Hydropower, Adaptive Management, and Biodiversity

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ABSTRACT / Adaptive management is a policy framework within which an iterative process of decision making is followed based on the observed responses to and effectiveness of previous decisions. The use of adaptive management allows science-based research and monitoring of natural resource and ecological community responses, in conjunction with societal values and goals, to guide decisions concerning man's activities. The adaptive management process has been proposed for application to hydropower operations at Glen Canyon Dam on the Colorado River, a situation that requires complex balancing of natural resources requirements and competing human uses. This example is representative of the general increase in public interest in the operation of hydropower facilities and possible effects on downstream natural resources and of the growing conflicts between uses and users of river-based resources. This paper describes the adaptive management process, using the Glen Canyon Dam example, and discusses ways to make the process work effectively in managing downstream natural resources and biodiversity.

To assist in understanding the concept of adaptive management and how it can be used to affect ecological communities and biodiversity downstream of hydropower dams, the following discussion presents a case study of the proposed application of the process to the operation of Glen Canyon Dam on the Colorado River near Page, Arizona, USA (Figure 1). The background for the case study is presented, followed by descriptions of the ecology of the Glen and Grand canyons before and after the construction of Glen Canyon Dam. The reasons for using an adaptive management program are explored, and the proposed adaptive management process for the Glen Canyon Dam described. The advantages of using an adaptive management process are analyzed. The paper concludes with some guidance on how to use the process successfully if applied to other hydropower facilities.

Background

In 1989, in response to ongoing concerns about impacts to natural resources in the Grand Canyon from the operation of the Glen Canyon Dam, the Secretary of the Interior (Secretary) directed the Bureau of Reclamation (Reclamation) to reevaluate its operation of the dam. A program of environmental investigation, the Glen Canyon Environmental Studies, had been initiated on the Colorado River in 1982 and was already well underway in Glen and Grand canyons. The data generated by those studies was used as the basis for an environmental impact statement (EIS) on the operation of the Glen Canyon Dam in response to the Secretary's direction. The final EIS, containing several alternatives and a recommended operational plan for the Glen Canyon Dam, was presented to the Secretary and the public in 1995. The majority of funding for the entire process was derived from hydropower revenues. Through fiscal year 1994, the cost borne by power customers to support environmental research and the Glen Canyon Dam EIS was $83.8 million. The Secretary's record of decision for the operation of Glen Canyon Dam is due in late 1996 or early 1997. Regardless of the operational alternative eventually selected, and despite the findings of the Glen Canyon Environmental Studies (DOI 1988, unpublished data), many uncertainties still exist regarding the impacts of various water-release patterns from Glen Canyon Dam on the ecological community downstream.

Grand Canyon Protection Act

In addition to the 1989 Secretary's decision calling for a reevaluation of Glen Canyon Dam operations, the Grand Canyon Protection Act of 1992 (Public Law 102-575) included provisions requiring completion of

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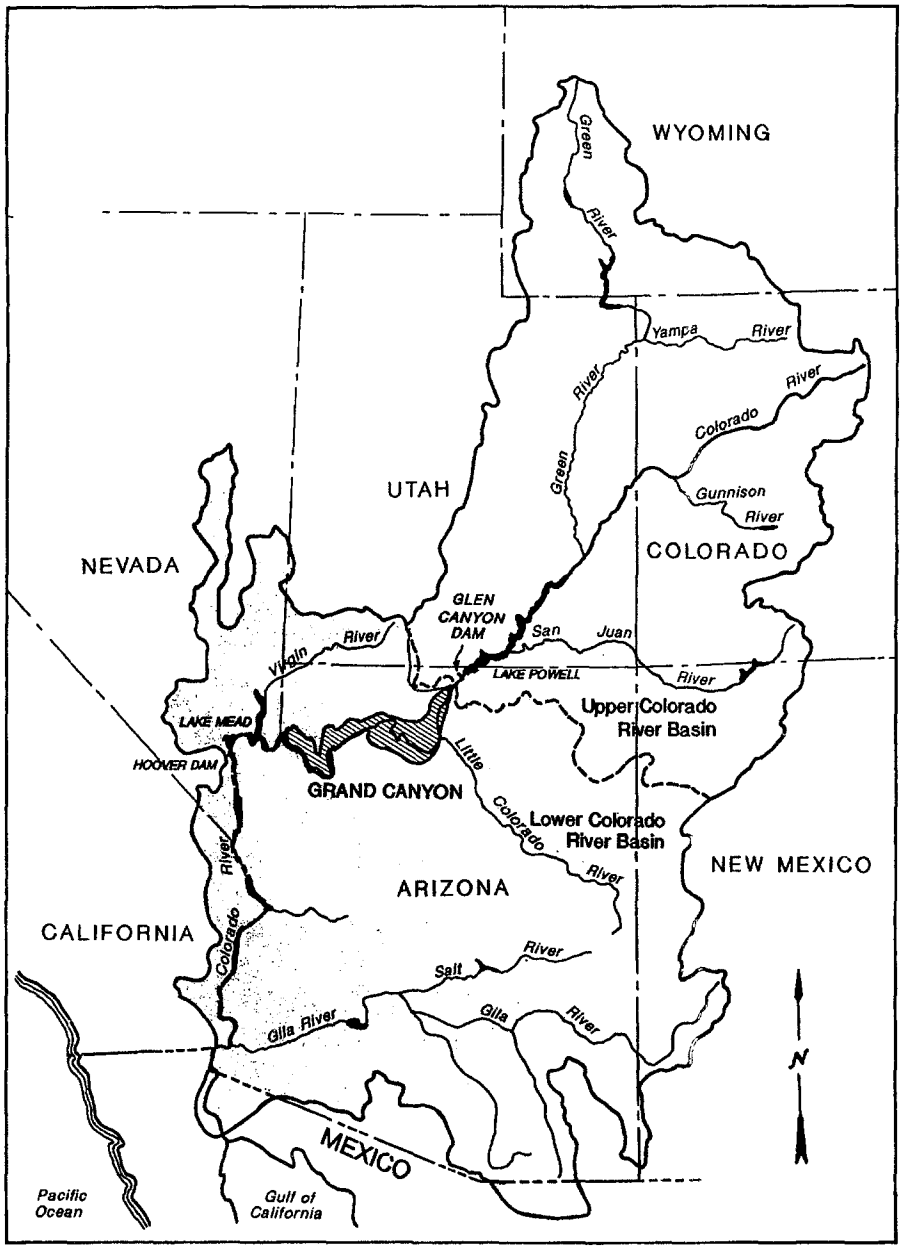

Figure 1. Colorado River Basin and Glen Canyon Dam.

the EIS for operation of Glen Canyon Dam. The act also confirmed that the dam was to be operated under certain restrictions, termed "interim flows," during the period that the EIS was being prepared, and set forth legal considerations and processes to be followed in determining how to operate the Glen Canyon Dam in the future. The act requires actions to protect, mitigate adverse impacts to, and improve the values for which the Glen Canyon National Recreation Area and Grand Canyon National Park were established. Those values include natural and cultural resources, visitor use, and other uses.

Given the diverse mandates of the federal and state agencies and the various competing interests of others involved in how the dam is operated, agreement on a preferred alternative for operation of Glen Canyon Dam appeared unreachable. The initial positions taken by the agencies and parties would have promoted certain resources or interests at the expense of others, sometimes with potentially serious consequences to one or more of the resources and economic interests of concern. Because of status of the Grand Canyon as a world treasure, there have been many intensely interested parties involved in deciding how to manage the

riverine ecosystem below the Glen Canyon Dam. A tentative, but optimistic, belief in and support for a program of adaptive management enabled the cooperating agencies and interested parties to proceed with some confidence that the record of decision on how to operate the Glen Canyon Dam would not be a once-and-forever decision.

According to provisions of the Grand Canyon Protection Act, consultation on operation of the dam will be maintained with appropriate agencies of the Department of the Interior, including the US Fish and Wildlife Service, the National Park Service, and Reclamation; the Secretary of Energy; the governors of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming; Native American tribes; and the general public, including representatives of academic and scientific communities, environmental organizations, the recreation industry, and contractors who purchase federal power generated at the Glen Canyon Dam. Adaptive management is viewed as the only way to avoid management gridlock when these groups meet to discuss progress towards management objectives, research and monitoring results, and potential changes in the operation of the dam.

Ecological Conditions Before the Dam

Before the dam was constructed in 1963, the natural ecosystem in Glen and Grand canyons was characterized by high spring and early summer floods and by low fall and winter flows. Large amounts of sediment were transported in the Colorado River during high flows and floods and deposited on beaches that were exposed when the water receded. The annual spring floods dominated the natural riverine processes in the canyons and limited the number of species and individuals in the predam ecological community. Riparian vegetation was concentrated in a narrow "old high-water zone," where it was protected from all but the most extreme flooding, but watered through annual substrate soaking during most years. Below the "old high-water zone" was a larger area normally scoured and redeposited during the annual floods, which in places could support a relatively thin cover of flood-resistant and annual plants. The dynamics of the hydrologic system kept most of the riparian zone from progressing beyond a youthful state of succession and held biodiversity to a relatively low level of species richness (NAS 1991b, DOI 1988, 1995, unpublished data).

Before exploring the reaction of the ecosystem to the new conditions imposed by the construction of the Glen Canyon Dam, it should be noted that changes were already taking place that were unrelated to the development of water-storage projects on the river. Exotic fish species, such as channel catfish (*Ictalarus punctatus*) and carp (*Cyprinus carpio*), introduced to the Colorado River had already caused a significant shift in the fish species composition of the river by the time the first dams were built (Carothers and Brown 1991, Woodbury, 1959). Tamarisk (*Tamarix* spp.), a hardy riparian small tree species introduced from the Near East for bank stabilization, was spreading naturally from the areas where it had been intentionally planted (DOI 1988, 1995). Changes to the riparian ecology and biodiversity were well under way before the era of mainstem dam building, and significant impacts would have occurred even if the Glen Canyon Dam and other dams had never been built.

Ecological Responses After Dam Construction

The construction of the Glen Canyon Dam initiated profound changes in Glen and Grand canyons by modifying the hydrologic regime and character of the river. The dam effectively moderates the dynamic nature of the hydrologic system, dramatically damping annual spring and early summer floods and increasing fall and winter flows. The reservoir, Lake Powell, acts as a sediment trap and heat sink, so releases at the dam are essentially sediment-free and vary only slightly from an average temperature of about 10°C. This contrasts with the high sediment loads and wide range of water temperatures, generally considerably warmer, present in the predam environment. The dam also acts as a barrier, preventing native big-river fish species from moving upstream and using historical habitat. Through these effects, the Glen Canyon Dam imposes an unnatural stability on the natural resources and ecological communities for hundreds of miles downstream of the dam (DOI 1988, 1995, unpublished data).

Although not the focus of this discussion, it should be briefly noted that Lake Powell also supports new and different habitats and resources. The reservoir provides open water habitat for fish and other species, lake margin habitat, and water recreation opportunities not available before the dam was constructed.

Once in place, the Glen Canyon Dam had an immediate effect downstream, initiating new environmental processes, changing others, and setting in motion a complex chain reaction of ecological responses to the new hydrologic regime as the system sought to establish a new equilibrium, a process that continues today. The removal of the high spring and early summer floods from the natural hydrograph has allowed riparian vegetation to colonize the former flood zone, greatly increasing the areal extent and diversity of this

important vegetation type. Tamarisk, which is not particularly resistant to flooding, has greatly expanded its presence in the canyons. It has encroached on sand beaches formerly maintained by annual flooding, but provides less food or shelter value to other species than native plant species (DOI 1995).

The increased water clarity and increased fall and winter flows have allowed a new diverse aquatic plant and insect association to establish itself, which in turn has provided a food base for other insects, lizards, bats, and birds. Peregrine falcons (*Falco peregrinus*) have become more numerous in the Grand Canyon, as their prey has thrived on the increased primary productivity. The clear, cold-water releases have formed the basis of an important introduced trout fishery in Glen Canyon. Bare sand beaches, favored for camping by river runners, have lost their main source of replenishment; are being subjected to erosion by wind, water, and human activity; or are being lost through vegetation encroachment. Native fish species have continued to decline or have disappeared. Marsh habitat, once rare in the Grand Canyon, has developed due to the more stable flow regime and has contributed to the species richness and productivity of the river corridor. Biodiversity, as measured by numbers of species and also of individuals present, has increased significantly since the construction of the dam. However, some native species have declined or disappeared, while some introduced species have prospered (DOI 1995).

Studies have concluded that the system below the Glen Canyon Dam was reaching a state of dynamic equilibrium before the 1983 floods and is again approaching that condition. However, subtle, long-term processes may have been set in motion that could have important effects over the long run. Given the highly dynamic nature of the river system, such influences are nearly impossible to detect and may only be revealed over a span of several decades.

Management Objectives

The determination of management objectives for the natural, cultural, and socioeconomic resources in Glen and Grand canyons has proven extremely difficult. Uses and users are in conflict, and there is no single way to operate the Glen Canyon Dam that results in acceptable conditions for all resources. Prioritization involves value judgements, and there is little agreement on relative values.

One school of thought holds that natural is always best, and management objectives should be based on maintaining or restoring natural conditions, including biodiversity, to the extent practicable regardless of the effects on other resources or economics. Another view accepts that the ecology of the canyons is irrevocably changed beyond man's means of restoring it and that the new ecological community and other resources should be managed to optimize the overall benefits. Other perspectives fall between these views. Regardless of position, any approach requires that a clear set of management objectives be defined. However, the definition of those objectives means that compromises among resources will have to be made and adverse impacts to some resources accepted.

For example, the humpback chub (*Gila cypha*), an endangered fish species, has a small but stabile population centered around the mouth of the Little Colorado River. The native fishes are adapted to the warm, turbid water of the Colorado River and the dramatic seasonal variation in flows. The humpback chub now have to contend with cold, clear water releases from Glen Canyon Dam and a much less variable hydrograph. Restoration of sediment and higher temperatures would undoubtedly improve spawning conditions for these fishes and reduce competition by nonnative species but would eliminate the economically important introduced trout fishery. Additionally, efforts to improve conditions for the humpback chub would negatively impact primary productivity in the river, and ultimately peregrine falcons, another endangered species, which have taken up residence in the canyons to utilize the food base provided by the nearly sediment-free releases from the dam. The breeding population of peregrine falcons in the Grand Canyon is now the largest in North America; their use of the canyon under predam conditions was likely minimal (DOI 1995). This is just one example of the difficult trade-offs in resources and shifts in biodiversity that must be made in order to set management objectives.

Biodiversity downstream of dams can be managed, to a certain degree, through the operation of hydropower facilities. The degree of influence depends on the local situation and will vary from location to location. The basic issue is to decide, within the framework of public policy, what the management priorities should be. Scientific data should form the basis for these decisions, in conjunction with social value judgments and political and economic realities.

Reasons for Using Adaptive Management

The adaptive management process can assist in making difficult management decisions by combining systematic scientific information gathering with a forum of interested or affected parties. The Glen Canyon Dam case is discussed below, with emphasis on how the

process might be adapted to other hydropower facilities.

It is especially important for managers who have hydrogeneration facilities to understand the distinction between effects caused by the construction and presence of the dam, compared with those caused by the operation of the facility. In general, most of the more significant changes to the downstream natural resources are the result of the existence of the dam and not how it has been operated. To a certain extent, modifying the operation of a dam may alter the magnitude, duration, or timing of a given effect, but because the impact is due primarily to the presence of the dam, operational changes cannot eliminate the effect. In most cases, the natural environment and its original level of biodiversity cannot be fully restored to its predam condition through changes in dam operations, and it should not be automatically accepted that dam operations should be managed to attempt a return to those conditions. There remains a definite bias against "new" resources created by dams, regardless of their demonstrated value and the impossibility of fully restoring natural conditions. In some cases, restoration of conditions approaching natural ones may be possible and may be politically and economically justifiable. However, in many cases restoration of natural conditions and functions may not be physically, politically, or economically possible, and management of the downstream natural resources may be better directed towards maintenance or enhancement of a partly unnatural system. A successful adaptive management program must recognize the presence of the dam and the postdam environment as givens and then work towards managing the downstream ecological community for mutually established objectives.

Returning to the Glen Canyon Dam case study, there is no question that the construction of the the dam has significantly increased species richness in Glen and Grand canyons, a finding reported in Reclamation's EIS on the operation of the Glen Canyon Dam (DOI 1995). However, arguments still rage over the worth of natural versus "unnatural" resources, the value of one resource as compared with others, and which resources should have priority for management. As a result, it has been very difficult to agree on what kind of ecological community to manage for, although it is recognized that the community, by necessity, will have both native and introduced components.

In general, ecological communities with higher species diversity are considered to have higher value, a commonly cited example being rain forests. In this case, the "unnatural" community exhibits higher species richness than the natural community it replaced, with many of the native components exhibiting an expansion of range or numbers. Even within resource categories there are conflicts; most white-water rafters view house-boating on Lake Powell with disdain, while the house-boaters place a high value on their chosen water recreation activity and obviously have very different perspectives and management priorities than the rafters. Adaptive management can provide a framework for identifying resource issues and establishing values and management objectives. Any management decision will entail difficult trade-offs among resources and constituencies, and the adaptive management concept can help to reach an equitable compromise.

Other primary reasons for using adaptive management include complications in linking specific management practices with resource responses, difficulty in scientifically measuring resource responses in the field, time lags between implementing management decisions and eliciting measurable resource responses, the complex and only partially understood interrelationships of many natural resources, and the confounding reactions of resources to natural variability or cycles. Adaptive management allows for a management decision to be made, based on the best available information, but also allows the decision to be revisited as new information is collected and more is learned about the functions and responses of the natural systems.

Adaptive management is flexible enough to incorporate another potentially useful management concept that is receiving increasing attention in resource management and scientific circles. This concept is built around the idea that efforts to provide the best possible conditions for the resources of primary concern need not, and should not, be made each and every year, especially if detrimental to other resources or economically costly. Instead, the natural variability of the system, primarily the annual water volume and the timing of runoff, should be considered and management for different groups of resources undertaken as indicated by the nature of the water year. This flexible management should benefit a wider range of resources and help maintain biodiversity in the ecological communities downstream. In the past, management decisions have tended to be inflexible, locking agencies into one narrow track that could benefit one resource to the continual detriment of others. Opportunities to achieve a more balanced management scheme beneficial to all resources have been foregone (Sparks 1995).

Native fishes, for example, evolved under extremely variable natural conditions and are long-lived because many water years were not conducive for successful reproduction. In favorable years, strong year classes made up for the poor years. Conversely, bad years for

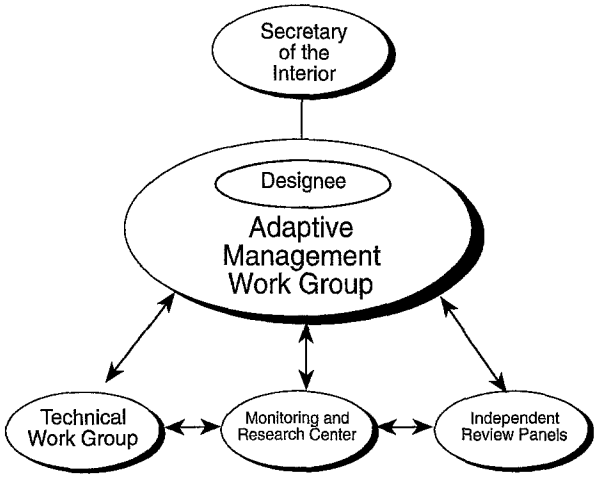

Figure 2. Organizational structure of the adaptive management program.

fish were more favorable for other resources. Over a number of years, conditions would favor each resource often enough to maintain that resource as a viable part of the canyon ecosystem. As more is learned about the interactions of resources in the Grand Canyon, resource managers will be able to better mimic the natural cycle of favoring certain resources one year and others the next. This style of resource management can be integrated into adaptive management, which, over the long term, may prove to be the most effective in the case of the Glen Canyon Dam (NAS 1991a).

Adaptive Management Program

Adaptive management for the operation of the Glen Canyon Dam is intended to provide an organization and process for cooperative and integrated protection and management of resources. Figure 2 shows the organizational structure of the proposed adaptive management program for the operation of Glen Canyon Dam, which would be under the Secretary of the Interior. The adaptive management program is discussed in the future tense herein because, although certain aspects of adaptive management are already being undertaken, Reclamation's record of decision on operations has yet to be issued.

An adaptive management work group, made up of representatives from agencies, states, Indian tribes, and private groups and interests, would provide the framework and management direction for the adaptive management program. A technical work group, comprised of technical experts from the entities represented on the adaptive management work group, would take policies and goals and translate them into resource management objectives and specific action recommendations.

A key provision of the proposed adaptive management program is the intentional separation of long-term monitoring and research from management. This would be accomplished by the establishment of an independent monitoring and research center administered by the United States Geological Survey. This center would coordinate monitoring and research in accordance with information needs of the adaptive management program. An independent review panel would provide a further quality check for the program (Carothers and Wegner unpublished data).

Although the Grand Canyon Protection Act does not specifically call for an adaptive management program for the Glen Canyon Dam, the program was proposed in the final EIS as a means to implement the decisions stemming from the EIS record of decision and the mandates of the Grand Canyon Protection Act. The Secretary or his designee would develop, as appropriate and as a consequence of the adaptive management program, modifications to operating criteria or other management actions (nondam operational options for managing downstream resources) in consultation with interested parties and the adaptive management work group. The process would include the formal consultation required by the Grand Canyon Protection Act concerning additional operating criteria for the Glen Canyon Dam and long-term monitoring and research programs. In addition, all adaptive management program activities would comply with applicable laws and permitting requirements.

Guiding Principles

Guiding principles for design of the Glen Canyon Dam Adaptive Management Program organization and process are:

- Monitoring and research programs should be designed by qualified researchers in direct response to the needs of management agencies.
- A process is required to coordinate and communicate management agency needs to researchers and to develop recommendations for decision making.
- A forum is required for the transfer of monitoring and research investigation results to the management agencies and to develop consensus on management response to information on affected resource conditions, trends, and processes.
- All monitoring and research programs in Glen and Grand canyons should be scientifically valid and independently reviewed. The adaptive management program proposal in the EIS calls for an indepen-

dent review panel(s) comprised of qualified individuals not otherwise participating in the long-term monitoring and research studies to be established by the Secretary in consultation with the National Academy of Sciences, Native American tribes, and other adaptive management work group entities. The review panel(s) would be responsible for periodically reviewing resource-specific monitoring and research programs and for making recommendations to the adaptive management work group and the center regarding monitoring, priorities, integration, and management.

- Interested parties identified in the Grand Canyon Protection Act should be provided opportunity for full and timely participation in proposals and recommendations.

The management of biodiversity is not a stated objective of the adaptive management program for the Glen Canyon Dam. However, since natural resource protection is a management objective, accomplished through proper management decisions and modified as appropriate through the adaptive management process, then the biodiversity of Glen and Grand canyons should be protected as well. Management of releases from Glen Canyon Dam will target specific resources of concern, such as maintenance of camping beaches and the humpback chub population, but will also consider nonnatural resources, such as the trout fishery in Glen Canyon. Management of biodiversity does not mean a return to natural conditions, a situation that is not possible at this location. In this case, management of Glen Canyon operations involves the balancing of a number of resources, some natural, some introduced or created, and some economic, with biodiversity indirectly managed through the focus on specific resources.

Long-Term Monitoring and Research

Long-term monitoring and research, essential to the adaptive management program, would measure the performance of the selected mode of Glen Canyon Dam operations in meeting resource management objectives and the resource responses to dam operations. The long-term data base provides information about the system's status in time, its degree of equilibrium, key ecosystem element interactions, and ecosystem processes that are useful for evaluating the impacts of management decisions.

Long-term monitoring and research allows managers to learn how the ecosystem responds to changes in dam operation. The primary assumptions on which Glen Canyon Dam research and monitoring will be based are as follows:

- Research and monitoring would be directed toward testing the effectiveness of initial operational decisions in meeting natural resource management objectives.
- Information learned would be reviewed in light of established management objectives and, if necessary, changes to operations would be made.

Among the factors that establish management objectives and monitoring and research programs are the priorities defined by the management agencies and various legal requirements. Agency priorities will often be in direct conflict; consequently, a process for dispute resolution is in order. However, it is hoped that the various resource managers will understand and accept the potential benefits offered by long-term monitoring and research encompassed in an effective adaptive management process. The scientific process would serve resource managers through identifying and assessing changes, objectively providing information needed to evaluate management goals and develop options, and modeling and developing predictions for potential operational modifications. Monitoring and research will also help to alleviate fears that certain operational decisions may adversely impact resources of concern, either by demonstrating that the fear is unfounded or by indicating that further changes to operations are required.

One of the objectives of the adaptive management program should be the identification of management options that achieve the objectives for key resources while having the least impact on other resources, including economic impact. The objectives are yet to be fully articulated, but will likely include minimizing erosion of beaches, maximizing sediment storage in the system, and protection of the humpback chub population, among others. This is particularly true for hydropower generation, which often is significantly impacted by operational modifications for natural resource management objectives. Operational modifications should have measurable and beneficial effects that clearly outweigh the adverse effects on other resources.

Every resource should be included in the long-term monitoring and research process. For the Glen Canyon Dam case, these resources would include physical resources such as the hydrology of the river and its major tributaries, the sediment budget of the system, and water quality of the river, including temperature changes, and nutrient dynamics associated with releases from the dam. Also included would be aquatic and terrestrial

biota associated with the river, as related to flow and water quality. The economic benefits of power generation and recreation use would be considered, as would cultural and archeological resources.

Adaptive Management and the Columbia River

The concept of adaptive management is presently being used in the management of fish and wildlife resources downstream of major hydropower generating facilities on the Columbia River in the Pacific Northwest. This example provides some indication of how the process might work on the Colorado River and other river systems in the country. The Pacific Northwest Electric Power Planning and Conservation Act of 1980 (Northwest Power Act) established the Northwest Power Planning Council. The council is an interstate compact agency of the states of Idaho, Montana, Oregon and Washington and has adopted the adaptive management concept as a policy framework.

Even though the Colorado River and Columbia River systems differ in many ways, they, like other big rivers in the world, are similar in that limited biological information is available, there is no agreement on the interpretation of this information, and there are conflicting interests as to how dams should be operated. Implementation of a program of adaptive management for the Columbia River has served to mediate conflict, establish ecological goals, and help provide for resource conservation within a program of water and power development.

The focus of the Columbia River program is to restore historic runs of salmon and steelhead, while the proposed Glen Canyon Dam Adaptive Management Plan is directed towards recovery of endangered native fish species (according to requirements of the Endangered Species Act) and management of a complex suite of other resource and economic values affected by dam operations. In addition, the Glen Canyon Dam Adaptive Management Plan seeks, to the extent possible, to establish a long-term equilibrium in sediment system storage as a basis for the development of relatively stable aquatic and terrestrial ecosystems and protection of cultural resource sites. Biodiversity is not specifically addressed in either effort; both are focused on solving specific resource problems. However, the sediment equilibrium objective in the Glen Canyon Dam effort carries with it implied stability for the ecological community established downstream, which would maintain the increased species richness that has developed since the construction of the dam.

Application of Adaptive Management to Other Hydropower Facilities

Experience with the Glen Canyon Dam case study, along with input from other sources, allows a discussion of anticipated benefits and potential problems related to the generic application of adaptive management to species richness and biodiversity issues at other hydropower generation locations. The following sections summarize what has been learned to date.

The use of adaptive management in one form or another is no longer optional in today's world. Short of removing dams, which is considered unfeasible in nearly all cases, resource managers are faced with managing dam-altered ecosystems, in many cases with no possibility of restoring natural conditions. Competing uses for rivers have increased public concerns about the effects of dams on resources, both natural and "unnatural." Much new knowledge of river systems and the influences of dams on them has been gained. The management of river systems is exceedingly complex, however, and much remains to be learned. Adaptive management is a tool for bringing all affected parties to a common table, reducing conflict, and identifying the most acceptable operational pattern that will allow for hydropower generation, while taking into consideration protection and enhancement of reservoir and downstream resources, including biodiversity.

Important resource and economic issues vary from place to place, and there is no single, optimal way to operate a hydro system to maintain ecological communities and biodiversity. For example, below the Glen Canyon Dam is a sediment-limited ecosystem with clear, cold-water releases providing an excellent tailwater habitat for introduced trout, but adversely affecting endangered fishes. Returning sediment to the system is technically possible, but economically unfeasible, and while raising the temperature of releases a few degrees is possible, temperatures will never reach the levels seen in the natural system. River recreation is also affected through hourly and daily fluctuations as power is generated in response to variable load demands.

In the Columbia River Basin, blockage of anadromous fish runs are the preeminent issue; water releases and sediment are nonissues. In the Central Valley Project in California, recreation is a minor issue but water temperature is a significant concern. There downstream releases are controlled by reregulating reservoirs, which eliminate fluctuating flows from power generation as an issue. For dams in the eastern part of the country, the effects of fluctuating reservoir levels on recreation are often considered more important than effects of releases downstream, although there may be

concerns about low dissolved oxygen levels. There is no single template for managing dam operations that would work equally well in each situation, as each presents unique challenges and requires tailored approaches. Adaptive management offers the flexibility for achieving workable solutions to such complex and variable situations.

Adaptive management emphasizes the role of science as a basis for sound decision making. Each participant in the process has a say in identifying issues and questions for science to address, based on their value judgments about individual resources, political and economic realities, and management objectives and concerns, and each participant is given the opportunity to understand the basis for decisions made. Adherence to scientific inquiry is intended to support the validity of value judgments, reduce the role of politics in decision making, and increase the credibility of the decision process. In the Glen Canyon Dam example, it has been learned that periodic controlled floods and dynamics in the riverine environment are essential to the maintenance of the desired ecosystems. Avoiding floods or establishing a static ecosystem would protect against certain impacts in the near term but would ultimately be contrary to the objectives of the program. The initial position of several parties was that no floods could be tolerated; scientific investigation was able to demonstrate that holding the system static would set in motion natural processes that would adversely affect the resources they sought to protect. The promise of adaptive management is also reflected in a report published by the National Academy of Sciences, entitled *Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy* (NAS 1991a), in which it addresses the need for the development of adaptive management policies and feedback mechanisms if aquatic ecosystems are to be restored to self-sustaining levels.

Managing hydropower operations can allow some degree of control over downstream ecological resources and biodiversity. As illustrated by the Glen Canyon Dam example, most of the effects downstream are the result of the dam being in place, not how it is operated. Thus, the question becomes: to what extent can desired management outcomes be achieved through control of water releases, and are there more effective means of reaching these goals in ways other than through control of flows? The economics of power generation need to be integrated and balanced with the effectiveness of using flow modifications to manage natural resources. It does not make sense to significantly impact power generation if the resultant flow patterns do not benefit the resources of concern or if more effective nonflow options, such as nonnative species control or temperature modification, are available. Theoretically, adaptive management will identify management techniques that are ineffectual and allow flexibility for power generation where restricted flows do not benefit natural resources to a significant degree.

Ecosystem processes are on a different time scale than those for the delivery of water and marketing of electricity. Due to the time lag in measuring an ecological response to operational changes, difficulty in collecting data on natural systems, and numerous confounding factors, it is hard to determine the long-term effects of an operational change, whether positive or negative. It may be decades before changes in biodiversity could be detected. Careful modeling may provide some assistance by predicting results and the time frame in which changes should be visible. Adaptive management bridges the gap and allows long-term responses to influence operational decisions once the information is known.

Advantages of Using Adaptive Management for Biodiversity Management

Decisions on hydropower operations can be staged, with the results of changes in hydropower operations evaluated for effectiveness in achieving specific desired management objectives. Scientifically validated ecological responses, together with previously defined management objectives, can then drive operational decisions. Hypothetically, operational decisions made to achieve specific natural resource management objectives, such as maintenance of biodiversity, which are found to have adverse effects on other resources, would be modified or eliminated if found to be ineffective in achieving those objectives.

Processes undertaken pursuant to the National Environmental Policy Act and the Endangered Species Act tend to force participants into an all-or-nothing mode, with the end of those processes seen as the end of any further opportunity to make changes or revisit decisions. Even if the decisions result in unforeseen adverse impacts to ecological communities or biodiversity, it is often difficult to modify those decisions. Adaptive management assumes that future changes can and will be made, and decisions revisited, based on sound scientific information on the true effects on the natural resources of concern.

Use of adaptive management makes it more likely that important decisions will be made based on sound science and reasoned thought, and not extreme philosophical, political, or economic agendas. Management objectives would be determined with consideration of public values and political and economic realities, but once established, scientific information should be used to measure progress towards the objectives. Part of the

Glen Canyon Dam Adaptive Management Program is currently being developed, even while the EIS record of decision is being drafted. Resource representatives are clarifying specific management objectives, carefully crafting them in light of the Grand Canyon Protection Act and not in terms of the ideal situation for particular resources of concern.

The adaptive management approach is essentially one of "learning by doing" (Lee and Lawrence 1986). In the case of the Glen Canyon Dam, scientists recommended interim limitations on dam operations directed at moderating impacts occurring to downstream resources while the EIS was being prepared. Acting on the scientists' recommendations, Reclamation and the Western Area Power Administration entered an agreement implementing interim flows, with the understanding that flows could be modified upon completion of the EIS record of decision. Monitoring of interim flows and numerous data gathering and research projects were established, with the results affecting the development of the preferred alternative.

Adaptive management provides opportunities for involving the interested public and actively seeking input from affected parties. The interests of any group should not be overlooked, and special attention should be given to the interests of any Native Americans in the area. As an example, in the plan for Glen Canyon, the proposed research center would include program managers on the staff who would be responsible for areas such as physical science, biological science, cultural resources, social sciences, engineering/infrastructure operations, and Native American coordination. In other cases, a program manager for biodiversity might be assigned.

Summary

The concept of adaptive management is not new, but its application to long-term management of complex ecosystems downstream of dams is in its infancy. A major test of the concept will be how well the process performs at Glen Canyon Dam, given the complexity of the resources downstream, the number of conflicting management objectives, and the many agencies and interested parties involved.

Adaptive management has promise for application as a tool for ecological community and biodiversity management at other hydropower facilities. It offers a flexible framework for involving all affected parties and providing a sound scientific basis for operational decisions. The quality of the output from the process (decisions) may be a derivative of the quality of the input (research, monitoring, and management objectives). However, the inputs can be adjusted for a better output in an iterative fashion. It is hoped that implementation of an effective program of adaptive management will result in benefits for all natural, recreational, and economic resources, including the management of biodiversity, in the Glen and Grand canyons, and wherever the concept might be applied in the future.

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