PROPOSED Knowledge Assessment II STEPS (WORKSHOPS) DURING FY 2011

Presented by: Ted Melis, USGS, Grand Canyon Monitoring and Research Center

March 8, 2011

STEP I – TWG reviews the 2006 draft Knowledge Assessment I report & participates in GCRMC WebEx – proposed dates: week of March 28th– 2-3 hour long session (please respond to Doodle Query from Linda Whetton the week of March 14th)

OBJECTIVES:

Review the GCDAMP resource goals - relative to AMWG's recently developed "*Desired Future Conditions*" 1) Colorado River Ecosystem, 2) Recreation, 3) Hydropower and 4) Cultural

Review Experimental Treatments – flow or non-flow treatments that *have been conducted* and for which data/models exist. Questions: Are there any new treatments that have been implemented since 2005? Should any treatments evaluated in 2005 be eliminated?

Review 2005 KA I Questions – also included in the 2007-11 Monitoring & Research Plan (Draft Final KA report, 2006, with particular attention to pages 59-64)

TASK for TWG WebEx: Are there any new questions that need to be considered in the KA II during 2011?

- Presumably new questions would then also be integrated into development of the new 5-Year Monitoring & Research Plan in FY 2012 (FY 2012-16).
- Can questions be removed from the 2005 list?

Step II – Convene Expert Workshops

GCMRC will solicit “expert” opinions on the questions in the various resource matrices and develop a more quantitative summary of “certainty” or “uncertainty” on basis of existing data and models that exist which might predict the direction of a given resource in response to various experimental treatments that have been previously tested, as well as the “magnitude” of that response if the direction can be predicted.

Step III – Convene Stakeholder Workshop

GCMRC proposes to convene a workshop with TWG in fall 2011 (early November) to review the "expert" input on the questions and discuss the next steps to reporting that update of the Knowledge Assessment and integrating the new information into the 5-Year MRP, 2013-16) and other efforts, such as the LTEMP EIS, etc. to support the GCDAMP program.

STEP IV – FY 2012, finalize report on KA II

GCMRC would complete and distribute final report to TWG and AMWG in late summer/fall 2012.

FACILITATION AND LEADERS IN KA II

Lead Facilitators: Josh Korman (Ecometric Research, Inc. [existing science cooperator]) & Ted Melis (GCMRC)

KA II Resource Leaders: Cooperating scientists and GCMRC staff who will convene "expert" panels and solicit quantified opinions on the ability of existing information to answer the questions specific to the resources, as grouped into the 4 recently developed DFCs.

Colorado River Ecosystem:

- **Aquatics (Fish and Food, Goals 1-4), Walters, Korman, Persons, Kennedy**
- **Terrestrial Spring Habitats & Riparian Vegetation (Goals 5-6), Ralston**
- **Sediment and Quality-of-Water + including Lake Powell (Goals 7-8), Grams**

Recreation:

- **Lees Ferry Sport Fishery, rafting, camping & related activities in GCNRA & GCNP (Goal 9), Fairley**

Hydropower:

- **Glen Canyon Dam electrical generating capacity (Goal 10), Fairley**

Cultural Resources:

- **TCPs, arch sites, etc. (Goal 11), Fairley**

Relating to Goal 12 (maintain quality adaptive management program), there may be additional KA II efforts to evaluate the past performance of the GCDAMP through questions that may be offered by DOI leadership, etc. The KA II would make every effort to incorporate the recent guidance on priorities for the GCDAMP.

Whetton, Linda A

From: Whetton, Linda A
Sent: Thursday, March 17, 2011 11:44 AM
To: 'Balsom, Jan'; 'Barrett, Clifford'; 'Bills, Debra'; 'Bulletts, Charley'; 'Capron, Shane'; 'Caramanian, Lori'; 'Christensen, Kerry'; 'Cox, Jerry'; Crawford, Marianne; 'Davis, William E.'; 'Dongoske, Kurt'; 'Halliday, John Dennis'; 'Harms, Paul'; 'Harris, Christopher S.'; 'Henderson, Norm'; 'Heuslein, Amy'; 'Johnson, Rick'; 'Jordan, John'; 'King, Robert'; Knowles, Glen W; 'Kowalski, Ted'; 'Kubly, Dennis'; 'Kyriss, LaVerne'; 'LaGory, Kirk'; 'McCraw, Patricia'; 'Nimkin, David'; 'Noojibail, Gopaul'; 'Orton, Mary'; 'Peterson, McClain'; 'Shields, John W.'; 'Spiller, Sam'; 'Sponholtz, Pam'; 'Stevens, Larry'; 'Stewart, Bill'; 'Wegner, David'; 'Yazzie, Curtis'; 'Yeatts, Michael'; 'Benemelis, Perri'; 'Bennion, David'; 'Cantley, Garry'; 'Jackson-Kelly, Loretta'; 'James, Leslie'; 'Jansen, Sam'; 'Lash, Nikola'; 'Makinster, Andy'; Ostler, Don; 'Palmer, S. Clayton'; 'Seaholm, Randy'; 'Thiriot, James'
Cc: 'Bennett, Glenn'; 'Daugherty, Mary'; 'Fairley, Helen'; 'Garrett, David'; 'Grams, Paul'; 'Kitchell, Kate'; 'Mankiller, Serena'; 'Melis, Ted'; 'Pistorius, Shelley'; 'Sogge, Mark'
Subject: Reminder: Availability for GCMRC WebEx
Attachments: Knowledge_Assessment_06aug30.pdf; KA II TWG briefing_MAR TWG_030811.ppt

Importance: High

This is a follow-up to the message I sent on March 10th requesting your availability to participate in a WebEx meeting/conf call for 2-3 hours during the week of March 28-April 1. Listed at the end of this message is the "doodle" link. Please fill in your availability for a 2-3 hour time block between the hours of 8:00 a.m. – 5:00 p.m. PLEASE RESPOND BY NOON THIS FRIDAY, March 18th so the date can be scheduled.

Attached is the PPT which contains the briefing information Ted presented at the last TWG meeting along with the Knowledge Assessment Report. TWG members/alternates should review it to get clarification about what their assignment is prior to the WebEx and the objectives that need to be accomplished during this STEP I exercise. This knowledge assessment concerns the status of knowledge about all GCDAMP resource goals, not just fish.

http://www.doodle.com/8f2ymnbc4fbsedrw

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2005 Knowledge Assessment of the Effects of Glen Canyon Dam on the Colorado River Ecosystem: An Experimental Planning Support Document

A report of the USGS Grand Canyon Monitoring and Research Center

By Theodore S. Melis, Scott A. Wright, Barbara E. Ralston, Helen C. Fairley, Theodore A. Kennedy, Matthew E. Andersen, and Lewis G. Coggins, Jr.

In cooperation with Josh Korman, Ecometric Research, Inc.

Final Draft, August 30, 2006

Acknowledgements

This report documents results from two knowledge assessment workshops conducted in May and July, 2005. The content of this report was enhanced by the wisdom of participants attending the Knowledge Assessment Workshop I, conducted during the May 18, 2005, Technical Work Group meeting held in Phoenix, Ariz., and the Knowledge Assessment Workshop II, which took place July 5–8, 2005, in Flagstaff, Ariz.

Andre Potochnik
Gary Burton
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Norm Henderson
David Topping
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Abe Springer
Lisa Leap
Wendy Batham
Mike Yard
Bill Werner
Chris Kincaid
Matthew Anderson
David Rubin
Bill Vernieu
Susan Hueftle
Lloyd Greiner

All participants were given a draft version of this report and asked to comment on it. This document was revised on the basis of comments received from the participants, as well as additional comments provided by the Science Advisors in February 2006.

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1.0 Introduction

Background - An active adaptive ecosystem assessment and management approach to managing resources below Glen Canyon Dam (GCD) has been applied since approximately 1990. At that time, and in conjunction with the preparation of a major environmental impact statement on dam operations, a series of test flows were released from the dam. These test flows were conducted from June 1990 to August 1991, and represented the initial attempt to experiment with alternative operations to promote learning about how dam releases influence downstream natural and cultural resources of the Colorado River in Grand Canyon. Additional experimental treatments were implemented following the test flows of 1990, such as the first test of the beach/habitat-building flows concept (BHBF) in March 1996, the first test of the habitat maintenance flows (HMF) in 1997, and the low summer steady flow (LSSF) of 2000. A significant turning point in the ongoing science planning process occurred during the 1996–97 period, following formation of the Glen Canyon Dam Adaptive Management Program (GCDAMP) and its Federal Advisory Committee, the Adaptive Management Work Group (AMWG). Since 1997, the AMWG and its Technical Work Group (TWG) have been actively involved in the science planning process and have periodically forwarded experimental recommendations to the Department of the Interior for testing Glen Canyon Dam operations.

At the recommendation of the AMWG, longer range experimental planning was intensively undertaken by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) in 2002, and the first phase of a long-term experimental design was recommended for implementation. Several flow and nonflow treatments described in the 2002 experimental plan began at the direction of the Secretary of the Interior in January 2003, and the first 4 years of experimental treatments in that design are set to continue through at least 2006. Testing of the BHBF concept immediately following tributary sand inputs of at least 800,000 metric tons was implemented in November 2004 (Topping and others, 2006), which was the primary recommendation of sediment researchers.

Overview of Experimentation - All of the experimental treatments implemented before 2003 were evaluated as isolated events in time and some were criticized by science reviewers as being of such short duration that biological hypotheses tied to them might never be resolved.

Between 1989 and 1995, planning for various flow experiments was undertaken jointly by the Bureau of Reclamation (Reclamation) and the U.S. Geological Survey, and included numerous and varied science cooperators. Most of this planning focused on the question of how various types of flows released from the dam would influence the transport and retention of fine sediment throughout Grand Canyon. The planning effort culminated in a large-scale field experiment in 1996, termed the controlled flood by scientists (Webb and others, 1999). This test focused on the concept of using an artificial flood release, termed the beach/habitat-building flows, or BHBF, to restore eroded sandbars using newly accumulated sand supplies provided by tributary floods. Following establishment of the Adaptive Management Work Group (September 1997), several attempts were made to deal with the issue of experimental design. For example, some design work was undertaken through competitively procured research contracts (identification of concepts and elements tied to a test of the seasonally adjusted steady flow operating alternative in 1998–99). Following this design study, a steady flow test was conducted from June through August 2000, termed the low summer steady flow, or LSSF, test. Results from this test are still being evaluated with respect to fishery responses, but humpback chub adult population data collected through 2005 suggests that this species may have benefited from the 2000 LSSF, which is indicated by a stabilization of the humpback chub adult population that began around 2000 (Melis and others, 2006).

In 2002, the GCMRC proposed implementation of a 16-year long experimental design to address uncertainties associated with management of sediment and fisheries resources below Glen Canyon Dam. The main treatments within the experimental design included: 1) additional testing of the BHBF concept to restore and maintain sandbars and related habitats, 2) evaluation of expanded diurnal fluctuations intended to limit reproduction and recruitment of nonnative fish, and 3) repeated mechanical removal of nonnative coldwater fish from the Colorado River ecosystem (CRE) in the vicinity of the Little Colorado River confluence. This last treatment was intended to limit competition for food between nonnative and native fish, as well as minimize predation of natives by nonnative species to promote recruitment of native humpback chub. Mechanical removal was proposed to be implemented in 4 consecutive years (2003–6), with six removal trips occurring each year. The flow-suppression treatment was intended to overlap with the mechanical removal treatment of the first 2 years, and then be suspended in the final 2 years of the mechanical removal effort. The sediment experiments (implementation of a 2.5-day BHBF release following introduction of new sediment supplies from the Paria River) was proposed to be implemented in the first year in which fine-sediment production from the Paria River reached or exceeded 800,000 metric tons.

In response to the 16-year experimental proposal, the AMWG recommended to the Secretary of the Interior that only the first two annual treatments (the BHBF and expanded diurnal fluctuations) be undertaken starting in 2003, and that the first of several proposed sediment tests be implemented at the first opportunity (agreed upon levels of fine-sediment enrichment from Paria River). The sediment test was conducted in November 2004, following the required inputs. Mechanical removal of nonnative fish in Marble Canyon was conducted from January 2003 to August 2006. Nonnative suppression flows were conducted for 3 consecutive years from 2003 to 2005 to be followed by a return to the modified low fluctuating flow (MLFF) alternative (the “preferred alternative” in the 1995 Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS)) in 2006.

The 2003 through 2006 treatments are unique in that some treatments were repeated over multiple years (alternative fluctuations in winter and nonnative removal) and coincided more closely with the early life-history stages and recruitment of higher trophic organisms such as native fishes. As a consequence of persistent upper Colorado River Basin drought and decreased storage in Lake Powell warmer water releases from Glen

Canyon Dam coincidentally started in the same year as experimental removal of nonnative fishes and have continued each summer and fall into 2006. Although unplanned, the combination of warm releases and successful reduction in downstream nonnative fish abundance has the potential to result in a recruitment signal with respect humpback chub response below Glen Canyon Dam. Because of the lag effect in the early life history of native fishes, recruitment data for humpback chub entering the system in 2003 through 2006 cannot be fully assessed through monitoring and modeling efforts until at least 2007 through 2010. Although qualitative in nature, catch-per-unit-effort data for data for native species of fish (derived from nonnative removal activities) in summer 2005, and seining data from backwater habitats in September 2005 in lower Marble Canyon, show that abundance of juvenile humpback chub increased compared with 2003 through 2004 data (Melis and others, 2006). While juvenile abundance cannot be interpreted to be an indicator for recruitment of native fishes, the data are an encouraging sign that may be tied to reduced trout and other nonnative fish abundance, newly modified sandbar habitats (resulting from the November 2004 sediment, high-flow test) and consistently warmer main channel water temperatures below the dam.

The process of evaluating new information from past or current experimental actions, as well as planning new experiments, is ongoing and can be historically characterized within at least four phases of study: (1) Phase I involved early studies by the National Park Service and the Glen Canyon Environmental Studies (GCES I, 1972–88), (2) Phase II was marked by the preparation of the EIS (GCES II, 1989–95), (3) Phase III included the formation of the GCMRC and transition monitoring and flow experiments (Post-EIS, 1995–2000), and (4) Phase IV as represented by research in support of monitoring design and conceptual modeling (Integrated Experimental Phase I, 2001–6). (For more details on the use of conceptual modeling of the Colorado River ecosystem in science planning, see Walters and others, 2000; and Melis and others, 2005.) Each of the phases represents a unique period of advancement in learning about how dam operations are related to downstream resources. However, Phase IV is perhaps the most unique era in the program because it represents the first period in which the concept of an experimental design was implemented for more than a single year.

To further promote the idea of learning under an ongoing experimental design, in 2005 managers involved in the Glen Canyon project embraced the idea of continuing the experimental process in future years. The goal of the planning process was to maintain an active adaptive management effort that focuses experimental research on reducing uncertainty about proposed management actions for achieving environmental objectives below Glen Canyon Dam. As a milestone in the planning process, which occurred near the end of Phase IV, a *knowledge assessment*, which relied on the participation of knowledgeable scientists and managers in a workshop setting, was mandated by the AMWG. The knowledge assessment was intended to document learning about the various experimental treatments that had been conducted since operations were first altered in 1991. In 2005, the scientists complied with this request as a first step in the next phase of planning and experimental design (Phase V).

The objectives of the knowledge assessment were to: (1) evaluate the uncertainties that persist regarding individual resource attribute responses of the Colorado River ecosystem to the various management actions (both flow and nonflow elements) undertaken as experiments over the last two decades, (2) develop strategic science questions that would need to be addressed to further reduce the uncertainties associated with the various flow and nonflow treatments, and (3) identify research and monitoring strategies that might need to be undertaken to answer the science questions identified. The 2005 knowledge assessment was conducted within two workshops (May and July 2005), both of which promoted information transfer between scientists, as well as focused discussion between scientists and managers about past research and monitoring relative to various treatments. The experimental treatments evaluated during the discussions, included knowledge gained about both flow and nonflow actions (artificial floods to restore beaches and mechanical removal of exotic coldwater fishes). As a frame of reference for evaluation and discussion purposes, particular emphasis was centered on the MLFF operating criteria for dam releases, the “preferred alternative” identified in the Record of Decision (ROD) that was implemented by the Department of the Interior in 1996.

One anticipated outcome of the knowledge assessment process was that certain treatments might be understood well enough that additional experimentation was not required to move the treatment into the category of a fully implemented management action. Alternatively, knowledge about a particular treatment might also be so complete and the benefit of the treatment with respect to downstream resources so small (or possibly even detrimental relative to stated environmental goals) that the treatment option might be abandoned completely. If an action was deemed beneficial and transferred to “management status,” it would be routinely implemented and only dealt with in the science program in the context of conceptual modeling and monitoring for status and trends of the targeted resources. It is important to note that classification of an action to “management status” is a decision that depends not only on scientific certainty, but also on values concerning restoration and financial impacts. For example, there is considerable scientific uncertainty about whether mechanical removal of nonnative rainbow trout and other nonnative fishes will result in a long-term increase in the abundance of native humpback chub. Nevertheless, mechanical removal could be given “management status” if the perceived potential restoration benefits outweighs the financial costs and impacts on other resources. We stress that our classification of certainty of various management actions is purely based on a scientific assessment using the available data. We make no attempt to integrate this assessment with our perception of stakeholder values to classify actions into “management” and “experimental” status.

This report documents and summarizes the results from the GCMRC’s 2005 knowledge assessment workshops. The report is not intended to provide a state of knowledge about the Colorado River ecosystem. This would require an extensive literature review and a level of effort that is well beyond the original scope of the knowledge assessment. This summary report documents what was discussed at the two knowledge assessment workshops. Citations are provided when they apply to particular discussions. This level of documentation is more than sufficient for experimental planning and framing of key science questions, which are the primary objectives of the knowledge assessment. During summer and fall 2006, the information contained in this summary report provided the basis or current knowledge for evaluating the biophysical and sociocultural resource implications associated with three experimental options (Options A, B, and C) proposed by members of the Science Planning Group (an ad hoc of the Technical Work Group). As in the knowledge assessment workshops of 2005, the MLFF operating policy for Glen Canyon Dam was used in those experimental evaluations as a frame of reference for comparing the three experimental operations and management alternatives. A recommendation from the Technical Work Group for one of the three options is anticipated on the basis of the resource evaluation in winter 2006.

The knowledge assessment report is divided into four sections, including this introduction. Section 2 defines the management actions that were considered in the exercise and the general approach taken in uncertainty classification. Section 3 summarizes the results in matrices for physical science (3.1), hydropower (3.2), aquatic food base/fish (3.3), riparian habitat (3.4); recreation (3.5), and cultural (3.6) resource groups. In Section 4, the uncertainties defined in the matrices are used to develop a series of scientific questions for each major resource group.

2.0 Definition of Management Actions and Uncertainty Rankings

A consequence table or decision matrix (hereafter, referred to as the ‘matrix’) predicting the response of key performance measures (rows) to particular experimental management treatments (columns) was populated at the Knowledge Assessment Workshop (KAW). This section defines the actions considered in the exercise. These were derived mainly from those considered as part of the Glen Canyon Dam Environmental Impact Statement, but also include new flow and nonflow actions that are currently being implemented but were not defined in the EIS. Definition of performance measures is provided in Section 3. Definitions of uncertainty rankings for each prediction are provided at the end of this section (Table 2.1).

The experimental management options considered in the KAW were evaluated relative to the MLFF operations, which for the purpose of the evaluation were considered to be the experimental control. Treatments discussed and evaluated during the KAW’s included:

Increases in GCD Release Water Temperature: The increased downstream temperatures could result from naturally occurring conditions, dam operations or a combination of both factors related to: 1) the construction of a Selective Withdrawal Structure (SWS) or Temperature Control Device (TCD) at the dam, 2) reduced lake elevations associated with diminished storage resulting from prolonged drought or increases in water use by Upper Basin states or 3) release of stable versus fluctuating flows from the dam. Until recently, release temperatures from Glen Canyon Dam (GCD) ranged from 9–11°C. The increased temperatures that were considered ranged from 14–17°C between June and November.

Increased Fluctuations Relative to the Modified Low Fluctuating Flow Alternative: The extent of daily fluctuations in discharge from GCD is determined by the constraints on releases as defined in Record of Decision (up and down hourly ramping rates, maximum and minimum daily flows, maximum daily flow change). Increased daily fluctuations, such as those before 1990 (no action period) or under the recent experimental fluctuations (January–March 2003–2005) involved changing all or many of the constraints. Making such changes has a confounding influence on scientific attempts to determine cause-affect relationships for flow parameters and downstream resource responses related to ramping rates versus daily range variations. In an attempt to provide informative assessments, we attempted to predict the overall effect of increased fluctuations in the resource matrix. For future experimental flow planning, however, it will be necessary to identify the individual dam operating constraints that are most important in determining performance measure responses downstream. When possible, predictions for individual flow constraints were made, but we recognized that hourly to daily operating rules were to a large extent interrelated for a given monthly volume release.

Reduced Variation in Monthly Volume: Changes in the monthly release volume from GCD can be large. This scenario reduced the variation in release volumes across months, further flattening the annual pattern of releases, while maintaining ROD peaking capabilities over the diurnal timescale tied to the monthly release volume.

BHBFs and HMFs: Predictions about the effects of beach/habitat-building flows (41,000 to 45,000 cfs) and habitat maintenance flows (powerplant capacity ~31,500 cfs) with and without an adequate sand supply on the bed were made. Fall and winter/spring floods were considered.

Sustained Low Steady Flow: The effects of low and steady flows were predicted (8,000 cfs, as was tested in the 2000 low summer steady flows test). The timing of this scenario sometimes varied among resources. For example, low and steady flows following the monsoon season (later summer through early winter) were considered for sediment performance measures, while fish performance measures considered the summer and fall period.

Sustained High Steady Flow: This scenario considers prolonged high and steady releases of 20,000 cfs or higher as would occur when inflows are high and Lake Powell is relatively full, or to meet a specific management objective such as causing ponding at tributary mouths. The timing and duration of high flows varied among performance measures but was generally during the spring for 2 weeks to 1 month.

Mechanical Removal: These scenarios consider mechanical removal of coldwater and warmwater nonnative fish species in the mainstem and tributaries; although, only data on coldwater species were available for evaluation from recent experimental work in Marble and Grand Canyons.

Humpback Chub Hatchery Supplementation and Tributary Translocation: These scenarios consider addition of hatchery-reared juvenile fish into the mainstem, and translocation of juveniles or adults from the Lower Colorado River (LCR) to the LCR above Atomizer Falls or to other tributaries.

A prediction of the direction of response of each performance measure [decline (-), no change (0), improvement (+)] to each action was made along with a ranking of the uncertainty of the predictions. If the direction of response could not be determined the prediction was defined as highly uncertain and colored RED. If a prediction of the direction of response could be made, but was based on limited data and there was a relatively low probability that the predicted direction of response was correct (50–70%), the prediction was considered uncertain and colored YELLOW. If the prediction was based on more data **and** there was a higher probability that the direction was correct (70–90%), the prediction was considered relatively certain and was colored LIGHT GREEN. If a quantitative prediction about the magnitude of response could be made, which required substantial data integrated into a model or stock assessment procedure, the prediction was considered very certain and colored GREEN. Table 2.1 summarizes the criteria that define the four levels of uncertainty used in this analysis.

Table 2.1. Summary of definitions used to rank uncertainty of predictions in the decision matrix.

	Very Certain	**Certain**	**Uncertain**	**Very Uncertain**
Prediction	Direction and magnitude of response	Direction only	Direction only	Cannot predict direction
Supported by Data from Colorado River Ecosystem	Peer reviewed, likely involving a model. Little debate on interpretation of predictions	Peer-reviewed results, no model	Limited data, data without peer review, and likely debatable inference	No or very limited data
Data from Other Reference Systems	Validated prediction in other system that is considered a good model for CRE	Validated prediction in other system that is a weaker model for CRE	Weaker prediction from other system that is a weak model for CRE	No or very limited data in other systems. Other systems are not good model of CRE
General Theory / Conventional Wisdom	Very Strong	Good	Moderate	Low
Probability that Predicted Direction is Correct	90–100%	70–90%	50–70%	<50%

3.0 Summary of Decision Matrices

The decision matrices developed at the KAW are described in the following six sections: physical resources (3.1); hydropower (3.2); aquatic food base/fish, and Lees Ferry angling (3.3); riparian habitat (3.4); recreation (3.5); and cultural (3.6).

3.1 Physical Resources Matrix

The decision matrix for physical resources (in this draft, only the ability to predict downstream water temperature on the basis of measured or predicted release temperatures from GCD, and suspended fine-sediment flux and channel storage) was populated at the KAW and is presented in Table 3.1. Owing to time limitations at the July KAW, only a subset of the physical resources of interest were discussed: 1) average downstream water temperature in the main channel (1-dimensional) and in a variety of nearshore habitats (multidimensional), such as eddies and backwaters as related to Goal #7 of the GCDAMP Strategic Plan; 2) suspended-sediment flux between sediment producing tributaries (influx) versus downstream transport in the main channel (efflux); and 3) fine-sediment storage throughout the channel at specific stage elevations described in the GCDAMP management objectives under Goal #8. Additional resources related to quality of water in Lake Powell and downstream, as well as the flux of coarse-grained sediment will be incorporated into future knowledge assessments as experimental and monitoring planning activities continue.

3.1.1 Quality of Water – Downstream Temperature

<u>Increased Fluctuations</u> – These result in higher flow velocities during part of the diurnal pattern of hydropower generation (peak) and lower flow velocity during the trough. Increased flow velocities (and water depth) generally equate to decreased warming of water released from Glen Canyon Dam owing to increased downstream travel times, and the opposite is true for decreased velocities during the trough (Vernieu and others, 2005). Thus, the overall effect on mainstem temperature is tied to the balance between decreased warming during the peak and increased warming during the trough, and is dependent on the specifics of the increased fluctuation. For example, if the peak is increased while the low remains unchanged, this would lead to overall decreased warming. On the other hand, if the peak is left unchanged but the low is decreased then this would lead to increased warming. Wider ranging fluctuations are generally known to promote exchange between colder main channel water and warming water in nearshore habitats, such as backwaters (Hoffnagle 1996; Korman and others, 2005b; Kaplinski and others, 2004). Additional information will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

<u>Reduced Variation in Monthly Volume</u> – For any given annual release volume scheduled at the dam under the current Record of Decision, months with lower release volumes will result in lower average flow velocities. The lower velocities and depths are known to

generally promote warming as water travels downstream from the dam over longer time periods and has less volume to warm (Vernieu and others, 2005), but this varies by season. Monthly volumes that are lower during portions of the annual release where warmer water from Lake Powell is passed through the powerplant (typically late summer through fall) will promote maximum warming owing to solar radiation, but the solar warming decreases as the annual cycle of release temperature increases in the fall. Reducing the variation in the typical pattern of annual monthly volumes would tend to decrease the volumes in July and August, but would also likely increase the September and October volumes. As warmer releases occur at the dam in late summer, additional downstream warming becomes progressively more limited as solar radiation decreases in the Canyon into fall. Canyon effects from the steep walls enhance the decrease in seasonal solar radiation reaching the river. Lower peaks and slower velocities will delay travel time and promote warming for months where the flattening of the annual pattern decreases the volume relative to what would be released under the typical ROD operating strategy. Additional information will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

BHBFs and HMFs – These sustained high flows greatly increase downstream flow velocity for relatively short periods of time (2–4 days) and elevate river stage, temporarily flooding shoreline habitats. The large volume and faster downstream travel time of releases limits warming that can occur owing to solar radiation in the main channel (Vernieu and others, 2005). Because nearshore temperatures are linked to mainstem temperatures, the decreased mainstem warming would result in cooler nearshore temperature at a given site. However, shallow areas along shorelines that are not normally inundated might temporarily warm owing to limited flow depth in stagnation zones. These types of releases were originally proposed as spring events when releases from Lake Powell are not as warm as they are in late summer or fall. The transient nature of these high-flow departures suggests that their influence on the temperature regime of the river habitats may be of limited concern. Additional information will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

Sustained Low Steady Flow During Summer – These types of releases promote stability in the depth and flow velocities of the main channel and nearshore environments downstream of the dam. Reducing the velocity and depth and increasing the travel time of releases from the dam is known to have the effect of promoting warming of the water as it moves downstream (Vernieu and others, 2005). The stable element of the flow, in terms of stage, also decreased water exchange between the mainstem and eddies, thus promoting warming in nearshore environments (Kaplinski and others, 2004). Additional information will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

High Sustained Flow During Spring – Owing to higher flow velocities and depths, and decreased downstream travel times, these releases will limit warming in the main channel derived from solar radiation. Because nearshore temperatures are linked to mainstem temperatures, the decreased mainstem warming would result in cooler nearshore temperature at a given site. However, shallow areas of nearshore habitat that are temporarily inundated during these sustained periods of high flow may warm, especially in areas where flow stagnation occurs within eddies. This type of effect will be less than when flows are low steady, but the area of warming might be larger. Additional information will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

Non-GCD Actions – Nonflow treatments, such as mechanical removal, do not influence downstream water temperature. However, other nonflow elements of interest mostly include the annual pattern of solar radiation in combination with the physical aspects of the river channel within Glen, Marble, and Grand Canyons (i.e., canyon orientation and geometry, reach morphology). Tributary spates versus base flow discharges also influence the temperature of the main channel and related nearshore habitats. Additional information on these factors will be available in the future through development and application of mainstem and nearshore water temperature models by Reclamation (Amy Cutler, oral communication, August 2005) in collaboration with the USGS (Scott Wright, oral communication, August 2005).

3.1.2 Fine Sediment Storage throughout Main Channel – Suspended-Sediment Flux and related Sand Habitats

Increases in GCD Release Water Temperature – Elevated temperature of dam releases has a limiting influence on suspended-sediment transport of fine sand in the river (e.g., Lane and others, 1949; Hubbell and Ali, 1961; ASCE, 1975). This is the result of viscosity effects in the water column that enhance settling rates for certain grain sizes of sand (sand particles spend less time in suspension and more time on the channel bed, hence slowing downstream migration or export from the ecosystem for a given daily dam release). Suspended transport may also be influenced by the types of bed forms that will persist along the channel bottom. This phenomenon is thought to be most significant over the annual range of river temperatures that naturally occurred in the predam era (1–28°C) and is now relatively limited due to the anticipated range of natural warming associated with Lake Powell under drought conditions or with operation of a Selective Withdrawal Structure designed and operated to release warmer water from the reservoir (~9–15°C). The size range of particles that are known to be most influenced by water temperature effects is centered around fine sand, a size range that coincides closely with the median grain size of sand produced by the Paria and Little Colorado Rivers (Colby and Scott, 1964; Lane and others, 1949).

<u>Increased Fluctuations Relative to the Modified Low Fluctuating Flow Alternative</u>– On the basis of suspended-sediment transport theory and data, increased diurnal fluctuating flows from Glen Canyon Dam result in increased downstream transport and export of both newly input <u>and</u> background sand from areas of the river channel within the range allowed under the current ROD (DOI, 1995). Laursen and others (1976) estimated that the Colorado River below Glen Canyon Dam would persist in a sand deficit state under the range of unconstrained fluctuating-flow operations associated with the legal mandates for downstream water transfers, the powerplant design, and historical Upper Colorado River basin hydrology. This conclusion was made on the basis of the limited sand supply available from tributaries below the dam as well as the fine-grained nature of those sand inputs. In fact, Laursen and others' (1976) over estimated the level of sand transport below the dam for operations that occurred during the so called "no-action" period from 1966 to 1990. However, more recent, high-resolution suspended-sediment measurements made over a range of sediment supply conditions below the dam (Topping and others, 2004; Topping and others, 2006) still support Laursen and others (1976) conclusion that the river system persists in a state of sand deficit, even under Modified Low Fluctuating Flow operations during consecutive years (2000 through 2004) of minimum hydrology and associated release operations required under the 1996 ROD (Rubin and others, 2002; Topping and others, 2000a; 2000b). The only documented departure from this persistent state of sand deficit occurred in association with the November 2004 high-flow sediment test which resulted in a net positive sand mass balance for the ecosystem (Topping and others, 2006) when a short-duration high flow of 41,000 cfs (60-hour duration) was released following a period of Paria River sand inputs (equal to about the long-term historical median annual input). The sand mass balance of the ecosystem also benefited during Water Year 2004–5, from intermittent sand inputs from the Little Colorado River following the 2004 test, throughout winter 2005–6.

<u>Daily Peak Flows</u> - Increasing the daily range of peaking power generation may result in: 1) higher peaks than would otherwise occur, 2) daily peaks that are of longer duration than would otherwise occur, or 3) a combination of both diurnal operational elements. Both the MLFF operation and any other operations that promote higher or longer-duration diurnal peak flows are known to promote: 1) export of new tributary sand introduced to the ecosystem that resides in the main channel, 2) export of pre-existing sand stored in similar environments and 3) sandbar erosion of deposits that exist both above and below the allowable daily fluctuating flow peak of 25,000 cfs (DOI, 1995; Topping and others, 2004; Rubin and others, 2002; Schmidt and others, 2004; Topping and others, 2006). Changes in the daily pattern of fluctuating releases that do not result in increased daily peak flow, but lower daily minimum releases will also result in higher sand export for a given monthly release volume as such patterns result in longer duration peak flows each day. The elevated sand transport occurs owing to the fact that sand conservation associated with suspended transport during the lower daily minimum releases is more than equaled by higher transport rates during the extended duration of the daily peak flow. This phenomenon is related to the exponential relationship that exists between suspended-sand transport and discharge in general. In the Colorado River

ecosystem, high-resolution suspended-sand monitoring indicates that this exponential relationship is to the 4^{th} or 5^{th} power.

The sand transport dynamics of the Colorado River below Glen Canyon Dam have been related to geomorphic changes of sand deposits through detailed studies and recent synthesis of those research results (Schmidt and others, 2004). Historical sandbar mapping data (Schmidt and Graf, 1990) showed rapid erosion rates between 1986 and 1990 (period of unconstrained fluctuations) following deposition of large sandbars created during the 1983–84 period of high-flow releases. Schmidt and others (2004) determined that the area of sandbars was decreased by about 25 percent between 1984 and 2002 despite the constraints imposed upon the daily fluctuating operations of the ROD. Ongoing erosion of these sandbars and related fine-sediment habitats during the period of MLFF operations parallels the documented sand mass-balance deficit reported by Rubin and others (2002) and Topping and others (2006) between 1999 and first half of Water Year 2004.

As reviewed by Wright and others (2005) conventional theory and field experiences have historically identified discharge as the primary factor governing suspended-sediment transport in most rivers and streams characterized as having alluvial channels. The bedrock controlled Colorado River in Grand Canyon is atypical in this respect, as was reported by Rubin and others (2002). Earlier studies by Rubin and Topping (2001) reported that the degree to which the Colorado River ecosystem has recently been enriched with fine sediment by tributary floods, or has been depleted of fine sediment by clear water releases between enrichment episodes, have as much or more influence on the suspended-sediment export rates as does discharge from Glen Canyon Dam. Topping and others (2005) also demonstrated that during most of the postdam era, main channel suspended sand transport has responded to the level of sand storage within eddies, during the periods that main channel sand supply conditions have been depleted or winnowed. Further, Melis and others, (2003), suggested that new methods of suspended-sediment monitoring in the Colorado River ecosystem [combined use of ***beta*** (also, see Rubin and Topping, 2001) and laser-acoustics technologies] might be used at discrete points below the dam to monitor the grain-size condition (level of fine-sediment enrichment with respect to sub-aerial distribution of the channel bed in real time) following periods of tributary enrichment.

Ramping Rates **–** There are two elements to this topic relative to sand conservation and sandbar stability: 1) influence on sandbar stability with respect to seepage forces within sandbars (destabilizing existing sandbars along shorelines through bank failures, etc. during and immediately following daily periods of river stage decrease) and 2) influence on sandbar erosion with respect to “tractive” or entrainment forces related to flow turbulence that promotes re-suspension and transport of sand away from eddies and downstream (promoting sand export).

Previous field studies undertaken during the Glen Canyon Dam EIS, and model simulations from those studies, led directly to current down ramping rates associated with MLFF and the Record of Decision (Budhu, 1992, 1995a, 1995b, 1997; Budhu and Gobin, 1994, 1995a, 1995b; Budhu and others, 1994). Only recently, as part of the November 2004 high-flow test, were additional field studies proposed to identify whether or not the ROD ramping rates are appropriate (or perhaps overly conservative) with respect to sandbar stability under MLFF operations. Additional studies are currently underway to better understand the groundwater dynamics that occur within sand banks under fluctuating flows with various rates of stage change (M. Schmeeckle, oral communication, GCMRC Science Symposium, October 2005).

While we may not fully understand the influence of the seepage processes related to sandbar erosion and ramping rates, the daily allowable fluctuating range is also an important part of the overall stability of sandbars. It is also clear that any change in the daily range and ramping rates directly influences the duration of the daily peak discharge (for a given monthly volume). Both sediment transport theory and recent high-resolution suspended-sediment transport data collected below Glen Canyon Dam indicate that longer periods at peak discharge increase downstream export of new sand supplies and increase erosion of existing sandbars within the allowable MLFF fluctuating range (up to 25,000 cfs) associated with the 1996 Record of Decision. These results are best documented for the experimental fluctuations (5,000 to 20,000 cfs) that occurred in January through March 2003, 2004 and 2005 (Topping and others, 2004; Topping and others, 2006).

Reduced Variation in Monthly Volume – If the pattern of monthly release volumes at Glen Canyon Dam was more evenly distributed throughout the annual release period, the daily peaks under the MLFF (or other non-ROD peaking strategies) would be more limited in magnitude and duration than those associated with historical patterns of monthly releases. This operational influence on sediment transport is most significant when annual release volumes are minimal (8.23 million acre feet); owing to the fact that daily peaks for equal monthly volumes would likely be limited to about 13,000 to 14,000 cfs (equalized monthly release volumes for each month of 686,000 acre feet). Recent daily peaks under the MLFF associated with minimal release hydrology (8.23 million acre feet) and historic monthly patterns (see Wright and others, 2005, p. 25), have ranged between 17,000 to 19,000 cfs (typically in June through August) and experimental winter fluctuating flows have been at 20,000 cfs (January through March).

Data reported by Wright and others (2005) and Topping and others (2004; 2006) have shown that these peak flow periods have been responsible for export of new tributary sand inputs within the same year as the inputs entered the ecosystem during Water Years 2001 through the summer of 2004. During the spring and fall months of these same years, MLFF operations resulted in much lower daily peaks ranging from 10,000 to 14,000 cfs and tributary sand inputs were allowed to accumulate in the main channel of the ecosystem (especially in the September through December periods), before the release of higher winter and summer peaks. The results reported by Wright and others (2005); Schmidt and others (in review); Hazel and others (2006); Topping and others (2006), indicate that new tributary sand inputs are clearly conserved and accumulated in the main channel at stable flows of 8,000 cfs (summer 2000, low summer steady flowtest) and under fluctuating flows ranging between 5,000 and 10,000 cfs (fall 2004 period before high-flow sediment test). Sand transport monitoring data collected since summer 1999 indicate that from 55% to 78% of tributary sand inputs accumulated within the main channel of the Colorado River below Glen Canyon dam during months when MLFF operations occurred during months with release volumes in the range of 610,000 acre feet. On average, between 82% and 91% of sand inputs were retained during MLFF operations in the monitoring reach during months have release volumes in the range of 490,000 acre feet (S. Wright, oral communication, 2006).

The 2001 through 2004 data suggest that by limiting daily peaks to 13,000 or 14,000 cfs throughout the year tributary sand inputs would tend to be more effectively conserved as export rates would be substantially limited relative to typical summer daily peaks. However, it is not currently possible to accurately predict whether or not such a flow regime would result in sand accumulation within the ecosystem over multiyear periods, as was predicted under the MLFF preferred alternative of the 1995 EIS (DOI, 1995). Suspended sand transport data collected in September through early November 2004 indicate that new sand inputs from the Paria River were mostly conserved within the upper reaches of Marble Canyon (mostly above river mile 11) under fluctuating flows that consistently ranged from 5,000 to 10,000 cfs (Topping and others, 2006). It is not possible to accurately predict the fate of similar inputs under flows of 7,000 to 13,000 cfs that might occur year around if an 8.23 million acre foot release volume were distributed equally throughout the water year under MLFF operating constraints. Hence, such an operation would be useful as a test to acquire the transport data needed to fully evaluate such a modification in operating strategies.

Both theory and data indicate that suspended-sediment transport and downstream export are exponentially related to discharge for a given fine-sediment supply (to the 4^{th} or 5^{th} power). As a result, reduced daily peaks of limited duration throughout the year will result in reduced downstream transport and export of limited sand supplies delivered to the ecosystem by the tributaries below the dam. This limitation of the sand transport rates would also limit erosion of sandbar habitats along the river banks. A test of annual peaks constrained by 8.23 MAF hydrology, equal monthly volume releases, and the Record of Decision (MLFF) operation would provide valuable new information to determine whether or not new tributary sand inputs can be accumulated over an entire year and across multiyear periods in the main channel, before release of beach/habitat-building flows intended to restore and maintain sandbar habitats.

BHBFs and HMFs – As recently described by Rubin and others (2002), these dam operations are a two-edged sword in that sandbars can only be deposited and maintained under conditions of elevated river stage, but those same elevated flows also promote much higher suspended-sediment transport rates. High flow velocities and sand transport rates therefore, can also result in large sand export volumes to Lake Mead, as well as sandbar erosion at sites where suspended-sediment concentrations are lower when new sand supplies are not abundantly available (Rubin and others, 2002; Rubin and Topping, 2001). Sand bars must be inundated by main channel river flow carrying sufficient suspended sand concentrations where the sand will rain out of suspension when flow velocity decreases abruptly, as in eddies and along stagnant shorelines. Hence, new sandbar deposition requires that there be abundant sand supply in the river during a period when river flows are elevated, in the case of the beach/habitat-building flows (BHBF), typically to somewhere in the range of 41,000 to 45,000 cfs. During such high-flow departures sand transport rates are increased to much higher levels than normally occurs under the typical MLFF operation (fluctuating diurnal flows not exceeding 25,000 cfs stages). The basic goal then for such operations is to optimize for sandbar deposition (highest stage under the most fine-sediment enriched supply condition) while limiting downstream export of new sand and erosion of existing sandbars (minimal export to Lake Mead).

Data from the 1996 controlled flood test (see Webb and others, 1999) indicated that the 7-day long duration of that BHBF experiment was far too long for the available sand supply in the main channel (Topping and others, 1999; Schmidt, 1999). Most sandbar responses that were measured during the 1996 test suggested that the bar geometry was altered (the higher, but not wider results documented in the NAU sandbar sub-sample), but sandbars were not increased in overall size through incorporation of new, tributary sand supplies that were assumed to have accumulated between 1991 and 1996, (as was hoped for to support sandbar restoration). Data from the three HMF tests conducted in 1997 and 2000 indicate that the sustained flows of 31,500 cfs (3–4 days) were very efficient in exporting sand downstream, but had what was interpreted as a stage-limited result with respect to depositing main channel sand within eddies to restore sandbars (Topping, oral communication, July 2005, Wiele and others, 2002; Hazel and others, 2006). Preliminary results from the November 2004, high-flow test (60-hours of sustained flow at about 41,000 cfs) suggest that the reduction in peak flow duration (168 vs. 60 hours) in the recent test was warranted under the more highly enriched antecedent sand supply conditions in the main channel, but that the uneven longitudinal distribution of the new tributary sand delivered by the Paria River throughout Marble Canyon may have actually limited sandbar restoration response to eddies immediately downstream from where new sand inputs were deposited in the main channel under low, diurnal, fluctuating flow operations (5,000 to 10,000 cfs) between the time of tributary inputs and release of the high-flow test in November (Topping and others, 2006).

Although data analysis is still underway for the 2004 test, future BHBF implementation might more effectively consist of even shorter duration peak flows (24 to 48 hours) under enriched sand supplies that are more uniformly distributed downstream throughout entire reaches where sandbar restoration is desired (for instance, Paria River sand inputs from summer and fall are allowed to be partially winnowed and distributed downstream by limited dam operations between 10,000 and 15,000 cfs from November through December or January, before release of the BHBF). An experimental test of such a “pre-conditioning” operation on new sand supplies might be useful as a means of learning how to further optimize sandbar restoration while limiting sand export and bar erosion. Despite two tests of the BHBF concept (1996 and 2004), it is still not clear whether a “flow-only” prescription exists operationally that can achieve the objective of restoring and sustaining sandbar habitats below Glen Canyon Dam using only 6 percent (Marble Canyon) to 16 percent (Marble and Grand Canyons) of the Colorado River’s predam fine-sediment supplied by the Paria and Little Colorado Rivers (Wright and others, 2005).

The utility of HMF's as a tool to "maintain" nearshore habitats is still unclear and additional analyses of data and future studies are needed. However, results to date on such operations suggest very limited potential for them to effectively promote sandbar restoration objectives (Wiele and others, 2002; Hazel and others, 2006; Schmidt and others, in review). One proposed purpose for the spring-timed HMF in the final EIS (DOI, 1995) was to rejuvenate and condition nearshore habitats, such as backwaters, before summer and fall when Young of Year (YoY) native humpback chub typically enter the main channel from spawning areas in the Little Colorado River.

Goeking and others (2003), assessed the historical abundance and distribution of sandbars associated with return-current channels, typically referred to as "backwaters", from a rich series of decadal-to-annual scale air photos taken throughout Marble and Eastern Grand Canyon between 1935 and 2000. These sandbar related habitats have been identified as being potentially important for native fishes in promoting elevated growth rates in their early life history, particularly for YoY fish that spend their early life stages in the main channel of the Colorado River below Glen Canyon Dam after emerging from the Little Colorado River. The potential critical element of such main channel habitats is that they are known to be relatively shallow, low-velocity aquatic, nearshore settings where substantial warming of river water occurs in summer and fall. The time series analysis of Goeking and others (2003), concluded that the abundance and distribution of backwaters in the upper one-third of the Colorado River ecosystem was greatest in the 1984 images (on the basis of two-dimensional return-current channel measurements made between about 5,000 and 8,000 cfs under steady flows) compared to any air photo record that recorded such features either before or after dam closure. Goeking and others (2003) also concluded that to achieve and/or sustain the 1984 level of abundance in backwaters in the postdam era, that periodic floods (perhaps as high as the bypass releases of 1983–84, of 45,000 to 96,000 cfs) must occur at some frequency under conditions of sufficient sand supply. The basis for suggesting this strategy concurs with the strategy of the final EIS (DOI, 1995) and is tied to data showing that sandbars typically experience a progressive pattern of erosion in between higher flows, while backwater return current channels tend to become filled in with fine sediment and become progressively colonized by plants that evolve into marsh habitats that do not promote access by young, native fish. Rubin and others (2002), reported that the concept of the BHBF as a means of restoring and maintaining sandbars was partially supported by data and experimental results, but that the sand mass flux data collected in the main channel below the dam indicated that MLFF operations, even under minimum hydrology and required releases, does not accumulate new sand supplies throughout the main channel over multiple years.

Sustained Low Steady Flow During Summer – Flows of 8,000 cfs during summer 2000, related to the LSSF test, were effective in limiting suspended-sediment of both sand, and to a lesser degree, finer sediment in the main channel of the Colorado River ecosystem (Rubin and others, 2002; Wiele and others, 2002; Hazel and others, 2006; and Schmidt and others, in review). Topping and others (2000a; 2000b) concluded that periods of flow in the predam river that roughly equated to the mean daily discharge (9,000 to 10,000) corresponded with periods in which sand accumulated in the channel bed of the river. On this basis, sediment scientists hypothesized that sustained flows of

8,000 cfs during the LSSF test should allow tributary sand inputs from the Paria and Little Colorado Rivers to accumulate throughout the bed of the main channel and lower eddies. Despite the fact that tributary sand inputs were limited during the June through August period of 2000, the sand mass balance measurements for the Marble Canyon reach of the ecosystem indicated that sand inputs were accumulated below the Paria River when flows remained constant at 8,000 cfs. The accumulated sand supply was quickly exported downstream during the HMF release that followed in September 2000. Sustained low flows also generally limit the degree to which existing sandbars are actively eroded through tractive forces owing to turbulent flow, although such periods may also promote adjustments of sandbars through bank collapse owing to seepage forces. Sand bars may be eroded by rainfall runoff events during periods of low, sustained flow, and may be subjected to reworking by wind.

Camping areas are also increased significantly during periods of sustained low flows. More recent information reported by Topping and others (2006) on the fate of Paria River sand inputs in the main channel under fluctuations of 5,000 to 10,000 cfs in September through mid-November 2004 indicate that such diurnal fluctuating flows are also highly effective at limiting downstream export of new sand supplies once they enter Upper Marble Canyon. The results from the LSSF test of 2000 (Schmidt and others, in review; Hazel and others, 2006; and Wiele and others, 2002), and the fall 2004 sediment transport data (Topping and others, 2006) support the idea of testing higher steady flows (above 8,000 cfs) or additional fluctuating flows with peaks between 10,000 and 14,000 cfs relative to questions concerning operations that promote accumulation of new sand supplies before future BHBF releases. Equalizing monthly volumes to meet annual minimum release would provide such a sediment test.

<u>High Sustained Flow During Spring</u> – See above section on HMF. The LSSF test of 2000 also included a multi-week period of sustained high flow (about 17,000 cfs) in April and May that was intended to cause ponding of the Little Colorado River inflow area, located near that river’s confluence with the Colorado River. It is unclear what role this flow may play in the spawning activity of adult humpback chub or the early life history of YoY native fishes, but this level of stable flow is definitely effective at transporting high sand loads downstream with little benefit to conservation of high-elevation sandbars and related habitats (Hazel and others, 2006; Schmidt and others, in review).

<u>Non-GCD Actions</u> – Treatments such as mechanical removal of nonnative fish are not thought to be an influence on sediment transport as there are no data suggesting that changes in abundance of fish (and their related behaviors, such as spawning, etc.) significantly influences suspended-sediment transport. Drought in the Upper Colorado River Basin and major tributaries below Glen Canyon Dam can have a significant influence on the abundance of fine sediment delivered to the ecosystem (diminished tributary flooding and sand production of Paria and Little Colorado Rivers). Minimal annual release volumes from the dam caused by reduced upper basin hydrology and Lake Powell storage has a limiting influence on suspended-sediment transport and export of sand from tributaries, as well as reduced erosion of existing sandbars.

Summary of Physical Matrix Assessment –

Fine Sediment – Following is a summary of what sediment scientists concluded during workshop discussions relating flows to fine-sediment and sandbar resources. These conclusions were derived on the basis of the Physical Matrix cells relating to fine sediment (see Table 3.1). The overall effect of increased fluctuations relative to the MLFF operation has the influence of increasing sand transport downstream and thereby does not promote retention of new sand inputs from tributaries. The result is opposite for less widely fluctuating flows or stable flows for a given month's release volume. Reduced variation in monthly release volumes, during at least minimal hydrology release years (8.23 million acre foot releases), is predicted to increase retention of new tributary sand inputs by limiting downstream export of new sand under high peaks in winter and summer months when volumes are typically increased compared with spring and fall months. This reduction in export for a given input of new sand is related to the fact that lower monthly peaks would occur as monthly volumes are equalized and reduced in winter and summer months. Sand transport data collected between 1999 and 2006 provide the basis for this conclusion. A summary of the sand transport data indicate that monthly release volumes associated with MLFF operations under monthly releases in the range of 610,000 acre feet retained from 50% to 78% of tributary sand inputs during the months and seasons when such flows occurred.

Test flow data from summer 2000, indicate that sustained low steady flows in summer and fall (flows of 8,000 cfs) can significantly promote accumulation of tributary sand inputs that occur in association with warm season rainfall runoff events. This is particularly important with respect to the Paria River inputs which occur predominantly in these seasons.

As a result of the 1996 controlled flood experiment, scientists have concluded that Beach/habitat-building flows (BHBFs) implemented under conditions of insufficient new sand supply result in erosion of sandbars in areas of the eddies and channel below 25,000 cfs stage (as determined by the 1996 controlled flood test response). Despite increases in sandbars above the 25,000 cfs stage in 1996, the net effect of the high flow under sand depleted conditions was a net deficit in the sand mass balance.

On the basis of previous testing, the concept of using habitat-maintenance flows (relatively short duration flows of approximate peak powerplant capacity) to restore sandbars does not appear to have a net positive effect on the sand mass balance of the river ecosystem during periods when sand supply is not enriched. Under sand enriched conditions that occurred during the first such testing in November 1997, some sand storage increases occurred within eddies below the 25,000 cfs stage, but these gains were relatively small in volume and transient. High, sustained flows, such as the flows that occurred in May 2000 to create ponding of tributary confluences (Little Colorado River) elevate sand export rates in the main channel and promote sandbar loss.

The 2004 High Flow test demonstrated a net positive effect on the sand mass balance of the river ecosystem and sandbar restoration was significant in the upper reach of Marble Canyon. However, it is still not possible to conclude from the 2004 results alone, whether repeated similar high flows under similarly enriched sand supply conditions will result in cumulative, sustainable sandbar restoration over decadal time periods. Additional testing in the form of a replicate of the 2004 sediment test (with respect to the level of sand supply enrichment) was recommended by sediment scientists as a means for determining whether or not such a strategy is viable. This appears to be the only viable science alternative owing to the fact that existing sediment models alone cannot determine the answer to this critical management question. If a replication of the 2004 test again results in net positive outcome to the sand mass balance along with accumulated sandbar restoration, then the strategy of implementing repeated BHBFs under sand supply enriched conditions might be considered a viable, long-term conservation strategy below the dam without additional need to sand supplies from upstream.

Increased water temperature tends to reduce suspended-sand transport by reducing the water viscosity in the river, which has the effect of allowing higher settling rates for suspended sand in the water column.

Downstream Water Temperature - Following is a summary of what physical scientists concluded during workshop discussion relating flows to downstream water temperatures. These points were derived on the basis of the Physical Matrix cells relating to downstream water quality, specifically water temperatures (see Table 3.1). Main channel water temperatures were documented to warm significantly downstream from the dam during summer months when stable flows of 8,000 cfs occurred in 2000. Warming of downstream water temperature has also been documented during 2003–6, as a result of reduced water storage and Lake Powell reservoir elevations associated with prolonged drought in the Upper Colorado River basin. These effects have mainly been notable in summer and fall months. Downstream water temperatures are also predicted to warm on a seasonally varied basis if water is passed through the dam from higher reservoir elevations, as simulated in association with a Selective Withdrawal Structure.

Operational factors known to limit warming of water released from the dam include release of high, sustained flows to create ponding of tributary mouths, as well as shorter duration flows of greater magnitude, such as BHBFs and HMFs. These types of releases tend to limit downstream water temperatures by reducing the residence time of water in the Canyon and thereby limit the amount of warming that can occur by influence of solar radiation before the water reaches Upper Lake Mead.

3.2 Hydropower Matrix

The decision matrix for HydroPower Resources (load-following capacity and replacement power costs) was populated at the KAW and is presented in Table 3.2. Data are collected by Federal agencies on both the energy and revenue derived from power peaking at Glen Canyon Dam and the costs associated with having to provide replacement power to customers during periods when energy capacity at the dam falls short of delivery commitments. Simulation modeling is also undertaken by Western Area Power Administration to project revenue and replacement power costs related to monthly volume releases scheduled by the Bureau of Reclamation as derived from its annual Colorado River Work Group planning activities.

During the July 2005 Knowledge Assessment workshop, participants concluded that the basic cause/effect relationships for the Hydro Power matrix were well known and documented. However, on the basis of later comments and discussions with managers, it became clear that such knowledge, while it might either be well known and predictable from modeling to some stakeholders or "knowable," to by some managers who have access to the information, that it was not widely available as published data in reports that are widely available to the public or other GCDAMP members.

3.2.1 Power Peaking Capacity and Financial Aspects of Replacement Power Costs

The following summary is made on the basis of discussions with power representatives and the flow-treatment evaluations were made relative to the MLFF operating rules. While data and related simulations for this resource area are either known or are "knowable," this information is typically only available from the Western Area Power Administration by request.

<u>Increased Water Temperature</u> – Has a relatively small limiting influence on the peaking capacity owing to reduced turbine efficiency that results from thermal limits of generator performance. Replacement costs may be slightly increased by limitations on the peaking capacity related to turbine efficiencies.

<u>Increased Daily Fluctuations</u> – Increasing the daily range, hourly ramping rates, or daily allowable peak, as well as reduced daily minimum, provides a great advantage with respect to daily peaking or "load-following" capacity. Higher daily peaks can be achieved and maintained for longer periods so as to more optimally follow daily energy demands. Replacement costs are limited as a result that peaking capacity is increased. The Glen Canyon Dam powerplant is operated in such a way that load following is more efficiently achieved than patterns associated with the MLFF operation.

<u>Reduced Variation in Monthly Volume</u> – Flattening of the annual pattern of monthly release volumes decreases the benefit of historically banking water in Lake Powell for release and energy generation during seasons of the year when replacement energy is derived at lower costs from other generating facilities on the Western Grid, such as northwest hydropower dams that have abundant water during shoulder seasons of fall and spring (Wayne Cook, oral communication, July 2005). Releasing less variable monthly volumes for a given annual release volume results in more peaking energy being produced in months when it would be more economical to purchase replacement power from other facilities. As a result, less water is then available in Lake Powell in summer and winter when the value of peaking power from Glen Canyon Dam is higher and replacement power costs associated with other producers may also be higher.

BHBFs and HMFs – Currently, any beach/habitat-building flows that is released from Glen Canyon Dam (flow at least 10,000 cfs above peak powerplant capacity, as described in the 1995 EIS) constitutes a bypass of the hydropowerplant. As such, these operations have two-fold influence on peaking capacity and replacement power costs. First, the bypass portion of the release has a negative influence on energy generation (no peaking or base load energy is generated) since the water never moves through the powerplant and once released is not available for energy generation again at the Glen Canyon Dam. The portion of the release that moves through the powerplant (sustained release of about 31,500 cfs) does not follow the daily peak demand for the duration of this operation and makes the facility a base loaded generating station. This element of the BHBF is virtually identical to the Habitat Maintenance Flow (HMF). The bypass results in both lost energy and revenue that increases replacement power costs, while the sustained, high releases through the powerplant generate energy, but in a way that does not optimize revenue relative to daily energy demand.

Sustained Low Steady Flow During Summer – Owing to the fact that there is less energy generated during this peak-demand season for electric power, this operation has a large negative influence on peaking capacity (since no peaking occurs) and greatly increases replacement power costs over significant periods of peak demand. Estimated costs from the 2000 Low Summer Steady Flow test were presented by Western Area Power Administration at the October 2003 Science Symposium convened by the GCMRC in Tucson, AZ (Clayton Palmer, oral communication, 2003). Replacement power costs associated with that test were reported to be in the range of 20 to 25 million dollars. The total cost of the test may not be fully identified for several more years owing to lag effects of that test that are propagated into future water years beyond the Water Year 2000 (David Harpman, oral communication, May 2005).

High Sustained Flow During Spring – The dam essentially becomes a "base loaded" powerplant owing to the fact that such releases are high and steady (assumed to be within powerplant capacity) and do not vary on a daily basis. As a result, such operations negatively affect peaking capacity and the revenue associated with load following is negatively influenced for the duration of this release pattern. Energy that is generated during such operations in the non-peak demand period of the day is typically less valuable. Revenue generation is not optimized since peaking capacity is compromised with respect to the daily pattern of peak energy demand.

Non-GCD Actions – Experimental treatments such as mechanical removal are conducted without impacting normally scheduled flows from the dam. Other experimental support activities, such as remote-sensing over flights, are typically conducted following sediment experiments and require low-steady flows for a period of days. This activity does limit peaking capacity and result in additional replacement power costs. Protracted drought in the Upper Colorado River Basin, as well as increased depletion of water supply through agreed upon uses, does limit storage in Lake Powell. Reduced storage levels in Lake Powell lead to minimal annual release volumes to the Lower Colorado River Basin and such minimal annual releases (10.2 Gm^3 or 8.23 million acre feet) limit the extent to which peaking capacity can occur under the ROD. Reduced peaking capacity forced by low hydrology therefore increases replacement power costs to the Colorado River Basin Fund.

Summary of Hydro Power Matrix -

Some operational changes were identified to have more influence on peaking capacity and replacement power costs than others by workshop participants representing hydropower resources. For instance, BHBFs can have a significant negative influence on replacement power costs (meaning those cost increase significantly) for two reasons 1) some volume of water release completely bypasses the powerplant and 2) release volumes in one of more months following the BHBF must be reduced to meet the annual release schedule. Hence, such reductions have the effect of reducing peaking capacity in some months following the BHBF while also increasing replacement power costs in those same months. The effects are greatest for the year if the monthly release volumes are reduced in summer months in the case where a BHBF might have occurred in the spring month of March, as occurred in the 1996 controlled flood test. In the case of reducing variability in the annual pattern of monthly volumes for a given annual release schedule, peaking power capacity would be limited in winter and summer months (relative to the variability in power demand) and replacement power costs in those seasons would be increased. Conversely, peaking power capacity would be available in spring and fall months when there would likely be reduced demand for it. Low, steady flows during summer and fall months do not fit well with energy demand patterns for summer and would result in increased replacement power costs. Increased water temperature can also have an effect in limiting the turbine efficiency and hence peaking capacity of the powerplant, but these types of effects are relatively minor compared with limitations on daily range of flows released or reduced ramping rates used to move from daily minimum to maximum flows, etc. Owing to the fact that operational models exist for determining releases from the dam and for determining economics associated with hydropower production, all of the operational influences can be predicted for the most part. As a result, the cells in Table 3.2 are all highlighted green.

3.3 Food Base, Fish, and Lees Ferry Angling Matrices

The decision matrix populated at the KAW is presented in Table 3.3. In contrast to the other sub-models, the effects of individual elements of ROD flow constraints were investigated. The overall effect of higher daily fluctuations is described in Table 3.3, while the effects of individual elements are presented in Table 3.4.

3.3.1 Food Base

The food base performance measure represents the flux of drifting invertebrates in the water column, referred to as drift rate. We selected drift rate as our metric of food base performance because humpback chub and rainbow trout, the fish for which food base research and monitoring are principally conducted, are generally drift feeders; drift rate is a better metric of food base performance than the standing stock of benthic invertebrates because it is a direct measure of the food items that rainbow trout and humpback chub most often encounter and consume. Drift rate will depend on the biomass or density of benthic invertebrates (g/m^2) that provides the source for drift, as well as the flow regime that determines the extent of disturbance to and distribution of the benthos; the effect of operations on both biomass and disturbance were considered when determining drift rate. Water temperature from Glen Canyon Dam was hypothesized to be an important driver of food base performance in both Glen and Grand Canyons because it has an overriding influence on invertebrate growth rates in stream and river ecosystems throughout the world (Benke 1993; Huryn and Wallace 2000). The daily variation in flow and minimum daily flow were hypothesized to be the most important flow constraints affecting the food base.

Water Temperature—Increases in water temperature will increase the flux of invertebrates in both Glen and Grand Canyon (Garrett and others, 2003). (**Note: July 2005 Knowledge Assessment Workshop participants coded this cell yellow +. After further research on the subject, Kennedy decided there was sufficient evidence to code this light green +. See discussion below and in Garrett and others, 2003**). Secondary production of invertebrates (i.e., biomass of invertebrates produced per area per time—$g/m^2/yr$) are a function of benthic biomass and growth rates (Production = Biomass*GrowthRate; Benke 1993). Across the range of water temperature increases that are likely with natural warming or installation of a TCD (i.e., release temperatures of up to ~16°C with higher temperatures possible downstream), growth rates of aquatic invertebrates that are important food items in the CRE (i.e., amphipods such as *Gammarus lacustris*, chironomids, and simuliids) are all strongly and positively related to water temperature (Sutcliffe et al 1981; Hauer and Benke 1987; Benke and others, 1988; Pockl, 1992; Benke, 1993; Huryn and Wallace, 2000). Vinson (2001) reported no change in the biomass of benthic invertebrates following installation of a TCD on Flaming Gorge Dam. The standing biomass of benthic invertebrates is not likely to increase with installation of a TCD on GCD, but it is almost certain that there will be more invertebrate biomass produced annually because of temperature driven increases in invertebrate growth rates. In fact, temperature-mediated increases in growth rates will probably lead to an additional 1–2 cohorts per year for invertebrates with short generation times (i.e., simuliids and chironomids with generation times of ~20 days; Benke 1993, Huryn and Wallace 2000).

If aquatic invertebrates were exhausting their food supply in the CRE, increases in temperature might actually have a negative impact on invertebrate flux because invertebrate metabolic and respiration requirements could increase without a concomitant increase in food supply. However, algae biomass and production in Glen Canyon will increase with temperature because light is not limiting (Phinney, 1965; Brock, 1970; DeNicola, 1996; Garrett and others, 2003; Yard, 2003), thereby increasing available food for invertebrates. In fact, the range of temperature increases that are possible fall within the temperature optima for *Cladophora glomerata* (maximum growth occurs between 13–16°C with upper limit of 24°C; Graham, 1982).

It seems likely that increasing water temperatures will lead to shifts in the species composition of algae, aquatic macrophytes, and invertebrates. Blinn and others (1989) found that epiphytic diatom composition shifted with increasing temperature, with the abundance of upright forms declining (combined relative abundance of *Diatoma vulgare* and *Rhoicosphenia curvata* went from 58% to 30%) and adnate or small forms increasing (combined relative abundance of *Cocconeis pediculus*, *Achnanthes minutissima*, and *Cymbella affinis* increased from 33% to 59%) with an incubation temperature of 18°C relative to the control of 12°C. Pinney (1991) found that *Gammarus lacustris* in the CRE preferentially consume the upright forms listed above and also *R. curvata*, a relatively small diatom, and tended to avoid *C. pediculus*, an adnate form. However, it is unclear how large a shift in diatom composition would occur over the range of warming that is likely with installation of a TCD (up to ~16°) or whether the shift in diatom composition that Blinn and others (1989) observed would actually affect invertebrate biomass or growth rates. Vinson (2001) documented shifts in the species composition of aquatic invertebrates following installation of a temperature control device on Flaming Gorge Dam. However, it is unclear if this shift in species composition affected food availability for fish. Even if there are shifts in the species composition of invertebrates and algae, the vast literature on invertebrate production provides compelling evidence that warming will increase invertebrate growth rates, and hence invertebrate flux, in Glen Canyon. In fact, there are robust models available that allow us to predict how much simuliid, chironomid, and *Gammarus* growth rates will increase with increasing temperature (Benke, 1993).

Increases in water temperature could also lead to no net benefit to the food base in Glen Canyon if growth rates for New Zealand mudsnails were to increase dramatically at the expense of other invertebrates. Hall and others (2006) measured growth rates for New Zealand mudsnails in streams of Yellowstone National Park that spanned a range of water temperatures and found most of the variation in growth rates was explained by differences in snail size—small snails grow fastest. Mudsnail growth rates were positively correlated with water temperature, but the temperature coefficient (0.0024, the increase in growth rate that will occur for a 1º C increase in water temperature) is considerably lower than for other macroinvertebrates in Glen Canyon (i.e., growth rate for amphipods such as *Gammarus* have a temperature coefficient of 0.111, the temperature coefficient for chironomids is 0.05, and for simuliids it is 0.031; Benke, 1993). Benke (1993) compiled secondary production data for a wide variety of invertebrate taxa and found that the growth rate of mollusks is actually negatively related to temperature. For individual species of mollusks it seems unlikely that growth rate is negatively related to temperature (unless temperatures begin to exceed their thermal optima), but averaging across all species of snails for which secondary production data were available (n=16) Benke (1993) found that growth rates were negatively related to temperature. We believe that growth rates for New Zealand mudsnails will in fact increase with temperature in Glen Canyon, as reported by Hall and others (2006). However, data from Hall and others (2006) and Benke (1993) suggests that growth rates for mudsnails may actually increase less with rising temperatures than growth rates of other invertebrates in the Lees Ferry reach.

Increasing water temperatures will also increase invertebrate growth rates in Grand Canyon. (**FootNote: July 2005 Knowledge Assessment Workshop participants coded this cell red. Main reason for uncertainty was because the relative importance of allochthonous and autochthonous carbon to secondary production is unknown. Algae production is unlikely to increase with increasing temperatures because it is strongly light limited. Participants felt that if invertebrate growth rates increase without a concomitant increase in food availability, invertebrates may exhaust their food supply. After further research on the subject, Kennedy decided there was sufficient evidence to code this light green +. See discussion below and in Garrett and others, 2003**) Increasing water temperatures will probably not increase algae production in Grand Canyon because it is strongly light limited (DeNicola, 1996). However, the most common invertebrates in Grand Canyon are filter feeders (simuliids) that capture small food particles from the water column and chironomids that tend to feed mainly on detritus (Stevens and others, 1997a); these types of invertebrates consume a miniscule fraction of available food (Edwards and Meyer, 1987) and thus are incapable of depleting their food supply in a large river such as the CRE. Thus, higher temperatures, even in the absence of increased food availability, will also increase invertebrate growth rates (Benke 1993, Huryn and Edwards 2000), and hence invertebrate drift rates, in Grand Canyon (Garrett and others, 2003).

It should be noted that temperature mediated increases in food availability will probably not lead to increases in fish condition or density because the energetic demands for fish will also increase with temperature (Peterson and Paukert, 2005).

<u>Increased Daily Fluctuations</u> - Flux of invertebrates was hypothesized to exhibit a dome-shaped response to increased daily fluctuations in flow from GCD. Very stable flows would likely maximize benthic biomass of both algae and invertebrates, but benthic algae *production* would be lower and reduced disturbance would limit the transfer of invertebrates from the benthos to the water column. At the other extreme, high fluctuations would limit benthic biomass and production to the point where flux is reduced.

In Grand Canyon, where light is limiting autotrophic production (Yard 2003), higher daily variation in flow will further reduce algae production to the point where it would reduce benthic invertebrate standing stock, and hence invertebrate flux. Further, simuliids, the dominant food item consumed by rainbow trout and humpback chub at downstream locations (Valdez and Ryel, 1995, Yard and Coggins *unpublished data*), have a limited range of optimum water velocities and preferentially occupy habitats with fast water velocities because these habitats provide a continual supply of food particles that are consumed via filter feeding (Ross and Merritt 1987). Increasing daily fluctuations in flow would likely reduce the standing stock or productivity of simuliids because water velocities would become more variable.

The direction of response of flux to increased flow fluctuations is unknown in Glen Canyon because the dome-shaped relationship between flux and fluctuating flows has not been adequately quantified. However, if increasing fluctuations are coupled with a decrease in the minimum daily flow it seems likely that there will be a decrease in invertebrate flux. Daily minimum flow is an important determinant of benthic standing crop because of the strong negative effects of desiccation on algae and invertebrates (Hardwick and others, 1992; Angradi and Kubly, 1993; Blinn and others, 1995; Benenati and others, 1998). Blinn and others (1995) estimated the energy content of various food base components in the Lees Ferry reach. They reworked the total *Gammarus* energy content at various minimum flows. Increasing the minimum flow from 142 m^3/s to 227 m^3/s leads to a 50% increase in the amount of *Gammarus* energy present in the Lees Ferry reach. Similar patterns were noted for epiphytic diatoms and chironomid larvae.

Increased daily fluctuations might benefit the food base if it had a strong negative impact on New Zealand mudsnails that exceeded potential negative impacts on other macroinvertebrates; mudsnail density in Glen Canyon is high (~40,000 individuals/m^2—Benenati and others, 2002) and it seems likely that mudsnails are having an indirect negative impact on other aquatic macroinvertebrates via competition for epiphytic algae. However, indirect evidence suggests that it is unlikely that mudsnails would be *more* adversely affected by increased fluctuations than other macroinvertebrates. In Glen Canyon, snails are present across virtually all habitats types (i.e., unstable substrates/habitats such as sandy beaches, large mats of *Cladophora* and other algae, and stable substrates such as boulders that will only move during extremely high flows—Blinn and others, 1995, Kennedy *personal observations*), whereas *Gammarus* and other macroinvertebrates are strongly dependent on unstable *Cladophora* for both habitat and food (Leibfried and Blinn, 1987). In other words, mudsnails occupy the same unstable habitats that will be affected by fluctuations as other macroinvertebrates, along with stable habitats that will be unaffected by fluctuations. Further, Blinn and others (1995) found that snails readily colonized newly submerged habitats, achieving densities equal to those of permanently submerged habitats within a week. In contrast, re-colonization by *Cladophora*, *Gammarus*, and chironomid larvae was significantly slower, with density on newly submerged habitats <30% of permanently submerged habitats even after 4 months of submergence. Thus, it seems unlikely that mudsnails will be more adversely affected by increasing fluctuations than other invertebrates such as *Gammarus*.

Increasing flow fluctuations might have a positive impact on invertebrate flux if they led to increases in drift rates without a strong concomitant negative effect on the standing stock of benthic invertebrates. Leibfried and Blinn (1987) found *Gammarus* drift rates were positively correlated with the range of discharge variation (i.e., high daily variation) and that drift rates were generally higher on the rising limb of the hydrograph for periods that followed low discharges. They noted that it was only during periods of widely fluctuating flows (minimum discharge of 2,000 cfs and maximum of 18,000 cfs) when they observed rates of invertebrate drift that exceeded those during more steady flows. For example, in October 1985 when the daily range was 9,000–21,000 cfs rates of invertebrate drift did not exceed rates during steady flows. It should be noted that the three month period of fluctuating flows that Leibfried and Blinn (1987) studied (minimum discharge as low as 1,500 cfs and maximum discharge typically around 20,000 cfs), were preceded by a three month period of ‘steady’ flows (daily range of less than 8,000 cfs with minimum flow never below 18,000 cfs). Leibfried and Blinn (1987) suggested that the three months of high steady flows allowed a large standing crop of algae and invertebrates to develop, and when flows began to widely fluctuate large numbers of *Gammarus* that were stranded during the descending limb of the hydrograph entered the drift as discharge began to rise. Thus, the high drift rates under fluctuating flows documented by Leibfried and Blinn (1987) were probably due in part to the steady flows that preceded them. These investigators suggested that the drift rates they observed reflected the short term effects of fluctuations, and that under long term fluctuations invertebrate drift rates might decline because the standing stock of invertebrates would eventually be reduced due to downstream losses. Shannon and others (2001) measured high rates of invertebrate drift during high steady flows of June 1996 that approached those observed by Leibfried and Blinn (1987) under widely fluctuating flows. Shannon and others (2001) concluded that high benthic invertebrate standing stocks associated with steady flows can result in invertebrate drift rates that are comparable to those present during large daily fluctuations, without the negative impacts of a widely fluctuating varial zone. In contrast to the findings of Leibfried and Blinn (1987), McKinney and others (1999a) found that drift rates for *Gammarus* were highest on the descending limb of the hydrograph.

It has been suggested that MLFF has allowed aquatic macrophytes to replace *Cladophora glomerata* in Lees Ferry, with negative consequences to the aquatic food base. *Cladophora glomerata* was the single dominant algae in Glen Canyon during the period of no action and aquatic macrophytes were virtually absent. With the onset of Interim Flows and MLFF, researchers noted that aquatic macrophytes such as *Potamogeton pectinatus* and *Chara contraria* ‘became co-dominant with *Cladophora* in the Lees Ferry reach by 1996…’ (McKinney and Persons, 1999). However, it appears that aquatic macrophytes are generally occupying habitats that *Cladophora* never did. *Cladophora* attach to hard and stable substrates using a holdfast (Blinn and others, 1998), whereas aquatic macrophytes are rooted into soft and unstable substrates. During the period of no action these soft and unstable substrates in Glen Canyon were no doubt very unstable and constantly shifting. With the implementation of Interim Flows and MLFF, the stability of sandy substrates increased as compared to the period of no action, so aquatic macrophytes were more readily able to colonize (Blinn and others, 1994; McKinney and Persons 1999). Thus, the presence of aquatic macrophytes on soft substrates in Glen Canyon has actually led to increases in the ‘food base and habitat for benthic invertebrate grazers and rainbow trout.’ (McKinney and Persons 1999). Hardwick et al (1992) found that large fluctuations caused a shift in the species composition of the epiphytic diatom community, with reductions in the abundance of loosely attached upright diatoms and an increase in the abundance of adnate or smaller forms; upright diatoms are the preferred food of *Gammarus lacustris* in the Glen Canyon reach (Shannon et al 1994, Pinney 1991). Ayers and McKinney (1997) in 1993–94 found that small and adnate diatoms occurred in proportionally greater densities than large upright species on cobbles and artificial substrates, in contrast to previous studies that noted upright diatoms were the most common form (Hardwick and others, 1992). However, McKinney and Persons (1999) suggested that this shift in species composition might be due to a diatom pathogen, rather than the effects of reduced fluctuations.

Increases in daily fluctuations that involve no change to the minimum daily flow may lead to increases in invertebrate flux if the antecedent density of *Gammarus* and other invertebrates in Glen Canyon is high. However, observations suggest that the benthic standing stock of *Gammarus* and other invertebrates is presently low relative to historical numbers (Scott Rogers, oral communication, 2005). Therefore, under the present conditions it seems unlikely that increasing fluctuations will increase invertebrate flux—there are not many *Gammarus* available to be captured by fluctuating flows.

Increases in daily fluctuations that involve an increase in the minimum daily flow may lead to measurable increases in benthic invertebrate densities and invertebrate flux. Increasing the minimum daily flow will increase the permanently submerged zone, which will have a significant positive impact on the total amount of *Gammarus* in the Lees Ferry reach (Blinn and others, 1995), and lead to faster average water velocities, which will increase rates of algae growth and production (DeNicola, 1996). If increasing the minimum daily flow leads to appreciable increases in benthic standing stock of algae and invertebrates, then increasing fluctuations may in fact lead to higher rates of invertebrate flux. However, all of this is predicated on increases in the benthic standing stock of invertebrates and available evidence indicates that increasing fluctuations alone will not accomplish this.

Although quantitative data are lacking, observations clearly indicate there has been a reduction in the standing crop and drift mass of *Cladophora* and *Gammarus* in the Lees Ferry reach in recent years (William Persons, Scott Rogers, Mark Steffan, oral communication, 2005). It is Kennedy's opinion, based on his reading of the available literature, that reductions in daily variation under MLFF are not the cause of this reduction in *Cladophora* and *Gammarus* abundance. Rather, Kennedy believes that the cause of these observed reductions in the Lees Ferry food base may be due to many consecutive years of minimum releases and the invasion of New Zealand mudsnails, among other things. Widely varying daily fluctuations during the 1980s were often associated with high steady releases and it may well have been the high steady releases that led to high standing crops of *Cladophora* and *Gammarus*.

<u>Reduced Variation in Monthly Volume</u> - In Glen Canyon, sudden changes in mean flow between months were hypothesized to temporarily reduce benthic biomass by either exposing large areas of previously wetted substrate following a reduction in flow (Hardwick and others, 1992; Angradi and Kubly 1993; Blinn and others, 1995; Shaver and others, 1997; McKinney and others, 1999b), or by increasing depth/light attenuation and reducing productivity of benthos after a flow increase (Yard, 2003). However, it was hypothesized that large increases in monthly volume would have a positive effect on the food base in the long-term as this would increase the permanently submerged zone of the benthos. The same reasoning holds for Grand Canyon; large decreases in monthly volume would have a short and long-term negative impact on the food base, whereas large increases in monthly volume would have a short-term negative impact on the food base by increasing depth/light attenuation and a long-term positive impact by increasing the permanently submerged zone of the benthos.

BHBFs and HMFs - The response of the flux of invertebrates to higher flows associated with BHBF's or HMF's was uncertain. During and shortly after a high flow event invertebrate flux has been show to increase (McKinney and others, 1999, Blinn and others, 1999, Shannon and others, 2001). Shannon and others (2001) reported high rates of invertebrate drift two months after the 1996 BHBF. Although only limited data on the food base were collected following the 2004 BHBF, anglers and AZGFD personnel working in Lees Ferry reported that *Gammarus* were extremely scarce for many months after the BHBF (Mark Steffan oral communication 2005, Scott Rogers, oral communication, 2005). The 1996 BHBF was conducted in spring whereas the 2004 BHBF was conducted in late fall. It seems likely that the timing of a BHBF has a major impact on food base response; the food base may respond positively and rapidly following a BHBF conducted in spring because light levels are high and algae can grow rapidly, while it may take many months for the food base to recover from a BHBF conducted in winter because of low light levels that limit algae growth. Seasonal differences in sunlight to drive primary productivity in Glen, Marble, and Grand canyons were reviewed by Yard and others 2005. It has been hypothesized that the community that recovers following the disturbance could be more productive than the pre-disturbance community due to scouring of unproductive and senescent algae and macrophytes leading to a long-term increase in flux. This prediction is highly uncertain because of the lack of long-term drift data.

Rogers and others (2003) found that HMFs in 2000 had no impact on macrophyte density, periphyton chlorophyll *a* content, or benthic invertebrate biomass. Total drift mass, which was dominated by *Cladophora*, was reduced in the weeks following the May 2000 HMF, but this may have been due to the low summer steady flows (Rogers and others, 2003).

Sustained Low Steady Flow - Sustained low steady flows during the summer are hypothesized to reduce the flux of invertebrates in both Glen and Grand Canyons, as supported by data collected during the LSSF experiment (Benenati and others, 2002; Rogers and others, 2003). The direction of response is certain in Glen Canyon, where the majority of the food base research was conducted during the LSSF, and is less certain in Grand Canyon where the relative importance of autochtonous vs. allochtonous sources of carbon is unknown.

High Sustained Flow During Spring - Food base responses to high-sustained flows during spring are likely to be positive. (**Footnote: July 2005 Knowledge Assessment Workshop participants coded this cell red. After further research on the subject, Kennedy decided there was sufficient evidence to code this light green +. See discussion below**) Rates of algae production and growth are positively related to water velocity because faster water delivers more dissolved nutrients for algae to take up than slower water (DeNicola 1996). Therefore, high sustained flows will lead to both faster rates of algae growth/production and a larger permanently submerged zone. Further, Leibfried and Blinn (1987) documented high standing mass of benthic algae and invertebrates during high steady releases during the summer months of 1985. Shannon and others (2001) documented high standing mass of benthic algae and invertebrates and high drift rates for invertebrates during high steady flows of spring 1996.

Non-GCD Actions - Mechanical removal of trout in Marble Canyon is hypothesized to increase the availability of drift by reducing losses due to consumption of drift by trout; humpback chub and rainbow trout have considerable dietary overlap in Marble Canyon (Coggins and Yard unpublished data, Valdez and Ryel 1995). The direction of response is uncertain because it is unknown whether the reduction in trout abundance in Marble Canyon results in a meaningful increase in food availability for native fish.

Summary of Food Base Element in Aquatic Matrix -
Because of the north/south orientation of Glen Canyon, light is generally not limiting to primary productivity in the reaches of the Colorado River below Glen Canyon Dam. Therefore, flows and temperatures will likely be very important to aquatic food production in this reach. The Knowledge Assessment Workshop participants concluded that warmer temperatures were likely to be of benefit to food base organisms, but were less certain about the effects of flows on the aquatic food base. Studies have been conducted during and after many different flow scenarios, compounding the ability to draw definitive conclusions. Although greater stability of the river increases the permanently wetted area, thereby allowing for more consistent production of algae and macrophytes, increased fluctuations seem likely to dislodge and transport this production, making it more readily available to fishes. The workshop participants concluded that uncertainty remained about what combination of steady and fluctuating flows provided the greatest benefit to the food base on which fish depend. Food availability is of great importance to both the rainbow trout population in the Lees Ferry reach and to native fishes farther downstream. The workshop participants identified that the relative contribution of autochthonous and allochthonous material is not well known and needs further study. These conclusions led to the development of strategic questions to be addressed (Section 4.3.1) and they are summarized and presented graphically in Tables 3.3 and 3.4.

3.3.2 Fish

3.3.2.1 Mainstem Spawning & Incubation

The mainstem spawning and incubation performance measure represents the conditions that promote spawning and the quality of incubation environments before larvae become free-swimming fish. Water temperature is the key management action expected to improve spawning and incubation for native fish, while the extent of daily fluctuations in flows was considered the key determinant for rainbow trout in Glen Canyon.

Water Temperature - There is certainty that native fish require warmer water temperatures for spawning than is currently available (Valdez and Carothers, 1998; Valdez and Ryel, 1995). Flannelmouth suckers can spawn at temperatures as low as 8º C but require a temperature of 14º C for hatching. Humpback chub require temperatures 16º C or higher for successful spawning and hatching (Clarkson and Childs, 2000).

Significant increases in water temperature from a TCD or low reservoir elevation are unlikely to occur during the months of spawning (Feb.–Apr.) and incubation (Mar.–Jun.) for rainbow trout (Korman and others, 2005a) and therefore will not influence reproductive success of that species. However, predictions for rainbow trout are uncertain because higher temperatures would be expected to increase metabolic energy demand of adults and possibly affect maturation schedules or fecundity.

<u>Increased Daily Fluctuations</u> - The effects of increased daily fluctuations in flow on spawning and incubation success for humpback chub are unknown. Fluctuations could expose eggs and larvae of broadcast spawners like humpback chub and flannelmouth sucker but the extent of this impact is uncertain. Spawning of flannelmouth sucker occurs over shallow riffles where exposure of eggs or early larval stages due to fluctuating flows is more likely (Scott Rogers, oral communication, 2005). Increased fluctuations can reduce incubation survival for rainbow trout in Glen Canyon if the extent of fluctuations is large (Korman and others, 2005a). A model predicting the magnitude of the effect is available but has not been validated. In Marble Canyon, the vast majority of mainstem spawning habitat is below the 5,000 cfs stage (Korman and others, 2005a); thus, spawning and incubation success is unlikely to be effected by daily operations of GCD conducted at higher volumes.

<u>Reduced Variation in Monthly Volume</u> - The effects of changes in monthly volumes on spawning and incubation success of native fish is unknown. It is uncertain whether increased flow during springtime, as recommended as part of the Seasonally Adjusted Steady Flow alternative, is required to stimulate humpback chub spawning. Reduced volumes during summer months reduce mean flow and increase travel time and therefore exposure to solar insolation, resulting in warmer water at downstream locations that may promote successful spawning for some native fish species (Vernieu and others, 2005). Decreases in monthly volumes during the incubation period of rainbow trout has the potential to increase incubation mortality in Glen Canyon, but not in Marble Canyon where almost all spawning habitat is below 5,000 cfs (Korman and others, 2005a).

<u>BHBFs and HMFs</u> - The effects of these high flows on spawning and incubation success for native fish and rainbow trout is very uncertain. High flows have the potential to stimulate spawning of native fish or displace eggs or larvae with limited mobility. Short-term changes in food availability caused by high flows could influence maturation schedules and are hypothesized to have reduced the condition and spawning intensity of rainbow trout in Glen Canyon.

<u>Sustained Low Steady Flow</u> - Lower and steady mainstem flows occurring during native fish spawning periods would lead to an increase in water temperatures that may promote spawning and minimize exposure of incubating and early larval stages (Trammell and others, 2002). There is less certainty for flannelmouth sucker because it is uncertain whether temperatures during the spring will be high enough to promote spawning. However, these fishes have been documented spawning later in the year when mainstem water temperatures would be more conducive under sustained low steady flows (Douglas and Douglas 2000). Steady flows during the rainbow trout spawning period would

increase incubation survival (Korman and others, 2005a). It is unlikely that steady flows would affect spawning and incubation of rainbow trout in Marble Canyon, as the majority of spawning habitat is below 5,000 cfs.

High Sustained Flow During Spring - The effects of higher flows during spring on spawning and incubation for native fish is highly uncertain. Higher flows during the spring could potentially reduce incubation mortality for rainbow trout in Glen Canyon, but high flows could also have no impact depending on timing relative to spawning (McKinney and others, 1999; Korman and others, 2005a). The effect of higher flows on trout spawning in Marble Canyon is highly uncertain. Higher flows could increase access to tributaries (positive effect) or could scour redds deposited in the mainstem (negative effect).

Non-GCD Actions - Removal of nonnative fishes is hypothesized to potentially reduce predation rates on eggs and early life stages of native fish, but the importance of this effect is uncertain (McKinney and others, 1999).

3.3.2.2 Young-of-Year/Juvenile Nearshore Rearing

The YoY/Juvenile nearshore rearing performance measure represents the physical conditions that promote growth and survival of young fish in nearshore environments. Water temperature and greater diurnal flow stability were hypothesized to be the key determinants. Responses of native fish and rainbow trout in both Glen and Grand Canyons were very similar across most management actions that were evaluated.

Water Temperature - Increased water temperature is known to increase growth rates of juvenile native fish and reduce thermal shock for YoY immigrating from the LCR into the mainstem (Valdez and Carothers, 1998). Increased temperatures will increase metabolic demand. Thermal optimum for trout is less than those for native fish but higher than normal GCD release temperatures. Increased temperatures combined with sufficient food availability would improve growth rates. This was considered likely to occur in Glen Canyon but there was increased uncertainty of this effect for rainbow trout in Marble Canyon where the food supply is lower and where temperatures can exceed 15º C, the thermal optimum for rainbow trout.

Increased Daily Fluctuations - Increases in daily fluctuations destabilize nearshore habitat (Hoffnagle 2000) and are hypothesized to reduce the growth and survival of young fish (McKinney and others, 1999; Stone and Gorman, 2005). This hypothesis is weakly supported by habitat use and modeling studies for native fish (Converse and others, 1998; Korman and others, 2003). Nearshore use in the LCR observed by Stone and Gorman (2005) shows that humpback chub young-of-year have a high affinity of shoreline habitats and use these areas as a refuge from predation. Stone and Gorman (2005) hypothesize that destabilization of shoreline habitats in the mainstem Colorado River by load following will impact young-of-year humpback chub survival rates. Strong year classes of rainbow trout in 2000 were possibly in response to steady flows during the

LSSF experiment (S. Rogers, oral communication). Korman and others (2005a) have shown improved growth of rainbow trout during Sunday steady flows based on analysis of otolith microstructure. The daily variation in flow and the daily minimum flow were hypothesized to be the most important components determining nearshore rearing habitat quality.

Warming in nearshore habitats has been shown to be substantially increased by decreased diel flow variation (Hoffnagle 2000; Korman and others, 2005b; Vernieu and others, 2005). Nearshore water temperatures increase under steadier flows. Flow stabilization therefore not only allows native young-of-year to remain in their preferred shoreline habitat, but provides warmer water temperatures which promote growth.

Reduced Variation in Monthly Volume - A reduction of changes in mean monthly volumes was hypothesized to improve nearshore rearing habitat by providing increasing shoreline stability (Stone and Gorman 2005; Korman and others, 2005a). Stranding or evacuations of juvenile fish from backwaters that are isolated from the mainstem following a flow reduction have been observed (Hoffnagle, 1996). Korman and others (2005a) found a statistically significant reduction in survival rates of YoY rainbow trout in Glen Canyon associated with the large change in monthly volumes from August to September in 2004.

BHBFs and HMFs - The effects of BHBFs and HMFs on nearshore rearing habitat for native fish are dependent on sand supply and the timing of the flood. High flows were hypothesized to potentially result in a short-term negative impact on juvenile fish (due to displacement and reduced food supply), especially if the flow occurred in the fall when smaller YoY fish are present in the mainstem. High flows in the absence of an adequate sand supply have been shown to result in only limited backwater development. Thus, high flows that do not provide any long-term improvement in backwater development were hypothesized to have an overall negative effect for both native fish and trout. The importance of backwaters to juvenile native fish is unknown, thus the direction of response for high flow events that were coupled with an adequate sand supply was uncertain. Because young trout are not as dependent on sandy or backwater habitats as are native fish, the negative impacts of high flows associated with displacement were not potentially countered by an increased availability of these habitats.

Sustained Low Steady Flow - Sustained low and steady flows would result in shoreline stabilization and higher temperatures that are hypothesized to improve nearshore rearing for native fish (Stone and Gorman 2005) and rainbow trout (Korman and others, 2005a). This is supported by strong year classes of flannelmouth suckers (S. Rogers, unpublished data) and rainbow trout (Speas and others, 2004) produced in the same year as the 2000 LSSF experiment was conducted.

High Sustained Flow During Spring - High and steady flows during the spring were hypothesized to provide greater shoreline stability for rainbow trout and allow juvenile fish to access flooded vegetation for rearing. It is uncertain whether ponding of tributary mouths improves juvenile survival rates of native fish in tributaries. Juvenile and young-of-year that remain in the LCR because of ponding would very likely have better growth rates than if they migrated to the mainstem, but predation rates in the LCR could be much higher (Stone and Gorman, 2005), offsetting any survival advantage associated with improved growth.

Non-GCD Actions - Mechanical removal of warmwater and coldwater nonnative fishes was hypothesized to improve the quality of nearshore rearing environments for native fishes through reduced competition and predation.

3.3.2.3 Invasive Fish Species

The invasive fish species performance measure reflects the population response for coldwater and warmwater nonnative species.

Water Temperature - Warmer water temperatures in the range of 14–18ºC are hypothesized to increase the abundance of both coldwater and warmwater nonnative fishes. Higher temperatures were hypothesized to be the most important factor controlling the abundance of warmwater nonnatives.

Increased Daily Fluctuations - Increased daily fluctuations in flow are hypothesized to reduce the abundance of both warmwater and coldwater nonnative fishes. The hypothesized mechanism is degradation of nearshore rearing environments. The daily variation in flow and the minimum flow were hypothesized to be the most important constraints.

Reduced Variation in Monthly Volume - The effects of changes in mean monthly flow on nonnatives is unknown.

BHBFs and HMFs - As coldwater nonnative fish species are not as dependent on backwater habitat and vegetated sandy shorelines as native fish, changes in these habitats resulting from BHBFs or HMFs were hypothesized to have little effect on abundance. The effect on warmwater nonnative fish that are more dependent on these habitats is unknown.

Sustained Low Steady Flow - Low and steady flows tested during the summer of 2000 have been shown to increase the abundance of rainbow and brown trout in Grand Canyon (S. Rogers, unpublished data; Speas and others, 2004) and the abundance of warmwater nonnative fishes (Trammell and others, 2002).

Non-GCD Actions - Mechanical removal of rainbow and brown trout in Marble Canyon has been shown to result in a substantial reduction in population sizes for these species (GCMRC, unpublished data). The effect of reductions in rainbow and brown trout abundance on warmwater nonnative fish species was considered highly uncertain and vice-versa. The efficacy of mechanical removal of warmwater nonnatives is uncertain.

3.3.2.4 Disease

The disease performance measure predicts the potential incidence of Asian Fish Tapeworm in humpback chub and whirling disease in rainbow trout (McKinney and others, 2001a). Water temperature was considered the driving factor for both cases.

Water Temperature - Increases in water temperature were hypothesized to potentially increase the incidence of disease in both humpback chub and rainbow trout although the extent of the response is uncertain. Currently, water temperatures in the mainstem Colorado River are too low for the Asian tapeworm to complete its life cycle and Asian tapeworm sources are thought to exist only in Colorado River tributaries. Increased water temperature in the Colorado River may allow the Asian tapeworm distribution and sources to expand.

Increased Fluctuations and other Flow Actions - The response of disease to changes in flows from GCD was highly uncertain.

3.3.2.5 Adult Populations

Adult population performance measures predict the response of humpback chub and flannelmouth suckers in Grand Canyon and rainbow trout abundance in Glen and Marble Canyons. The size of trout in Glen Canyon, an important determinant of angling quality, was also predicted.

The direction of response of native fish to all the management actions that were considered in almost all cases was highly uncertain. Potential benefits of improvements in the food base and improved spawning/incubation and/or YoY/juvenile rearing environments could potentially be outweighed by increased incidence in disease or increased abundance of nonnative fish populations.

Water Temperature - A significant increase in the abundance of juvenile age classes in the flannelmouth sucker population in Grand Canyon have been observed over the last few years (S. Rogers, unpublished data, Trammell and others, 2002). It is possible that these increases could be the result of lower flows and higher release temperatures from Glen Canyon Dam. The observed stabilization of the humpback chub population (Melis and others, 2006) may have resulted, in part, from warmer water temperatures during low steady summer flows in 2000 and warmer Glen Canyon Dam releases in 2003–5. Rainbow trout abundance and size were hypothesized to increase in Glen Canyon in response to warmer temperatures. This hypothesis is supported by the strong recruitment in 2000 (Speas and others, 2004). The response in Marble Canyon was highly uncertain because increased metabolic costs associated with higher temperatures could result in a negative overall effect in the absence of a concomitant food supply increase to meet increased metabolic energy demand.

Increased Daily Fluctuations - Reductions in daily fluctuation in flow have been shown to increase the abundance of trout in Glen and Marble Canyons with a subsequent reduction in fish size (McKinney and others, 1999; McKinney and others, 2001b). It has been hypothesized that some level of higher daily fluctuations will increase food availability and adult size-at-age. Responses of native fish to increased daily fluctuations are highly uncertain.

Reduced Variation in Monthly Volume - The reduction in mean volumes between August and September 2004 were shown to result in a significant decrease in YoY survival rates for rainbow trout in Glen Canyon, however, the effects of such a decrease on the adult population size is uncertain (Korman and others, 2005a). No data on population response for native fish are available.

BHBFs and HMFs - The effects of occasional high flows to build sandbars was not considered to have any long-term and significant effects on rainbow trout populations in Glen or Marble Canyons. There was no evidence of any significant effect associated with the 1996 flood. Responses of native fish populations are highly uncertain because the importance of backwaters and vegetated shorelines to overall recruitment has not been determined.

Sustained Low Steady Flow - Strong year classes of flannelmouth suckers and rainbow trout were produced from the 2000 LSSF experiment (S. Rogers, unpublished data, Trammell and others, 2002). The 2000 flow experiment may also have contributed to the stabilization of the Grand Canyon humpback chub population (Melis and others, 2006). Low and steady flows during the summer and fall months is part of the reasonable and prudent alternative in the biological opinion for humpback chub. Recent habitat use studies document the importance of nearshore habitats for humpback chub young-of-year, which was used to support a recommendation to implement a low and steady summer flow test to increase adult population size (Stone and Gorman 2005). The overall effect of low and steady flows on the adult humpback chub is uncertain because improvements in young-of-year survival rate or adult growth could be offset by an increased incidence of disease or an increase in the abundance of warmwater nonnative fish which compete with and prey on humpback chub and other native fishes.

Sustained High Flows During Spring - The effects of sustained high steady flows on fish populations in Glen and Grand Canyons is unknown.

Non-GCD Actions - Mechanical removal of rainbow trout in Marble Canyon has been shown to significantly reduce the population size of trout in this area and the extent of the reduction can be quantified (GCMRC, unpublished data). However, the response of humpback chub and other native fish to this reduction is unknown. The effect of reducing the abundance of warmwater nonnative fishes on the population of rainbow trout in Marble Canyon is also unknown.

3.3.3 Angling Opportunity and Quality

Criteria used for this performance measure were the abundance and size of rainbow trout in Glen Canyon, the availability of drift, and the access of anglers to fish.

Water Temperature - Increased water temperature is predicted to increase the size and abundance of rainbow trout in Glen Canyon that would result in benefits to the fishery. Increased temperature will also increase metabolic demand and feeding rate that may improve "catchability." (See the food base section for specific references on the expected relationships between water temperature and aquatic productivity).

Increased Daily Fluctuations - Increased fluctuations are hypothesized to reduce angling opportunities. Increases in the hourly up ramp rate decrease the period of high drift rates when fish are feeding most actively and the duration of angling during this period. Increasing the daily flow to above ca. 15,000 cfs significantly reduces the number of angling locations. Increases in the daily maximum and range in flows, or a decrease in the daily minimum flow, increase the distance between the areas where adult fish are holding and where anglers can fish from. This increase in distance reduces angling opportunity and catchability. This assessment is backed up by two different studies (Bishop and others, 1987; Stewart and others, 2000) that relied on statistically reliable social science survey methods to determine angler preference for certain types of flows. In both studies, most anglers expressed preference for constant flows over fluctuating flows. Changes in flow (rising or falling water) were considered an important attribute of an excellent fishing experience for slightly more than half of all anglers, but rising or falling water ranked behind several other attributes that were considered more important for an excellent trip, such as "good weather" and "low water". In the Bishop et al. (1987) study, anglers were specifically asked to consider the likelihood that fluctuating flows promoted more drift and therefore improved feeding behavior, when making their assessment of flow preferences, yet even when presented with this information, the majority of respondents preferred moderate to moderately low (25,000 to 10,000 cfs) stable flows over fluctuating flows. Fluctuating flows were also perceived to be more problematic at higher flows (averaging around 25,000 cfs) than at lower volume flows.

Reduced Variation in Monthly Volume - Reductions in the change in monthly volumes is likely to result in a more stable food supply for rainbow trout and a decrease in the distance between the bank and the area where fish are feeding.

BHBFs and HMFs - High flows eliminate angling opportunities during the high flow event and result in reductions in food availability for weeks to months (depending on timing) following the high flow. This negative assessment is supported by data from two different social science studies (Bishop and others, 1987; Stewart and others, 2000) that relied on statistically reliable samples and survey methods to determine angler preference for certain types of flows. In both studies, high flows (flows of 25,000 cfs and above) were considered by the majority of anglers to be somewhat or very unsatisfactory (with the percentage of very unsatisfactory responses increasing steadily as flow levels increased.)

As flow levels increased above 15,000 cfs, angler satisfaction ratings decreased, with the highest levels of dissatisfaction correlated with the highest flows. At flows of 40,000 cfs, 50,000 cfs, and 60,000 cfs, the percentage of anglers characterizing these flows as "very unsatisfactory" was 65%, 69%, and 71% respectively (or 72%, 74%, and

74% when “very unsatisfactory” and “somewhat unsatisfactory” responses were combined.)

Sustained Low Steady Flow - Steady flows reduce the availability of drift and catchability as experienced during the 2000 LSSF experiment. Additionally, low steady flows during summer promote the establishment of seedling tamarisk trees at low elevation. These seedlings then temporarily hinder fishing activity following a return to higher flows. This negative assessment must be qualified in relation to previous findings by Bishop and others (1987) and Stewart and others (2000), in which anglers expressed preference for moderate (10,0,000–15,000 cfs) and moderately low (7,500–10,000) flows over lower (<7,500), higher (>15,000 cfs), or fluctuating flows. In the Stewart study, 39% of anglers rated flows of 7,500 cfs as very or somewhat satisfactory, 38% rated 7,500 cfs as “neutral” (neither satisfactory nor unsatisfactory), and less than a quarter (24%) rated this flow level as somewhat or very unsatisfactory. As flow levels decreased below 7,500 cfs, however, anglers expressed increasing dissatisfaction, e.g., 40% rated flows of 5,000 cfs as somewhat or very unsatisfactory, 50% rated flows of 4,000 cfs as somewhat/very unsatisfactory, 54% were very or somewhat unsatisfied with 3,000 cfs, and 56% somewhat to very unsatisfied with 2,000 cfs. According to the Bishop and others (1987) study, the increasing dissatisfaction with lower flows has more to do with increasing difficulty of boat access upriver and increasing potential for equipment (motor/prop) damage as flows decreased than with decreasing drift or fish catchability.

High Sustained Flow During Spring - Flows in excess of ca. 15,000 cfs increase the distance between areas from which anglers can fish and the area where fish are holding, thereby reducing catchability. This negative assessment is supported by data from the Bishop and others, 1987, and Stewart and others, 2000, studies, both of which employed statistically reliable social science sampling and survey methods to determine angler preference for certain types of flows. In both studies, anglers expressed a strong preference for flows in the 10,000–15,000 cfs range. As flow levels increased above 15,000 cfs, angler satisfaction ratings decreased, with the highest levels of dissatisfaction correlated with the highest flows. At flows of 20,000, 25,000 and 30,000 cfs, the presumed range of these sustained high flows, the percentage of anglers characterizing these flows as “very unsatisfactory” was 19%, 39% and 54% respectively (or 36%, 56% and 67% when “very unsatisfactory” and “somewhat” unsatisfactory responses were combined), compared with 6% “very unsatisfactory” responses for flows in the 15,000 range. Conversely, one third of all respondents (33%) applied the “very satisfactory” rating to flows in the 15,000 cfs range, whereas 17% rated flows in the 20,000 cfs range as “very satisfactory” and only 5% and 3% of respondents rated flows of 25,000 and 30,000 cfs as “very satisfactory.”

Summary of Fishery Portion in Aquatic Matrix -
The Glen Canyon Dam Adaptive Management Program has identified maintenance and improvement of two distinct fish populations that both inhabit the Colorado River below Glen Canyon Dam in the Program Goals: the introduced rainbow trout population in the Lees Ferry reach (subject to recreational angling) and the native fish population in Grand Canyon, especially the federally listed endangered humpback chub. The Knowledge

Assessment Workshop participants recognized the fundamental linkage of these populations with their food sources (primarily the production of algae, macrophytes, and invertebrates, but also allochthonous material produced in the riparian zone and organic material delivered from tributary flows) although the food base is presented as a distinct resource in this report. This linkage is reflected in some of the strategic questions presented in Section 4.3. Because metabolic rates in fishes is dependent on water temperature, increased release temperatures from Glen Canyon Dam can be expected to increase growth rates for both rainbow trout and native fishes. Increased water temperatures can also be anticipated to provide some benefit to nonnatives adapted to warmwater, and so require ongoing research to determine how much they limit survival of native fish species. The effects of various flow regimens on fish is less certain, and should be the subject of additional study. Rainbow trout in the Lees Ferry reach appear to benefit from additional food that can be made available by fluctuating flows, though apparently not the artificial floods, but this deserves additional research. Workshop participants recognized that humpback chub reproduction is being naturally maintained in the Little Colorado River but that survival and recruitment of these fish to maturity is limited. Humpback chub reproduction in the mainstem Colorado River in Grand Canyon appears to be dramatically reduced from historic levels. What is less certain is which factor or suite of factors is most limiting to these young fish. It is not clear whether mainstem water temperatures, predation by nonnatives, displacement by flows, habitat availability/quality, parasites, or some combination of factors is most limiting to maturation and reproductive success of native fish, and so elucidation of limiting factors deserves additional study to help guide management. Researchers in this area will need to be cognizant of the potential impacts of their sampling on fish populations. Strategic questions associated with these resources are presented in Sections 4.3.1 – 5, and the state of knowledge is summarized graphically in Tables 3.3 and 3.4.

3.4 Riparian Habitat

Riparian vegetation was initially separated into large geomorphic reach designations (e.g., Glen and Grand Canyon) to represent the response of riparian vegetation to local and large scale variables. However for the purposes of this exercise, it was determined that the focus should be on garnering a general understanding of the response of riparian vegetation, throughout the CRE, to operations. To identify where uncertainty exists within riparian vegetation, the shoreline was divided by stage elevations. The categories are: fluctuation zone with stage elevation to 708 cms (<25,000 cfs,); lower riparian zone with stage elevation to 708–1,274 cms (25,000–45,000 cfs); upper riparian zone with stage elevation to 1,274–1,680 cms (45,000–60,000 cfs); predam high water zone with stage elevation to >1,680 cms (>60,000 cfs); and uplands. In the case of the last three stage elevation categories, the flow options considered during this workshop were generally not applicable (Table 3.5). However, the lack of flows above 1,274 cms on these zones is discussed briefly. This section concludes with a discussion of wildlife resources and dam operations, but is restricted to southwestern willow flycatcher (*Empidonax traillii extimus*) and Kanab ambersnail (Succineidae: *Oxyloma haydeni* *kanabensis*). It should be noted that these resources were not a focus of discussion during the workshop and are not included in the matrix.

Water Temperature - The effect of warmer temperature on riparian habitat is largely unknown for vegetation below the 1,274 cms stage elevation, in the CRE. Studies in the Walker River Delta in Nevada (Young and others, 2004) indicate that tamarisk germinates throughout a range of seed bed temperatures (0–40°C). These temperatures may be constant or vary diurnally. Optimal germination was diurnal with 16 hours of 10°C and 8 hrs of 20°C. Germination was variable by seed lots. A similar response was noted for coyote willow *Salix exigua*) a species native to the CRE (Young and Clement 2003). Other factors contributing to the uncertainty include physiological responses associated with germination and clonal growth of wetland and riparian species (Farnsworth and Meyerson, 2003; Güsewell and others, 2003). Vegetative growth rates would likely increase under a warmer regime, resulting in denser marsh and riparian vegetation within the fluctuation zone. Besides temperature, nutrient concentrations in water also come into play and would likely differentially affect native and exotic species found in the fluctuation and lower riparian zones (Biondini, 2001; Farnsworth and Meyerson, 2003; Güsewell and others, 2003). This effect would likely be more pronounced in the fluctuation zone that is also subject to daily disturbance. These changes could cascade up the trophic food web by changing invertebrate composition and types of plant species that provide nearshore cover for aquatic species.

Increased Daily Fluctuations **-** Overall riparian vegetation in the fluctuation and lower riparian zone would respond positively to increased fluctuations. The group agreed that the “certain” category could be applied to the fluctuation zone, citing Stevens and others (1995). The lower riparian zone response was likely trending to “uncertain” with a potential increase in vegetation volume among woody species (Kearsley, 2004). GCMRC has in hand several annual reports (Waring, 1995; Kearsley and Ayers, 1996; 1998; Kearsley and others, 2003; 2004), but few peer reviewed articles (Turner and Karpiskac, 1980; Johnson, 1991; Ralston, 1995) for this zone.

Reduced Variation in Monthly Volume - For all zones the group identified that uncertainty existed and, like temperature, the amount of available information for the CRE was too small to know or infer positive or negative effects.

BHBFs and HMFs – Beach/habitat-building flows have only occurred twice, under different sediment enrichment conditions, and at different times of the year. Habitat maintenance flows took place under depleted sediment conditions, and at different times of the year. Seasonal differences confound interpretation of the effects on vegetation. The participants felt that short duration high flows were ranked as uncertain, but with positive effects. There is some peer-reviewed literature available regarding the 1996 event (Kearsley and Ayers, 1999; Stevens and others, 2001). The authors found significant changes in vegetative cover immediately following the high flow, but species composition remained little affected. The number and extent of sampled area (i.e., polygons) dominated by obligate wetland species (e.g., cattails, common reed) did increase following the high flow, but these increases were not statistically significant.

Understory cover was eliminated, largely through burial. Substrate grain size was more homogeneous following the high flow event. Recovery from burial was by species that could withstand burial including both native species such as coyote willow (*Salix exigua*) and introduced species, such as tamarisk (*Tamarix ramosissima*). Operations appear to affect water availability up to approximately 400 cms above river surface elevation (Kearsley, 2004, Ralston, 2005). A flow that exceeds 1260 cms (45,000 cfs) may be beneficial to the predam high water zone, but this certainty falls in the yellow to light green color designation. Higher flows would result in a loss of vegetation in the lower and upper riparian zone (Waring, 1995), but the magnitude of loss is difficult to predict. A lack of high flows has, with certainty, limited recruitment in the predam high water zone (Anderson and Ruffner, 1988).

In the absence of sediment enriched conditions, questions remain regarding how coarsening of the substrate changes vegetation composition and dominance. In the same vein, silt and clay contribution to nutrient cycling and riparian dynamics would likely be different under enriched versus starved sediment conditions. The seasonality question is also an area of uncertainty. Although high flows historically occurred in late spring, the daily range in July through October (during the monsoon period) was also extreme (Topping and others, 2003) but of shorter duration. The high flow tests that are of short duration may need to be considered in this context rather than in the context of a spring flood scenario. In general, high flows were thought to likely result in some reworking of return channel/marsh sites and a redistribution of carbon sources. There would be less material involved, but these high flows would still deliver nutrients and transport seeds, implying a benefit to riparian vegetation.

<u>Sustained Low Steady Flows</u> **-** The only point of reference for sustained low steady flows is for the summer of 2000. In this context, the group felt that there was certainty that the flows had a negative affect on the fluctuation zone and a neutral to negative affect on the lower riparian zone. The negative affect was attributed to invasive species establishment, particularly tamarisk (Porter and Kearsley, 2001) that germinates under constant moisture conditions. Observations of tamarisk seedling establishment in the Glen Canyon Reach in the cobble bars and along the shoreline were also made by fishing guides. The response of riparian vegetation to sustained flow during other parts of the year, fall for instance is unknown.

<u>High Sustained Flow During Spring</u> **-** High sustained flow effects were considered certain and positive for the fluctuation zone, subject to more specific delineation of the duration and timing. The marsh/fluctuation zone would likely increase in area shoreward and upslope (Stevens and others, 1995; Kearsley and Ayers, 1999). A similar level of certainty was given for the lower riparian zone with respect to high sustained flows, but again the duration and timing would require definition. High sustained flows during spring and summer may support increased diversity in the lower riparian zone (Kearsley and Ayers 1998) and may have, with some certainty, negative affects on exotic species like camelthorn (*Alhagi maurorum*) and pepperweed (*Lepidium latifolium*), through loss of these seeds in the seedbank, though the weeds studies had low representation at the sample sites (Kearsley and Ayers, 1998).

Non-GCD Actions **-** These were not applicable for all zones.

Wildlife Resource Linkages – Two wildlife resources of concern that were not the focus of discussions during the workshop, owing to time constraints, are the southwestern willow flycatcher (*Empidonax traillii extimus*) and Kanab ambersnail (Succineidae: *Oxyloma haydeni kanabensis*). Both are impacted by high flows (BHBF) with some certainty.

The impacts to southwestern willow flycatchers are associated with inundation of rearing habitats located in the upper riparian zone and possibly foraging habitats within the fluctuation zone. The latter is more uncertain. The willow flycatcher is a riparian breeding bird that has had historic nesting sites along the river corridor since 1963 and possibly before the dam (Sogge and others, 1997; Holmes and others, 2005). The bird's nests are usually found in tamarisk trees, at heights well above inundation levels (Sogge and others, 1997; Stevens and others, 2001). Timing and magnitude are variables associated with high flows that might impact willow flycatchers. If flows exceed 1274 cms (45,000 cfs), and occurred during the breeding or into the period when young birds fledge (May – August or September), then this species could be affected with some certainty. Stevens and others (2001) reported nominal impacts associated with the March 1996 high flow including reduction in groundcover and branches located lower than 0.6 m. The high flows did not reach nest trees. Stevens and others (2001) speculated that the high flows might have had an impact on foraging habitat (i.e., marsh areas), but studies that make these linkages are not available (Holmes and others, 2005).

The linkages between riparian vegetation and breeding bird habitat quality are not well defined for the river corridor. However, vegetation density (volume) associated with trees rather than shrubs, and vegetated area are two variables that correlate well with breeding bird abundances and diversity (Mills and others, 1991; Sogge and others, 1998). This correlation was strongest with tamarisk and mesquite (*Prosopis glandulosa*) and less so with willow, arrowweed (*Pluchea sericea*), or seep willow (*Baccharis emoryi*) (Sogge and others, 1998). Operations that would promote expansion of trees over shrubby species might include high flows that promote seed scour and redistribution of mesquite or acacia (*Acacia greggii*) and habitat reworking, though this is uncertain. A retrospective analysis following the 1984 high flow event of mesquite distribution would help elucidate this question. Fluctuating flows like those seen in the winter of 2002–4 would also promote growth of existing vegetation (Kearsley, 2004), but this would include both shrubs and trees. This can be stated with some certainty.

The habitat of Kanab ambersnail at Vaseys Paradise is affected by both spring discharge and river stage elevations. Spring discharge influences available wetted area above river stage elevation, while river stage determines how far down the slope vegetation can be established along the river's edge. The available wetted area and amount of moisture influences plant composition which in turn influences snail distribution (Stevens and others, 1997b; 1998; Meretsky and Wegner, 2000). High flows that occur in low frequency may temporarily reduce snail habitat for several years (Stevens and others, 2001). However these impacts may be alleviated through temporary removal and replacement of vegetation. A conservation effort associated with the 2004, high flow test that involved temporary removal and replacement of habitat appears to have promise for the conservation of this species (Cox and others, 2005).

Summary of Vegetation Element of Terrestrial Matrix -
Knowledge Assessment Workshop participants found it practical to assess resource impacts in this area within the context of various flow elevations, where the lowest elevations are closest to the river and therefore are most affected by dam operations. The participants considering riparian vegetation were uncertain how various temperature releases would affect this resource, and so developed a strategic question focused on this habitat aspect. Some increased flows and flooding appear to benefit riparian vegetation through seed distribution and mechanical disturbance, which might be anticipated of species adapted to a historically fluctuating environment. Steady flows, conversely, are thought to have negative impacts on riparian vegetation, especially through the mechanism of allowing for establishment of nonnative invasive species, particularly tamarisk. These responses to flows are not certain, and so managers can benefit from additional research. Strategic questions associated with riparian resources are presented in Section 4.4, and the state of knowledge of effects of various treatments is presented graphically in Table 3.5.

3.5 Recreation

3.5.1 Campable Area

The campable area performance measure represents the conditions that promote the maintenance (or increase) of sandy areas suitable for use as campsites. In general, the results of this analysis track closely with the sediment matrix findings, since conditions that promote sediment retention on a systemwide basis are generally thought to be beneficial for campsite retention, as well. This perception is supported by data from 15+ years of campsite area monitoring at a sample of popular riverside campsites (Kaplinski and others, 2005a; 2005b) BHBFs are the key management action expected to maintain or improve campsite areas over the long run.

Water Temperature - There is certainty that warmer temperatures decrease water viscosity, allowing fine sediment to settle out faster, and thereby reducing the suspension of sediment in the water column and the amount of sediment available for downstream transport (Lane and others, 1949; Hubbell and Ali, 1961; ASCE, 1975). In theory, warmer water reduces the amount of sediment transported from sandbar deposits (S. Wright, oral communication, 2006), thereby increasing the longevity of sandy deposits used as camping beaches.

Increased Daily Fluctuations - The effects of increased daily fluctuations on campable area is reasonably well known from campsite area data collected sporadically during the 1980s and early 1990s (Beus and Avery, 1992), as well as from recently and historically compiled sediment transport data (Topping and others 2000a; 2000b; 2003, 2006; Hazel and others 2006). It is well established that increased fluctuations will result in higher sediment transport rates, with sediment derived from eddy storage complexes, which are the primary setting of most campsites in the CRE. However, as discussed by Beus and Avery (1992) responses of sandbars to higher fluctuating flow regimes are complex and highly variable. For example, during experimental fluctuating flows in 1990–91, higher fluctuations under sediment enriched conditions allowed some bars to aggrade, while others eroded or showed no net change. On the other hand, higher fluctuations under sediment depleted conditions generally resulted in net erosion, while under lower steady flows, bars can not aggrade above the level of the highest low flow, and therefore, over time (without occasional higher flows), the subaerial volume and height of sandbars will likely decrease even though sediment transport out of the system has been reduced.. Based on the work of Budhu (1992), Beus and Avery also concluded that "seepage induced erosion processes intensified as the range of daily stage fluctuations and down-ramping rates increased" while tractive erosion processes increased with higher upramping rates. Ultimately, these data led Beus and Avery (1992, Chapter 10, p.15) to conclude that: "Without bar building flows, the dynamic equilibrium condition achieved through seepage-driven erosion will keep the system at or near the minimum sandbar area and volume for this system. Large fluctuations or bar building flows may be used to maintain or rebuild the remaining sandbars . . . provided that adequate sediment supplies are available for bar building. In situations where sediment supplies are low or unknown, a general strategy of sediment storage is recommended [including] low ramping rates, low range of daily flows, and low maximum flows."

<u>Reduced Variation in Monthly Volume</u> - The effect of changes in monthly volumes on availability of camping beaches is unknown, because the changes in monthly volumes were not clearly defined. Decreases in monthly volumes during the summer high-use season would increase the available campable area during the peak recreational use season, but since the distribution of monthly volumes was not specified, the relative effects of monthly volume changes could not be gauged.

<u>BHBFs</u> - The effects of high flows above powerplant capacity is relatively well documented and appears to be the only mechanism available for restoring sand to elevations above the highest level of normal dam operations (Beus and Avery 1992; Kaplinski and others, 2005b). BHBFs have been demonstrated to increase campable areas on a systemwide basis, at least temporarily (Kearsley and Quartoroli, 1997; Hazel and others 1999; Kaplinski and others, 2005a; 2005b).

<u>HMFs</u> - The effect of powerplant capacity flows on campsite size is reasonably well documented (Kaplinski and others, 2005b), at least for HMFs under sediment depleted conditions. HMFs under sediment depleted conditions have been shown to not appreciably increase campable area (Kaplinski and others, 2005b). The work of Beus and Avery (1992, Chapters 6 and 10) suggests that under sediment enriched conditions, short-duration higher flows or higher fluctuating flows could potentially benefit some sandbars, while others would either continue to erode or show minimal measurable change.

Sustained Low Steady Flow - Results reported by Wright and others (2005); Schmidt and others (in review); Hazel and others (2006); Topping and others (2066) indicate that new tributary sand inputs are clearly conserved and will accumulate in the main channel at stable flows of 8,000 cfs (summer 2000, low summer steady flowtest) and under fluctuating flows ranging between 5,000 and 10,000 cfs (fall 2004 period before high-flow sediment test). Given that sustained low steady flows below 9,000–10,000 cfs are known with certainty to constrain the amount of sediment transported out of the system to negligible amounts (Topping and others, 2003), it follows that low sustained flows would significantly reduce the rate of sediment loss from campable sandbar areas. In addition, sustained low flows would expose more campable area on a sustained basis, increasing the amount of campable area exposed at lower elevations (Hazel and others 2001). However, over time, sustained low steady flows may result in decreases to the size and volume of sandbars above the low flow level due to the cumulative effects of repeated cut bank failures and the consequent redistribution of higher elevation sediment to lower elevations (at or slightly below the level of the highest flows). In other words, unless low steady flows are accompanied by occasional periods of higher fluctuating flows, the conserved sand may ultimately end up stored in the river system at or below a level that is beneficial for use by campers. Low steady flows will also permit tamarisk and other vegetation to encroach on sandbars (Porter and Kearsley, 2001), which could eventually offset any gains resulting from greater bar exposure at lower elevations. Unfortunately, measured information that would allow us to quantify rates of vegetation encroachment on sandbars under low flows (or any other flows, for that matter) are lacking, so the overall impact of vegetation encroachment on campable area is unknown.

Sustained High Flow - Sustained higher flows are certain to increase the rate and volume of sediment transported out of the system (Wiele and others 2002; Topping and others 2003; Hazel and others, in press), therefore sustained high flows would increase the rate of sediment loss from sandbars used for camping. Furthermore, sustained high flows would consistently inundate lower elevation campable areas, resulting in a sustained loss in campable area up to the level of the highest flows (Kaplinski and others, 2005b). Sustained high flows would obviously impact and remove vegetation growing below the zone of inundation, but since lower areas of sandbars would be constantly inundated, the benefits of removing vegetation would not be realized for campable area.

Non-GCD Actions - Mechanical removal of trout was the only type of mechanical removal considered in the matrix development, and obviously, trout removal would not affect campable area. However, we did *not* consider the option of mechanical removal of terrestrial exotics (such as tamarisk). Mechanical removal of tamarisk thickets or other exotics such as tumbleweed and camel thorn could hypothetically increase campable area, but the practicality and sustainability of applying such an approach with the goal of increasing campable area is untested and therefore unknown at this time.

3.5.2 Access to Attraction Sites

The access to attraction sites performance measure represents the conditions that enhance accessibility to popular recreation sites in the CRE.

Water Temperature - The assumption is that warmer water would not measurably enhance or detract from access to attraction sites, but this assumption has not been subject to serious scrutiny.

Increased Daily Fluctuations - The effects of increased daily fluctuations on access to attraction sites is not well documented, but anecdotal information suggests that increased fluctuations would reduce access to attraction sites by creating unstable and less predictable boat mooring conditions, resulting in the need to shortened side trips and/or leave some members of a boating party with their boats at all times, so that they could deal with the changing parking conditions under fluctuating flows.

Reduced Variation in Monthly Volume - The effect of changes in monthly volumes on access to attraction sites is unstudied and unknown.

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

Sustained Low Steady Flow - Sustained low steady flows reduce the amount of time row boaters have available to spend at attraction sites, because the slower current requires boaters to spend more time rowing to get downstream. Low flows do not appreciably affect motor boaters' use of attraction sites, since they can make up for the slower flow velocity by motoring faster and floating less often (Jonas and Stewart, 2002, p.23). Lower flows may improved the ease with which boaters can pull over and park their boats, and the parking at attraction sites would be stable, therefore low sustained flows may somewhat improve access to attraction sites overall. The relationship between low flows and access to attraction sites remains to be evaluated through formal study.

Sustained High Flow - The effects of sustained high flows at or above powerplant capacity on access to attraction sites is not well documented, but anecdotal information suggests that it would have neither a generally positive nor significant negative effect. In theory, higher flows would allow rafters to spend less time on the river and more time exploring attraction sites, but higher flows may also make some sites less accessible due to loss of mooring sites. Once again, the hypothesized relationship between specific flows and access to attraction sites remains to be evaluated through formal study.

Non-GCD Actions - Mechanical removal of trout was the only type of mechanical removal considered in the matrix development. It seems self-evident that trout removal would not affect access to attraction sites, except perhaps on a short term, infrequent basis. However, we did *not* consider the option of mechanical removal of terrestrial exotics (such as tamarisk). Mechanical removal of tamarisk thickets or other exotics such as tumbleweed and camel thorn could hypothetically increase accessibility to certain attraction sites that are currently difficult to access due to the density of nearshore vegetation; however, it is doubtful that the NPS would support the use of mechanical vegetation removal solely to improve accessibility to attraction sites.

3.5.3 Rafting Navigability

The rafting navigability performance measure represents the conditions that enhance navigability of the river in general and the white water rapids specifically. Initially, this variable was combined with human health and safety, but the knowledge assessment participants found it difficult to address this multi-component variable due to the fact that for any given flow scenario, the outcomes from a health perspective could be very different from those for navigability or safety. There was also considerable debate among the knowledge assessment workshop participants about how to define this multi-component variable and what indicators could best represent this variable. There were also concerns with how health and safety elements overlap with the visitor experience performance measure. In the end, we agreed that the original health and safety variable should be split into three separate components – navigability of rapids, human health, and safety (the latter interpreted as numbers of injuries and/or documented incidents putting human safety at risk) – and that the navigability variable would be limited to evaluating the ease with which boats are able to navigate downstream without getting stranded, damaged or overturned.

<u>Water Temperature</u> - Common sense suggests that water temperature does not affect the navigability of rapids. Therefore, temperature is considered to be “not applicable” or a known “non-issue” relative to navigability.

<u>Increased Daily Fluctuations</u> - Effects of increased daily fluctuations on rafting navigability are not well documented. We do know (from anecdotal information and common sense) that higher fluctuations improve the possibility of a stranded boat becoming unstuck within a reasonable timeframe (less than 24 hours); on the other hand, increasing the down ramping rates increases the likelihood of rafts getting stuck in the first place. One workshop participant expressed the opinion that higher fluctuations would improve navigability because it offered boaters more options on when and where to run a given rapid. However, the general consensus of workshop participants was that the effects of increased fluctuations on navigability were too poorly understood to confidently evaluate at this time.

<u>Reduced Variation in Monthly Volume</u> - The effect of changes in monthly volumes on rafting navigability is unknown. While there is anecdotal information suggesting that navigability may improve or decrease under higher or lower flow levels, the change in distribution of monthly volumes was not specified at the time this knowledge assessment was undertaken, therefore the effects of monthly volume changes on navigability could not be gauged.

<u>BHBFs and HMFs</u> - The effects of high flows above powerplant capacity on navigability is not well documented in the peer-reviewed literature, but anecdotal information and several in-house NPS studies (that have not yet been subject to peer review) (Jalbert,

1996; Jalbert, 2001) suggest that higher flows improve the navigability of most rapids by covering rocks that would otherwise be exposed and by creating more channels for boaters to chose from as they navigate downstream. Also, Webb's work (1999) shows that BHBFs can clear channels of rock debris accumulations, which generally (but not always) creates easier passage for boats after flows diminish. The NPS studies found a slight increase in flipped row boats and inadvertent swimmers under experimental high flows in the 45,000 cfs range, but the difference in numbers of these incidents under high and lower flows was not statistically significant (Jalbert, 1996.)

<u>Sustained Low Steady Flows</u> - Studies by Jonas and Stewart (2002) and Stewart and others (2000) provide limited data on rafters' perceptions of navigability under low sustained steady flows, and Jalbert (2001) has provided some preliminary data on accident rates during the 2000 LSSF experiment (showing a 100% increase in "incidents" under low flows), but most of the currently available information is anecdotal and in some instances, also contradictory. Lower flows certainly expose more rocks in the channel, and they constrain the options available to boaters for navigating the rapids, but at the same time, these flows slow the velocity of the current, thereby increasing the ease with which boaters can avoid obstacles in their path. There was general agreement among workshop participants that lower flows decreased the navigability of rapids for motor boats, but effects to oar powered crafts were strongly debated (e.g., Larry Stevens was adamant that lower flows improved navigability, while Andre Potochnik argued for the opposing viewpoint.) Workshop participants were in general agreement that lower flows would likely allow rocks to accumulate in the rapids more quickly than at higher flows, due to the reduced carrying capacity of the river, thereby decreasing navigability of rapids over time. This conclusion is supported by the work of Webb and others (2005), although Webb and others (2005, p.145) also found that several factors besides flow velocity and volume influence the rate and amount of debris fan reworking. The knowledge assessment participants generally concluded that low sustained steady flows would have either no appreciable effect or would have a negative effect on navigability overall, but solid consensus was lacking on this issue.

<u>Sustained High Flows</u> - The effects of sustained high flows at or slightly above powerplant capacity on rafting navigability is generally thought to be positive (Bishop and others, 1987; Stewart and others, 2000), with Crystal Rapid being a notable exception. The available anecdotal information suggests that high sustained flows would have either a generally positive effect or a neutral effect, for the same reasons as noted under BHBF.

<u>Non-GCD Actions</u> - Mechanical removal of trout was the only type of mechanical removal considered in the workshop, and it seems self-evident that trout removal would not affect navigability. We did *not* consider the option of mechanical removal of rocks or channel clearing with dynamite as viable nonflow options, as it seemed doubtful that the NPS would support the use of such approaches to improve navigability.

3.5.4 Quality of Water and Human Health Issues

This performance measure addresses conditions that influence the quality of water from a human health perspective, as well as the conditions that may influence the retention or dissolution of human pathogens in shoreline deposits, beach sand, etc. To our knowledge, no studies specifically evaluating the effects of flows on human health are available from the CRE, so this assessment is based on information from sources outside the system and from anecdotal information.

<u>Water Temperature</u> - An increase in waterborne pathogens is certain to occur with warmer water temperatures, based on information from EPA and elsewhere, therefore this cell was coded as negative light green.

<u>Increased Daily Fluctuations</u> - It was hypothesized that higher ramping rates and increases in the range of fluctuations could possibly improve water quality (through increased aeration of the water) and could reduce concentrations of bacteria near the shore lines of campsites where organic refuse and human pathogens tend to concentrate by constantly reworking and repeatedly “flushing” the sediments under fluctuating flows.

<u>Reduced Variation in Monthly Volume</u> - The effect of changes in monthly volumes on quality of water and human health is unstudied and unknown.

<u>BHBFs and HMFs</u> - The effects of high flows at or above powerplant capacity on quality of water and human health has not been scientifically documented, but scientific studies demonstrate that higher flows significantly rework shoreline deposits (Beus and Avery 1992). Anecdotal information suggests that this reworking of shoreline sediments flushes out viral and bacterial loads that tend to concentrate along the shorelines of camping areas under lower flows. This hypothesis warrants testing through formal study.

<u>Sustained Low Steady Flow</u> - Sustained low steady flows are assumed to negatively affect human health and quality of water through increasing temperatures, thereby increasing the volume of pathogens in the water. Also, sustained low flows reduce the volume and velocity of water flowing along the shorelines, as well as limiting the change in shoreline levels, thereby allowing pathogens to accumulate in shoreline sediment, especially in the vicinity of campsites. River guides have observed algae blooms associated with human urine along shorelines that are not regularly inundated by periodic higher flows, and they experienced increased incidents of waterborne viral infections during the 2000, LSSF, adding further anecdotal support to the notion that low steady flows promote conditions that are not conducive to maintaining optimal human health conditions.

<u>Sustained High Flows</u> - For the opposite reasons of those noted above (e.g., colder water, higher volumes, and increased velocity near shorelines), sustained high flows at or slightly above powerplant capacity are assumed to have a positive effect on quality of water and human health, but once again, actual data to support or refute this hypothesis, which is currently based on “commonly accepted river guide knowledge”, is lacking.

Non-GCD Actions - Mechanical removal of trout was the only type of mechanical removal considered. It is assumed that this activity does not affect human health either positively or negatively; however, once again, data is lacking to support or refute this assumption.

3.5.5 Human Safety

This category evaluates the likelihood of recreationists sustaining injuries or death from accidents associated with various flow regimes.

Water Temperature - Hypothermia and heart attacks due to thermal shock are some of the greatest risks to boaters and anglers who fall out of their boats in the CRE (Meyers and others, 1999, p. 37). Under normal dam release temperatures of 8–12°C, people can lose motor control in a matter of minutes and may lose consciousness in less than 10 minutes. This reality forces potential rescuers to take additional risks in their attempts to get swimmers out of the water as quickly as possible. Although no specific studies have been done in the CRE to document the relationships between water temperature and safety incidents, the well-known and well-documented hypothermia risks associated with typical dam release temperatures (Meyers and others, 1999) leaves little room for doubt that warmer water would significantly reduce safety risks associated with Colorado River recreation. Therefore, this cell was coded as light green and positive.

Increased Daily Fluctuations - The effects of increased fluctuations on visitor safety are unknown. There is some anecdotal information suggesting that higher ramping rates increase safety risks for anglers (as anglers are more likely to become stranded on gravel bars due to rapidly rising water, and anglers' boats are more likely to swamp if anchored, or to drift away if not anchored), but this relationship has not been formally documented. There is also anecdotal information suggesting that the increased unpredictability of flows increases risks for downstream boaters, but it is unclear whether either of these perceived increased risks would be substantiated upon further study.

Reduced Variation in Monthly Volume - The effect of changes in monthly volumes on human safety is unstudied and unknown.

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

Sustained Low Steady Flow – Effects of sustained low steady flows on safety were rated as positive by workshop participants because the river is warmer and slower, and the runs in the rapids are more predictable than under fluctuating flows. However, this conclusion contradicts data collected by NPS staff (Brown and Hahn, 1987; Jalbert 1996) and cooperating scientists (Shelby and others, 1992; Jonas and Stewart 2002) since the mid 1980s which indicates that boaters have a greater likelihood of incurring equipment damage and hitting rocks at flows below 9,000 cfs than at flows above 9,0000 (Jalbert, 1996, p.16). Also, preliminary data from the NPS LSSF safety study (Jalbert, 2001) documented a 100% increase in incidents such as hitting rocks in rapids and damage to equipment during the LSSF experiment (flows of 5,000–8,000 cfs), compared with normal ROD (MLFF) flows, adding further support to the "common consensus" of river guides that more accidents and injuries occur under low flow conditions. Once again, a formal, up-to-date, and comprehensive study evaluating the effects of flows on safety is currently lacking; a rigorous, peer-reviewed study to test the hypothesis that low steady flows positively affect safety is warranted in the future.

Sustained High Flows - For the opposite reasons of those noted above (e.g., colder water, greater velocity), sustained high flows at or slightly above powerplant capacity are assumed to have a somewhat negative effect on human safety. Actual data supporting this conclusion are limited to a single, non-peer-reviewed study (Brown and Hahn, 1987), which showed a correlation between flows in the low 30,000 cfs range and increased flips and swims at selected rapids. At flows in the low to mid 20,000 there was also a slightly elevated risk of having an incident, compared with flows in the 10,000 to 17,000 cfs range (which were rated as the safest flows by Brown and Hahn, (1987)). With higher flows, there are less rocks exposed, hence the increased safety risks that come with colder, swifter water may be offset to some degree by the simultaneous reduction in risk from hitting rocks during lower flow conditions. Once again, a formal study to evaluate safety risks associated with different flows is currently lacking and is clearly warranted in the future.

Non-GCD Actions - Mechanical removal of trout was the only type of nonflow action considered in the assessment. Several workshop participants felt that risks to visitor safety increased due to the use of electricity in the water near shorelines and camps, however, other workshop participants argued that this risk was being mitigated through public outreach and education, and therefore, recreational safety was not relevant in the evaluation of this activity. To date, no injury incidents associated with electro-fishing in the CRE have been reported.

3.5.6 Recreational Experience

The recreational experience category proved difficult to evaluate for several reasons. First and most importantly, there is no universally agreed upon definition of what this visitor experience variable encompasses. Secondarily, the concept of recreational experience is multidimensional, i.e., recreational experiences in the CRE are framed by distinct but interrelated physical, place-based attributes (beaches, scenery, local environmental conditions) as well as an array of different recreational activities (camping, rafting, angling, wilderness exploration, social interactions with others, etc.) making a single evaluation in relation to flows problematic (i.e., a given flow regime may benefit one aspect of the overall experience while simultaneously causing negative effects to others.) Furthermore, although we have ample evidence to demonstrate that flows are important influences—both directly and indirectly—on the attributes considered important for a high quality visitor experience (Bishop and others, 1987; Shelby and others, 1992; Stewart and others, 2000), we lack a solid understanding of the relative importance of flows compared with other potential experiential "drivers" such as visitor use levels, scenery, weather, quality of social encounters, and so forth. The workshop participants felt that the GCDAMP should undertake some basic, foundational studies to do this assessment exercise properly. Nevertheless, we attempted to evaluate how various regimes might affect recreational experience, as follows:

<u>Water Temperature</u> - Studies documenting the relationship between water temperature and recreational experience are lacking, but anecdotal information, plus some social science survey data, indicate that warmer water would likely improve the boating and angling experience because warmer water would allow visitors to enjoy being in the water and getting soaked in the rapids. Furthermore, warmer water would expand the range of river-based recreational opportunities, as swimming in the river is currently discouraged by most commercial outfitters due in part to the coldness of the water and associated risks of hypothermia. Anecdotal information suggests that most visitors currently manage to enjoy their recreation experience *in spite of* the very cold water temperatures. The Stewart and others (2000) study found that a small majority of commercial passengers (53%) did not believe that their trip would have been any more enjoyable with warmer water, but a slightly larger majority of private boaters and river commercial guides shared the opposite opinion (i.e., 57% of private boaters and 58% of commercial guides felt that warmer water would have improved their overall experience.) The trade offs associated with different aspects of visitor experience affected by warmer water (i.e., improved "swimmability" vs. possible increase in viral or bacterial infections) have never been studied and remain unknown.

<u>Increased Daily Fluctuations</u> - Visitors' perceptions about fluctuating flows have been documented to a limited degree in studies by Bishop and others (1987) and Stewart and others (2000). Both studies concluded that most rafters preferred stable, predictable flows over fluctuating flows. Both the Bishop and Stewart studies also demonstrated that, contrary to the opinions of many members of the Lees Ferry fishing guide community, anglers generally preferred stable flows over highly fluctuating flows (Bishop and others,

1987, p.132–133; Stewart and others 2000, p.49). This opinion held even when anglers were reminded that higher fluctuations could potentially improve the amount of drift in the water and thereby might increase the quality of the fishing experience (Bishop and others, 1987, p.126).

Reduced Variation in Monthly Volume - The effects of changes in monthly volumes on recreational experience are unknown.

BHBFs and HMFs - Several studies by the NPS have evaluated the effects of high flows at or above powerplant capacity on visitor safety, an important component of visitor experience. Studies by Bishop and others (1987) and Stewart and others (2000) specifically evaluated the effects of different flows on recreational experience, and these studies concluded that for both boaters and anglers, moderate flows of 10,000 to 20,000 cfs were preferred over higher flowers; however, Jalbert (1996) found that most boaters who were interviewed during the 1996 BHBF were excited to be running on the high experimental flows, and some deliberately scheduled their trip to maximize time spent on the high flow. The results of the Jalbert study (which was not subject to independent peer review), plus additional anecdotal information from river guides, indicates that flows over 40,000 cfs are perceived as both positive and negative by different user groups, with boaters who have more experience generally having a more positive perception of the high flow experience than less experienced boaters. This issue warrants a future focused study.

Sustained Low Steady Flow – Jonas and Stewart's (2002) study on the 2000 low summer steady flow experiment examined effects to various attributes of the recreational experience (perceptions of safety, campsite quality, crowding and intergroup encounter rates, etc.). Jonas and Stewart (2002, p.28) concluded that there was relatively little impact to visitor experience at sustained flows of 8,000 cfs, although this conclusion might change if flows were significantly lower than 8,000 cfs. Several participants in the knowledge assessment workshop (river guides) felt that low flows detracted from the recreational experience because boaters had to spend considerably more time on the water, and therefore they had less time to spend exploring side canyons or enjoying camp life. Also, there was an increased likelihood of having equipment damage or injury (discussed in previous safety section) that further detracted from the visitor experience. However, it was also noted that the improvement in size and availability of campsites at low flows countered the negative attributes of low flows to some unknown extent. Workshop participants felt that a study involving a trade-off analysis was needed to properly evaluate the effects of sustained low flows on recreational experience.

Sustained High Flows - Both Bishop and others (1987) and Stewart and others (2000) concluded that rafters preferred moderately high sustained flows (16,000–33,000 cfs in the Bishop study, 20,000–25,000 cfs in the Stewart study) over fluctuating flows, low flows (<10,000 cfs), or very high flows (>33,000 cfs). However, they also expressed a general preference for moderate to moderately low flows (10,000–20,000 cfs) over higher flows. These studies did not examine the potential negative trade offs to visitor experience that could accompany sustained high flows (i.e., smaller and less numerous camping opportunities, increased competition for camp sites, etc.) Once again, the workshop participants felt that a study involving a trade-off analysis was needed to properly evaluate the effects of sustained high flows on recreational experience.

Non-GCD Actions - The effects of mechanical trout removal (or mechanical removal of exotic species in general) on visitor experience is a subject of continuing speculation, but one for which no actual data is currently available.

Summary of Recreation Matrix Elements
Effects of flows on recreation are multidimensional, but this topic has received relatively little attention from social science researchers in the past 25 years. Studies evaluating the trade offs between attributes that are important to maintaining a high quality recreational experience are very limited, therefore these multidimensional effects are difficult to quantify. Nonetheless, available data on flow impacts to single attribute components are fairly robust in some cases (such as campable area) and there is abundant anecdotal information related to others, allowing for a general evaluation of flow effects to recreation. The available data suggest that flows that conserve sediment and allow for its redeposition and maintenance at higher elevations benefit the recreational experience, as do flows that improve navigability and safety. Warmer, moderately low (8,000–15,000 cfs) and steadier flows are likely to benefit recreation in many (but not all) respects. Conversely, higher fluctuating flows with higher daily ranges, lower lows, or higher peaks are not considered beneficial to the overall recreational experience. Warmer temperatures are generally believe to improve the recreational experience, both in terms of enjoyment and safety, but there may be negative consequences from warmer, steadier flow in relation to water quality and human health issues. All of these assessments warrant further evaluation and rigorous testing through future focused research efforts. The strategic questions that resulted from the workshop focus on the key areas of uncertainty that remain to be resolved through future experimentation and research.

3.6 Cultural Resources (National Register Historic Properties)

The historic properties performance measure represents the conditions that support the preservation of National Register eligible properties within the CRE. In general, the results of this analysis track closely with the sediment matrix. This is because the conditions that promote systemwide sediment retention are also thought to benefit historic properties, specifically archaeological sites, by helping to preserve the sedimentary matrices that bury, and to some degree, stabilize, these actively deteriorating, non-renewable resources. Specific quantified studies tracking rates of change to historic properties under varying flow regimes are currently lacking; therefore, the matrix evaluations were mostly coded yellow to reflect reliance on anecdotal knowledge as well as knowledge based on interpretation of general conceptual models about how the terrestrial system operates in physical and biological realms under current and experimental flow scenarios.

The knowledge assessment evaluated likely outcomes for various flow parameters in two separate settings: above the 45,000 cfs flow level and below the 45,000 cfs flow level

(Table 3.7). In the end, the assessments were identical for both settings in all but one instance (sustained low steady flows.)

Periodic re-deposition of sand at elevations above powerplant capacity are considered to be an essential component of future management actions designed to maintain or improve the condition of archaeological sites in the CRE, but the long term effects of conducting periodic, sediment-enriched high flows on cultural resource sites remains largely untested.

Actions required for maintaining the integrity of traditional cultural properties (TCPs) in the CRE, other than archaeological sites, are largely unknown at this time, due to the lack of clear TCP definition in the CRE. Mechanical removal of trout is the only proposed management activity for which there is any degree of certainty about its potential effect on a known tribally valued TCP (the mouth of the Little Colorado River).

<u>Water Temperature</u> - Warmer temperatures decrease water viscosity, allowing fine sediment to settle out faster (Lane and others, 1949; Hubbell and Ali, 1961; ASCE, 1975), thereby reducing the suspension of sediment in the water column and the amount of sediment available for downstream transport. In theory, warmer water should therefore reduce the amount of sediment transported from the system (potentially by as much as 5%, according to S. Wright, personal comm. 2006) and increase the longevity of sandbars and sandy deposits along the shoreline. With larger sandbars, there is more sand potentially available for downwind transport to terrestrial settings, where archaeological sites and other terrestrial resources may ultimately benefit from the addition of wind transported sediment.

<u>Increased Daily Fluctuations</u> - The effects of increased daily fluctuations on sandbars is reasonably well known from survey data collected during the 1980s (Schmidt and Graf 1990) and early 1990s (Beus and Avery 1992), as well as from historical and recently compiled sediment transport data (Topping and others, 2000a, 2000b, 2003; Hazel and others, 2006; Topping and others, 2006). Increased fluctuations would result in higher sediment transport rates, reducing the overall sediment supply in the CRE. Also, increased fluctuations prevent sandbars from drying out, thereby decreasing opportunities for the sandbars to serve as sources for fine sediment to be picked up, transported and re-deposited by wind into areas where archaeological sites are located.

<u>Reduced Variation in Monthly Volume</u> - The effect of changes in monthly volumes on historic properties is unknown. Decreases in monthly volumes during the summer high-use season would certainly increase the exposed sandbar area, making more sediment available for transport by wind to higher elevations within the CRE; however, since the distribution of monthly volumes was not specified for the cultural matrix, the effects of monthly volume changes on historic properties could not be gauged.

<u>BHBFs</u> - The effects of high flows above powerplant capacity on sandbars and high elevation sediment supply is relatively well documented (Webb and others, 1999; Topping and others, 2006). Various short term studies to evaluate the effects of the 1996

experimental flood on historic properties within the CRE documented either no effects, no adverse effects, or potentially beneficial effects from the BHBF (Balsom and Larralde, 1996).

BHBFs appear to be the only mechanism available for restoring large volumes of sand to elevations above the highest level of normal dam operations. BHBFs have been shown to increase higher elevation sandbar areas systemwide, at least on a temporary basis (Hazel and others, 1999; Kaplinski and others, 2005b). BHBFs have also been demonstrated to deposit sand in arroyo mouths up to the highest flow level (Yeatts, 1997; Hazel and others, 2000), thereby temporarily reducing the gradient of arroyos and potentially slowing rates of down cutting in the lower reaches of the drainage. More focused studies are needed to evaluate the long-term effects of BHBFs on cultural resources in the CRE.

HMFs - HMFs under sediment depleted conditions have been shown to not appreciably increase sandbar area or channel margin deposits (Kaplinski and others, 2005b; Hazel and others, in press) while increasing sediment transport rates relative to MLFF (Wiele and others, 2002; Hazel and others, in press); hence HMFs were considered to be potentially detrimental to historic properties.

Sustained Low Steady Flow - Sustained low steady flows at or below 9,000–10,000 cfs constrain the amount of sediment transported out of the system to negligible amounts (Topping and others, 2000a; 2000b; Rubin and others, 2002; Topping and others, 2003), therefore low sustained flows would allow sediment to accumulate in the channel and, after a period of adjustment to the lower flow regime, would reduce the rate of sediment loss from sandbar erosion. In addition, sustained low flows would expose more dry sand at the higher elevations of bars, increasing the amount of sand available for potential transport by wind. On the other hand, sustained low flows without occasional higher flows (under sediment enriched conditions) would be likely to eventually result in systemwide reduction of sandbar area at higher elevations (Beus and Avery, 1992, Chapter 6, p.49) and a concomitant increase in bar area and volume at lower elevations; this would potentially reduce the amount of dry sand available for aeolian transport over time. Also, low steady flows would permit tamarisk and other vegetation to encroach on sandbars, eventually reducing the sand available for wind transport over time. We currently lack measured information that would allow us to quantify rates of vegetation encroachment under low flows (or any other flows, for that matter), so the relative importance of vegetation encroachment in reducing aeolian transport is uncertain.

Sustained High Flows - Sustained higher flows are certain to increase the rate and volume of sediment transported out of the system (Rubin and others, 2002; Topping and others, 2003); therefore sustained high flows would increase the rate of sediment loss from sandbars and ultimately diminish the overall sand supply in the CRE. Furthermore, sustained high flows would consistently inundate lower elevation sandbars and channel margin deposits, resulting in a sustained loss in sand available for wind transport up to and slightly above the level of the highest flows.

Non-GCD Actions - Mechanical removal of trout was the only type of mechanical removal considered in the matrix development. Obviously, trout removal would not affect the physical integrity of archaeological sites directly, although there is some (slight) potential of impacts from on-shore activities associated with the trout removal project.

The killing of trout and other life forms in the vicinity of the mouth of the Little Colorado River has been identified by several Native American tribes as an issue of concern and a potentially detrimental impact to traditional cultural property values associated with this area. Therefore, the matrix shows a negative impact to TCPs from this activity. This is the only matrix variable for which an assessment of knowledge about potential benefits or negative impacts to TCPs could be made with a fair degree of confidence.

We did *not consider* the option of mechanical removal of terrestrial exotics (such as tamarisk). Mechanical removal of tamarisk thickets or other exotics such as tumbleweed and camel thorn could hypothetically increase sediment transport from lower to higher elevations within the CRE, but the practicality and sustainability of applying such an approach with the goal of increasing aeolian sand transport is untested and therefore unknown at this time.

Summary of Cultural Resource Portion of the Terrestrial Matrix

Effects of flows on cultural resources are poorly understood, despite many years of monitoring cultural resource condition in the CRE. This is because, with few exceptions, cultural resource condition has not been monitored in direct relation to flow variables. Nonetheless, because archaeological site integrity is closely linked to the stability of the sediment matrix in which most archaeological sites and other types of cultural resources are found, and because many cultural resources are embedded in sediments deposited by or derived from the Colorado River, flows that conserve sediment throughout the ecosystem and allow for its redeposition and maintenance at higher elevations are considered to be most beneficial for maintaining or improving cultural resource condition. Thus, the assessment of flow effects tracks closely with those in the sediment matrix, even though these assessments were developed independently by different groups of participants during the Knowledge Assessment Workshop. The hypothesis that flows benefiting high elevation sediment retention will also benefit cultural resources warrants further testing and refinement through future focused research, experimentation, and monitoring. The science questions that resulted from the K knowledge Assessment workshop reflect the key areas of uncertainty that remain to resolved in order to improve future understanding of how dam controlled flows effect cultural resources.

4.0 Science Questions (revised after comment by the Science Advisors)

The key uncertainties highlighted in the knowledge assessment matrices were helpful in framing key scientific questions that need to be resolved. There was not sufficient time at the workshop to develop a complete list of questions for each sub-model. What follows is a revised list of strategic science questions developed at the workshop as well as others developed by the authors following the meetings. These questions were reviewed by the Science Advisors at the request of the GCMRC and the questions were subsequently revised in response to those comments and suggested revisions. Following the 2005 Knowledge Assessment workshop, those science questions determined by the GCMRC and Science Planning Group were incorporated into the GCMRC's 2007–11 Strategic Science and Monitoring and Research Plans.

The critical experimental section of the Monitoring and Research Plan is still in development and the information in this report provides the basis for current knowledge with respect to evaluations of resource responses under three experimental design options. A recommendation in support of one of the options is anticipated in fall 2006, on the basis of resource evaluations for each of the options, including economic implications to hydropower resources.

Both the Strategic and Monitoring and Research Plans provide the basis for development of the GCMRC's FY2007 annual work plan, as well as future work plans, such as the proposed Biennial FY 2008–9 work plan that is currently in development.

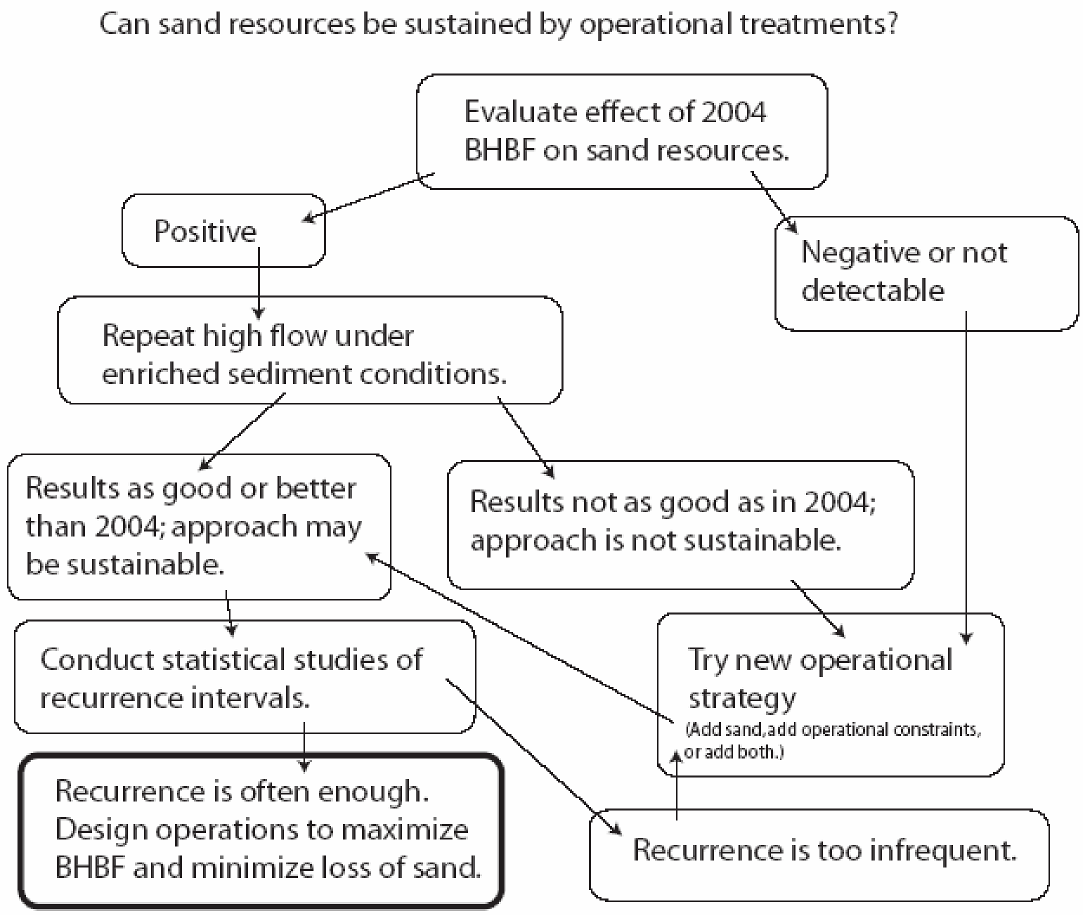
4.1 Physical Resources (fine sediment and downstream quality of water)

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

Several related, but subordinate questions related to fine sediment were also identified by participating sediment researchers during the workshop:

- What are the short-term responses of sandbars to BHBFs?
- What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?
- How does the grain-size distribution of the deposits affect sandbar stability? Main channel turbidity?
- What are the effects of ramping rates on sediment transport and sandbar stability?
- Can we develop a relationship between suspended sediment concentration and turbidity to support fisheries research?

At the summer 2005 Knowledge Assessment workshop, sediment researchers recommended that the first priority strategic science question for sediment, be addressed by replication of the 2004 High Flow test, with respect to the level of sand enrichment for the replicate being equal or perhaps greater than antecedent sand supply conditions before that test. The schematic diagram below, shows the proposed strategy for an experimental approach to answering the sediment question.



The experimental approach to answering the fine sediment question might also be supported with sediment and flow models for identifying an optimal prescription for beach/habitat-building flows if replication of the sand enriched High Flow test results in net positive response in sandbar resources.

<u>Downstream Quality of Water:</u>
2) How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and nearshore water temperatures throughout the Colorado River ecosystem (CRE)?

At the 2005 workshop, physical scientists also suggested that addressing the priority quality of water question was best undertaken through a modeling development research phase. Existing and future temperature monitoring data for the main channel and selected nearshore areas of the river was also identified as a critical element of the model development and support activity. Downstream temperature modeling was initially undertaken by the Bureau of Reclamation before the 2005 workshop and following the workshop in January 2006, a second phase of modeling began, with renewed emphasis on development of an approach that might allow for prediction of nearshore temperatures throughout the river ecosystem using existing channel geometry data.

4.2 Hydropower

1) What are the hydropower replacements costs of the MLFF (annually, since 1996)?
2) What are the projected costs associated with the various alternative flow regimes being discussed for future experimental science (as defined in the next phase experimental design)?

Following the 2005 workshop, experimental planning conducted by the Science Planning Group in cooperation with the GCMRC sought approval from the Technical Work Group to conduct an economic assessment of three experimental options being considered for implementation in FY2008 and beyond. This experimental support activity represents a new era for the GCMRC in attempting to evaluate a wider range of resource influence tied to future experimental designs.

During external review of the draft Knowledge Assessment report and strategic questions, reviewers suggested that the Hydropower questions be reconsidered as part of a broader strategy for potential tradeoff analyses in support of assessing experimental policies:

Science Advisors Recommended Question: *"What are the most appropriate resource values and tradeoff methods for managers to use in evaluating the composite resource changes that occur under differing flow and nonflow treatments?"*

4.3 Food Base, Fish, and Lees Ferry Angling

4.3.1 Food Base

1) What are the important pathways, and the rate of flux along them, that link lower trophic levels with fish?
2) How is invertebrate flux affected by water quality (e.g., temperature, nutrient concentrations, turbidity) and dam operations?
3) Are trends in the abundance of fish populations, or indicators from fish such as growth, condition, and body composition (e.g., lipids), correlated with patterns in invertebrate flux?

4.3.2 Native Fish

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

2) To what extent does temperature and fluctuations in flow limit spawning and incubation success for native fish?
3) What is the relative importance of increased water temperature, shoreline stability, and food availability on the survival and growth of YoY and juvenile native fish?
4) How important are backwaters and vegetated shoreline habitats to the overall growth and survival of YoY and juvenile native fish? Does the long-term benefit of increasing these habitats outweigh short-term potential costs (displacement and possibly mortality) associated with high flows?
5) Will increased water temperatures increase the incidence of Asian Tapeworm in humpback chub or the magnitude of infestation, and if so, what is the impact on survival and growth rates?
6) Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance? To what extent could predation impacts by nonnative fish be mitigated by higher turbidities?

Following review of the questions developed at the KAW, above, and discussions with TWG members, the following two questions were appended to the KAW list so that other pressing, relevant questions were considered:

7) Which tributary and mainstem habitats are most important to native fishes and how can these habitats best be made useable and maintained?
8) How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?

Following review of earlier drafts of this document, the GCMRC Science Advisors proposed a synthetic approach to determining important questions to pursue in regards to native fishes in Grand Canyon. Their two questions are as follows:

SA HBC 1: What are the most limiting factors to successful HBC adult recruitment in the mainstem: spawning success, predation on YoY and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

SA HBC 2: What are the most probable positive and negative impacts of warming the Colorado River on HBC adults and juveniles?

4.3.3 Rainbow Trout in Glen Canyon

1) To what extent is the adult population of rainbow trout controlled by survival rates during incubation and YoY/juvenile rearing stages, or by changes in growth and maturation in the adult population influencing egg deposition?
2) To what extent is the size of rainbow trout in Glen Canyon controlled by density and food availability?
3) Does increased water temperature result in the occurrence of whirling disease in rainbow trout and if so, what affect will this have on population size and adult growth and condition?
4) Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and if so, during what life stages? To what extent to Glen Canyon immigrants support the population in Marble and eastern Grand Canyons?

4.3.4 NonNative Fish in Marble and Eastern Grand Canyons

1) Does a decrease in the abundance of rainbow trout and other coldwater and warmwater nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?
2) Will a limited number of years of mechanical removal of rainbow trout in Marble and eastern Grand Canyons result in a long-term decrease in abundance or will re-colonization from tributaries and from below and above the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species.

4.3.5 Lees Ferry Angling

1) Assuming a trade-off between trout density and size, what is the preferred combination for anglers?
2) What GCD flow constraints (ramping rates, daily flow range, etc.) maximize fishing opportunities and catchability?

4.4 Riparian Habitat

1) How do processes occurring at a variety of spatial scales (i.e., population level to community to landscape scales) interface to influence riparian habitat?
2) What is the nature and timing of terrestrial — aquatic linkages and what is their influence on the recipient habitat?
3) How do terrestrial habitat and cultural/recreation resources interface?
    i. What are the rates of vegetation encroachment (trees vs. shrubs) on camp sites?
4) How do flows, including the absence of flows (e.g., predam high water zone), affect productivity and decomposition rates of riparian vegetation including the absence of flows (e.g., OHWZ)?
5) How do warmer releases affect viability and productivity of native/nonnative vegetation?
6) To what extent and in what respects can BHBF's (magnitude and frequency) achieve reduction of exotic species?
7) How could monthly volumes be changed to beneficially affect riparian habitat?

4.5 Recreation

1) How do dam controlled flows affect visitors' recreational experiences, and what is/are the optimal flows for maintaining a high quality recreational experience in the CRE?
2) What are the drivers for recreational experience in the CRE, and how important are flows relative to other drivers in shaping recreational experience outcomes?
3) How do varying flows positively or negatively affect campsite attributes that are important to visitor experience?

4) What are the minimum size, quantity, distribution and quality of campsites to meet NPS goals for visitor experience?
5) Can changes in quality of recreational experience be quantified for single event opportunities (e.g., white water rafting, angling, and camping) vs. multi-opportunity experiences (e.g. white water rafting with overnight camping)?
6) How can safety & navigability be reliably measured relative to flows?
7) How do varying flows positively or negatively affect visitor safety, health, and navigability of the rapids?
8) How do varying flows positively or negatively affect group encounter rates, campsite competition, and other social parameters that are known to be important variables of visitor experience?

Following a review of an earlier draft of this document, the GCDAMP Science Advisors proposed a synthetic approach to determining important science questions for GCMRC to pursue in regards to recreation in Grand Canyon. They recommended that the above questions be distilled and subsumed within two broad questions, as follows:

R1.0 What are the drivers for recreational experience in the CRE, and how important are flows and campsite beaches relative to other drivers in shaping this experience?

R2.0 How do dam controlled flows affect visitors' recreational experience, and what are optimal flows for maintaining a high quality recreational experience?

4.6 Cultural Resources

1) Do dam controlled flows affect (increase or decrease) rates of erosion and vegetation growth at arch sites and Traditional Cultural Property (TCP) sites, and if so, how?
2) How do flows impact the sedimentary matrix of the higher terrace deposits, and what kinds of important historical/legacy information about the CRE ecosystem is being lost due to ongoing erosion of these older Holocene sedimentary deposits?
3) If dam controlled flows are contributing to (influencing rates of) arch site/TCP erosion, what are the optimal flows for minimizing future impacts to historic properties?
4) How effective are check dams in slowing rates of erosion at archaeological sites over the long term?
5) What are the TCPs in the CRE, and where are they located?
6) How can tribal values/data/analyses be appropriately incorporated into a western science-driven adaptive management process in order to evaluate the effects of flow operations and management actions on TCPs?
7) Are dam controlled flows affecting TCPs and other tribally-valued resources in the CRE, and if so, in what respects are they being affected, and are those effects considered positive or negative by the tribes who value these resources?

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Table 3.1. Knowledge assessment matrix for the physical resources sub-model. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals.

Performance Measure	Increase in GCD Release Water Temperature	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)
Fine- Sediment above 25 kcfs	+	-	+	+	0/+	0	0	+	-
Fine-Sediment between 8 and 25 kcfs	+	-	+	+	-	0/+	-	+	-
Fine-Sediment below 8 kcfs	+	-	+	+	-	-	-	+	-
Mainstem Water Temperature	+	-	+	-	-	-	-	+	-
Nearshore Water Temperature	+	-	+	-	-	-	-	+	-

Table 3.2. Knowledge assessment matrix for the power sub-model. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals.

Performance Measure	Increase in GCD Release Water Temperature	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)
Hydro Power Load-Following Capacity	-	+	-	-	-	-	-	-	-
Hydro Power Replacement Costs	-	+	-	-	-	-	-	-	-

Note: Although information about hydro power capacity and replacement power cost impacts are known by some stakeholders (and as a result identified as being known with high certainty in the above matrix (highlighted as GREEN in all cells), this information was not readily accessible for use during the KAW. Participants identified that improved approaches for assessing economic resources and data sharing were needed in the future to support future planning during the KAW. Such activities were initiated by the Science Planning Group and Technical Work Group in summer 2006.

Table 3.3. Knowledge assessment matrix for food base and fish sub models. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals with the exception of performance measures for invasive fish species, disease, and rainbow trout abundance in Marble Canyon.

Performance Measure	Location and/or Species	Increase in GCD Release Water Temp.	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)	Mechanical Removal of Coldwater Exotics (Mainstem and Trib)	Mechanical Removal of Warmwater Exotics
Food base	Glen	+		+					-	+		
	Grand	+	-						-	+	+	
Mainstem spawning & incubation	HUMPBACK CHUB	+							+		+	+
	FMS	+	-						+		+	+
	RBT-Glen	**0**	-	+					+	+		
	RBT-Marble	**0**	-	+					+			
YOY/Juvenile nearshore rearing	HUMPBACK CHUB	+	-	+		-		-	+		+	+
	FMS	+	-	+		-		-	+		+	+
	RBT-Glen	+	-	+	-	-	-	-	+	+		
	RBT-Marble		-	+	-	-	-	-	+	+		

Table 3.3. Con't.

Performance Measure	Location or Species	Increase in GCD Release Water Temp.	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)	Mechanical Removal of Coldwater Exotics (Mainstem and Trib)	Mechanical Removal of Warmwater Exotics
Invasive Fish Species	Coldwater	+	-		0	0	0	0	+		-	
	Warmwater	+	-						+			-
Disease	Asian Fish Tapeworm	+										
	Whirling Disease	+										
Adult Population	HUMPBACK CHUB											
	FMS	+							+			
	RBT #s - Glen	+	-		0	0	0	0	+			
	RBT Size - Glen	+	+		0	0	0	0	+			
	RBT #s- Marble		-		0	0	0	0	+		-	
Angling Opportunity and Quality	Glen	+	-	+	-	-	-	-	-	-		

Table 3.4. Detail of food base and fish sub models KAW matrix describing elements of ROD flow constraints that contribute to the overall effect of increased fluctuations in daily flow. Also shown are responses to humpback chub translocation and hatchery supplementation options. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals with the exception of performance measures for invasive fish species, disease, and rainbow trout abundance in Marble Canyon.

Performance Measure	Location or Species	Overall Effect of Increased Fluctuations Relative to MLFF	Increase Upramp Rate	Increase Downramp Rate	Increase and/or Lengthen Maximum Daily Flow	Increase Daily Variation in Flow	Decrease Minimum Daily Flow	Supplementation from Hatchery	Translocation of HBC
Food base	Glen								
	Grand	-				-	-		
Mainstem spawning & incubation	HBC								
	FMS	-				-			
	RBT-Glen	-			-	-	-		
	RBT-Marble	**0**			-	-	-		
YOY/Juvenile nearshore rearing	HBC	-				-	+		
	FMS	-				-	+		
	RBT-Glen	-				-			
	RBT-Marble	-				-			

Table 3.4. Con't.

Performance Measure	Location or Species	Overall Effect of Increased Fluctuations Relative to MLFF	Increase Upramp Rate	Increase Downramp Rate	Increase and/or Lengthen Maximum Daily Flow	Increase Daily Variation in Flow	Decrease Minimum Daily Flow	Supplementation from Hatchery	Translocation of HBC
Invasive Fish Species	Coldwater	-				-	+		
	Warmwater	-				-	+		
Disease	Asian Tapeworm								
	Whirling Disease								
Adult Population	HBC								+
	FMS								
	RBT #s - Glen	-				-	-		
	RBT Size - Glen	+				+	+		
	RBT #s- Marble	-				-	-		
Angling Opportunity and Quality	Glen	-	-		-	-	-		

Table 3.5. Knowledge assessment matrix for the riparian habitat sub-model. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals.

Performance Measure	Location and/or Species	Increase in GCD Release Water Temp.	Overall Effect of Increased Fluctuations Relative to MLFFA	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)	Mechanical Removal of Coldwater Exotics (Mainstem and Trib)	Mechanical Removal of Warmwater Exotics
Fluctuation zone <25 kcfs	Glen & Grand Canyon		+		+	0/+	0/+	0/+	-	+		
Lower Riparian 25-45 kcfs			+		+	0/+	0/+	0/+	0/-	0/+		
Upper riparian zone 45-60 cfs												
> 60 kcfs												

Table 3.6. Knowledge assessment matrix for the recreation sub-model. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals.

Performance Measure	Location and/or Species	Increase in GCD Release Water Temp.	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)	Mechanical Removal of Coldwater Exotics (Mainstem and Trib)	Mechanical Removal of Warmwater Exotics
Campsites (available campable area)		+	-		+	+	+	-	+	-		
Access to attraction sites		0	-		0	0	0	0	+	0		
Rafting navigability					+	+	0	0	0/-	0/+		
qw and human health		-	+		+	+	+	+	-	+		
safety		+							+	-		
Recreational experience		+	-						0/-	+		

Table 3.7. Knowledge assessment matrix for the cultural sub-model. '+', '-', and '0' indicate positive, negative, and no effect (if color is green or yellow) or unknown (if color is red) responses. Dark green, light green, yellow, and red denote increasing uncertainty in the predicted response direction (see Table 2.1 for definitions). A positive response of a performance measure corresponds with the direction of AMP goals.

Performance Measure	Location and/or Species	Increase in GCD Release Water Temp.	Overall Effect of Increased Fluctuations Relative to MLFF	Reduce Variation in Monthly Volume	BHBF with adequate sand supply	BHBF without adequate sand supply	HMF with adequate sand supply	HMF without adequate sand supply	Sustained Low Steady Flow (summer-fall)	High Sustained Flow (ponding-spring)	Mechanical Removal of Coldwater Exotics (Mainstem and Trib)	Mechanical Removal of Warmwater Exotics
Conservation> 45 kcfs stage	arch. sites	+	-		+	0/+	0	0	0/+	-		
Conservation <45 kcfs		+	-		+	0/+	0	0	0	-		
Conservation> 45 kcfs stage	TCPs										-	-
Conservation <45 kcfs											-	-

PROPOSED Knowledge Assessment II STEPS (WORKSHOPS) DURING FY 2011

Presented by: Ted Melis, USGS, Grand Canyon Monitoring and Research Center

March 8, 2011

USGS

STEP I – TWG reviews the 2006 draft Knowledge Assessment I report & participates in GCRMC WebEx – proposed dates: week of March 28th– 2-3 hour long session (please respond to Doodle Query from Linda Whetton the week of March 14th)

OBJECTIVES:

Review the GCDAMP resource goals - relative to AMWG's recently developed "*Desired Future Conditions*" 1) Colorado River Ecosystem, 2) Recreation, 3) Hydropower and 4) Cultural

Review Experimental Treatments – flow or non-flow treatments that *have been conducted* and for which data/models exist. Questions: Are there any new treatments that have been implemented since 2005? Should any treatments evaluated in 2005 be eliminated?

Review 2005 KA I Questions – also included in the 2007-11 Monitoring & Research Plan (Draft Final KA report, 2006, with particular attention to pages 59-64)

TASK for TWG WebEx: Are there any new questions that need to be considered in the KA II during 2011?

- Presumably new questions would then also be integrated into development of the new 5-Year Monitoring & Research Plan in FY 2012 (FY 2012-16).
- Can questions be removed from the 2005 list?

Step II – Convene Expert Workshops

GCMRC will solicit “expert” opinions on the questions in the various resource matrices and develop a more quantitative summary of “certainty” or “uncertainty” on basis of existing data and models that exist which might predict the direction of a given resource in response to various experimental treatments that have been previously tested, as well as the “magnitude” of that response if the direction can be predicted.

Step III – Convene Stakeholder Workshop

GCMRC proposes to convene a workshop with TWG in fall 2011 (early November) to review the “expert” input on the questions and discuss the next steps to reporting that update of the Knowledge Assessment and integrating the new information into the 5-Year MRP, 2013-16) and other efforts, such as the LTEMP EIS, etc. to support the GCDAMP program.

STEP IV – FY 2012, finalize report on KA II

GCMRC would complete and distribute final report to TWG and AMWG in late summer/fall 2012.

FACILITATION AND LEADERS IN KA II

Lead Facilitators: Josh Korman (Ecometric Research, Inc. [existing science cooperator]) & Ted Melis (GCMRC)

KA II Resource Leaders: Cooperating scientists and GCMRC staff who will convene "expert" panels and solicit quantified opinions on the ability of existing information to answer the questions specific to the resources, as grouped into the 4 recently developed DFCs.

<u>Colorado River Ecosystem:</u>

- **Aquatics (Fish and Food, Goals 1-4), Walters, Korman, Persons, Kennedy**
- **Terrestrial Spring Habitats & Riparian Vegetation (Goals 5-6), Ralston**
- **Sediment and Quality-of-Water + including Lake Powell (Goals 7-8), Grams**

<u>Recreation:</u>

- **Lees Ferry Sport Fishery, rafting, camping & related activities in GCNRA & GCNP (Goal 9), Fairley**

<u>Hydropower:</u>

- **Glen Canyon Dam electrical generating capacity (Goal 10), Fairley**

<u>Cultural Resources:</u>

- **TCPs, arch sites, etc. (Goal 11), Fairley**

Relating to Goal 12 (maintain quality adaptive management program), there may be additional KA II efforts to evaluate the past performance of the GCDAMP through questions that may be offered by DOI leadership, etc. The KA II would make every effort to incorporate the recent guidance on priorities for the GCDAMP.