Fish and Wildlife Service 1978).
- 1988: Glen Canyon Environmental Studies acknowledged that little information was available on temperature effects in Grand Canyon and requested additional study (Reclamation 1988).
- 1995: Glen Canyon Dam Environmental Impact Statement identified the need for further study of selective withdrawal as a common element of the preferred action (Reclamation 1995) and the 1995 Biological Opinion directed the Bureau of Reclamation (Reclamation) to *"…implement a selective withdrawal program for Lake Powell waters…"* and to determine effects of temperature modification on the reservoir and on downstream resources, especially native and endangered fish (U.S. Fish and Wildlife Service 1995).

- 1997: Reclamation conducted a value planning study to screen various design alternatives to modify the intakes of the dam to control temperature and to develop appraisal level costs (Reclamation 1997).
- 1999: Reclamation released a Draft Environmental Assessment (EA) for a temperature control device (TCD) on Glen Canyon Dam with five design alternatives (U.S. Bureau of Reclamation 1999). The preferred alternative was a single inlet, fixed elevation design with an estimated cost of $15,000,000.
- 1999: A scientific review of the EA expressed concern for unintended negative effects (i.e., nonnative fish proliferation) as a result of warm releases, as well as the lack of a detailed science plan to measure those effects (Mueller 1999).
- 1999: A hydraulic model study was conducted to collect hydraulic design data for the proposal to develop modifications, if necessary, to improve hydraulic performance; this study used data for head losses, submergence criteria, near-field velocities, vortex formation potential, and qualitative water hammer pressures (Vermeyen 1999).
- 1999-2001: The 1999 EA was withdrawn before being finalized, and Reclamation convened workshops of scientists and managers to evaluate the feasibility of a TCD and to further develop a research and monitoring program for evaluating ecosystem responses to warmer dam releases.
- 2003: Glen Canyon Dam Adaptive Management Program (GCDAMP) Science Advisors evaluated a temperature modification and recommended the installation of a TCD on Glen Canyon Dam as soon as possible and the construction of a pilot TCD in the interim (Garrett et al. 2003).
- 2004: Sufficient progress letter from Reclamation to the Service indicated that following the results of scientific investigations, expert workshops, a risk assessment by the AMP Science Advisors, and a recommendation by AMWG, it was justified to proceed with environmental compliance on a selective withdrawal device for Glen Canyon Dam.
- 2005: Reclamation initiated development of a new EA to provide NEPA compliance on a 2-unit selective withdrawal. This effort was discontinued when the decision was made to include compliance for a TCD within the Long-Term Experimental Plan EIS.
- 2007: During development of the Interim Surplus Criteria EIS, Reclamation discovered that projections of the 1999 EA for utilization of the preferred alternative design for the temperature control device, previously estimated at 85 out of 100 years, were considerably overestimated and were closer to 45-50% of those years. This discovery prompted re-evaluation of the engineering designs for the temperature control device (Reclamation 2007).
- 2007: The U.S. Fish and Wildlife Service in its Biological Opinion on Interim Guidelines concluded that the action is not likely to jeopardized the continued existence of the humpback chub (U.S. Fish and Wildlife Service 2007), and acknowledges that release temperatures may affect the species and it critical habitat, but no conservation recommendation is made regarding TCD.
- 2007: A risk assessment for implementation of a TCD (Valdez and Speas 2007) concluded that little effect would be seen with a 2-unit modification, but with 4 units all native fishes

would benefit for spawning, egg incubation, and growth, but correspondingly higher benefits to many nonnative fish species were likely to occur; similar benefits were seen for fish parasites and other invasive aquatic species.

- 2008: The U.S. Fish and Wildlife Service in its Biological Opinion on Operation of Glen Canyon Dam concluded that the action is not likely to jeopardize the continued existence of the humpback chub (U.S. Fish and Wildlife Service 2008), and determined that due to the high cost of design investigation and no specific design work or feasibility analysis, the feasibility of a TCD with both warm- and cold-water release capability remains a question and an information need.
- 2010: The U.S. Fish and Wildlife Service in its Supplement to the 2008 Biological Opinion on Operation of Glen Canyon Dam affirmed that the action is not likely to jeopardize the continued existence of the humpback chub (U.S. Fish and Wildlife Service 2010), and reiterated that due to the high cost of design investigation and no specific design work or feasibility analysis, the feasibility of a TCD with both warm- and cold-water release capability remains a question and an information need.
- 2012: The U.S. Fish and Wildlife Service in its Biological Opinion on the HFE Protocol and nonnative fish control EAs concluded that the action is not likely to jeopardize the continued existence of the humpback chub (U.S. Fish and Wildlife Service 2010). As with prior BOs, this document reiterated that due to the high cost of design investigation and no specific design work or feasibility analysis, the feasibility of a TCD with both warm- and cold-water release capability remains a question and an information need.

The following is a history of Lake Powell elevation and dam release temperatures:

- For about the first 10 years that Lake Powell was filling, water released from Glen Canyon Dam underwent a seasonal variation in temperature as had been seen in the Colorado River prior to dam construction (Figure D-2).
- Starting in about 1971, as the reservoir reached an elevation of about 3600 feet, the temperature of water released from the dam began to vary dramatically less and by 1974, the temperature ranged from about 8°C to 10°C.
- From about 1974 to 2004, the temperature of dam releases has generally stayed in this range because the elevation of the reservoir remained high and the power intakes continued to draw water from the lower water level (i.e., hypolimnion). Water from the warmest surface layer (i.e., epilimnion) and the middle layer (i.e., metalimnion) was not withdrawn from these intakes because of the high reservoir elevation.
- In 2004, Lake Powell reached a historic low elevation because of an extended drought in the Colorado River region (U.S. Department of the Interior 2011), and for the first time in 30 years of dam operations (1974-2004), average daily releases reached 14.5°C on October 5, 2004, and 15.6°C on October 15, 2005. The reservoir elevation at which warm surface water is entrained in the power intakes varies depending on time of year, the amount of inflow for the year, and the thickness of the epilimnion and the metalimnion (Vernieu et al. 2005), but generally occurs at about 3615-3620 ft elevation (Figure D-3). The warmest water temperatures in Lake Powell typically occur in October and November.

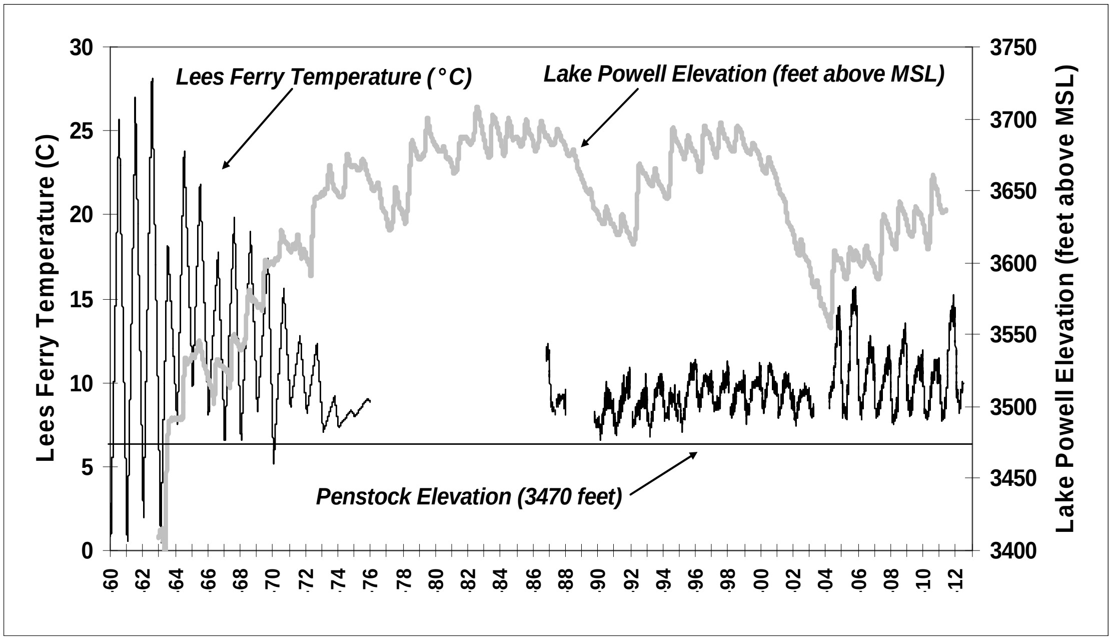


Figure D-2. Volume of Lake Powell and temperature of the Colorado River at Less Ferry, about 24 km downstream from Glen Canyon Dam, from January 1960 to June 2012. Data from USGS 09380000 Colorado River at Lees Ferry, AZ; Lake Powell volume: Upper Colorado Region Reservoir Operations, Upper Colorado Reservoir Data, **http://www.usbr.gov/uc/crsp/GetSiteInfo.**

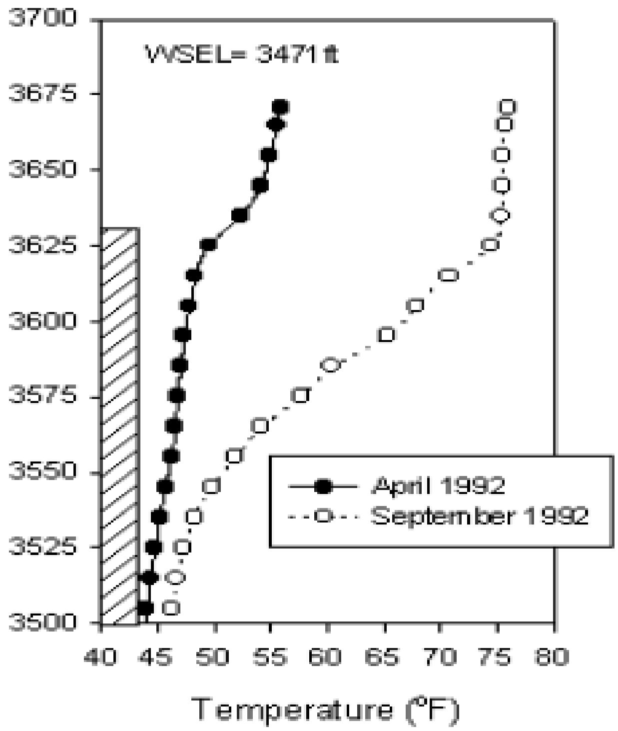


Figure D-3. Forebay temperature profiles for April and September 1992. Figure from Vermeyan (1999).

Generators on the River Outlet Works (bypass valves)

Adding generators to the river outlet works would increase the operational flexibility of Glen Canyon Dam while increasing control of release temperatures for the benefit of downstream resources. The primary purpose of the outlet works is to enable the facility to bypass flows around the powerplant to meet downstream flow commitments when the powerplant is not in full use. The river outlet works were first used during the final closure of the diversion tunnels until the reservoir elevation reached the penstocks of the powerplant. The intakes for the bypass tubes are located 315 feet below the minimum elevation for powerplant operations. The outlet works have also been used to bypass additional flows around the powerplant during periods of high flows and during high flow experiments (HFEs).

In 1975, Reclamation studied the feasibility of adding a second powerplant at the outlet works in order to increase generation at the facility (Reclamation 1983). The initial designs of the outlet works powerplant was to utilize up to 7,000 cfs of the 15,000 cfs capacity of the bypass tubes to run two-125 MW turbines. The study analyzed the use of these additional generators to operate as power-peaking units, running 3 to 5 hours a day for up to 90 days during the summer and 60 days during the winter. Reclamation identified that the addition of a second powerplant at the outlet works would necessitate the construction of a second powerhouse and the extension of the bypass tubes further downstream to a new set of outlet works. Valves installed under the existing parking deck would route water from the bypass tubes to either the new powerhouse or to the new outlet works. Reclamation determined that if turbines on the outlet works were operated to meet peak-power demands, the facility had a benefit-cost ratio of nearly 2:1 with construction costs (in 1981 dollars) of approximately $165.5 million and an annual power benefit of approximately $30 million.

In the period of time since the development of the 1975 feasibility study was concluded, several other environmental and economical benefits to powered releases from the outlet works have been identified. Adding power generators to the outlet tubes would also:

- Allow for cold water releases to be made if river temperatures need to be cooled to control a non-native, warm-water fish or parasite invasion;
- Allow for power generation during HFE releases;
- Increase flexibility at the facility by allowing continued operations when a generator in the main powerplant goes out of operation for repair or maintenance;
- Be used to fulfill Western's spinning reserve requirements;
- Allow for power generation at lower reservoir levels; and
- Reduce the cost of a TCD, if one is ever installed, by eliminating the need for a multi-level intake structure to provide cold-water releases below the dam.

Having additional turbines on site would allow more flexibility to produce power while one or more turbines in the powerplant are being serviced. In 2011, high inflows into Lake Powell required increased releases to Lake Mead to equalize reservoir storage between the two reservoirs. Beginning on April 4, 2011 and extending through December 27, 2011, Glen Canyon Dam was operated near its maximum generating capacity to release the required volumes of water to Lake Mead. During this time, between one and three of the eight units at Glen Canyon Dam were out-of-service for scheduled maintenance. It was necessary to shift reserves from Glen Canyon Dam to other CRSP power plants such as Flaming Gorge, Blue Mesa, and Morrow Point to allow Glen Canyon Dam generators to operate at a higher capacity and release more water.

Additional turbines on the outlet works could also be used to fulfill Western's spinning reserve contracts. Spinning reserves are the portion of unloaded synchronized generating capacity, controlled by the power system operator, which is capable of being loaded in 10 minutes, and which is capable of running for at least two hours. Non-spinning reserve is capacity that can be brought on line within a specified period of time, but is not currently connected to the system.

The power plant at Glen Canyon Dam can currently be operated with a reservoir elevation down to 3490 feet ASL. The bypass tube intake structures at the dam are located 315 feet below the intake structures for the power plant. In 2005, water elevations at Lake Powell came within 60 feet of the powerplant's intake structures. Although the 50-year reservoir elevation CRSS model for Lake Powell generated by Reclamation indicates a stable reservoir elevation of approximately 3,640 ft ASL, increased water use in the upper basin and climate change have the potential to reduce inflows into Lake Powell and impact power production at Glen Canyon Dam. The prospect of reservoir elevations on the Colorado River being drawn down enough to curtail power production is not unprecedented. In 2010, Lake Mead fell to within 31 feet of the minimum lake elevation for power production at Hoover Dam. These low reservoir levels resulted in a reduction of Hoover Dam's hydroelectric generating capacity by 23 percent.

Being able to utilize the lower intakes on the bypass tubes would eliminate the need for a dual, cold/warm-water TCD structure thus allowing the construction of only the warm-water TCD. A cost estimate for a dual cold/warm-water TCD was never undertaken but, because of its added complexity, it would be expected to be substantially more than the 2009 estimate of $100 million to construct a warm-water only TCD. Combining a single-level TCD structure with releases from the bypass tubes would allow releases that could be targeted to a temperature warm enough to disproportionally benefit valued resources below Glen Canyon Dam such as humpback chub, the Lees Ferry trout fishery, and the aquatic food base while disadvantaging elements that may negatively impact these resources (i.e. introduction or expansion of other nonnative fish species and parasites).

Generators on the river outlet works (bypass valves) to work with a warm-water only TCD in targeting downstream temperatures was not considered for this alternative as the prospect of using mainstem water temperatures to disproportionally advantage desirable resources over undesirable resources without irreversibly altering the aquatic community below the dam is still in question.

Appendix D – Literature Cited

Blinn, D.W., and G.A. Cole. 1991. Algal and invertebrate biota in the Colorado River: comparison of pre- and post-dam conditions, Colorado River ecology and dam management: Washington, D.C., National Academy Press, p. 102–123.

Bureau of Reclamation. 1997. Documentation of feasibility designs for Glen Canyon Dam multi-level intake structure. Technical Memorandum No. GCD-8110-FEA-97-1. Technical Service Center, Denver, CO.

Coggins, L.G., Jr. 2008. Active adaptive management for native fish conservation in the Grand Canyon: implementation and evaluation. Ph.D. Dissertation, University of Florida, Gainesville.

Garrett, D., J. Baron, V. Dale, L. Gunderson, A. Howard, D. Hulse, J. Kitchell, J. Loomis, M. Palmer, R. Parker, D. Robertson, D. Schwartz, and J. Watkins. 2003. Evaluating a Glen Canyon Dam temperature control device to enhance native fish habitat in the Colorado River: A risk assessment by Adaptive Management Program Science Advisors. July 2003. Upper Colorado Region, Bureau of Reclamation, Salt Lake City, UT.

GCMRC. 2012. Draft FY 2013-14 Budget and Workplan.

Korman, J., M. Kaplinski, and T.S. Melis. 2010. Effects of high-flow experiments from Glen Canyon Dam on abundance, growth, and survival rates of early life stages of rainbow trout in the Lees Ferry reach of the Colorado River: U.S. Geological Survey Open-File Report 2010–1034, 31 p.

Korman, J., M. Kaplinski, and T.S. Melis. 2011. Effects of fluctuating flows and a controlled flood on incubation success and early survival rates and growth of age-0 rainbow trout in a large regulated river. Transactions of the American Fisheries Society 140(2):487-505.

Mueller, G. 1999. Scientific panel review of the Glen Canyon Dam modifications to control downstream temperatures, plan and Draft Environmental Assessment (EA). Gordon Mueller, Carl Walters, Paul Holden, Pete Walker, Jerry Landye and Brett Johnson. Bureau of Reclamation, Salt Lake City, UT.

Pine, B., B. Healy, R. Ahrens, C. Walters, R. Valdez, R. Vanhaverbeke, D. Stone, M. Yard, E. Omana-Smith, M. Trammel, D. Speas. 2011. An individual-based model for population viability analysis of humpback chub in Grand Canyon. Proceeding of A Workshop to Develop Cropping Recommendations for Young Humpback Chub in the Little Colorado River, July 6-8, 2011, National Park Service, Flagstaff, AZ.

Pine, B., and C. Finch. 2012. Personal communications as part of the science panel for the development of this alternative proposal.

Ralston, B.E., 2011, Summary report of responses of key resources to the 2000 low steady summer flow experiment, along the Colorado River Downstream from Glen Canyon Dam, Arizona: U.S. Geological Survey Open-File Report 2011–1220, 129 p.

Reclamation. 1995. Environmental Impact Statement on the Operations of Glen Canyon Dam. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT.

Reclamation. 1998. Glen Canyon Environmental Studies, Final Report, January 1988. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT.

Reclamation. 1999. Glen Canyon Dam modifications to control downstream temperatures; Plan and Draft Environmental Assessment. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT.

Reclamation. 2011a. Biological Assessment: Development and implementation of a protocol for high-flow experimental releases from Glen Canyon Dam, Arizona, 2011 through 2020. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT.

Reclamation. 2011b. Environmental Assessment: Non-native fish control downstream from Glen Canyon Dam, 2011–2020. Bureau of Reclamation, Salt Lake City, UT.

Randle, T.J., Lyons, J.K., Christensen, R.J., and Stephen, R.D., 2007, Colorado River ecosystem sediment augmentation appraisal engineering report: U.S. Bureau of Reclamation, Technical Service Center, Sedimentation and River Hydraulics Group, Denver, Colorado.

Runge, M.C., E. Bean, D.R. Smith, and S. Kokos. 2011. Non-native fish control below Glen Canyon Dam—Report from a structured decision-making project: U.S. Geological Survey Open-File Report 2011–1012, 74 p., at http://pubs.usgs.gov/of/2011/1012/.

Topping, D.J., Rubin, D.M., and Vierra, L.E., Jr., 2000, Colorado River natural sediment supply limitation and the influence of the Glen Canyon Dam. Research, v. 36, no. 2, p. 515–542, doi: 10.1029/1999WR900285.

Trammell, M., Valdez, R.A., Carothers, S.W., and R. Ryel. 2002. Effects of a low steady summer flow experiment on native fishes of the Colorado River in Grand Canyon—final report: Flagstaff, Ariz., SWCA, Inc. Environmental Consultants, submitted to U.S. Geological Survey, Grand Canyon Monitoring and Research Center, cooperative agreement no. 99–FC–40–2260, 77 p. [Available upon request by contacting the Center Director, U.S. Geological Survey, Southwest Biological Science Center, 2255 N. Gemini Drive, Flagstaff, Ariz. 86001.]

U.S. Department of the Interior. 2011. SECURE Water Act Section 9503(c) – Reclamation Climate Change and Water, Report to Congress, 2011. U.S. Department of the Interior, Bureau of Reclamation, Upper Colorado Region, Salt Lake City, UT

U.S. Fish and Wildlife Service. 1978. Biological opinion of the effects of Glen Canyon Dam on the Colorado River and its effects endangered species. U.S. Fish and Wildlife Service, Phoenix, AZ.

U.S. Fish and Wildlife Service. 1995. Final Biological Opinion on the Operation of Glen Canyon Dam. U.S. Fish and Wildlife Service, Albuquerque, NM.

U.S. Fish and Wildlife Service. 2008. Final Biological Opinion for the Operation of Glen Canyon Dam. U.S. Fish and Wildlife Service, Phoenix, AZ.

U.S. Fish and Wildlife Service. 2009. Supplement to the 2008 Final Biological Opinion for the Operation of Glen Canyon Dam. U.S. Fish and Wildlife Service, Phoenix, AZ.

Valdez, R.A., S.W. Carothers, D.A. House, M.E. Douglas, R.J. Ryel, K.R. Bestgen, and D.L. Wegner. 2000. A program of experimental flows for endangered and native fishes of the Colorado River in Grand Canyon—final report: Flagstaff, Ariz., SWCA, Inc. Environmental Consultants, submitted to U.S. Geological Survey, Grand Canyon Monitoring and Research Center, 68 p. [Available upon request by contacting the Center

Director, U.S. Geological Survey, Southwest Biological Science Center, 2255 N. Gemini Drive, Flagstaff, Ariz. 86001.]

Valdez, R.A., T.L. Hoffnagle, C.C. McIvor, T. McKinney, and W.C. Leibfried. 2001, Effects of a test flood on fishes of the Colorado River in Grand Canyon, Arizona: Ecological Applications, v. 11, no. 3, p. 686-700.

Valdez, R.A., and D.W. Speas. 2007. A risk assessment model to evaluate risks and benefits to aquatic resources from a selective withdrawal structure on Glen Canyon Dam. Bureau of Reclamation, Salt Lake City, UT.

Vermeyen, T.B. 1999. Glen Canyon Dam multi-level intake structure hydraulic model study. Water Resources Services, Water Resources Research Laboratory, Technical Service Center, Denver, CO.

Vermeyen, T.C., W. DeMoyer, W. Delzer, and D. Kubly. 2003. A survey of selective withdrawal systems. Denver Technical Service Center Water Resource Services, Bureau of Reclamation, Denver, CO.

Vernieu, W.S., S.J. Hueftle, and S.P. Gloss. 2005. Water quality in Lake Powell and the Colorado River. Pages 69-85 in S.P. Gloss, J.E. Lovich, and T.S. Melis, eds. The state of the Colorado River ecosystem in Grand Canyon: U.S. Geological Survey Circular 1282, 220 p.

Yard, M.D., Coggins, L.G., Baxter, C.V., Bennett, G.E., and J. Korman. 2011. Trout piscivory in the Colorado River, Grand Canyon—effects of turbidity, temperature, and fish prey availability: Transactions of the American Fisheries Society 140(2):471-486.

APPENDIX E – LEARNING, ASSUMPTIONS, AND SCIENCE QUESTIONS

Critical Learning

It is important to assess what critical knowledge has been gained since the last EIS was completed and the ROD signed in 1996. In this section we focus on the key knowledge gains and assumptions that will be carried over into the proposed alternative. This provides the basis for answering new critical questions and the science framework necessary to get there.

Humpback Chub

Most of the issues revolve around juvenile humpback chub recruitment. Adults are fairly resilient to environmental conditions and annual survival rates are high and seem to be getting higher. Humpback chub have 5 key life stages: egg, larval drift (minimal), use of shorelines and backwaters as juveniles, then a period with more movement between habitats, and then by around age-4 (depending on growth rates) they become less susceptible to predation by trout and move offshore to deeper habitats. Adults live 30-40 years, and are regarded as tough tolerant fish. There is a storage affect against population declines because adults are long-lived and reproducing individuals accumulate from 4-40 years under a robust age structure (pyramid shaped). Adults are capable of spawning every year, but the survival of eggs and fry depends on annual environmental conditions, and there are likely some individuals that exhibit skip spawning.

The principle issues that drive humpback chub populations are reproduction and recruitment. Redundancy, or the existence of multiple populations, is an important attribute of species conservation and eventual recovery. In Grand Canyon, the majority of spawning occurs in the LCR, a relatively small seasonally warmed tributary that is susceptible to catastrophic events, such as a toxic chemical spill at the Cameron Bridge. An evaluation for a second spawning aggregation determined that the most likely and most effective strategy would be for a mainstem population to become established downstream of the LCR, specifically in Middle Granite Gorge, or at the confluence of Shinumo, Havasu, Tapeats, or Kanab creeks. Tributaries in the Grand Canyon, other than the LCR, are too small to support a sizeable spawning population. Larvae and juvenile humpback chub were found in these areas during warm dam releases in 2004-2011, suggesting mainstem spawning. Translocations of humpback chub to Shinumo Creek and Havasu Creek may help mainstem populations become established in the vicinity of these tributaries. Monitoring in these areas has been insufficient for determining if spawning is occurring, the extent of that spawning, whether young are surviving and recruiting, and the likelihood of a spawning population becoming established independent of the LCR population. Given the recent increases to the LCR population of humpback chub, the viability of the species in the Grand Canyon could be secured with a second separate population.

No specific flow actions have been implemented and linked directly to benefit adult humpback chub, although there are indirect relationships to increased trout predation, food base, and temperature. However, there appear to be direct and indirect linkages between flow and juvenile humpback chub.

1. Annual juvenile humpback chub survival in the mainstem is about 45-80% in the NSE reach near the LCR confluence. Survival rates elsewhere are unknown. There were no obvious differences in survival rates during the fall periods of experimental steady flows in 2009 and 2010 (Pine *et al*. unpublished). The NSE study was designed to address flow fluctuations and steady flows – Do fish survive better under MLFF or fall steady flows? Growth declined during steady flows, despite higher water temperatures in fall periods compared to summer MLFF. Steady flows were confounded with potential seasonal declines in daily growth rate, but summer steady flows in 2011 offered a contrast over previous years, and juvenile humpback chub still had lower growth than during MLFF. Humpback chub survival was lower during steady flows, but the difference was not significant as the 95% confidence intervals overlapped. Maximum likelihood point estimates for apparent survival have been declining since beginning of NSE (2008) but that may be due to low sample size or increasing trout abundance especially in the NSE reach below the LCR.
2. Juvenile humpback chub use a variety of habitats generally in proportion to their availability. During the NSE study, backwaters were disproportionally selected for when available and humpback chub density was relatively high in backwater habitats. However, in the NSE study reach backwaters made up only a small portion (1-2%) of available habitats in the NSE study area, so the contribution to the overall population coming from humpback chub living in backwater habitats was small compared to other more common habitats. Additionally, backwater habitats in the NSE reach were not permanent (would become submerged or erode away), yet juvenile humpback chub persist in the NSE reach despite intermittent loss of backwaters. This suggests backwater habitats are not required. Occupancy was high across all habitat types—may be because humpback chub are in high abundance and thus all habitats are being utilized.
3. Volume of flow is the greatest determinant of the rate of downstream warming of stream flow – higher volumes of flow decrease the rate of warming. There is no significant difference between steady and fluctuating flows. Flow volume, not release pattern, controls downstream warming. Refugia areas along the shore warm to a greater extent during steady flows but are of limited area.
4. Backwaters exhibited lower relative predation risk by aquatic predators than other habitat types in the NSE tethering experiments. Note that this study did not consider avian predation risk which has been demonstrated as an important factor in the upper basin.
5. The humpback chub is an obligate warm-water species that requires relatively warm temperatures for spawning, egg incubation, and survival of larvae. Highest hatching success is at 19–20°C with incubation time of 3 days, and highest larval survival is slightly warmer at 21–22°C. Hatching success under laboratory conditions was 12%, 62%, 84%, and 79% in 12–13°C, 16–17°C, 19–20°C, and 21–22°C, respectively, whereas survival of larvae was 15%, 91%, 95%, and 99%, at the same respective temperatures (Hamman 1982). Although humpback chub may spawn in the LCR over a period of time, spawning activity is generally highest in March. There is little evidence of mainstem spawning readiness (i.e., coloration, tubercles, expression of gametes) until May. Any attempts to provide warm water for mainstem spawning must take into consideration this seasonal

timing of spawning readiness and also suitable warming for larval development and growth to juveniles. The only availability of warm water to the mainstem is from the surface waters of Lake Powell where warmest temperatures during low reservoir elevation occur in September and October. At a rate of 1ºC/35-40 miles, dam release temperature would have to be at least 12 ºC in April, May, or June to warm to the minimum spawning temperature of 16 ºC at the Middle Granite Gorge aggregation (RM 126 + 16 = 142 miles). Even at low reservoir elevation, surface temperatures of Lake Powell do not warm to 12 ºC until July. This complicates efforts to use flows to warm the mainstem during ecologically important times using current infrastructure.

Sediment for Beaches and Habitat

1. Concentration of suspended sand increases exponentially with increasing discharge. HFEs are intended to occur during the highest sand concentrations. Predicting the amount of sand transport for any specific discharge has great uncertainty, but generally shows that there is a 1.5x to 2x greater transport rate for a typical large fluctuation range than for a steady flow of the same volume. Mainstem transport rate greatly increases when there is very fine sediment available for transport. Implications are that immediately after an input of very fine sand from a tributary (Paria River), the mainstem exports that fine sand quickly. Rubin *et al.* (2002) estimated a few weeks to a few months to export half a hypothetical 500,000 ton supply.
2. Maintaining positive mass balance is very hard downstream of Glen Canyon Dam. The available supply is quickly depleted under an HFE and there is significant transport even during typical base flows (Topping et al 2010).
3. Sediment input minus output in the mass balance model represents a change in storage on river bed and banks.
4. Not every sandbar has eroded to the same extent; some are relatively stable or have increased, while others have eroded. Changes in sand bar area are the result of geomorphic and biological processes.
5. Total amount of campsite area has declined (NAU time series). Campable area (a.k.a. campsite capacity) is declining faster/more steadily than sand bar area, thus vegetation encroachment appears to be a primary (but not the only) cause of this difference.
6. We know it is important to follow sediment inputs with an HFE so that the sediment isn’t transported out of the canyon. The more stability of flows between HFEs the better for sediment retention, but there is a tradeoff with other resources.
7. It may be possible to maintain sandbar size between HFEs, such that sandbar size can be increased and maintained over several years. But, this is based on only 3 HFEs, with 6% of the natural sand supply. We should have different expectations for different reaches (Glen Canyon, Marble Canyon, Grand Canyon east and west).

Aquatic Food base

Glen Canyon

1. Autochthonous organic matter, specifically diatoms, is the base of the aquatic food web in Glen Canyon. Evidence for this conclusion comes from diet and stable isotope analyses, and trophic basis of production calculations for invertebrates and rainbow trout (Kennedy *et al.* 2012).
2. The production of native and non-native fishes throughout Glen and Grand Canyons is principally fueled by two aquatic insect taxa, *Chironomidae* and *Simuliidae* (midges and black flies); this is a shift from a predominance of Gammarus and Cladophora pre-MLFF. Evidence for this conclusion comes from diet and trophic basis of production calculations for the entire assemblage of fishes. Midges and black flies account for 45-61% of production and Diatoms and detritus are an additional 20-40% of production at native fish sites, (e.g., 60 mile, LCR). Fish production throughout the river appears limited by the availability of high quality food, demand appears to be higher than availability at the LCR (in 2008)
3. Fish production throughout Glen and Grand Canyons appears limited by the availability of high quality prey, particularly *Chironomidae* and *Simuliidae*, and fish may exert top-down control on these prey species. This conclusion derives from calculations of the trophic basis of fish production and interaction strengths between fishes and their invertebrate prey (*Kennedy et al.* 2012; Donner 2011).
4. High flow events can exert a strong control on invertebrate assemblages and secondary production in the tailwater reach. Evidence for this conclusion comes from intensive sampling of benthic and drifting invertebrates before and after the March 2008 artificial flood. The 2008 spring HFE caused a reduction in snails and scuds but increased populations of black flies and midges resulting in an increase in trout. This resulted in increased downstream migration of rainbow trout to LCR, but didn't increase food supply in Grand Canyon, only increased food supply in Glen Canyon, which only benefited trout not native fish. Increased immigration of trout to native fish reaches has resulted in increased predation and competition with native fishes.
5. Fish production was dominated by rainbow trout at upstream sites (i.e., RKM 0 and 48) and flannelmouth sucker at downstream sites (i.e., RKM 204, 266, and 362), and production was comparable among sites. Evidence for this conclusion comes from fish production calculations for two years and six sites (Kennedy *et al.* 2012).

Grand Canyon

6. A combination of autochthonous and allochthonous organic matter is the base of the aquatic food web in Grand Canyon, but high quality algal matter supports the food web to an extent disproportionate to its availability. Evidence for this conclusion comes from organic matter budgets, diet and stable isotope analyses, and trophic basis of production calculations for invertebrates and rainbow trout (Kennedy et al. 2012).
7. Native fish in Grand Canyon rely on a limited supply of invertebrate prey populations (midges and black flies) that may be limited by food supply.

8. Invertebrate production exhibits stepped declines below the Paria and Little Colorado Rivers, and production at sites below the Little Colorado River is extremely low relative to other streams and rivers. Evidence for this conclusion comes from three years of benthic invertebrate sampling and secondary production calculations at six sites (Kennedy et al. 2012).
9. The trophic basis of production of fishes overlaps and because these resources may be in limited supply there is strong potential for competition among native and non-native species. This conclusion stems from detailed analysis of fish diets, and calculations of trophic basis of fish production, and interaction strengths between fishes and their invertebrate prey. Nonnative fish prey on and compete with native fishes.
10. Production is limited and that limitation may be caused by the invertebrate taxa found in Grand Canyon (food for fish).
11. Dam operations (e.g., artificial floods) that affect invertebrates can cause changes in fish production. Fish movement downstream may also change these food webs. Evidence for this conclusion comes from detailed descriptions of food webs in Glen and Grand Canyons before and after the 2008 artificial flood. Thus, any factors that affect primary production or invertebrate prey will likely affect fish populations.
12. Turbidity strongly controls algal production in Grand Canyon (Hall *et al.* in prep or Kennedy?). Daily estimates of metabolism for the Colorado River near Diamond Creek across a range of flows and turbidity support this conclusion (Kennedy *et al.* 2012).

<u>Lees Ferry Rainbow Trout Fishery</u>

1. Rainbow trout have responded positively to a variety of flow events, e.g., MLFF, 1996 BHBF, 2000 LSSF, Drought (2000s), and 2008 HFE (Korman *et al.* 2011).
2. Present juvenile trout abundance in Glen Canyon is unprecedented, higher than record and may be extending into Marble Canyon.
3. The Lees Ferry recreational fishery was once a stocked fishery, but now is self-sustaining with perhaps a different strain of trout than in the “trophy” years.
4. No signature of trout production seen from the 2004 fall HFE. Possible factors which may have masked a result include: timing, warm temperatures, low dissolved oxygen (DO), or trout management flows. In addition, the number of replicates is too small.
5. Trout production at Lees Ferry and then emigration to Marble Canyon and the LCR are tightly linked. Timing and specific conditions which cause emigration are somewhat uncertain but the Natal Origins study is focusing on these questions now.
6. It is well established that rainbow trout significantly reduce feeding attempts under low water clarity (i.e., < 30 NTUs). Introducing turbidity into the mainstem may help to control abundance of trout below the Paria River and eliminate the need for mechanical removal.

Science and Management Questions

It is critical that this alternative ask and describe how it will answer critical science and management questions. Below is a list of the most critical questions which must be answerable by the end of the LTEMP EIS lifetime (20 years):

Humpback Chub Recovery (and Other Native Fish)

1. What is the importance of the mainstem to humpback chub recovery?
2. What is the relative importance of predation and competition by trout in the mainstem on humpback chub at the individual and population level?
3. Is the LCR humpback chub population limited based on current humpback chub population numbers or expected future numbers?
4. Will a return to colder mainstem water temperatures result in a stabilization or decline in the humpback chub population? Are the drivers related to growth rates or food base availability, or other related factors?
5. Is there humpback chub reproduction in the mainstem? What are the factors limiting humpback chub reproduction in the mainstem?
6. Can the recovery of humpback chub be expanded and ensured by expanding the current range of humpback chub into suitable unused tributaries (e.g., Shinumo creek, Havasu Creek, Bright Angel Creek, and in the LCR upstream of Chute Falls)?

Sediment for Beaches and Habitat

1. Can the decline in sediment and campable area be reversed using flow and non-flow options with remaining downstream sand supplies from tributaries (Paria and Little Colorado Rivers and lesser tributaries)?
2. What is the need of native aquatic resources for sediment, specifically backwater habitats?
3. Can dam operations be used to enhance sediment conservation to promote in-situ preservation of archaeological sites?
4. Will high flow experiments affect the water quality released from Glen Canyon Dam?
5. Can rapid response high flows result in greater or more ecological important sediment retention in beaches and backwaters than the store and release HFE?

Aquatic Food Base for Biological Goals

The Aquatic Food Base Study provided a great deal of critical information needed for Glen Canyon Dam Adaptive Management Program Strategic Goal 1, but also identified several key information needs.

1. What would a more naturalized flow and thermal regime do in Grand Canyon for the food base? What can existing research tell us about the status of the food base in the upper basin?
2. What is the importance of tributaries (especially the LCR) in influencing or augmenting the food base for fishes in the Colorado River mainstem? What drives humpback chub recruitment (good year classes), is it food related?
3. How do flow manipulations affect aquatic food webs and food resources for desired fish species in Glen and Grand Canyons? Will future planned spring-timed High Flow Events elicit a similar food web and ecosystem response as observed in 2008? Can flows be used to enhance food base, or is everything temperature related?
4. Increased fluctuations increase food availability to a point. Is there a threshold between steady and high fluctuating flows where food availability is maximized?
5. How have increases in the rainbow trout population near the Little Colorado River confluence altered the food web and potential competition for food?
6. What were the food web and ecosystem characteristics of the pre-dam Colorado River?
7. To what degree do desired fish species limit their food base, and does this limitation directly influence the reproduction and recruitment of desired fishes—particularly humpback chub?
8. How might aquatic food webs and food resources for desirable fish species be affected by changes to Glen Canyon Dam releases anticipated to result from long-term changes in climate, runoff, and water management? In particular, future dam releases may include wider swings in water temperature and quality.
9. The transition in flow volume from one month to the next can be a substantial change. Low volume months, such as a 600,000 af month, can be followed by a month that exceeds 900,000 af. These large transitions may have a negative impact on food base productivity. To what degree do changes in monthly volumes affect food base production? If there are impacts, what type of transition flows would be necessary to support a healthy food base?

Lees Ferry Rainbow Trout Fishery

1. To what extent do fall- and spring-timed HFEs stimulate rainbow trout production and growth?
2. How effective are rainbow trout management flows at reducing recruitment in Glen Canyon?
3. To what extent does the level of rainbow trout recruitment in Glen Canyon affect migration rates into Marble Canyon and eventually to the LCR inflow reach? How do other aspects of the flow regime affect migration?
4. What factors control the size and condition of rainbow trout in Glen Canyon (density, food density, size of prey items) and how can dam operations be altered to improve food availability and maximize growth?

Appendix E – Literature Cited

Donner, K.C. 2011. Trophic basis of production of fishes in the Colorado River, Grand Canyon: An assessment of potential competition for food. M.S. Thesis, Department of Biological Sciences, Idaho State University, Pocatello, ID.

Hamman, R.L. 1982. Spawning and culture of humpback chub. Progressive Fish-Culturist 44: 213–216.

Kennedy, T., C. Baxter, R. Hall, E. Rosi-Marshall and W. Cross. 2012. A Summary of Research Conducted in Support of the Glen Canyon Dam Adaptive Management Program's Goal 1—Aquatic Foodbase—Including Draft Monitoring Protocols. Unpublished.

Rubin, DM, D.J. Topping, J.C. Schmidt, J. Hazel, M. Kaplinski, and T.S. Melis. 2002. Recent sediment studies refute Glen Canyon Dam hypothesis: EOS, June, 2002.

Topping, D.J., D.M. Rubin, and L.E. Vierra, Jr. 2000. Colorado River sediment transport 1. natural sediment supply limitation and the influence of Glen Canyon Dam. Water Resources Research 36:515-42.

Topping, D.J., D.M. Rubin, P.E. Grams, R.E. Griffiths, T.A. Sabol, N. Voichick, R.B. Tusso, K.M. Vanaman, and R.R. McDonald. 2010. Sediment transport during three controlled flood experiments on the Colorado River downstream from Glen Canyon Dam, with implications for eddy-sandbar deposition in Grand Canyon National Park: U.S. Geological Survey Open-File Report 2010-1128, 111 p.