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Perspectives on River Restoration in the Grand Canyon

On 26 March 1996, a week-long controlled flood began when the by-pass tubes through Glen Canyon Dam were opened, releasing about 1270 m^3/s down the Colorado River through Grand Canyon in north-central Arizona. The flood was (1) an experiment to test predictions about flow and sediment transport, and (2) a demonstration of the utility of using large discharges to achieve specific river corridor management objectives. This event focused attention on future management goals for the numerous dams of the Colorado River Basin.

Background

Glen Canyon Dam has been a controversial structure since it was proposed as part of the Colorado River Storage Project of 1956 (Martin 1989). Authorization of a high dam in Glen Canyon was obtained after lengthy debate that also resulted in withdrawal of a proposal to construct Echo Park and Split Mountain Dams in Dinosaur National Monument. Although most initial arguments centered on resource values to be lost in a flooded Glen Canyon and the threat to Rainbow Bridge National Monument, by the mid-1970s, attention shifted to effects of the dam on the downstream river (Dolan et al. 1974). Early concern developed over eroding eddy sandbars, used as camping beaches by recreational river runners. Hydropower load-following on a daily schedule was causing dramatic stage changes in the river that eroded sand over a wide range of elevations and deposited sand on the channel bed (Bureau of Reclamation 1995).

In 1978, the U.S. Fish and Wildlife Service (1978) filed a biological opinion that Glen Canyon Dam and its operation were jeopardizing the continued existence of an endangered cyprinid fish, the humpback chub (*Gila cypha*) in Grand Canyon. This led to the establishment, by the Bureau of Reclamation (Reclamation), of the Glen Canyon Environmental Studies, a program that organized and supported research in Grand Canyon from 1983 to 1995 (National Academy of Sciences 1987). In 1989, the Secretary of Interior directed Reclamation to initiate an Environmental Impact Statement on the dam operation that was completed in 1995. Passage by Congress of the Grand Canyon Protection Act of 1992 (PL 102-575) mandated preservation of values in the National Park as a purpose of dam operations. A second biological opinion in 1995 affirmed the 1978 jeopardy determination.

Use of periodic flood releases from Glen Canyon Dam is intended to ameliorate the dam's negative effects on some of the natural resources of Grand Canyon National Park. What is unclear, however, is how much restoration can be achieved, at what cost, and how decisions about incompatible management goals can be reached (Schmidt et al. 1998).

The underpinning geomorphology

Grand Canyon National Park is one of the most visited national parks in the world. Carved by the Colorado River as the Kaibab Plateau rose 4–6 million years ago, the Grand Canyon exposes rock formations that span over 2 billion years. This is the river that John Wesley Powell first descended in 1869, the last major U.S. river to be explored (Powell 1957). Prior to the large dams, the Colorado carried high sediment loads during annual spring snowmelt and summer and fall monsoon floods. The river's steep gradient provided great transporting power, capable of moving many of the large boulders delivered to the river by debris flows emanating in steep tributaries (Webb et al. 1997). The largest flood in the U.S. Geological Survey gage record is 3,588 m^3/s, but high river deposits suggest that even larger floods approached 11,300 m^3/s. The average annual flood for the period of USGS measurements prior to dam construction (1922–1957) is about 2,260 m^3/s. These high flows transported large amounts of sand, silt, and clay through the canyon. During the period 1925–1957, nearly 100 million tons of sediment per year were carried through Grand Canyon by the Colorado River (Andrews 1991).

Flow of the Colorado River is often constricted by debris fans, and downstream from these fans are large recirculation zones, or eddies (Webb et al. 1989, Schmidt 1990, Schmidt and Graf 1990), which are efficient sediment traps. Prior to construction of Glen Canyon Dam, scour and fill of eddy sand bars occurred during high-water periods each year. When each flood receded, the bare, exposed bars constituted a distinctive attribute of the pre-dam river landscape, and were used as camping beaches by river runners (Kearsley et al. 1994). Today, parts of these eddy bars are detached from the adjacent river banks, and the intervening deep channel contains low and stagnant flows when the Colorado River is at low stage; these backwaters are used by early life stages of some native fishes.

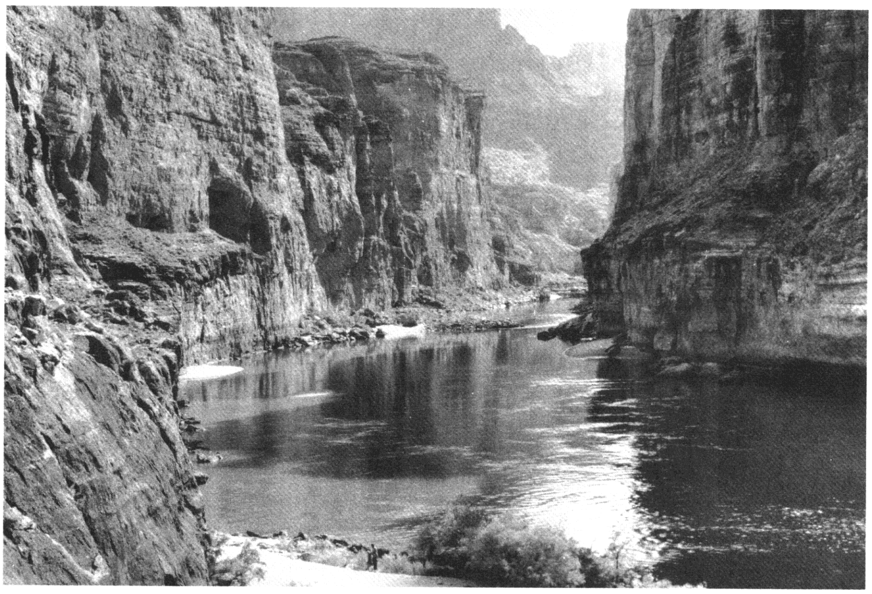

Fig. 1. The Colorado River in Marble Canyon, a critical reach of the river in Grand Canyon National Park, because the sand supply from which sandbars are deposited may be limited. Boats in the foreground are grounded on a separation bar associated with the debris fan on which the man is standing. The reattachment bar associated with the resultant eddy is beginning to emerge against the canyon wall on the river left downstream. A second debris fan may be seen farther downstream on the left in the center of the photograph. The channel geometry generated by these features traps sand in transport and fixes the locations and bedforms of sand deposition.

Consequent effects on endangered species

The conditions for life in the pre-dam Colorado River resulting from this array of physical characteristics were extraordinary. Not many plants could live in the river because it was often too turbid for light to penetrate for photosynthesis. Without plants, grazing animals were few and probably existed only in the tributaries. The combination of high-velocity reaches through rapids, turbid water, and limited food supply led to the evolution of a unique group of fishes that existed nowhere else in the world (Minckley 1991). Approximately 74% of the fishes in the basin prior to modern nonnative introductions were endemic. Understanding details of the dependent couplings of the biota and the physical system has just begun, and continues to be the challenge for river science and management in the next decade. Future research will be focused on the survival and recovery of these endangered fish species. Of these, the humpback chub is one of eight endemic fish species in the main stem Colorado River. Four of these species are extirpated from Grand Canyon and a fifth is extremely rare. The humpback chub continues to exist in Grand Canyon because a spawning population persists in the Little Colorado River (LCR), one of the largest tributaries in Grand Canyon. This fish is physi-

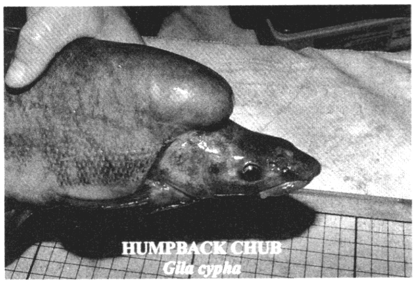

Fig. 2. The humpback chub (*Gila cypha*). "The special morphologies of the Colorado River fishes are combined in adult humpback chubs to form the most unique physiognomy of any North American minnow. Its most bizarre feature is the pre-dorsal hump, rising in extreme individuals from the nape to extend anteriorly over the back of the skull. The hump is of muscle connected through a wedge-shaped caudal peduncle to the large, stiff caudal fin. All fins are expansive and thickened anteriorly. The body appears almost naked, since the scales are small and deeply imbedded. The eyes are small, the snout is bulbous and fleshy and over-hangs the mouth." (Minckley 1991).

ologically limited and cannot spawn at low temperatures currently prevailing in the main stem river. (Hamman 1982, Valdez and Ryel 1997).

Today, young native fish hatched in the LCR may migrate into the main stem, where they find refuge from cold temperatures in warmer, more productive backwaters associated with eddies. Backwaters, as depositional features, are a promising link between a biological element and a physical feature of the modern river that may be manageable, because periodic flood releases from the dam create and maintain these habitats. Maintaining backwaters such that access to them is assured may require larger and more frequent flooding than has been anticipated. Other selective features resulting from floods to which the endemic fishes are adapted (such as turbidity, import of terrestrial food material, reduction of exotic predators and competitors) could be additional benefits of floods.

Although the 1996 controlled flood demonstrated that a flow regime including floods could be reinstated, not even floods of greater magnitude and frequency will necessarily restore the condition of all river corridor resources. Although resumption of flooding will restore primarily those resources that remain from the pre-dam river, flooding may damage many valued resources that have developed since completion of the dam. For example, floods may jeopardize exotic, but valued, riparian vegetation in freshwater marshes that have developed at low elevation along wide reaches and are now essential habitat for an endangered bird, the Southwestern Willow Flycatcher (*Empidonax traillii extimus*). The flycatcher frequently nests in non-native tamarisk, which has widely expanded its range in Grand Canyon. A non-native nasturtium has expanded its range at Vasey's Paradise, the largest spring in the river corridor. This expanded vegetation is now essential habitat for the endangered Kanab amber snail (*Oxyloma haydeni kanabensis*). These larger habitats used by currently endangered species are, in a sense, artifacts of the regulated river, and their existence presents difficult challenges for recovery and restoration efforts that are intended also to improve the status of resources that are relicts of the pre-dam river.

Other endangered species also live in the Grand Canyon, but the habitats of these riparian animals are fundamentally different from habitats of the endangered fishes. The primary habitats of these animals are in riparian vegetation of the new high-water zone. This zone of vegetation exists at lower elevation than the old (pre-dam) high-water zone, because the magnitude of post-dam floods is controlled (Carothers and Brown 1991, Johnson 1991). Riparian vegetation was virtually absent at low elevation along the pre-dam river (Turner and Karpiscak 1980, Webb 1996). Vegetation at and above the old high-water line no longer receives annual wetting because large floods are nonexistent; thus, this community is declining.

Restoration floods confront resource managers with potentially incompatible results. If it is true that frequent flooding is required to recover flood-adapted species, such as the humpback chub, *and* those floods jeopardize critical habitat of other endangered species that now occupy artifact post-dam habitats, then managers are faced with an intractable dilemma (Schmidt et al. 1998). Timing and careful control of managed flooding may offer opportunity for clever implementation of recovery plans, but the monitoring required to document responses at various places in the canyon and at the various time scales imposed by different life history schedules will require knowledge beyond present understanding, and monitoring attention beyond present commitments. Complex ecological modeling efforts may elucidate some linkages between the river regime and general trends of endangered species, but these models are unlikely to adequately describe biotic responses, and the incompatibility of floods creating some habitats while destroying others will remain a poorly understood dilemma.

Other recovery strategies

Other engineering strategies could be used to improve the status of river corridor resources, but none would resolve the dilemma of yielding contradictory impacts to pre-dam and post-dam resources.

Warming the river

The jeopardy opinion of the Service requires a good faith effort to recover the humpback chub. Reclamation is examining the costs, feasibility, and effects of constructing temperature control structures on Glen Canyon Dam so that river temperature might be increased by drawing water from different depths in Lake Powell reservoir during the summer. Presumably, this will relieve the fish population from the restriction of spawning only in the warmer LCR and allow for a mainstem-spawning population to be reestablished. Some aquatic ecologists suspect, however, that a warmer river will favor introduced predatory and competitive fish species, and that these impediments to chub survivorship would more than offset reproductive gains, thus yielding a net loss for this recovery strategy.

Sediment augmentation

If continued investigation supports a management need to increase the magnitude and frequency of flooding, then the resupply of sediment to the river below the dam may be too limited in relation to the mass of sediment transported by tributary floods. Resupply would involve a yet-to-be-resolved transfer of sediment from the deltas in Lake Powell reservoir to the downstream river. When looking for sources of sand in these deltas, managers will have to be attentive to potentially contaminating materials buried in these deposits for the 30 or so years of accumulation. This and other features of sediment augmentation may conflict with provisions of the Clean Water Act.

Sediment augmentation would increase the river's turbidity, thus perturbing the exceptional and popular trout fishery and the photosynthetic production that supports the fishery in the 25 km immediately downstream from the dam. Thus, the point at which sediment introduction would occur is thought to be most desirable below the tailwater reach at Lees Ferry. Turbidity may have some restorative effect on the native fishes. Increased turbidity provides a low-visibility refuge from predation for humpback chub and other native fishes that are adapted to floods and turbidity. These turbid conditions might offset predation effects anticipated from warming the river.

Decommission and removal of the dam

This radical concept has gained attention recently because it has been proposed by some influential environmental leaders. The presumption that simply removing the dam will return the Colorado River in Glen and Grand Canyons to a pristine, more desirable condition compels objective examination (Schmidt at al. 1998).

Ecosystem response to reservoir draining would likely take decades to centuries. When the dam was built, most river processes changed, but the river resources and some river processes responded more slowly. For example, high annual flood peaks were diminished immediately, annual low flows were higher, the sediment load was diminished to virtually zero, and dam releases were clear (Andrews 1991, Dawdy 1991). Other changes proceeded on slower time scales. For example, dam releases were not cold until the reservoir reached sufficient depth to stratify thermally *and* the water was drawn from the cold layer 20–30 m below the surface; erosion of sand bars, used as camping beaches, extended over years or decades; decline of the endangered humpback chub, a long-lived species, continues 35 years after the dam was closed. Other post-dam changes were not expected. Likewise, if the dam were to be removed, some things would happen immediately, others would proceed more slowly, and we should have more reason to expect surprises than to expect a return to the pre-dam condition. What would be the pattern and pace at which sediment, accumulating since 1963, would be remobilized and transported into Grand Canyon? Would this sediment pass directly into Lake Mead reservoir, or would all of the eddies in Grand Canyon be completely filled? At what rate, and for how long?

In Glen Canyon, what would be the condition of canyon walls, now covered by Lake Powell, that have been infiltrated by water moving to the water table since the reservoir filled in 1980? How rapidly would water in the Navajo sandstone drain back into Glen Canyon? How much water would drain? Where would it go? Would the integrity of the sandstone in the basin have been compromised? Would the sandstone be capable of maintaining the pre-dam Glen Canyon configuration, or would parts of it collapse? What would become of the introduced lake fishery? Would these fishes move into Grand Canyon? Would release of predators and competitors further exacerbate the endangered status of the humpback chub?

On the social and value issues, what would be the effect of losing the hydropower production? What would be the reaction of that portion of the population in the Southwest that has come to value the recreational opportunities afforded by Lake Powell? What of the tourist economy developing near Lake Powell?

The point here is not to ask all of the pertinent unanswered questions or even to phrase a few of them correctly, but to present enough of them to make colleagues in the Ecological Society of America aware of the complex and wide-ranging issues and to stimulate discussion.

The implications for adaptive management

The current situation for management of the Colorado River in the Grand Canyon provides unique challenges and opportunities. Some of the challenges involve competing or conflicting management goals, and some of these goals may be impossible to meet. The Colorado River is the centerpiece of a highly valued national park, but the river probably has been irreversibly changed by Glen Canyon Dam and a host of nonnative plants and animals. Society now realizes that dam operations can be used to meet management objectives in the park. A new law (1992 Grand Canyon Protection Act) provides for new uses of the dam and requires a closer working relationship between the environmentally oriented public, river scientists, and river managers. This arrangement, called for in the Glen Canyon Dam Operations EIS (Bureau of Reclamation 1995) is referred to as "adaptive management," wherein parties with interests in various resources (stakeholders) participate in a forum to develop management goals (Lee 1993). Collectively, they address the question "What does society want from this river?" (Schmidt et al. 1998). The inclusion of all stakeholders, however, does not necessarily mean that each interest ought to be considered of equal merit. Even the stakeholder approach does not avoid the necessity of prioritizing the interests and objectives of river management. Society must still find a way to ask, "Trout or endangered fish?" when a management or monitoring technique helps one resource at the expense of the other.

Successful implementation of adaptive management requires close iteration of science and management. Scientists provide objective information about status and trends, causes and effects, prediction, feasibility of management strategy, and interpretation. Thus, they must be involved in the process to learn and understand management needs. In this way, research and monitoring stay focused. Science has no inherent mechanism for making the required value judgments about where management should be directed. Although necessary to the process, science must be separated from these immediate management decisions (Marzolf 1991). More to the point, control and design of science by politically driven stakeholder interests will compromise the science and kill adaptive management. To be objective, free of bias, and useful to a stakeholder's forum, science must be protected from political whim. Politically astute stakeholders know this, and scientists must be constantly alert to the pressure to act otherwise.

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