Integration of Grand Canyon Physical and Biological Information: A Progress Report

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Abstract. Ecosystem management of regulated rivers requires not only integration of different kinds of data, but also effective communication between researchers and managers. We report on recent efforts to improve both processes in lower Colorado River ecosystems of Grand Canyon. Between 1989 and 1995, the Bureau of Reclamation and its cooperators conducted Phase II of the Glen Canyon Environmental Studies to supplement earlier (Phase I) scientific river-based research in Grand Canyon, and produce an environmental impact statement on Glen Canyon Dam operations. Phase II studies were designed to provide "an integrated approach to studying and understanding the relationships between the operations of Glen Canyon Dam and the ecological components of Grand Canyon." By the end of Phase II environmental impact studies, researchers had identified linkages between their own databases and other studies, and opportunities to integrate research were numerous. For example, geomorphology reports contained information relevant to understanding habitat availability for humpback chub. To facilitate integration, the Bureau of Reclamation convened a meeting of Grand Canyon researchers in August 1995. The goal of the meeting was to solicit input on strategies for future integration of abiotic and biotic information. Meeting discussions focused on scientific questions relating to endangered species issues that are best addressed through integrated analyses. Other discussions revolved around the meaning of the term "adaptive management" from a scientific perspective, and the role of science in environmental management. We present an abridged history of past research under the Glen Canyon Environmental Studies program, summarize the results of this first integration meeting, and outline an approach to future integration of physical and biological analyses to improve ecosystem management.

Key words: Adaptive management, biological opinion, ecosystem management, environmental impact statement, integrated management.

Summary History of the Glen Canyon Environmental Studies

Use of integrated scientific information in the management of regulated river ecosystems has been identified as a key to preserving freshwater resources and maintaining biodiversity in rivers (Naiman et al. 1995, Stanford et al. 1996). Currently, an integration effort is underway on the Lower Colorado River within Grand Canyon National Park, Arizona. This effort is a result of previous research surrounding operation of Glen Canyon Dam. To provide a perspective on the current state of scientific integration on the Colorado River in Grand Canyon, we begin with a brief summary history of the Glen Canyon Environmental Studies. No review of this limited scope can do justice to the complexities of many years of political and scientific history; we intend merely to sketch the relevant background that provides some perspective on present integration efforts.

Overview of Phase I Studies

The Glen Canyon Environmental Studies were initiated by the Bureau of Reclamation in 1982 to further investigate relationships between Glen Canyon Dam operations and changes in Colorado River resources throughout Grand Canyon (Dolan et al. 1974, Laursen et al. 1976, Turner and Karpiscak 1980, Howard and Dolan 1981). Although some effects of flow regulation were relatively obvious by that time, many other cause-and-effect relationships and ecosystem links between Glen Canyon Dam operations and the downstream river environment were still uncertain some 20 years after closure of the dam in 1963.

Phase I studies involved federal and state research primarily from 1983 to 1986, with some studies and summary efforts extending to 1988. The program included descriptive studies of aquatic and terrestrial biology, avifauna, sediment-transport processes, hydrology, and recreational use. The results of Phase I research were presented as a series of single-discipline technical reports and publications (U.S. Department of the Interior 1988a,b). These studies confirmed that dam operations affected downstream resources. However, reservoir spills from 1983 through 1986 limited scientific understanding of effects from fluctuating flows resulting from typical hydropower operations – the primary focus of the original research.

Following their review, the National Research Council commented that despite extensive research during Phase I, the resulting single-discipline reports lacked integration, particularly in the planning phase (National Research Council 1987). Information from the different disciplines had not been linked, and the resulting understanding of the system was therefore less complete than it could have been had the studies been integrated from the start. For example, information on hydrology and organic material in the water column had not been brought together with information on humpback chub diet to examine food availability over time and space. To provide deeper insight into the implications of initial research, documentation was prepared to summarize the results and conclusions of Phase I research (U.S. Department of the Interior 1988b).

The National Research Council concluded that the Glen Canyon Environmental Studies had met the overall goals and objectives, and demonstrated that impacts on Grand Canyon related to Glen Canyon Dam operations could be reduced (National Research Council 1987). The Council also noted that the effectiveness of Phase I would have been enhanced by early, rather than after-the-fact, involvement of an integration group, and by greater use of historical data from Grand Canyon and external literature derived from similar fluvial systems. In 1988, the Department of the Interior concluded that additional technical information was needed before dam operations could be modified in order to minimize impacts on downstream resources. Phase II studies were implemented to meet this objective.

Overview of Phase II Studies

Phase II studies began in 1988. At the recommendation of the National Research Council, a senior scientist was appointed to provide direction and oversight for the overall study plan (Patten 1991). Shortly after Phase II studies began, the Department of the Interior mandated an environmental impact statement on the operation of Glen Canyon Dam. The goals and schedule of Phase II studies were modified and accelerated to support the environmental impact statement process. This redirection of Phase II studies eliminated aspects of integration that had originally been planned, in favor of rapid evaluation of areas of special concern for the environmental impact studies.

Phase I reports, available Phase II draft reports, and additional information solicited from scientists were used to: (1) design and implement research flows during the first year of Phase II (1990); (2) implement "interim" flows following cessation of research flows (beginning in August, 1991); and (3) evaluate seven proposed operating alternatives for the Environmental Impact Statement (1990–1995; U.S. Department of the Interior 1995). Interim flow releases were set at 8,000–20,000 cfs to minimize impacts to downstream resources. Interim flows, implemented as part of the annual operating plan for the Lower Colorado River, continued at least until a Record of Decision finalizing the impact statement process was signed by the Secretary of the Interior in October 1996 (the time of completion of this manuscript).

Phase II studies investigated many ecosystem-level responses to dam operation between Glen Canyon Dam and Lake Mead, including research on tributary-process effects, mainstem sediment transport, hydrology, water quality, limnology, geomorphology, aquatic resources, native and endangered

species, recreational uses, cultural resources, and economics related to Glen Canyon Dam operations (U.S. Department of the Interior 1995). The relationships among these diverse areas were formalized in a diagram (Patten 1991) that is still undergoing development (John C. Schmidt, personal communication). Although the intent of Phase II research was to promote an integrated approach, as a result of the EIS process, Phase II focused on individual disciplines and research needed before integration could be accomplished. Thus, despite being centrally coordinated through the Bureau of Reclamation's Glen Canyon Environmental Studies office, most Phase II research reports completed in 1995 still required an expanded degree of scientific and technical integration to provide managers with comprehensive information relating river resources to dam operations (National Research Council 1996). Additional integration efforts are underway to integrate various aspects of fisheries research and, separately, sediment-related research.

The Ad-Hoc Interdisciplinary Integration Work Group

As Phase II studies concluded and final reports were submitted, the Glen Canyon Environmental Studies office and its cooperators faced the task of consolidating the scientific information available. More information was available from existing databases than was presented in existing reports, and critical linkages and relationships between river resources and Glen Canyon Dam operations were not fully described by the largely single-discipline reports and publications. It was recognized that additional information might be obtained through interdisciplinary debate, data sharing, and ongoing discussion. To this end, the Glen Canyon Environmental Studies office invited a group of researchers with ongoing ties to the Grand Canyon to discuss possible approaches to integrating existing data.

The Ad-Hoc Interdisciplinary Integration Work Group (hereafter Ad-Hoc Working Group) provided a forum for scientific integration of Lower Colorado River data related to ongoing management needs, particularly those related to Biological Opinion issues. In late 1995, a research center recommended by the Glen Canyon Dam Operations Environmental Impact Statement (U.S. Department of the Interior 1995), was approved, although its full operation is not anticipated until 1997. The Grand Canyon Monitoring and Research Center is intended to take the responsibility of directing long-term monitoring and research of resources below Glen Canyon Dam. In the last months of 1996, the Center began contacting Grand Canyon researchers to continue the process begun by the Ad-Hoc Working Group.

The first meeting of the Ad-Hoc Working Group was convened in August 1995, and was comprised of representatives from federal and state agencies, academia, the private sector, and Native American tribes. Researchers who could not be present were and continue to be encouraged to participate in the

integration process as opportunities and interests arise. To better focus discussions on science, three topics were accepted by the group for further exploration and debate: (1) physical-habitat relations (divided into geomorphology/sedimentology and hydroclimatology subcomponents); (2) trophic dynamics; and (3) population ecology of humpback chub (divided into subcomponents of life-history strategies and species interactions). In addition, the group recognized a strong need to discuss the role of science and scientists in the adaptive-management process. Thus, an additional section (4), on adaptive management and its relation to science and scientists was added to the core topics.

Evaluating Approaches to Science Integration

Core-topic discussions concluded with the formation of writing groups. From August through November 1995, principal topic authors presented integration documents to their respective groups, received and incorporated comments, and completed draft integration prospectus modules. The resulting core-topic integration reports were brought together with introductory and background information and presented as an informal, but comprehensive draft prospectus to the research community (Ad-Hoc Interdisciplinary Integration Work Group 1995). The following sections summarize the main points of the integration prospectus and discuss future integration goals of that process.

Physical-Habitat Relations – Geomorphology, Sedimentology, and Hydroclimatology

Environmental studies of the effects of Glen Canyon Dam operations on downstream river resources indicate that physical attributes of habitats are controlling factors in the ecology of many species in Grand Canyon (U.S. Department of the Interior 1995). Other controlling factors include food availability, river temperature, and biotic interactions. Most Colorado River researchers attending the August 1995 Fern Mountain meeting agreed that integration of existing biotic and abiotic data bases generated during Phases I and II of the Glen Canyon Environmental Studies would lead to the development of specific, testable hypotheses regarding these habitat relationships. For example, relationships between life histories of native fish, decade-scale climate variability, and mainstem and tributary geomorphology might be explored through such hypotheses. The group also recognized that scientists and managers working together towards integration of scientific data will be better able to manage endangered/critical species by managing operations at Glen Canyon Dam, but only after specific relations between habitat and species distributions are understood.

The following section outlines discussions that occurred during the meeting with regard to the potential significance of incorporating physical data into Biological Opinion related research on the Lower Colorado River. Owing to the dynamic nature of Grand Canyon's climate and geomorphic processes, the habitats of endangered species change naturally through time, but these changes have also been influenced by regulated dam releases since 1963. Physical changes in the river's geomorphic framework are linked to regional geologic characteristics and climatic variability. Significant geomorphic changes in the mainstem Colorado River below Glen Canyon Dam have been recently documented (Schmidt and Graf 1990, Webb et al. 1991, Melis and Webb 1993, Melis et al. 1994, McGuinn-Robbins 1995, Melis et al. 1995, Schmidt and Rubin 1995, Stevens and Wegner 1995, Stevens et al. 1995, Webb and Melis 1995, Webb 1996, Webb et al. 1996). These changes will likely continue as a result of natural and man-caused disturbances resulting from unregulated geomorphic processes in Grand Canyon (e.g., floods, rock-falls, and debris flows), and dam operations (e.g., suppression of flooding, unplanned reservoir spills, prescribed experimental floods, and thermal effects from selective-withdrawal implementation). The next step towards understanding the subtle implications of these changes on the physical resources and aquatic ecosystem below Glen Canyon Dam is a comprehensive integration of existing data and conclusions derived from past studies.

The hydroclimatology of the Colorado Plateau affects a variety of physical and biological processes in Grand Canyon related to critical species' ecology. Flows in the Colorado River upstream from Lake Powell, the Little Colorado River, and other tributaries in Grand Canyon respond to topography in concert with regional climate variability that is driven by global-scale processes. Global processes include general circulation patterns in the atmosphere, and Pacific Ocean sea-surface temperatures and currents (Rasmusson and Carpenter 1982, Liu et al. 1995). Anomalous circulation in the atmosphere and the global-scale phenomenon of El Niño (Diaz and Markgraf 1992) in the eastern Pacific Ocean affect climate and weather on the Colorado Plateau (Andrade and Sellers 1988, Cayan and Webb 1992), as well as the rest of the western United States (Redmond and Koch 1991, Kahya and Dracup 1993). In addition, recent studies suggest that daily precipitation intensities have increased during the twentieth century throughout the United States (Karl et al. 1995), a trend which has potential significant geomorphic implications on river systems such as the Colorado River Basin.

Another first step toward understanding the significance of habitat changes along the Colorado River is integration of biotic life-history data for critical species. These data include demography, distribution, behavior, relations to associated species, reproduction, and habitat requirements. Once data on the geomorphology of the river and species ecology are individually integrated, life-history models may be linked to physical-habitat information. Abiotic data likewise require synthesis for integration to succeed, including basin-to-macro scale characteristics controlling the geomorphic framework of the Colorado River, tributary/river process interactions, relations of pre- and post-regulated hydrology to river resources, macro-to-micro scale characteristics of the river channel, its canyons and tributaries, present climate effects of regulation on the river, relations of paleohydrology and paleoclimatology to the present geomorphic framework of the system, and models of sediment transport and hydraulics. Developing links between abiotic and biotic systems is a difficult task, but the Ad-Hoc Working Group concluded that such a task can be accomplished through ongoing scientific integration and interdisciplinary research designs that are supported during long-term monitoring.

At present, relationships between the geomorphic framework of the Colorado River, including its hydrology, geology and sedimentology, and its aquatic and riverine habitats, are only generally understood despite considerable research efforts aimed at understanding the individual components of the river system. For example, Valdez and Ryel (1995) hypothesized that a distinct, grouped distribution of humpback chub aggregations in Grand Canyon occurs because of a unique combination of temperature and physical habitat parameters, along with specific life-history requirements for both adult and subadult life stages. Also, Stevens et al. (1995) documented spatial scale impacts of geomorphology and dam operations on marsh development. Predictions of impacts of higher flows on these habitats and assemblages require testing.

Scientists who participated in the August 1995 integration meeting at Fern Mountain, Arizona developed questions designed to begin investigating the links between habitat and endangered species distributions below Glen Canyon Dam. Primary questions posed regarding habitat relationships included: (1) which physical and geomorphic attributes of the Colorado River limit or control distributions of endangered species below Glen Canyon Dam; and (2) how do long/short-term dam operations affect those physical/geomorphic attributes, and how do these effects relate to management objectives for preserving critical species? Neither of these questions can be answered solely by assembling and interpreting existing data bases. However, the timely integration of such information is an essential next step towards an ecosystem-science approach aimed at addressing Biological Opinion issues (U.S. Fish and Wildlife Service 1994).

Additional research on relationships between climate, Lower Colorado River flows, and unregulated tributary processes will provide greater insight into the importance of physical habitat changes and relationships to critical species and ecosystem responses. Besides several integrated research topics on sediment transport and the other natural processes controlling the geomorphic framework of the river, other topics were suggested by the Ad-Hoc Working Group that focus on climate related issues:

- relations between climatic non-stationarity and basin hydrology (Graf et al. 1991);
- climate forecasting related to reservoir and dam operations (Pulwarty and Redmond 1997);
- climate-driven tributary processes and their influence on mainstem habitats (Webb et al. 1991, Melis et al. 1995, 1996, Stevens et al. in press);
- climate's role in the Colorado River basin's long- and short-term sediment balance (Hereford and Webb 1992);
- climatic forcing of the river's bottom-up ecosystem, including the food base (Grimm 1993);
- modeling climate variability effects on water resources (Leavesley 1994);
- the role of localized weather and micro-climate at river level (Marcus et al. 1996).

Another step towards integration of abiotic and biotic information includes designing long-term monitoring so that the above questions can be formulated as focused, management-driven hypotheses and be tested. This task was started in 1996 by the Grand Canyon Monitoring and Research Center staff as part of developing the long-term monitoring and research plan. The questions listed above might ultimately be answered through a wide range of experimental and historical studies that successfully link documented relationships of species' distributions and ecology with physical habitat, water quality, and biotic factors such as aquatic productivity and population dynamics. Such a complex ecosystem approach to this science/management challenge can succeed only through continued institutional support of innovative, interdisciplinary efforts by a diverse group of scientists and decision makers. The potential success of this approach in turn relies on a commitment by decision makers to pursue holistic management of resources through integrated scientific research, with integration implemented from the proposal development phase on through to final report completion. The objective of this prospectus development process was to identify critical habitat hypotheses that required testing. With this integration, decision makers will be better informed as they prioritize resources, direct ongoing research, and achieve management objectives in the future.

Trophic Dynamics

Phase II studies addressing trophic dynamics included research on sediment transport (Schmidt and Graf 1990, Andrews 1991, Cluer 1991, Cluer and Carpenter 1993, Schmidt 1993, Schmidt and Rubin 1995), organic drift (Angradi and Kubly 1994, Ayers and McKinney 1995), benthic ecology (Czarnecki and Blinn 1978, Blinn et al. 1994, Shannon et al. 1994, Stevens et al. in press), photosynthetically available radiation (Yard et al. 1993, Bureau of Reclamation, unpublished data), water quality studies in Lake Powell (Stanford and Ward 1991, Ayers and McKinney 1996, Vernieu 1996, Bureau of Reclamation, unpublished data, U.S. Geological Survey, unpublished data), primary and secondary production (Blinn and Cole 1991, Hardwick et al. 1992, Angradi and Kubly 1993, Ayers and McKinney 1995, 1996), diet of humpback chub (Carothers and Minckley 1981, Kaeding and Zimmerman 1983, Maddux et al. 1987, Kubly 1990), and overview studies (Carothers and Minckley 1981, Maddux et al. 1987, Angradi et al. 1992, Blinn et al. 1994, 1995, Angradi 1994). The Ad-Hoc Working Group suggested that synthesis in this area should be aimed towards the development of large-scale models that relate dam operations and physical factors to food web interactions and population dynamics of species of concern. The following were suggested as a non-exhaustive list of major topics:

- nutrient and other chemical dynamics in Lake Powell,
- light limitations on riverine production over time,
- the role of temperature on river assemblages and food web interactions,
- tributary and mainstream nutrient dynamics and spiraling,
- the role of different size fractions of drift,
- reservoir and riverine decompositional and microbial processes,
- basic life histories and requirements of cornerstone species (e.g., *Oscillatoria* and *Simulium*),
- the role of spatial scale in geomorphology controlling aquatic food base development,
- the role of climate and climatic variability in aquatic food base development, and
- food web and ecological linkage between aquatic and riparian domains.

These topics do not have equal value to managers, and management input would be needed to prioritize/modify the list. In the long term, overall ecosystem models would be useful to predict effects of dam operations.

Key areas of information needed to address these topics included potential production; resource availability; invertebrate, fish, and riparian fauna diets; habitat development and distributions; ecosystem linkages; and management considerations. Selected research hypotheses were also generated, with assessments of existing data and syntheses required.

Population Ecology of Grand Canyon Humpback Chub

Life History Strategies

The Grand Canyon and its tributaries currently support only one viable population of the four endangered big-river fish species: the humpback chub (*Gila cypha*). For this reason, the status of the humpback chub is of major concern, and many dam operations are potentially constrained by their impact on the chub. Data on this species have been collected from the Upper Colorado River Basin above Lake Powell (Valdez and Clemmer 1982, Valdez et al. 1990, Kaeding et al. 1990, Karp and Tyus 1990), from the mainstem Colorado in Grand Canyon (Kaeding and Zimmerman 1983, Valdez and Ryel 1995, 1996), and from the Little Colorado River (Kaeding and Zimmerman 1983, Minckley 1992, Gorman et al. 1994, 1996, Douglas and Marsh 1996, Meretsky et al. 1996). To date, these data have not been integrated. Efforts are needed to combine demographic, distribution, movement and diet information in order to develop a conceptual life-history model for the species, along with information on how life history varies among populations. Such a model will indicate the range of physical conditions chub can tolerate, and identify factors which potentially limit growth and reproduction. Many researchers believe much of this model can be constructed using existing data.

Interactions Between Native and Nonnative Fish

Dam operations differentially affect fish species, and the present understanding of effects of dam operations on interactions between native and nonnative fish species, and between fish species and disease and parasite organisms (Carothers et al. 1981, Valdez et al. 1982, Minckley 1991, Minckley and Deacon 1991, Angradi et al. 1992), is limited. Thus, it is difficult to predict impacts of actions such as high flows or modifications to water temperature regimes.

Four primary questions were identified by the Fern Mountain work group:

1. What are the present effects of fish species interactions in Grand Canyon?

2. What are the important species that interact with native fishes and are these interactions negative, neutral, or positive?

3. How will future management actions related to dam operations affect these interactions?

4. Do fish interactions result in increased levels of parasites or pathogens in native fish?

Grand Canyon fisheries researchers stated that some existing research, especially from outside Grand Canyon, will help answer these questions, but many aspects of the questions had not yet been addressed.

The Role of Science and Scientists in Adaptive Management

Three different laws define decision making for Glen Canyon Dam operations. The preferred alternative of the Operation of Glen Canyon Dam Environmental Impact Statement (environmental impact statements are mandated by the National Environmental Policy Act of 1970) relies on adaptive management (U.S. Department of the Interior 1995:36) to ensure that dam operations comply with the Endangered Species Act of 1973, as defined by a Biological Opinion from the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1994). The Grand Canyon Protection Act of 1992 is intended to restore and preserve resources downstream of Glen Canyon Dam, and to see that science is linked to management so that the concerns of all parties interested in Glen Canyon Dam operations and resources are considered. Well-informed decisions will rely not only on timely integration of existing information, but also on effective communication of scientific knowledge to managers and other decision makers (stakeholders).

The Ad-Hoc Working Group maintained that in addition to the scientific integration topics, the role of science and the level of participation by scientists in the planned Grand Canyon adaptive management process needs to be better defined. On the basis of the consensus that the adaptive management process has been extensively described in literature (Holling 1978, Walters 1986, Lee 1993, Wegner 1995, Gunderson et al. 1995), but is inherently open to many misunderstandings and difficulties (Marzolf 1991), Ad-Hoc Working Group scientists agreed to outline a separate prospectus on that topic. It was decided that a position statement on the role of technical scientific support in assisting the future Glen Canyon Dam Adaptive Management Work Group might be useful to both scientists and decision makers as the adaptive management process begins. At the time of manuscript preparation, this group was anticipated to become a Federal Advisory Committee sometime during 1997. The adaptive management group would be composed of basin-wide stakeholders who would evaluate relationships between future operations of Glen Canyon Dam on downstream resources. Based on science and management objectives, this adaptive management advisory committee is intended to make recommendations directly to the Secretary of the Interior (or designee) on whether operations should be modified to ensure protection of downstream resources (U.S. Department of the Interior 1995:36). The adaptive-management discussion group at Fern Mountain explored ways to ensure that the results of basic science and its interdisciplinary integration would be communicated to managers, and that such information would be used in decision making. In addition, discussion

group participants emphasized the need for management concerns and objectives to be effectively communicated to scientists in a manner that permitted prioritizing research efforts. Integration can improve understanding of the Grand Canyon ecosystem, but without adequate communication between researchers and other stakeholders, integrated scientific information cannot fully benefit decision making.

Discussion-group participants recognized the principles guiding the design and intent of the adaptive management program and process, as outlined in the Operation of Glen Canyon Dam Environmental Impact Statement, including:

- A long-term monitoring and research program that is designed by qualified researchers in direct response to the needs and objectives defined by management agencies.
- A process that coordinates and communicates management agency needs to researchers and that develops specific recommendations for decision making,
- A forum that effectively transfers monitoring and research findings to the management agencies, and that results in consensus on management responses to information on affected resource conditions, trends, processes, and prioritization of actions.
- Monitoring and research programs in Glen and Grand Canyons that are independently reviewed.
- A forum for all interested parties that allows opportunities for participation in proposals and recommendations that result from adaptive management (U.S. Department of the Interior 1995).

The Ad-Hoc Working Group strongly agreed that the principles stated above require that management, maintenance, prioritization, and integration of diverse information found in varied data bases be pursued, in concert with clear mechanisms for resolving disputes.

In general, the Ad Hoc Working Group recognized that many management related questions could be answered through integration of existing and future scientific data if a holistic and open approach was supported. Although many Lower Colorado River research issues are complex, most participants believed that solutions to many Biological Opinion challenges were possible through ongoing, integrated monitoring and research. The group also agreed that integrated results from Colorado River monitoring and research below Glen Canyon Dam must be communicated to decisionmakers in timely, clear and concise ways that address specific management objective issues directly. For this communication process to

occur, management questions and objectives must be clearly stated to managers and researchers well before studies are planned and implemented, so that management objectives are specifically addressed by long-term monitoring and research. Meeting this objective is one of the primary duties of the Grand Canyon Monitoring and Research Center's Chief Scientist. In 1995, management objectives were drafted by a working sub-group of stakeholders, and reviewed by the interim Adaptive Management Working Group (known informally as the Transition Work Group until designated as a Federal Advisory Committee). The draft management objectives were used extensively in 1996 by the Grand Canyon Monitoring and Research Center Chief and his planning group to develop a draft long-term plan for monitoring and research of river resources below Glen Canyon Dam. This plan was scheduled for full implementation in October of 1997 through a variety of competitive proposal requests and interagency agreements (L. D. Garrett, personal communication, 1996).

The Operation of Glen Canyon Dam Environmental Impact Statement recommends that an adaptive management process be implemented to facilitate a management-directed discourse between scientists, decision makers, and all other interested parties (U.S. Department of the Interior 1995:34–37). The Ad-Hoc Working Group was very supportive of this approach. The group thought that general questions such as "How has mainstem fish habitat structure changed since closure of Glen Canyon Dam?" might provide insights to managers on Biological Opinion related issues. This question could be answered by physical scientists using existing databases, and results could be used to pose more complicated hypotheses about how such changes have influenced population dynamics of native and nonnative fishes, in light of documented dam operations. However, questions such as this one may need to be more tightly focused if research results are to be applied; adaptive management would provide a useful arena for the process of focusing objectives. The Chief Scientist of the Grand Canyon Monitoring and Research Center undertook the task of developing a long-term monitoring and research plan in winter 1996 within an open process with help from involved scientists and stakeholders.

Fern Mountain meeting participants emphasized that synthesis of reach-by-reach comparisons of geomorphic data, such as reach-varied debris-flow frequency and magnitude (Melis et al. 1994, 1995), channel/eddy characteristics (Schmidt and Graf 1990), backwater habitats (McGuinn-Robbins 1995, Stevens et al. 1995), shoreline-type distributions (Valdez and Ryel 1995), etc. would eventually be required by Biological Opinion researchers. The timeliness of physical and biotic data integration was deemed important, because experiments requiring that information were being planned at the time of the meeting (e.g., experimental beach/habitat-building test flow, implemented in spring 1996). Incorporation of integrated physical data into conceptual ecologic models for species of interest was a stated priority, as well as a comprehensive synthesis of biotic data. The Ad-

Hoc Working Group also recognized that opportunities to learn are presented by both anticipated and "surprise" outcomes resulting from management decisions and implementation of new conservation measures, including large-scale experiments (Walters and Holling 1990).

Summary

The Ad-Hoc Working Group concluded that whenever integration questions and results are obtained, they must be reported in a timely manner so that decision makers have abundant opportunities to incorporate new physical system information into management strategies aimed at Biological Opinion issues. Addressing as many relevant research and management issues as possible will allow interdisciplinary scientists to better understand what is and is not known about the physical controls of the river's ecosystem, and how such information is relevant to resource management objectives. Only then can integrated biotic models be coupled with the geomorphic framework of the river, and climatic processes in ways that are meaningful for decision makers. The Ad-Hoc Working Group also recognized that opportunities to learn are presented by both anticipated and "surprise" outcomes resulting from management decisions and implementation of new conservation measures, including large-scale experiments (Walters and Holling 1990). Several predicted and surprise results occurred from the 1996 Glen Canyon Dam Beach/Habitat-Building Test Flow. The Ad-Hoc Working Group expressed support for the timely incorporation of those experimental results into the long-term monitoring and research plan design.

Successful scientific integration depends on establishment of links between existing biotic/abiotic databases, an inherently difficult task requiring coordination, ongoing support, multi-disciplinary scientific debate, and flexibility in developing ongoing interdisciplinary research strategies. The Ad-Hoc Working Group also recognized the importance of continually adding to the existing knowledge of river hydrology and sedimentology, because water and sediment together form the river ecosystem's physical framework; this will occur through long-term monitoring and research. Meeting participants advocated that future geomorphic research and monitoring efforts should be designed and coordinated in ways that allow questions to be scientifically examined and tested by methods that cross discipline boundaries, a process that requires open communication among researchers and stakeholders. As stakeholders and scientists work together to continue establishing and prioritizing resource preservation and restoration objectives, many links between species ecology, habitat, and climate will likely arise. Many new developments in management of the Lower Colorado River ecosystem likely will be difficult to anticipate. If an integrated science program is in place when unforeseen issues arise, these unanticipated developments can be addressed more efficiently. In the future, it will be important to promote and nurture new types of working relationships, modes of communication, and methods of coordinating interdisciplinary studies, and these strategies may be difficult to implement initially. However, with the 1995 development of a draft integration prospectus focused on Biological Opinion issues, the Glen Canyon Environmental Studies office took an important step required to achieve true scientific integration.

Aftermath

Shortly after the Fern Mountain meeting, the Glen Canyon Environmental Studies office received permission to conduct a habitat-building test flow – an experimental flood – in Grand Canyon. The exercise involved over 100 scientists in a tightly-focused, logistically complex set of experiments. Because of the earlier integration work, most of the researchers were now familiar with each others' research; much potential redundancy was eliminated, and planning was streamlined. In the months after the experimental flood, cross-discipline partnerships have persisted, and several integrative papers are in progress that would not have been considered before the Fern Mountain meeting. We hope that opportunities for such collaboration will continue as oversight of Grand Canyon research moves from the Glen Canyon Environmental Studies office to the Grand Canyon Monitoring and Research Center.

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