GRAND CANYON MONITORING AND RESEARCH CENTER

Protocols Evaluation Program

Final Report of the Aquatic Protocol Evaluation Program Panel

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Executive Summary

In May 2001 a panel of 6 scientists was convened to review the aquatic resources program of the Grand Canyon Monitoring and Research Center (GCMRC, 'the Center') as part of the Protocol Evaluation Program (PEP). The panel was asked to determine if the research and monitoring programs for Colorado River aquatic biological resources were adequate to evaluate the status of aquatic resources in relation to the interim qualitative management goals. In addition, the panel considered whether the monitoring programs were sufficient to evaluate Adaptive Management experiments, particularly those that involved changes to the operation of the Glen Canyon dam. Finally, responses were provided to a list of specific questions given to the panel.

Overall, the panel was impressed by the quality of the work that has been conducted, and the dedication of researchers working in the Grand Canyon. Much has been learned. But, an adequate monitoring program is not yet in place.

The panel recommends that the Center urgently needs to specify the linkages between the qualitative management goals and the results from current and proposed monitoring programs. This process likely result in more focussed monitoring activities, and will expose the uncertainties that remain to be resolved. The panel supports the ongoing process of assembling existing data, and urges the quantitative analysis of those data to determine the utility of those metrics currently in use for long-term monitoring.

A program designed to monitor long-term trends in the ecosystem may not be suitable for the evaluation of short-term responses to flow experiments. The latter will likely have to be evaluated with a combination of management and process-oriented research.

Individuals of the panel took the lead in conducting more detailed review for each major component of the Grand Canyon aquatic ecosystem. The following are key recommendations from those reviews:

1. *Water Quality*: A water quality program that monitors physical and biological parameters of the Colorado River in Grand Canyon should be established. This program could be tied to physical sampling sites at non-boat access points associated with USGS gauging stations.

2. *Food Base*: The food base program needs to be critically reviewed because the current level of understanding about the linkages between lower trophic levels and food availability of native fishes is not adequate to interpret food base data in relation to the management goal. Lower trophic levels can also be used to monitor ecosystem changes. GCMRC needs to explicitly identify the goal of the food base program, determine what metrics to use to monitor the lower trophic levels, and decide what level of detection of change is required. Sufficient data and experience exists to design a program that meets the identified needs with appropriate power.

3. *Humpback Chub*: The Panel recommends that further work be conducted to develop a conceptual model of the metapopulation biology of chub in the GCE to provide a context for a long-term monitoring program. Consideration should be given to the inclusion of genetic concerns in the monitoring program. GCMRC needs to develop explicit linkages between the results of annual monitoring and the management goals to ensure that the monitoring programs produce results appropriate to review progress to the goals. The Panel supports the completion of the current review of existing data, and the development of population models, as these programs will yield sufficient information to make decisions about sampling programs for chub.

4. *Other Native Fish*: The Panel was concerned that there no plan for monitoring the status of the 3 other extant native fish of the GCE. The Panel supports the ongoing synthesis of existing information and attempts to develop a population model for flannelmouth sucker as the first steps for developing a program for this species. The Center should develop explicit linkages between management goals and monitoring programs, and once all available data for the non-native species have been assembled, review options for monitoring these species.

5. *Exotic Fish*: For the GCE below Lee's Ferry, the management goals for non-native fish are related to their impacts on native species. The Panel was impressed by the efforts to develop a program to estimate the abundance of salmonids in the Colorado River, but felt some effort should be (re-) allocated to the other components of risk to native species, especially with respect to predation. There is no explicit program for warm-water exotic fish species. The Panel suggests that the species should be ranked for their potential for impacting native species, and that monitoring metrics be developed for the important species that address potential risk to native fish. Thorough analysis of available data should assist in the evaluating the feasibility of monitoring programs for these species.

6. *Management Issues*: The panel observed considerable variation in the analytical effort expended, the timeliness of reporting, and the availability of standardized databases among programs for aquatic resources. A standardized annual reporting cycle is a key component of any monitoring program. The Panel recommends that the contracting process needs to be much more tightly controlled, and wonders whether greater 'in-house' capability is required at GCMRC to achieve long-term consistency and quality in the monitoring program.

Chapter 1. INTRODUCTION

The construction of Glen Canyon Dam on the Colorado River has affected the physical and biological attributes of resources downstream in Grand Canyon (Webb et al. 1999). Despite nearly two decades of monitoring and applied research there remains considerable scientific uncertainty about effects of Glen Canyon Dam on the physical environment and dynamics of biological components of the aquatic ecosystem of the Colorado River (NRC 1999). In 1996 the Secretary of the Interior's Record of Decision (ROD) on the operation of Glen Canyon Dam authorized the long term monitoring and research and experimentation on river ecosystem and dam operation management options. The Record of Decision called for the formulation of the Glen Canyon Dam Adaptive Management Group (AMWG) as a Federal Advisory Committee to guide the development of the adaptive management program, review results of monitoring and applied research activities, and make recommendations to the Secretary of the Interior about the long term operation of Glen Canyon Dam. As part of the ROD the Grand Canyon Monitoring and Research Center (GCMRC) was established to co-ordinate/conduct monitoring and research on the influence of operation of Glen Canyon Dam on the physical, biological (aquatic and terrestrial) and cultural resources of the Colorado River ecosystem (NRC 1999). The goals of aquatic monitoring activities were to: 1) provide surveillance on key ecological index variables associated with the qualitative management goals and 2) to provide information on the effects of dam operations on the ecosystem.

One component of the development of a monitoring and research program is independent peer review of monitoring and research protocol. The Protocol Evaluation Program (PEP) to assess monitoring and research activities to identify strengths and weaknesses and to make recommendations for reliable and cost effective long-term monitoring and research program for the CRE. On May 7, 2001, GCMRC convened a six-member peer review panel with expertise in aquatic ecology, water quality, fish stock assessment, and monitoring program design to conduct the Aquatic Protocol Evaluation (see Appendix Table 1). The review was conducted in two stages. In the first stage, the PEP panellists were hosted on a seven-day raft trip from mile 0 to mile 225 of the Colorado River (May 8 - May 15, 2001). The PEP panellists were accompanied on the trip by GCMRC staff, independent scientists conducting monitoring and research on the physical environment, aquatic ecology, and fish populations of the study area. This trip greatly facilitated direct interaction between GCMRC staff, scientists conducting monitoring and research on the physical environmental, aquatic ecology, and fish populations of the study area. It also benefited the panel members by providing site-specific experience and appreciation of the scope and practical issues relevant to conducting aquatic monitoring and research in the Colorado River ecosystem (CRE). Information transfer during this trip occurred in a variety of ways including:

1) *Plenary presentations* (all panel + all contractors) to describe the fundamental purpose, general findings, assessment of limitations, and required future directions of field of research in the CRE (Physical Science Program: Ted Melis, GCMRC;

Aquatic Food Base Program: Joe Shannon, Northern Arizona University, Flagstaff AZ; Fish Studies: Carl Walters, UBC, Conceptual Model: Josh Korman, Ecometric Research; Background of Environmental Studies: Adaptive Management, and the Role of PEP, Barry Gold, GCMRC)

2) *Panel convened sessions* (all panel + individual researchers) to allow less formal discussion of the individual programs and protocol (Humpback Chub/Flannelmouth sucker stock assessment; Carl Walters, UBC; Non-native fish populations Bill Persons, Arizona Game and Fish; Mainstem fish sampling, Mellisa Trammel, SWCA Inc. Flagstaff AZ., Little Colorado River Chub Program Lew Coggins USFWS, Flagstaff AZ,)
3) *Adhoc informal discussion* between panel members and contractors.
4) *Review of technical reports* provided to the panel by GCMRC representatives.

On the day following the raft trip (May 16, 2001), a half-day workshop was held at the GCMRC facility in Flagstaff so that additional presentations could be made to the panel (Allan Haden; bioenergenetics of Humpback chub in the Little Colorado River; Mike Yard, GCMRC, water quality; Carl Walters, chub stock sythesis model). Several members of the Technical Working Group were also present.

In the second stage of the review panellists undertook a detailed review of available technical documents and prepared assessments of the protocol for specific aquatic monitoring and research program areas. For the purposes of discussion in the evaluation, the aquatic monitoring program was arbitrarily subdivided into five primary program areas: 1) Water Quality; 2) Food Base; 3) Humpback chub; 4) Other Native Fish; and, 5) Non-Native Fish. These program areas were indirectly linked to qualitative goals of the program as they relate to aquatic ecosystem (Adaptive Management Working Group, Draft Strategic Plan 2001). The fundamental objective of the Aquatic PEP was to identify the strengths and weaknesses in each program area and to supply recommendations for required activities to address documented shortcomings. Each program area was evaluated to assess the degree of understanding about key ecological processes, the expected statistical reliability of monitoring, and the ability of the current monitoring and research effort would allow evaluation of management goals associated with the aquatic ecosystem. For the protocol evaluation the Panel considered the following four primary questions:

1) Are there well-defined linkages between ecosystem response indicators and the management goals?

There are significant uncertainties associated with choosing appropriate measurement variables and designing monitoring programs that truly reflect ecological response and provide acceptable levels of statistical reliability. Choice of indicator variables will be largely based on current understanding of key interactions for the ecosystem indicators. Subjective decisions have to be made about what indicator variables to measure and this can influence the perception of response to changes in dam operations. For example, selection of a early life index such as the abundance young of the year for long lived fish populations such as humpback chub can be risky if there is some other factor that acts later in life which controls the number of fish that recruit to the spawning population.

2) *Is there sufficient scientific understanding about the response of the key indicator variables to be confident that selected measurement variables used in monitoring program are appropriate and can be reliably measured? Is the ecologically significant effect size known?*

Monitoring programs follow a typical ontogenetic pattern of development that evolves with time as more is learned about what is appropriate to measure and how to those measurements are collected. The first phase of monitoring is where a comprehensive inventory of the components of the ecosystem is collected. This information is useful because it provides basic information such as species composition and documents spatial variation in assumed key indicators variables. In the second phase of monitoring basic sampling continues and additional detailed studies are conducted to fill data gaps, and refine sampling protocols where weaknesses are detected. Process research can produce a deeper knowledge of the interactions among ecosystems processes. The results of monitoring and research must be closely linked so that new information is integrated into the monitoring protocol to improve the statistical reliability of monitoring protocol or aid in the identification of new monitoring variables. These studies provide managers information about what are the appropriate variables to monitor and what sampling protocol is most likely to allow judgment whether management objectives are met. The third phase of monitoring is where scientists and managers are confident that there is sufficient scientific understanding and experience in measuring key ecological indicator variables. At this point, long-term data collection begins. The need for research is not eliminated but rather monitoring becomes a process of iteration between collecting routine information and more focused research to better understand the impacts of management actions.

3) *Does the current sampling strategy allow sufficient statistical reliability to protect managers from adverse or irreversible impacts? Does the current protocol allow reliable detection of "signal" of the impacts of dam operations through the "noise" of natural variation in ecological variables or confounding effects of factors other than habitat alteration dam operations?*

Ecological communities undergo wide fluctuations in both space and time and because of this it is has proven difficult to design and implement reliable monitoring programs that provide reliable statistical inference. Distinguishing ecological changes that result from the operation of Glen Canyon Dam from all other sources of natural variation therefore requires understanding of both the magnitude and the structure of variance in key ecological indicator variables. Consideration of the relative contribution of spatial and temporal components of variance in relation to total variance is an important consideration for the design of such programs for two reasons: 1) it determines how available resources for replication in space and time should be allocated ; and 2) it determines the magnitude of treatment effects that can realistically be differentiated from unexplained sources of variation.

4) *Does the monitoring provide required information to support a weight-of-evidence approach to strengthen inferences resulting from monitoring?*

Monitoring will provide inferences about trends in abundance or the response of indicator variables to changes in dam operation. However, because of incomplete knowledge about the response of the ecosystem to management actions, difficulties in detecting responses, and the high likelihood of surprise, or unexpected responses, there will usually be a need to support data from the monitoring of key indicators with inferences through a weight-of-evidence approach. This approach involves systematic description of hypotheses about the expected response of each component of the ecosystem to the management action, and the assembly of all data available data to evaluate those hypotheses.

This report is divided into eight sections. Sections 2 though 6 address protocol evaluation and provide recommendations for each aquatic monitoring program areas. While not specified in the original scope of the protocol evaluation, the panel recognized other broader implementation; management and institutional issues influenced that implementation. Section 7 addresses those considerations and the recommendations of the panel. Written questions were also posed to the panel associated with particular aspects of the aquatic monitoring program and the implementation of adaptive management. The panel's responses to the questions are provided Section 8 of the report.

Chapter 2. Water quality

Recommendation: *A water quality program that monitors physical and biological parameters of the Colorado River in Grand Canyon should be established. This program could be tied to physical sampling sites at non-boat access points associated with USGS gauging stations.*

This section addresses Goal 7 of the April 2001 Strategic Plan of the Glen Canyon Dam Adaptive Management Workgroup, which is to "Establish water temperature, quality and flow dynamics to achieve GCDAMP ecosystem goals." The "ecosystem goals" addressed by this panel includes the biological goals as related to food base and fish and also the potential to use water quality as an indicator of ecosystem change as a result of changes in dam operation.

A robust water-quality monitoring program can act as a "barometer" to assess linkages among water quality parameters (temperature, turbidity, nutrients, carbon, suspended sediment) and aquatic food base and fish. Water quality can be defined in terms of the physical, chemical, and biological characteristics of the river ecosystem. To date, water quality monitoring has focused more on the physical measures (temperature, suspended sediment, turbidity, and specific conductance) with some monitoring of nutrients and carbon as part of the food base program. While these physical measures affect species distribution, biological processes (e.g., metabolism, primary production, nutrient dynamics), instream habitat, predation, etc., nutrients (nitrogen and phosphorus) and carbon (dissolved and particulate forms) are important because they "fuel" the food web (i.e., the food base and fish). Additionally, monitoring water quality can provides supplementary information for a "weight of evidence" approach for identifying plausible mechanisms that cause changes in the aquatic resources in response to dam operations.

A comprehensive long-term water-quality monitoring program currently does not exist. With the exception of the physical measures mentioned above, water quality sampling has been primarily tied to the food base sampling sites and sampling has not been conducted to develop a long term consistent data base at time and spatial scales relevant to impacts of dam operations. Changes in water chemistry can cascade throughout the food web. For example, the type of phytobenthos assemblage (*Cladophora* versus a mixture of algae, macrophytes, and moss) was related to the seasonal variation in nutrient concentrations and flow regime downstream of Glen Canyon Dam from 1995-1998 (Benenati et al., 2000); the dominant type of phytobenthos assemblage, in turn, affected the invertebrate assemblage. In addition, the form (e.g., dissolved versus particulate, nitrate versus ammonia) of nutrients and carbon at any point along the Colorado River Ecosystem is a function of upstream inputs, lateral inputs (from backwaters or springs), tributary inputs and biological processes (e.g., uptake of nutrients by algae). Future studies should include a more thorough examination of these changes in water chemistry throughout the Colorado River Ecosystem (upstream to downstream).

Specific Water-Quality Program Recommendations

1. Water-quality objectives should be clearly articulated as they relate to food base and fish (Management Objectives 7.1 and 7.2). Only then can a water-quality monitoring program be designed to appropriately address these objectives.

2. Use the existing turbidity (surrogate indicator of light) and temperature networks as a starting point for additional water-quality monitoring. Adding key nutrient and carbon sampling to this network will serve two purposes: 1) to provide information on the physical and chemical factors that directly and indirectly affect the food web, and 2) to detect changes in water quality along the entire river system. At a minimum, consider building on the routine sampling conducted by the physical program at the four accessible sites al Lee's Ferry, Paria River, Bright Angel Creek and Diamond Creek. By using these sites that have discharge measurements, concentrations and flux (loads) of sediment, nutrients, and carbon can be measured in the long term.

3. Establish regular temporal sampling (at minimum use physical program sampling sites and schedule) and begin spatial sampling along the Colorado River and at the mouth of tributaries on at least a seasonal basis. We suggest that tributaries should be included for water-quality monitoring, due to their potential affect on mainstem water quality (e.g. sediment from Paria River). This minimal sampling design can be used to:

a. Address the spatial and temporal variation of water-quality parameters and discharge as they relate to food base and fish.

b. Address whether the system meets the legally defined State water-quality standards where appropriate (also a part of Management objective 7.2).

4. After examining existing nutrient data, we determined that a better low-level analysis of nutrients in needed. The technology to analyze nutrients at lower levels (1-10 μg/L range for N and P) is widely available and it is strongly recommended that this be utilized to provide better resolution of changes in nutrients concentrations. Also, a Quality Assurance/Quality Control protocol needs to be developed as a part of the water-quality program

5. Measurements of carbon should include all forms [dissolved organic carbon, fine particulate matter, coarse particulate matter (organic drift)] if feasible. At a minimum the dissolved organic carbon and the particulate material collected on the glass fiber filter should be analyzed.

6. Consider adding diurnal measurements of dissolved oxygen to the routine monitoring sites to measure autotrophic/heterotrophic metabolism if resources permit. Metabolism could be used as a biological response to nutrient and carbon dynamics. Along with this measurement, chlorophyll should also be measured in the water column. Use of oxygen probes for extended periods (weeks) can be problematic due to fouling. However, if the

probes can collect dissolve oxygen for a two-day period monthly (i.e., service probe and download data for the first two-day period from the previous sampling trip) then a long-term record of metabolism can be collected throughout the river system (see monitoring primary production/community metabolism in Chapter 3).

7. Consider using benthic organisms as an indicator of water-quality changes if this is an important water-quality objective and resources are available. This would require a different sampling design and taxonomic resolution than what has been used in past but would be valuable to assess changes in water quality over time and with changes in dam operation (see Food base as indicators of system health or integrity in section 3).

8. Link the water-quality sampling in the Grand Canyon Ecosystem to the Glen Canyon Dam sampling and the Physical Program sampling. Changes in the water released from the dam and tributary inputs can have profound downstream effects. These databases need to be linked.

Chapter 3: Food Base

Recommendations: *The food base program needs to be critically reviewed because the current level of understanding about the linkages between lower trophic levels and food availability of native fishes is not adequate to interpret food base data in relation to the management goal. Lower trophic levels can also be used to monitor ecosystem changes. GCMRC needs to explicitly identify the goal of the food base program, determine what metrics to use to monitor the lower trophic levels, and decide what level of detection of change is required. Sufficient data and experience exists to design a program that meets the identified needs with appropriate power.*

This chapter addresses Goal #1: "Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels"

The five management objectives relating to this goal strive to attain or maintain primary producers (algae and macrophytes) and secondary producers (benthic invertebrates) at different locations for different fishes along the all sections of the river. The terms of references for the Aquatic PEP, however, deals with native fishes below Lee's Ferry, and thus is concerned with the accompanying food base for the fishes occurring there. The well being of the trout populations has been addressed by other PEPs and will be considered here only as they impact native fishes.

The PEP Panel was impressed with recent and ongoing research conducted on lower trophic levels in the Colorado River and some of its tributaries. While these studies were not often directly oriented toward answering specific monitoring questions, they will be important in determining possibilities for a meaningful and efficient monitoring program.

A long-term monitoring program for the food base does not presently exist. This is understandable because the research needed to ensure a successful monitoring program has not yet been completed. The panel does not necessarily consider the goal of monitoring the food base for native fishes a priority at this time because of the unanswered questions dealing with the native species life histories, population dynamics and habitats. That is, there is not enough known about many of the life requirements and ecology of native fish species in this ecosystem to concentrate so much on one aspect – their food. The panel was concerned that the assumed linkages between food base and fishes have not been empirically established. While increased primary and secondary production (food base) may relate to increased native fish production other consequences are also likely- the most important being that a maintaining or attaining a healthy food base may benefit non-native species which are possible competitors with, or predators on, native species. However, if the GCMRC deems this goal worthy, or might revisit it after suitable research, we offer the following suggestions.

The stated objective dealing with food base is to ensure adequate food resources available for native fishes, yet our conversations with GCMRC personnel and

Cooperators suggest an interest in using primary and secondary producers as indicators of ecosystem processes or ecosystem health. The panel addressed both aspects: food base and biological integrity. These topics are in some ways mutually exclusive and will require different approaches. However, the panel assumed that the monitoring objective is the same: **to obtain ecologically useful data of known precision such that trends in those data can be detected over time.** This fundamental assumption that the objective of food base monitoring has a good relation to the management objective, such that a detected change in the object of monitoring signifies an ecological change of some importance. Finally, we adhere to the philosophy that simple and inexpensive ecological indicators are the best insurance against problems of ever-changing professional and technical staff, political winds, and fluctuating budgets.

We agree that managing dams to benefit native fishes would be enhanced if we had a sound understanding of the benthic algal and invertebrate communities and their response to different flow and sediment regimes. However this understanding will require considerable research before it can be incorporated into a regular monitoring program. There are many potential indicators of "food base" for the system. We suggest that whatever approach is considered the GCMRC should use the existing historical data, excellent in some cases but limited in others, to examine for spatial and temporal variability. Next GCMRC should determine the effort involved to achieve any particular ability to statistically detect changes (statistical power), and if possible, determine the sensitivity of any particular measurement to potential alterations in dam operation. A good start to this end is work like that reported by Stevens et al. (1997) where algal and invertebrate biomass on the Colorado River were examined at specific habitat types at 11 sites bimonthly for a year. Data from this project should be used to examine the effort necessary to sample over a large area to obtain the ability to detect changes over time.

Food for Native Species:

A fish-food monitoring program could be more specifically targeted if the nutritional preferences and requirements of native fishes were better known. If there is a desire to understand the implications of changes in the food base that might be associated with management actions more research must be directed to understanding food-fish linkages. Some progress has been made using stable isotopes of C and N has been made (Angradi 1994; Shannon 2001;G. Allan Haden, unpublished MS) both in the mainstem river and in tributaries, especially the LCR. However, stable isotope research is evolving rapidly, especially with respect to the complexities of C isotopes, and there may be a need to revisit these results in the near future (Finlay 2001). Research utilizing Cesium isotopes (Rowan and Rasmusson 1996) along with C and N to better understand the amount as well as the source of food paths should be considered. An effort should be made to analyze fish stomachs that have been recently collected. Bioenergetics modeling, such as the recent study by on humpback chub in the LCR (Haden unpublished MS) could be pursued to roughly understand limits the GCE environment may have for native fish feeding.

We recommend the continued evaluation of fish condition indices – perhaps developing a standard weight for all native species – may be a better and more precise indication of the adequacy of the food base that now exists. The decline in weight-at-length observed by Meretsky et al. (2000) for chub over the past 20 years is cause for concern, and may be related to feeding conditions. Other venues may be analysis using proximate composition (i.e. lipids, see Marshall et al. (2001) for an example of how lipid composition is related to reproductive success), or RNA/DNA ratios.

Since there are scientific as well as statistical uncertainties associated with any approach for study the relation of food base to trends in abundance of fish populations the best approach is likely a fully integrated one, utilizing data on the abundance of prey available to fish in the GCE, the apparent food habits as indicated by stomach content analysis, and indicators from the fish themselves, including isotopes, growth and condition, and body composition.

Because the food habits of specific life stages of most native species are not well known a broad look at the potentially available food is required for a monitoring program. The best indicator of potential energy available is a measure of production – both primary and secondary – which is a measure of organic matter creation over time (mass/area/time). Neither measurement is routinely carried out in a monitoring program, especially one with the spatial extent of the Colorado River.

Monitoring Primary Production (Community metabolism) - Estimating total stream metabolism is often used to evaluate production or the potential food base. Two methods have been tried on the Colorado River during the experimental flood of 1996 – an open stream method (Marzolf et al. 1999) and enclosed chambers method (Brock et al. 1999). Both were able to detect the effects of the experimental flood in P/R (the ratio of primary production to community respiration), gross and net primary production. Both approaches might be evaluated as endpoints for monitoring primary producers, as they are relatively easy and inexpensive to perform. As with other monitoring tools, initial efforts are required to evaluate variability in both space and time, and power analysis must be conducted to determine the changes that can be detected. The key question to be resolved by research is whether primary production is actually related to the well being of native fishes.

Monitoring Secondary Production: Directly measuring secondary production of even a single species to estimate energy available to fishes is a daunting task. Regular, at least monthly, multiple quantitative samples over at least a year, rigorous determinations of sizes or weights and an excellent understanding of life histories are required. We know of no examples where secondary production is used in a regular monitoring program, although it has been successfully carried out in the Colorado River in a research effort by Blinn et al. (1994). It is unlikely this effort could be sustained in a long-term monitoring program.

Biomass (mass/area) is often used as a surrogate for production as it often has some relation to production, and is relatively easy to obtain. Algal biomass can be estimated by in-situ measurements of lengths of strands, harvesting and weighing, or indirectly by estimating chlorophyll content. Invertebrate biomass is estimated by quantitative sampling of the river bottom, removing invertebrates from associated debris and obtaining a dried weight. The problems associated with estimating biomass with any reasonable precision in a system as large and dynamic as the Colorado River are likely large. However, Colorado River researchers (e.g., McKinney et al 1999) have shown that when taxonomic level is kept relatively coarse a sample size somewhat <100 is sufficient to obtain reasonable variations. While 100 samples (Hess samples in this case) seems like a lot, identifying only to the level of algae or macrophyte for primary producers and *Gammarus*, Chironomidae, Gastropoda and Oligochaetes for secondary producers keeps efforts and costs to a minimum while presenting data at a sufficient resolution to understand benthic biomass that is available for fishes. One caution for directly relying on a biomass approach is the order of magnitude variation in the turnover rate of benthic organisms under different habitat conditions. For example, turnover rate (i.e. production/biomass ratio) of chironomids in lotic environments can vary between 10 to >250. Without knowledge of site-specific estimates of spatial variation in turnover in CRE, as well as the impact of dam operations on habitat conditions that drive turnover rates, projections of benthic productivity are highly uncertain.

Monitoring Drift: Research on the river has indicated a shift in energy sources longitudinally along the Colorado River below Glen Canyon Dam (Shannon 2001), and from tributaries (Angradi 1994), some of which may be from outside the main channel. Significant allochthonous sources would complicate the use of primary production measurements as the sole measure of river productivity. A way to address this concern is by monitoring drift. Drift, composed of algae, detritus and invertebrates that have been either washed into the river or detached from the river substrate and are being carried by water currents, has been used as an indicator of river productivity. Because particulate organic matter is likely important to downstream filter-feeding invertebrates (e.g., Simuliidae and some Chironomidae) drift estimates of coarse particulate organic (CPOM) and fine particulate organic matter (FPOM) would seem prudent. A start on a monitoring program for particulates can be obtained from the recent work on the Colorado River by Blinn et al. (2001), and Shannon et al. (1996). The most appropriate methodology for collecting drift (CPOM) is a depth and flow integrated sample across the channel as described by McKinney et al. (1999).

Advantages of drift as an indicator of system productivity are that the sample is relatively simple to collect; it integrates processes over a wide spatial area, and thus likely will have moderate intersample variation, allowing a reasonable number of collections. A drift program could be conducted at land-based access points that are currently used for physical science monitoring. Research questions to be addressed before knowing if this approach is feasible for the Colorado River include relating production to drift, and examining existing data on sample variability.

Finally, the interpretation of invertebrate biomass or drift density is contingent on an understanding of the degree to which the system is 'bottom-up' or 'top-down' controlled. That is, determining whether invertebrate abundance is limited by its food sources, or by grazing pressures from fish will influence how a management action might affect invertebrate abundance. Unfortunately, the response of intermediate trophic levels in tightly coupled systems is quite unpredictable (e.g., Power 1990).

Food base as indicators of system health or integrity.

The use of food-base organisms, benthic invertebrates, is a common and widespread approach to evaluating the biotic integrity of riverine systems. The benthic community is assumed to integrate numerous environmental features including water quality, quality of nutrients and carbon, physical habitat conditions, biotic interactions, and flow regime. While the most-used practice of having regional reference conditions to compare against obviously cannot be used in the Colorado River, a system whereby species composition is monitored for changes over time is eminently reasonable. The approach can be tailored to resources in terms of frequency of sampling, number of sites, and type(s) of habitats sampled. The most sensitive, and most difficult, system would encompass the presence or relative abundance of all taxa. However, even relatively simple indices such as ratios of *Gammarus*/Chironomidae/Simuliidae or some other dominant invertebrate groups would be valuable in indicating changing conditions. The value of long-term monitoring of invertebrates downstream from a large dam (Flaming Gorge Dam) is demonstrated in recent paper by Vinson (2001). This paper examined about 50 years of invertebrate data that included pre-dam and post-dam and pre and post thermal restoration. His major conclusion was "Changes in dam operation done long after dam construction may not be effective in restoring native species because the new community may have considerable tolerance to new operations". One caveat brought out in this study was that the difficulty in examining long-term trends because data were collected by different investigators and at varying taxonomic levels. Thus, establishing a robust systematic program is critical to examining changes in biological communities over time.

Finally, because primary and secondary producers are closely related to substratum conditions the food base monitoring program could be linked to high-resolution physical habitat modeling presently being conducted. Also, linking the food base monitoring program with the terrestrial invertebrate sampling program would provide a better invertebrate species list for the Grand Canyon Ecosystem.

Chapter 3 Humpback chub

Recommendations- *The Panel recommends that further work be conducted to develop a conceptual model of the metapopulation biology of chub in the GCE to provide a context for a long-term monitoring program. Consideration should be given to the inclusion of genetic concerns in the monitoring program. GCMRC needs to develop explicit linkages between the results of annual monitoring and the management goals to ensure that the monitoring programs produce results appropriate to review progress to the goals. The Panel supports the completion of the current review of existing data, and the development of population models, as these programs will yield sufficient information to make decisions about sampling programs for chub.*

The Humpback chub (HBC) is an endemic cyprinid (minnow) species that has the distinction of being the first fish species listed under the Endangered Species Act (ESA). The listing was prompted by concerns over decreases in range and abundance, which have been attributed to anthropogenic changes physical and biotic environment of the Colorado River (Douglas and Marsh 1996). Consequently, there has been considerable work conducted on HBC that has lead to a large body of knowledge on the biology of the species (see Valdez and Ryel 1995, Gorman and Stone 1999). Most HBC in the Grand Canyon are found in the region of the Little Colorado River (LCR), although smaller numbers of mainly adults are scattered throughout the mainstem Colorado River. Consistent successful reproduction appears to occur only in the LCR, although there are occasional reports of spawning and the presence of early life stages at other locations in the mainstem (Valdez and Ryel 1995).

The management objectives (Goal 2.1 to 2.5) for humpback chub (HBC) are generally driven by endangered species considerations and call for the establishment and maintenance of viable populations, and the 'removal of jeopardy'. Although the management target of a 'viable population' is difficult to define quantitatively, the likely monitoring needs will include the determination of the absolute abundance, trends in abundance, and measures of recruitment and other biological indicators of population status.

The Panel did note a lack of an explicit consideration of genetic issues in the HBC management goals. Genetic considerations can constitute an important basis for conservation. Any strategy for the conservation of a particular species or component subpopulations should be, at least in part, determined by knowledge or inference regarding that species' genetic structure (Franklin 1980). Such information can provide insight into the value and importance of individual subpopulations relative to a species' genetic diversity, and population viability and persistence. However, genetic structure, and population persistence and viability are inexorably linked with census population size (N), effective population size (N_e), and the number of breeders (N_b) available in a particular population at any given time.

The effective population size (N_e) for a population to retain its evolutionary potential sets a lower limit for viable population size (e.g. minimum viable population, MVP, Soule 1987). Franklin (1980) suggested two primary considerations when determining a minimum N_e for perceived population viability: 1) immediate danger in small populations due to inbreeding; and 2) loss of quantitative genetic variation that could limit future evolutionary change in the longer term. Franklin (1980) also argued that in small populations the rate of change in additive genetic variation is essentially determined by genetic drift minus the rate of gain due to mutation. Population and effective population size in turn profoundly influence the rate and potential directionality of genetic drift.

Although the principle that conservation of quantitative genetic variation is an important factor in managing endangered species is generally accepted, disagreement over appropriate N_e values continues (Franklin 1980; Shaffer 1987; Lande and Barrowclough 1987; Lande 1995; Franklin and Frankham 1998). Franklin (1980), Shaffer (1987), and Lande and Barrowclough (1987) provided theoretical arguments to suggest a minimum N_e of 500 for population viability and persistence. Lande (1995) argued that because only a fraction of newly generated mutations are beneficial (i.e. useful in providing adaptive potential for evolutionary change), an N_e of 5,000 is necessary to maintain evolutionary potential. Franklin and Frankham (1998) reviewed these and other arguments for an N_e of 5,000 and concluded that an N_e of 500-1,000 appears appropriate at this time. However, Lynch and Lande (1998) suggest that this number should be revised upwards to a range from 1000 to 5000.

It should be noted that the number N_e is generally much less than N, the census or total number of adults that could spawn. The difference is caused by fluctuating population sizes, sex ratios among spawners, and variation in the survival of offspring from particular matings, and subpopulation extinctions (Avise 1994). Based on recent census estimates, genetic concerns may be significant for HBC, and researchers may want to obtain estimates for N_e to monitor this surrogate viability metric.

The Panel concludes that significant uncertainties about the population biology of the chub need to be resolved before a long-term monitoring program for demographic or genetic concerns can be implemented. Specifically, the relative roles of the LCR-region fish and some of the smaller aggregations in the mainstem to overall population viability is not clear. This uncertainty might be represented by 2 strawman hypotheses about the population biology:

1. The only successful spawning and subsequent recruitment of HBC occurs in the Little Colorado River. Some spawning adults reside in the LCR, but perhaps most migrate to the LCR from the adjacent reach of the mainstem. Most recruitment results from juveniles that spend 2-3 years in the LCR. Juveniles that leave the LCR at small size (<100mm) likely experience low survival and contribute little to the population. Individuals that migrate or are displaced long distances from the LCR do not return to the LCR to spawn. These individuals may attempt to reproduce but recruitment does not occur.

This scenario is an extreme 'source-sink' metapopulation model where there is only one source of new individuals (the LCR) and a large 'sink' area (much of the Mainstem), where individuals are effectively lost from the reproductive population.

If this hypothesis is confirmed, the appropriate monitoring program would involve estimating the size of the LCR spawning population. Supplemental sampling to estimate the abundance of juveniles might provide an early warning to changes in the adult population. The Panel sees limited value in extensive surveys to estimate the size of the mainstem population (a difficult task), especially at times of year when the LCR spawning population becomes remixed with fish in the mainstem. Occasional (but nonetheless rigorous and repeatable) surveys of the mainstem might be appropriate for checking changes in the distribution of adults, and the occurrence of mainstem spawning or recruitment. Estimates of the effective population size for genetic monitoring would be derived from LCR spawning population estimates.

2. The second hypothesis would propose that there are one or more spawning sub-populations in the Colorado mainstem contributing some individuals to the overall recruitment. These other aggregations may still be sinks, in that immigration from the LCR to the mainstem populations may occur. However, overall population viability is enhanced by the presence of these other spawning locations because of the opportunity to 'spread the risk' of a population failure at any single location. There may also be genetic benefits to multiple, somewhat isolated, populations.

   Under this scenario, monitoring related to the management goal of maintaining a viable population of HBC necessarily entails estimating the abundance of adult fish throughout the drainage. Sampling chub in the mainstem Colorado River is not an easy task because they are relatively scarce, and occupy habitats (deep water, bedrock ledges) that are difficult to sample. It was suggested to the Panel that previous sampling efforts might not be appropriate for estimating relative or absolute abundance of chub because they were focussed on the known aggregations of fish, not in surveying the whole river in a statistically robust manner. Simulation studies based on the analysis of the variability in existing data indicate that a very large number of samples (ca. 500) are needed per year to obtain reasonable estimates of relative abundance that might be used in trend analysis. These results highlight the need to resolve the uncertainty about population structure before embarking on a mainstem program as described above. Consideration will have to be given to the degree of genetic isolation and mixing for any genetic conservation goals for HBC. If in fact hypothesized humpback chub aggregations turn out to be maintained by geographically exclusive spawning and rearing, estimates of N, N_e, and N_b should be applied separately to each chub aggregation in the GCE.

Review of Current Activities- The panel used a multiagency documented entitled 'Fisheries Monitoring Activities in the Colorado and Little Colorado Rivers within Grand Canyon During 2001' as the basis for our review of the existing monitoring program for HBC. The current (2000-2001) monitoring program consists of a very intensive sampling to obtain a spring estimate of the number of spawners in the LCR, a second intensive effort to estimate abundance of HBC in the mainstem near the LCR some 6 months later, and possibly scattered sampling throughout the mainstem, either as part of directed efforts, or incidental to other programs. Additional sampling in the LCR for sub-adult fish in the fall has also been proposed.

It was not clear to the Panel how all of these components would be integrated into a monitoring program that addresses the management objectives for chub. In particular, the LCR spring program and the summer-fall mainstem sampling appear to be trying to estimate the abundance of the mostly the same group of fish. One possibility would be to redefine the management goal of maintaining 'a viable population' to the maintenance of an abundance of reproductive individuals. Then, the 'viable population' should be assessed by monitoring trends in spawner abundance. The number of individuals contributing to subsequent generations, both in a genetic and demographic sense, will determine the persistence of the population over time.

The Panel believes that the resolution of the population biology of HBC to be a critical information need for the implementation of a long-term monitoring program. A useful first step would be to explore the use of geochemical markers on scales of HBC caught in different locations of the Colorado River to determine if all adult fish had originally been spawned (and perhaps reared as juveniles) in the LCR (hypothesis 1), or if some of the non-LCR fish were the survivors of mainstem (or other tributary) spawning events (hypothesis 2). Recent work by Thorrold et al. (2001) provides a good example of this approach. There may be potential in using scale archives to determine the distribution of spawning in the pre-dam era, if distinct geochemical signatures exist for various waterbodies. Upon resolution of these uncertainties a conceptual model of the biology of the chub can be developed, and appropriate monitoring programs designed.

The use of existing information- Recently, significant efforts have been undertaken to assemble and review the results of the past decade of sampling for HBC to determine whether these data could form the baseline for a monitoring program, be used in a population model, and to aid in the development of future programs. Concern was expressed to the Panel about the utility of past data, because of changing techniques, sampling intensity and the orientation of past programs for goals other than monitoring population abundance. The Panel strongly encourages the completion of the assembly of past data into a single database, including the documentation, where possible, of details of sampling to enable future researchers to comprehend the complexities of the data that has been collected.

Historical capture data for HBC have recently been integrated into a 'Stock Synthesis Model'. This type of model has the potential for detecting annual variations in recruitment that might be related to changes in habitat for the early life stages. Usually, the model is used to estimate cohort strength by examining the relative abundance of specific age-classes, corrected for age or size-specific vulnerability to sampling or fishing gear and density-dependent survival caused by habitat limitation. Once the model is fully parameterized it potentially can be used for forward simulations to make predictions about future trends in the population, and impacts of habitat change on those trends. From material presented to the Panel, it was evident that there may be significant limitations to this approach for chub, as the historical database are results from a variety of programs over the past two decades that have changed almost continuously with respect to sampling procedures and gear types. Further, the use of a length-based, rather than age-based model reduces the sensitivity of the approach to detect small changes in recruitment. Nonetheless, the Panel encourages completion and documentation of the HBC stock synthesis model, as it is clearly an important step in extracting information from the data collected to date.

The Panel was made aware of a very recent reconstruction of catches of young chub in the lower LCR from a variety of sampling programs conducted in the spring months from 1984-1998. These data have the potential to provide an index of cohort strength from the LCR, and provide information on the relative abundance of other native and non-native fishes. Since long-term trend data for HBC are lacking, the Panel recommends that these data be thoroughly examined for their utility as a 'real-time' indicator of recruitment, and consideration be given to the continuation of the program. If the proposed fall sampling of young chub is successful, it may be worth running both the lower LCR spring program and the fall program in parallel for a few years to allow the calibration and linking of data to extend the length of the series. These data may also have utility to cross-validate the stock-synthesis model, or could be used as an additional source of information to refine year-class estimates.

In the spring of 2001 an intensive, structured, marking program was initiated for chub in the LCR. This program should yield a reasonably accurate estimate of the number of adult chub in the LCR at the time of spawning. Such estimates would be the cornerstone of an assessment program under the single-spawning population hypothesis described above. The 2001 population assessment should be documented and reviewed after its completion. Some issues the Panel identified during its review are:

1. Whether the timing of the sampling mid-May and re-sampling in June will yield reasonable estimates of the total number of spawning fish, given the complexities that arise because of the immigration and departure of some spawners (especially larger ones) from the LCR.
2. Bias caused by tag loss (either through the mortality or emigration of repeatedly handled fish, or expulsion of tags). In controlled experiments 5-10% of PIT tags are lost soon after application; higher figures might be expected in the field.
3. Whether this program needs to be conducted annually, given the longevity of adult fish and the likely slow changes in the abundance over time.

The Panel was concerned about the impacts of handling and tagging of fish in the LCR. The intensity of the program results in some fish being handled repeatedly, and the timing of the program results in handling of recently spawned spent fish that may not as robust as in other times of the year (Meretsky et al. 2000). The panel was not made aware of any studies to assess the impacts of capture and tagging on chub, but experience with many other fish suggests these impacts cannot be dismissed, especially given the harsh nature of the LCR environment. We recommend that a fish handling protocol be developed that considers the relative impacts on the LCR chub population of an intensive marking program, and describes the appropriate techniques for capture, handling, anaesthesia, tagging, recovery and release. Experiments with captive fish may assist in development of the protocol.

A second part of the proposed 2001 program is the sampling and tagging of small chub (<200mm) in the LCR to provide population estimates of the pre-adult cohorts. This program should yield a year-class or recruitment index that will provide insight into the cause of trends in the adult population. Year-class strength can potentially be used to identify relations between habitat and recruitment, although these types of analyses are often unsuccessful because the causative link is usually unknown and spurious correlations are not infrequent. The 2001 sampling will be a pilot program, and the assessment of the results should include a consideration of the factors identified by the adult program, especially with respects to the effects of tagging small chub.

In summary—Two decades of investigation on the biology of humpback chub has left a body of information that is perhaps unparalleled for a non-game fish. The Center is thus well positioned (after investigation of some of the outstanding uncertainties listed above) to design a monitoring program that should allow the evaluation of the management goals with reasonable reliability.

The Center should refine the links between management goals for HBC and each of the monitoring activities by specifying how the outputs from monitoring will be used in decision-making. Quantitative analyses of past and currently collected data should yield estimates of the precision of the various programs, allowing calculations of the power of different types and intensities of monitoring programs to detect change in the population.

Finally, it should also be recognized that there may a large distinction between monitoring the chub population for ESA considerations, and monitoring to detect changes that may occur in response to the operation of the Glen Canyon Dam, or other management actions that change chub habitat (physical or biological). In particular, it has been hypothesized that the main linkage between GCD operations and chub result from changes the survival of juvenile chub that emigrate from the LCR at small size. The proposed programs and current programs need to be critically reviewed to determine if they are likely to be successful in detecting increasing recruitment from the mainstem as a result of a habitat manipulation. This problem is exacerbated by the observation that recruitment from the LCR is (and has probably always has been) highly variable, because of the extreme nature of that environment. Monitoring the fate of juvenile chub that leave the LCR may require more focussed research-type programs, preferably with sufficient pre- and post-treatment years of sampling to detect any changes that may have occurred as result of dam operations.

Chapter 5. Other native fish

Recommendations- *The Panel was concerned that there is no plan for monitoring the status of the 3 other extant native fish of the GCE. The Panel supports the ongoing synthesis of existing information and attempts to develop a population model for flannelmouth sucker as the first steps for developing a program for this species. The Center should develop explicit linkages between management goals and monitoring programs, and once all available data for the non-native species have been assembled, review options for monitoring these species.*

Management goal 2.8 is the maintenance of viable populations of the other native fish species of the GCE, the flannelmouth (*Catastomus latipinnis*) and bluehead suckers (*C. discobolus*) and the speckled dace (*Rhinichthys osculus*). Razorback suckers (*Xyrauchen texanus*) have been virtually extirpated from the GCE and will not be considered in this review of monitoring programs.

As with the other taxa, the Panel was not presented with an explicit plan of how results from present and future monitoring activities would be used to evaluate progress towards the management goals. In fact, there does not appear to be a coherent program of field activities for these three native species that would constitute the basis of a monitoring program. Certainly the elevated status of the humpback chub (*Gila cypha*) and the razorback sucker under the US Endangered Species Act imposes elevated priority to assessment and protection of these species. However, from ecological, conservation. and biodiversity protection perspectives, flannelmouth and bluehead suckers and speckled dace constitute species no less worthy of equitable research, management, and protection. Therefore, the Panel recommends consideration of directed, proactive attention to these native species, prior to possible population declines currently exhibited by other native fish populations in the GCE.

Flannelmouth and bluehead suckers and speckled dace currently appear to be represented by reasonable numbers of fish, however absolute abundances are not available, making it difficult to evaluate the significance of genetic conservation concerns for these species.

As with the humpback chub, there is a great deal of uncertainty about the population structure for these species, the location of major spawning areas, and the interchange of individuals among aggregations. Sampling of these species appears to be largely the result of incidental catches for other programs, rather than directed efforts to address key uncertainties, or rigourous programs to generate data suitable for monitoring. Thus, the Panel recommends directing significant resources to the collection of important basic biological information for these species.

The panel encourages the continued development of the 'stock synthesis' model for flannelmouth suckers. If successful, the model could provide a means to evaluate past natural and management-induced variation in abundance. If a link between habitat (i.e., flow, or physical and biotic conditions) and recruitment can be established, the model can be used for gaming management policy alternatives. While the data may limit the potential for this application, the exercise should result in a thorough summary of the available information. The Panel also encourages the use and documentation of the quantitative sample design program (as developed by C. Walters) for the development monitoring programs consistent with detection requirements of the adaptive management program.

An additional concern of the Panel involves analysis of fish data collected from backwater habitats. A great deal of effort has been expended on sampling backwaters for larval and juvenile fishes in the mainstem, which has been summarized in the review by Hoffnagle (2000). The Panel recommends the backwater fish data be reanalyzed with the express goal of evaluating the utility of this information as a real-time recruitment index.

Some of the native fishes use tributaries to the Colorado River as spawning habitat, and the Panel recommends consideration be given to the use of an upstream migration collection weir, as widely used with spawning salmonids, to effectively capture, mark, and estimate the number and biological attributes of spawning native fishes. Alternative, passive counting devices also exist (using sonar or resistivity) that may prove useful in estimating abundances. Bright Angel Creek is an obvious candidate for pilot studies of this approach. While the proportion of the total spawning population being monitored by the approach may be small and variable, the implementation of an 'index stream' program does provide some hard data that can complement less intense programs on other tributaries or the mainstem. Collection of increased numbers of fish could also provide useful population age class structure and spawning periodicity information. In addition, access to these aggregations provides the opportunity to collect samples for use in isotopic or elemental analyses. Such analyses could possibly usurp the need for longer-term, iterative mark-and-recapture studies currently used to delineate habitat use and distribution of native fishes in the mainstem Colorado River and its tributaries.

Chapter 6- Non-native Fishes

Recommendations- *For the GCE below Lee's Ferry, the management goals for non-native fish are related to their impacts on native species. The Panel was impressed by the efforts to develop a program to estimate the abundance of salmonids in the Colorado River, but felt some effort should be (re-) allocated to the other components of risk to native species, especially with respect to predation. There is no explicit program for warm-water exotic fish species. The Panel suggests that the species should be ranked for their potential for impacting native species, and that monitoring metrics be developed for the important species that address potential risk to native fish. Thorough analysis of available data should assist in the evaluating the feasibility of monitoring programs for these species.*

As presented to the Panel, the focus of the non-native fishes monitoring program in the overall aquatic resources monitoring program is on the extent to which these fishes pose a risk to native fish species (management objective 2.6). Non-native fishes that pose threats can be categorized into two groups, coldwater and warmwater non-natives, with major differences in distribution and natural history that will likely make their responses to changes in dam operations very distinct. The Panel therefore considered them separately throughout.

Coldwater Non-Natives

Coldwater non-native fishes that are well established in the Grand Canyon reach of the Colorado River are two species of salmonids, rainbow trout (*Onchorhynchus mykiss*) and brown trout (*Salmo trutta*). It is not anticipated that any other coldwater salmonids are likely to invade the system. Maintenance of a naturally reproducing rainbow trout population, while potentially a major threat to native fishes, is a management goal for the section of the Colorado from Glen Canyon Dam to the mouth of the Paria River. There is no similar management goal for brown trout. Abundances of both species are thought to be increasing, with estimates of ~ 1 million trout in the Grand Canyon reach of the Colorado River (Bill Persons, Arizona Game and Fish, Phoenix, Arizona; pers. comm). We will focus on the dominant species, rainbow trout, with a section on special issues concerning brown trout.

From the information provided a number of expected responses of non-native salmonids have been identified (see Table 6.1). Based on these potential effects, Panel attempted to whether current monitoring efforts are sufficient to detect changes in the threat to native fishes from coldwater non-natives. Interactions between non-native and native fishes may take several forms, including predation, competition, and parasitism. We will focus on monitoring changes in the predation risk posed by coldwater non-natives, as the most obvious route of impact. We cannot comment on the potential for the transmission of parasite or disease organism among species.

Table 6.1 Proposed responses non-native salmonids to changes in dam operations

	Eggs and Alevins	Small Juveniles	Large Juveniles	Adults
Low Steady Flows	Increased survival due to reduced exposure/scouring of redds	Increased survival due to availability of stable nearshore habitats; Increased dispersal	?	?
Temperature Control (Increased to favor native fish)	Decreased survival due to reduced oxygen in redds	Suboptimal growth due to increased energy expenditures	Suboptimal growth due to increased energy expenditures	Suboptimal growth due to increased energy expenditures
Sediment Augmentation	Decreased survival due to smothering	Decreased growth due to decreased foraging efficiency	Decreased growth due to decreased foraging efficiency	Decreased growth due to decreased foraging efficiency
Spike Flows	Decreased survival due to redd scour	?	?	?

Predation Risk Posed By Non-Native Coldwater Fishes—Monitoring changes in the abundance of non-native coldwater fishes alone is insufficient to understand the predation risk imposed on native fishes. Monitoring changes in predation risk requires more detailed understanding of biotic and abiotic factors. In the following sections we review monitoring efforts in the context of a generalized predation risk equation:

Per Capita Risk to Native Fish = f(Predator Density, Per Capita Predation Rate, Spatial and Temporal Overlap between Predators and Native Fish)

Monitoring Issues

Predator Density

The current monitoring plan is focused on detecting changes in trout density and distribution. Overall, the panel was impressed by the amount of effort and organization involved in this program, and felt that it provided a model for other programs, particularly in terms of clearly-stated goals, standardized sampling methodology, and informative, useful data summaries showing analyses to date. In fact, it might be useful at this point in the program to assess, using power analysis, whether adequate monitoring of trout abundance and distribution might be accomplished with less sampling effort.

One issue we felt could be more rigorously addressed is the interrelationship between trout density, recruitment, growth, and dispersal. This relationship is particularly important in assessing any potential change in risk resulting from a change in dam operations. For example, it was suggested to the Panel that experimental low steady flows had increased the survival of young juvenile rainbow trout by increasing the availability of stable nearshore habitat. However, these young juveniles are not likely a predation threat to native fishes. If trout recruitment is strongly density-dependent, which has been demonstrated in many previous studies in other systems, then increased survival of young juvenile trout may have no influence on overall risk to native fishes. Similarly, if trout growth is highly density-dependent (Bohlin et al. 1994), and the ability of trout to prey on non-natives is size-dependent (see next section), high trout densities may actually reduce predation risk, by reducing the number of large, highly piscivorous individuals in the population. We suggest that efforts to use existing data to assess these functional relationships would be well worthwhile.

Per Capita Predation Rates

Per Capita predation rate on any particular prey type depends on overall consumption rates, along with the proportion of the particular prey type in the diet.

The panel feels that insufficient attention has been given to this aspect of non-native influences on native fishes. Without knowing the propensity of trout to prey on natives, it is very difficult to assess predation risk. The panel was informed that a large number of trout stomach contents (>800) had been collected in association with fish sampling activities. We strongly suggest that these samples be analyzed, and the data brought to bear on this issue. Other factors that influence consumption may also be directly linked to changes in dam operations. For example, trout consumption rates are strongly influenced by temperature. The effects of dam operations that modify stream temperatures may therefore influence overall risk to non-native fishes. Bioenergetics models have proven to be very effective tools for assessing the influence of temperature change on potential consumption by trout in other tailwater fisheries (Filbert and Hawkins 1995), due to relatively limited diel temperature fluctuations in these systems. Also, several recent papers have discussed the effect of changes in turbidity on trout consumption rates (Swetka and Hartman 2001). We suggest that this information be used in assessing potential changes in suspended sediment concentrations resulting from changes in dam operations, and should be tied directly into output of the physical program.

Spatial overlap between predators and prey; spatial and temporal heterogeneity in predation risk

Distributions of both trout and native fishes appear to be very spatially heterogeneous in the Grand Canyon section of the Colorado River. In particular, humpback chub appear to be highly aggregated (although there is some contention about this point). Recent work dealing with the impact of predators on migratory river fishes indicates that the majority of total predation on a population may occur infrequently, and at limited spatial locations (Peterson 2001). We urge the monitoring program to develop protocols that can quantify the spatial overlap between predators and prey, particularly during critical and vulnerable life history stages of native fishes such as larval and juvenile dispersal. Predation on fishes with distinct migration/dispersal episodes may be difficult to document without knowing the timing and spatial extent of these episodes. For example, the impact of rainbow trout predation on humpback chub populations may be largely determined by predation on juveniles leaving the Little Colorado River. We additionally urge that diet and environmental (temperature and suspended sediment) data also be targeted towards these potential overlap zones.

Brown trout: special concerns

In addition to rainbow trout, brown trout have been increasing in abundance, and becoming more widely distributed in the Grand Canyon section of the Colorado River. Brown trout populations have some distinct issues from rainbow trout in the river. For example, while rainbow trout are believed to be able to spawn successfully in the main channel, Brown trout spawning is thought to occur mainly in tributaries, particularly in Bright Angel Creek. Monitoring the extent to which brown trout spawn in locations other than Bright Angel is likely to be important in determining whether proposed mitigation strategies, particularly the use of blocking weirs for predator control, are likely to be affected.

Warmwater Non-Native Fishes

The potential effects of changes in dam operations on warmwater non-native fishes pose a special challenge for monitoring. At present, cold thermal regimes currently maintained by the operation of Glen Canyon Dam strongly limit warmwater non-native abundance, likely reducing any negative impact on native fishes. However, there is considerable concern that proposed changes in dam operations designed to benefit native species may also benefit these warmwater non-natives, who may in turn negatively affect native species. The panel was charged with evaluating how well the current monitoring program would be able to detect these changes resulting in altered dam operations and experimental flows.

At present there is no specific monitoring program targeted toward warmwater non-native fishes. Part of the challenge facing any warmwater non-native program is the diverse array of species that have historically or currently occur in the Grand Canyon section of the Colorado River. These include large piscivores (channel catfish, black bass, striped bass), small invertivores (redside shiner and fathead minnow) and large detritivores (common carp). Individual stock assessments on each of these species is likely to be unfeasible, and many not be necessary. However, at least coarse-scale detection of trend in abundance for those species that are likely to pose the greatest threat to native species is essential.

We suggest several steps towards the development of a warmwater non-native monitoring program. First, existing catch per unit effort (CPUE) data on warmwater non-natives needs to be compiled, documented, and subjected to analysis to determine the level of change in population abundance that could be detected, given observed spatial and temporal variability and current sampling procedures. The GCRMP could then use the results of this analysis, along with existing knowledge and best professional judgment concerning threats to native species to target certain species for intensive monitoring. For example, a species which is highly piscivorous, able to be sampled with high precision, and whose abundance tracks the abundance of other warmwater species, would be an ideal target for intensive monitoring. The GCMRP also needs to decide whether this monitoring program should be targeted toward documenting changes in abundance at a given point, or towards documenting changes in distribution (i.e. upstream extent).

Once a method for monitoring changes in abundance has been established, additional considerations of risk to native species can be considered (see previous section on coldwater non-natives). Like trout, there are well-established bioenergetic models for several warmwater non-natives (particularly black bass and striped bass) that can be used to model predation risk as a function of both abundance and temperature. Some of these additional considerations could even be targeted in the initial stages of the monitoring program. This could include intensive monitoring of warmwater non-natives in the vicinity of native fish aggregations and important spawning tributaries, potentially including gut content analysis.

One important point of distinction between warmwater and coldwater non-natives is that predation may not be the only, or even the dominant mode of interaction with native species. Due to biological and ecological similarities between natives and non-natives, competition and parasitism may be equally as important. Therefore, it is important that in addition to monitoring for population trends, additional research be considered that focuses on aspects of warmwater non-native populations that are likely to influence the range of potential interactions.

Chapter 7. Management and institutional issues

Recommendations: The panel observed considerable variation in the analytical effort expended, the timeliness of reporting, and the availability of standardized databases among programs for aquatic resources. A standardized annual reporting cycle is a key component of any monitoring program. The Panel recommends that the procurement process needs to be much more tightly controlled, and wonders whether greater 'in-house' capability is required at GCMRC to achieve long-term consistency and quality in the monitoring program.

In the first chapter we described the necessary ontogeny of monitoring programs-from the initial description of the resources of concern, to the in-depth research on the processes and metrics of interest to the final decisions about the nature of the long-term monitoring program. Each of the aquatic components we reviewed was at a different point along this trajectory.

In many cases enough experience and data has been gained to allow development of explicit links between the management goals and monitoring outputs. In each of the preceding chapters we have noted that these links are required to permit the full development of the monitoring program. The management objectives and goals are currently qualitative, but are sufficiently described to permit the Center to determine the types of metrics (e.g., number of adult chub, abundance or diversity of invertebrates) and how they would be used analytically to describe performance with respect to the management goals. While the types of metrics and their use might change in time, the Panel feels the Center should devote considerable attention to exactly how the monitoring results will be used with respect to the management goals. This exercise should comprise a thorough review of the results collected to date, and will assist in the refinement of the long-term program. This exercise would also require more tightly defined hypotheses about the linkage between dam operations and the management goals

The process of establishing monitoring programs would be greatly assisted by stronger leadership by GCMRC. The Panel felt the program would benefit from an enhanced 'in-house' capability for quantitative analysis and synthesis, to make greater use of existing data, and to integrate results across disciplines (and contractors). We observed inconsistencies in the level of analytical effort among program elements, and recommend analytical effort of the quality and level of detail consistent with the existing rigor of many of the field data collection programs. It is particularly important that existing and future data be archived and analyzed in a manner consistent with the goal of long-term monitoring. The Panel notes the need for timely reporting, improved accessibility of data resulting from monitoring programs, and to the extent practical, standardization of data entry forms, database formats, and annual reports which can increase program efficiency and utility. We have often noted the need for database development, and laud the attempts that are underway to assemble existing information. The Panel wonders whether database management should be a role for the Center itself, rather than contractors.

Long-term monitoring requires long-term stability in the study design, sampling protocol, analysis and reporting requirements. The Panel gained the impression that the process of executing the work with short-term contracts was not meeting these requirements, and was not a particularly effective use of resources. The Panel thought that the Center should play a larger role in the design of the monitoring program, detailed articulation of sampling protocol, and the interpretation of results. Following this, the panel recommends that the Request For Proposal's used in the solicitation process and resulting contracts should be more focussed to include specifics on the sampling program, have a standard report framework and rigidly enforced data assembly and reporting timelines. Consideration should be given to longer term contracts to permit continuity in data collection.

Our final comment lies somewhat outside the purview of the Panel's charge, but was a concern that overshadows many of the issues that we have commented on. The Panel was concerned about the nature of the Adaptive Management Program with respect to its likelihood of success in providing new information about the response of the GCE to management actions. A successful Adaptive Management program will result from a coupling of a planned management experiment sufficient to evoke a change in the ecosystem, and a monitoring program reliable enough to detect that change. For the GCE the adhoc or stochastic (but not random) nature of baseline hydro operations of Glen Canyon Dam, and the important role of this variability on detecting ecosystem or trophic indicator responses is of great concern. Assuming that adaptive management is predicated on statistically powerful documentation of baseline ecosystem conditions, excessive baseline system variability (relative to perceived treatment effect scales) may provide a perilous context in which to detect treatment effects at desired levels of resolution. Secondly, the time scale of ecological responses for some taxa could span many years, both for the equilibration of lower trophic communities to be reached, and for the effects of change to be manifest in the longer lived organisms. We concur with NRC (1999), who call for explicit articulation 1) of what the core experiment is, and 2) the hypotheses to be tested by the experiment; such an articulation will allow a determination of the likelihood of success of the detection of the hypothesized effects.

Chapter 8: Panel Responses to Questions Posed by GCMRC

1. *What are the appropriate indicators to be monitored to adequately track trends in fish and aquatic food base resources? Given funding constraints, what are the fewest, most important, overarching indicators to monitor?*
   a. Is the approach associated with the food base appropriate?
   b. Would diet analysis be more informative/useful or should it be a combination of survey and consumption, and how can we adequately address the spatial scale question in Grand Canyon?

Chapter 2 and 3 provide details on options for monitoring programs of varying levels of intensity. The most basic and cheapest monitoring program for the lower trophic levels would entail a small number of fixed sampling stations, located at land-access points, where basic water quality parameters, and carbon and invertebrate drift would be estimated on a monthly or seasonal basis.

Because the relation between estimates of abundance of lower trophic levels and fish population abundance or recruitment is not well understood, we have proposed measures to directly use fish-based indicators (including diet analysis) to measure the effects of the lower trophic levels on fish abundance.

2. *How should sample sites be selected?*
   Geomorphic reaches?
   Using tributaries as demarcation points?
   Completely random?

No generalizations are possible here, as the sampling design will depend on the variability of the attribute being sampled over space and time as well as the goals of the program. Randomized or stratified random designs are required for whole-river estimates of populations or densities, but for long-term trend monitoring of variables such as nutrients, temperature, and drift, fixed sites are suitable and logistically more practical. Standard sampling regimes often make use of stratified designs to subdivide the sampling area into more homogenous regions to reduce the variance in the final estimates. Stratification is usually based on a priori knowledge of how the variable of interest is distributed. Whether that stratification should be based on geomorphic reaches, at tributaries or other features depends on whether the organism's distribution is related to these strata.

3. *Concerns have been expressed that past fish researchers in Grand Canyon (and the program under which they were funded) did not adequately analyze, synthesize, and integrate their data. What is the PEP's view of the status of information assessment for native and non-native fishes in Grand Canyon? Is it sufficient to serve as a basis for recommendations on future management actions, particularly those that may involve high risk to these species?*

Throughout the review the Panel has noted the need for long-term databases that collate information collected to date, and it supports recent efforts to bring such information together. While most of the past work was not focussed on long-term monitoring needs there is much to be gained from the re-analysis of existing data, either 1) help define/re-define hypotheses about the effects of dam operations on key physical and biological monitoring variables with data; 2) to ensure that monitoring data is generated in a form comparable to current and future programs; or 3) for 'components of variation' analysis to assist in the design of future programs. The Panel strongly supports current efforts to assemble and examine the data collected to date for its utility in the monitoring context.

A great deal has been learned about the GCE. However, many other cases have shown us that the most consistent result of large-scale ecosystem manipulations is that of surprise or unexpected responses. That is, no amount of research and investigation will yield completely reliable predictions about the responses of organisms to changes in their environment. However, the panel felt that more has yet to be learned about the ecosystem and continued efforts to understanding the response of the aquatic community to dam operations will likely reduce risk of adverse impacts. The expected responses can be bounded, and particular attention can be paid to negative consequences, and the resilience of populations and ecosystems to manipulations that did not turn out as planned.

4. *Is there a large benefit to be gained from measurements (water quality, macrobenthos, phytobenthos, physical habitat, fish, stable isotopes, microbes, etc.) being collected at the same times and places? If so, should a common or integrated sampling design be applied to all resource groups?*

The sampling depends on the time and spatial scale of the variability of the distribution of the organism, and the goals of the program. For example, if the goal is a food web study, then there is obvious benefit to sampling at the same space and time scale as the foraging organism. This linkage allows more direct (certain) relation of abiotic conditions, primary and secondary response indicators providing a stronger weight of evidence to resulting inferences. However, for monitoring, there is a need for consistency over time and space (and methodology). Most monitoring programs involve fixed stations because these are the logistically easiest to implement, and have the highest likelihood of assuring continuity. In the strict statistical sense there is a shortcoming for fixed stations (i.e. repeated measures design), because the level of inference about the results is restricted to those sites, not the whole reach or river. This comment mainly applies to the objects of sampling that are relatively sessile, not time and space integrated variables such as temperature or drift. In summary it seems unlikely that a common sampling design can be expected for all resource groups, but where it is possible linkage of the sampling can help to provide more defensible inferences.

5. *Can a protocol be developed that will monitor trends effectively year to year in the Canyon regardless of the hydrology, other natural events that occur, or*

management actions implemented in any given year? [Is there too much noise in this system to track trends specific to dam operations?]

All natural systems vary from year-to-year, and in the GCE there is an unusual form of variation imposed by the operations of the dam. Whether the response to a management action can be detected depends on the natural variation, the sampling or measurement variability and the size and duration of the management perturbation. For the lower trophic levels there is probably sufficient information already available to assess the likelihood of detecting changes that result from management actions, and the fish programs should yield similar information soon. Usually, the outcome from these analyses is that it is often very difficult to detect changes in the taxa of most interest (i.e. adult fish; Korman and Higgins 1997). Multiple lines of evidence, including the results of monitoring of a variety of biota, as well as focussed investigations on the hypotheses being tested by the management action will be required to judge the outcome of an experiment.

6. *If, as is currently being discussed, fish (HBC) recruitment trends are only evident two to three years after a designed management action is taken, what can be accomplished in the intervening years without altering the developing trend?*

    a. Emphasis in assessing native fish and the rainbow trout fishery has shifted strongly to stock assessment and stock synthesis. For the humpback chub, recruitment does not occur until age 3 or 4, and not until 2-3 years after fish are first marked. Hydrology of the Colorado River is, and will remain, unpredictable in the years between reproduction and recruitment. Thus, it is not a treatment that can be applied consistently in the years between reproduction and recruitment. If the primary question being addressed is, what is the relationship between dam operations, i.e. hydrology, and recruitment, how do we parse out the effects of different dam operations and tributary inputs in the relationship?

The significance of these issues depends on the hypotheses being tested about the relation between chub recruitment and dam operations. For example, if dam operations are expected to assist the survival of larval and age-0 fish only, dam operations in the intervening years are not as important because their effects will be limited to the first year of the chub's life. But, if dam operations are hypothesized to affect all pre-recruit years, then the full effect of the experiment on a single cohort will not be realized unless the operating regime is continued for 3-4 years.

The Panel was surprised that one-year flow experiments have been used and were being considered for future experiments useful for evaluating the relation between dam operations and aquatic ecosystems. While some information about physical processes affecting fish (temperature, stranding) and those of the most rapidly growing organisms might be obtained, most components of the ecosystem will take longer (perhaps generations) to fully respond to changes in the physical and biological components of the ecosystem to flow regime. Further, any one-year experiment is completely confounded with the natural events of that year, and will have to be repeated a number of times to average out those effects. Repeating the management action in successive years will generate much more information.

> *b. Movement to stock assessment and stock synthesis has resulted in movement away from measurements of native fish species, particularly humpback chub, in early life stages. Is this prudent, assuming that the majority of mortality from dam operations is visited upon humpback chub in the first year of life and the major responsibility of the Glen Canyon Dam Adaptive Management Program (GCDAMP) is to determine the effect of dam operations on native fish and other resources?*

There are other cases in fisheries where the trade-off between estimating recruitment as entry into the adult population and year-class strength as indicated by the indices of the abundance of the early life stages has been examined. The former is a measure of the variable that is of real interest (new adult fish), while the latter is more timely, but is often more difficult to do properly. There is also the possibility of considerable variation in survival after the early life stage and actual recruitment that can hinder the utility of juvenile indices. It should be possible to evaluate this trade-off between these strategies quantitatively using juvenile information from the backwater, mainstem sampling, LCR trammel program and the stock synthesis model.

7. *How do we assure a trend is related to a specific management action and not other influences affecting the resource? Type I and Type II error.*

Adaptive management in the GCE is a spatially unreplicated experiment as there is no 'control' river from which one can estimate the effects of large-scale factors such as decadal-scale changes in climate that could affect the aquatic ecosystem. The only method to control for external influences is to vary the treatments in randomized blocks over time (which could be an 'on-off' cycle) to avoid the coincidence of a treatment and a particular source of natural variation. In cases where the influence of natural variation is well known, it may be possible to collect ancillary data and use these as additional explanatory variables in the analysis to help remove their effects.

Adaptive Management questions.

8. *A primary purpose of science in the GCDAMP is to assess the relationship between dam operations and responses of target resources. Most of the funding advocated by managers seems to be for what they deem core monitoring, with much less emphasis on research. Many scientists argue that status and trend of resources can be measured effectively by core monitoring, but much of the cause and effect relationships will need to be addressed through experiments and associated research. Is there a process known to the PEP that would facilitate resolution of these issues between scientists and managers?*

Adaptive management has been widely advocated in the CRE as the 'process' for 1) reducing scientific uncertainty about the response of the aquatic ecosystem to dam operations; 2) the integration of research and management activities to most effectively manage water resources and aquatic conservation objectives (NRC 1999). Flow experiments have been explicitly proposed to empirical assess the relation of key ecosystem response indicators. Core monitoring in adaptive management programs provide time series of changes in the relative state of key aquatic resources and allow correlation of responses to dam operations. However, alone, this information is unlikely to provide enough information to make informed decisions about dam operations and aquatic conservation. We have identified many instances where additional research is required to before a monitoring program can be established, so requirement for research still exists. For planned flow experiments, we have also suggested that the routine long-term monitoring may not be sufficiently powerful to detect expected responses.

To resolve these problems, there is a need for better linkage between research and research through experimental manipulation, and managerial research to learn how to effectively deal with uncertainty and design management approaches to reduce it (see Underwood 1994). Experiments should be framed as tests of hypotheses, as defined by research and monitoring is required to provide the data needed to test them. Thus for the Adaptive Management program there should be a mix of both monitoring and directed research studies.

9. *Are management objectives appropriate?*

Management objectives are policy determinations based on an array of values- the Panel was not charged with the review of the objectives. The Panel did note that, given limited resources, the management goals and their monitoring activities might have to be prioritized. In all cases, there is a need to link the management objectives to the metrics that result from monitoring programs.

10. *How important is it to attempt replication in large-scale experiments like beach-habitat building flows? How much of the response in target variables might be attributed to driving variables other than dam operations? How does one compare tradeoffs between repeating large-scale experiments and the cost of conducting such experiments?*

The need for replication depends on the extent to which the ecosystem response varies with the management action, the magnitude of 'noise' or variability unrelated to the treatment, and the inherent time-scale the responding variable to the management action. For some variables (especially physical ones) replication may not be needed, however, the detection of responses in biological variables will almost always require replication. Since ecosystems may take some years to adjust to an altered physical regime, treatments should be replicated in successive years rather than isolated events.

To justify conducting large scale replicated experiments the proponents of such an approach must show how deliberate flow manipulations will generate new information about the relative effectiveness of management actions or about hypotheses about ecological processes and thereby improve future management of the dam. Peterman and Peters (1998) suggest three general types of analyses can be conducted to quantify the value of information produced in adaptive management programs: 1) expected value of incorporating uncertainty; 2) expected value of collecting sample information; and 3) expected value of perfect information. The reasoning behind using the value of information calculations is to estimate whether it is worthwhile to acquire new data about how the ecosystem will respond to management actions and thus add value to management decisions in terms of net economic performance or some other manner of assessing utility (i.e. conserving a threatened species). Value of information calculations therefore is useful to help screen for opportunities to conduct adaptive management.

Where it appears to be worthwhile to conduct experimental management actions the next step is to construct a management policy accounting framework for the evaluation of alternative experimental approaches (including baseline non-adaptive policies experimental design options). To be effective this policy accounting framework must:

1) Evaluate management actions based on explicit definition of benefits (and costs);
2) Account for the dynamic nature of fish populations and other aquatic and riparian resources and the influence of flow management actions on those dynamics;
3) Permit management actions to be constrained by economic, social or political factors;
4) Account explicitly for uncertainty as to the effects of management actions and uncontrolled environmental factors; and,
5) Define explicit linkages between management policies, operational monitoring, and assessment programs

In this management policy accounting framework, dynamic models for predicting physical and ecological response to instream flow changes are developed and used to simulate how managers learn from implementing different experimental management strategies. By structuring the models to treat uncertainty as a dynamic variable of inherent in the management system, they can be used to compare different strategies for assessment and management and to design deliberate strategies for reducing uncertainty over time (Walters 1994). This analysis usually involves developing a conceptual model that incorporates the physical-ecological response model and an observation/management model that simulates how managers collect and respond to information. The model is then used in a Monte Carlo framework to investigate how realistic levels of natural variation and measurement error to establish the performance of a given proposed management experiment. The basic idea behind these evaluations is to determine whether conducting the experiment can reduce ecological uncertainty and how reduced uncertainty influences expected long term net economic and ecological benefits from management (Walters and Green 1997). To evaluate the net value of alternative designs for instream flow experiments managers must be able to compare the short term costs of conducting flow experiments and monitoring programs to the long term net benefits that accrue from managing based on the experimental results (Walters and Green 1997).

11. Control or suppression of non-native species, primarily fish, has been advocated in conjunction with modified dam operations, particularly with a temperature control device. How effective does the panel think such actions could be in Grand Canyon? Which non-native fish would be most susceptible?

To scope these questions the Panel suggests a simple population model of native fish be used to game (experiment) the response of fish populations to various management actions. While many parameters will have to be guessed at, the exercise should provide order-of-magnitude impacts of each management action on the target population. The relative risk of each exotic species could be estimated, and the likelihood that a proposed predator control program might succeed could be estimated. Brown trout appear to be the easiest predator species to control, and actions on this species could probably be justified for other reasons (i.e., elimination of exotic species in National Parks). Consideration might also be given to the removal of non-native fish from the Little Colorado River, given its importance for the recruitment of chub.

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Table 1 Field of expertise and institution of Aquatic Protocol Evaluation Panel Members

Name	Field of Expertise	Institution
Paul Anders	Fish ecology, Population genetics	Department of Fish and Wildlife Resources, University of Idaho
Mike Bradford (chair)	Fish ecology, Population dynamics	Fisheries and Oceans Canada and Simon Fraser University, Vancouver, B.C.
Paul Higgins	Fish ecology Monitoring design	B.C. Hydro Vancouver, B.C.
Keith H. Nislow	Aquatic ecology, Experimental design	USFS and Univ. Mass. Amherst, Mass.
Charles Rabeni	Aquatic Ecology Fisheries Ecology	USGS, and Univ. Missouri
Cathy Tate	Aquatic ecology, Fisheries ecology Water Quality	USGS, Denver

Table 2 Contributions and institution of other participants in the 7 day field trip associated with the Aquatic Protocol Evaluation (May 8 to May 15, 2001)

Name	Activity	Institution
Lew Coggins	Little Colorado River Humpback Chub Stock Assessment Program	United States Fish and Wildlife, Flagstaff, Arizona
Barry Gold (p/t)	Environmental Studies Background Adaptive Management, and Role of PEP panel	GCMRC Flagstaff, Arizona
Stewart Jack (p/t)	Observer	United States Fish and Wildlife, Pinetop, Arizona
Josh Korman	Conceptual Model	Ecometric Research, Vancouver, B.C.
Dennis Kubly (p/t)	Observer	United States Bureau of Reclamation
Ted Melis (p/t)	Physical Science Program Coordinator	GCMRC Flagstaff, Arizona
Bill Persons	Non-Native Fish Stock Assessment	Arizona Game and Fish Phoenix, Arizona
Barbara Ralston	A/Biological Program Coordinator	GCMRC Flagstaff, Arizona
Joe Shannon	Aquatic Food Base	Northern Arizona University, Flagstaff, Arizona
Melissa Trammell	Native Fish Biology	SWCA, Inc Flagstaff, Arizona
David Topping	Physical Science Program	USGS Flagstaff, Arizona
Carl Walters	Native Fish Stock Assessment	University of British Columbia, Fisheries Center, Vancouver, B.C.
Mike Yard	Water Quality, Fisheries Biology	GCMRC Flagstaff, Arizona