Executive Summary: Future Challenges for Science and Resource Management of the Colorado River

By John F. Hamill[1]

Introduction

Since the 1980s, four major science and restoration programs have been developed for the Colorado River Basin to address primarily the conservation of native fish and other wildlife pursuant to the Endangered Species Act (ESA). The programs are listed below in the order in which they were established.

- Recovery Implementation Program for Endangered Fish Species in the Upper Colorado River Basin (commonly called the Upper Colorado River Endangered Fish Recovery Program) (1988)
- San Juan River Basin Recovery Implementation Program (1992)
- Glen Canyon Dam Adaptive Management Program (1997)
- Lower Colorado River Multi-Species Conservation Program (2005)

Today, these four programs, the efforts of which span the length of the Colorado River, have an increasingly important influence on water management and resource conservation in the basin. The four efforts involve scores of State, Federal, and local agencies; Native American Tribes; and diverse stakeholder representatives. The programs have many commonalities, including similar and overlapping goals and objectives; comparable resources and threats to those resources; and common monitoring, research, and restoration strategies. In spite of their commonalities, until recently there had been no formal opportunity for information exchange among the programs. To address this situation, the U.S. Geological Survey (USGS) worked in coordination with the four programs and numerous Federal and State agencies to organize the first Colorado River Basin Science and Resource Management Symposium, which took place in Scottsdale, AZ, in November 2008. The symposium's primary purpose was to promote an exchange of information on research and management activities related to the restoration and conservation of the Colorado River and its major tributaries.

Jeff Sorenson, Arizona Game and Fish Department

The Colorado River from Deer Creek overlook in Grand Canyon National Park, Arizona. Four collaborative management programs span the length of the Colorado River. Working in different parts of the basin, each program seeks to conserve or restore species listed under the Endangered Species Act and meet water and hydropower demands.

A total of 283 managers, scientists, and stakeholders attended the 3-day symposium, which included 87 presentations and 27 posters. The symposium featured plenary talks by experts on a variety of topics, including overviews of the four restoration programs, water-management actions aimed at restoring native fish habitat, climate change, assessments of the status of native and nonnative fish populations, and Native

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American perspectives. Intermixed with plenary talks were four concurrent technical sessions that addressed the following important topics:

1. Effects of dam and reservoir operations on downstream physical and biological resources
2. Native fish propagation and genetic management and associated challenges in co-managing native and nonnative fish in the Colorado River
3. Monitoring program design, case studies, and links to management
4. Riparian system restoration, monitoring, and exotic species control efforts

In her opening remarks, Kameran Onley, then U.S. Department of Interior's Acting Assistant Secretary for Water and Science, encouraged better coordination and information sharing among the various recovery and restoration programs. She recounted the history of water management in the basin and emphasized the complex challenge of balancing competing societal needs such as water delivery, hydropower generation, and natural resource protection. Ms. Onley also underscored the importance of independent scientific research as a critical ingredient in the decisionmaking process. In closing, she asked the "USGS to provide recommendations on how science and restoration efforts could be enhanced collectively through better basinwide cooperation and integration." Today, Ms. Onley's request still seems relevant as the Obama Administration considers water, energy, and environmental priorities for the Colorado River Basin.

Anne Phillips, USGS

Eight hydroelectric generation units make up the the powerplant at Glen Canyon Dam. The Department of the Interior balances competing societal needs for water, power, and environmental protection.

San Juan River Basin Recovery Implementation Program

Operated by the Navajo Nation, the fish passage at the Public Service Company of New Mexico Weir in the San Juan Basin provides educational opportunities for local students.

It is difficult to distill a 3-day conference to a few pages of an executive summary, so the following is an attempt to highlight the most compelling issues and themes that emerged from this first symposium. These highlights are drawn not only from the papers that follow (a third of the papers presented at the symposium), but also from symposium presentations that did not result in papers.

Ms. Onley's opening remarks were followed by overviews of each of the four Colorado River Basin restoration programs, which were provided by program leaders. All four programs focus on meeting ESA compliance requirements and, in the case of the Glen Canyon Dam Adaptive Management Program, the 1992 Grand Canyon Protection Act (GCPA). All four programs are designed to conserve or restore endangered species and mitigate the impacts of existing and new water-development and hydropower projects. Each program has implemented an impressive list of actions to conserve native fish, including extensive efforts to control nonnative fish that compete with or prey upon native fish. Other efforts include the construction of fish ladders to expand the range of native fish, the installation of fish screens on irrigation diversions, the acquisition of flood-plain habitats, and the restoration of several thousand acres of riparian and marsh habitat. Hundreds of thousands of native fish have been raised in hatcheries and isolated predator-free ponds and stocked in various locations throughout the basin. Some documented evidence of survival and recruitment of the hatchery fish exists, although overall survival rates for hatchery fish generally are very low.

Water resources also are being managed by the programs in order to benefit native fish. The San Juan River Basin Recovery Implementation and Upper Colorado River Endangered Fish Recovery Programs are regulating flows from a variety of Federal reservoirs to more closely mimic a natural hydrograph (reservoir releases are increased to maximize the spring peak). The hypothesis is that a natural flow regime is best suited to native fish recovery. For example, spring releases from Flaming Gorge Dam are timed with high flows from the Yampa River to maximize peak flows in the Green

River near Jensen, UT. Similar flow-management strategies are being employed at the Aspinall Unit—Blue Mesa, Morrow Point, and Crystal Reservoirs—to improve habitat for native fish found in the Gunnison River. Efforts are underway to enhance base flows in the Yampa River and the "15-mile reach," a segment stretching east of Grand Junction for 15 miles, of the Colorado River with water stored in several upstream reservoirs (for example, Ruedi Reservoir).

Flows from Glen Canyon Dam are being managed to benefit downstream natural, cultural, and recreational resources. The annual release volumes from Glen Canyon Dam are determined by upper Colorado River Basin hydrology and systemwide water storage in combination with downstream water delivery requirements directly tied to the "Law of the River" and the requirements of the 2007 Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operation of Lake Powell and Lake Mead Final Environmental Impact Statement. Monthly and daily flows are designed to generate hydropower at times of peak demand, although diurnal variations have been attenuated since the early 1990s to minimize downstream environmental impacts in Glen Canyon National Recreation Area and Grand Canyon National Park. In addition, since 1996, a series of experimental high flows have been released from Glen Canyon Dam as part of an adaptive strategy intended to restore sandbars in Grand Canyon. The Glen Canyon Dam Adaptive Management Program has also conducted several stable flow tests to benefit humpback chub (*Gila cypha*) and promote a better understanding of how different flow regimes will contribute to meeting program goals.

Populations of native Colorado River fish have responded variably to this extensive suite of recovery actions, although none of the populations have achieved established recovery or restoration goals. While it is difficult to get a complete picture of the population status of native fish on the basis of information presented at the symposium, Colorado pikeminnow (*Ptychocheilus lucius*) have decreased in the Green River Basin and increased in the upper Colorado River. According to the U.S. Fish and Wildlife Service, humpback chub populations have declined in the Yampa River and in the upper Colorado River (Black Rocks and Westwater Canyon). After more than a decade of decline, adult (age 4+) humpback chub in Grand Canyon have increased by about 50 percent since 2001. Populations of razorback suckers (*Xyrauchen texanus*) are being maintained in the lower basin reservoirs and the Green and San Juan Rivers through active stocking programs, and limited natural reproduction and recruitment is evident in some locations.

Assessing the effectiveness of individual recovery or conservation actions is a common challenge for all four of the restoration programs. The implementation of multiple recovery actions in combination with natural ecosystem variability and the long period of time needed to document successful recruitment of native fish species make it difficult to evaluate the success of any individual experiment or management action.

Upper Colorado River Endangered Fish Recovery Program

A biologist holds an adult Colorado pikeminnow (*Ptychocheilus lucius*), an endangered species. Recently, the number of adult fish captured in the upper Colorado River Basin increased from 440 in 1992 to 890 in 2005.

Monitoring is one of the consistent features of science necessary to assess progress in river restoration programs. When coupled with experiments or management actions that purposefully introduce change to the system, monitoring is critical to the assessment of cause and effect relations. This assessment of cause and effect is an important part of the learning process to determine what works and what does not in achieving the restoration objectives of a given program. The importance of monitoring cannot be overstated, yet historically it has not been included consistently in restoration programs. Additionally, when monitoring has been completed, it has often been done qualitatively or anecdotally and not sustained for a sufficient time or intensity to adequately track resource conditions. Several papers were presented on monitoring programs used to track the status of bats, endangered fish, and campsites used by river runners.

Climate Change Impacts

Brad Udall, director of the University of Colorado at Boulder's Western Water Assessment, spoke about the influence of climate change on the water supply in the Southwestern United States and made one of the symposium's most compelling presentations. The mean warming of the Southwest is likely to exceed the global mean. In fact, Udall noted that temperatures in the lower Colorado River Basin have increased 2 degrees Fahrenheit (°F) (1.1 degrees Celsius, °C) from 1970 to 2005, which may be the most rapid rate of temperature change for any region in the United States. As the result of higher temperatures, the upper Colorado River Basin will have less precipitation falling as snow, increased evaporative loss, and an earlier peak spring snowmelt. Based on the analysis of multiple models, the scientific evidence suggests that warmer temperatures will reduce the streamflow of the Colorado River. The flow of the river could be reduced

by 6 to 45 percent according to the various model projections. Climate change represents a significant challenge for water-resource management in the West because warming may create substantial water-supply shortages in the Colorado River Basin as the region adds population. In contrast, flows and water temperatures in Grand Canyon are linked to the reservoir elevation of Lake Powell. Decreased inflows and increased evaporation from Lake Powell could lead to releases from the warm epilimnion and result in water temperatures in Grand Canyon approaching 30 °C, temperatures similar to pre-dam conditions (William Vernieu, U.S. Geological Survey, oral commun., 2008).

The recent basinwide drought (2000–2007) had markedly different impacts on native fish populations in unregulated sections of the upper Colorado River Basin relative to the regulated section of Grand Canyon. In the Yampa River, the recent drought has been associated with a large increase in nonnative fish populations and a concomitant decrease in native fish populations. From 2000 to 2007, annual peak discharge and base flow in the Yampa River was significantly reduced, and water temperatures were significantly higher. Very low summer base flows may have reduced habitat volume, increasing the potential for competition and predation by nonnative species. Humpback chub declined in the Yampa River during the recent drought. In contrast, the humpback chub population in Grand Canyon increased during the recent drought. From 2000 to 2007, release volumes from Glen Canyon Dam declined to the minimum allowed by law. During this period, rainbow trout (*Oncorhynchus mykiss*) populations declined by 50 percent, and humpback chub populations increased. Water temperatures during this period of low reservoir elevations were as much as 5 °C higher than the 40-year average because withdrawal structures were drawing warm water close to the surface of Lake Powell. Warmwater releases may have allowed for faster growth rates of humpback chub, and reductions in the population of predaceous rainbow trout may have tipped the system in favor of native fish.

Andrew "Frick" Pernick, Bureau of Reclamation

An aerial view of Lake Powell taken in 2004. The white "bathtub ring" indicates how much the water level dropped as the result of a drought that began in 2000.

Terry Fulp and others (this volume) reported that the Bureau of Reclamation has an active research and development program to evaluate the impacts of climate change on water supplies, water delivery, and power operations in the basin. However, so far there has been no parallel effort to evaluate the likely impacts of prolonged drought and climate change on water quality or the natural and recreation resources in the Colorado River Basin.

The Ongoing Threat of Invasive Species

The ongoing threat from the more than 60 nonnative species present in the Colorado River represents one of the most serious challenges to achieving the native fish goals of each of the four restoration programs. A large body of researchers concludes that the establishment of nonnative fish in the Southwest is the primary cause of the deteriorating status of native fish in the region and prevents their recovery (see Clarkson and Marsh, this volume). However, each of the restoration programs is attempting to promote the recovery of native fish while maintaining politically and economically important nonnative sport fisheries.

Numerous papers were presented that document how nonnative fish threaten the long-term sustainability of native fish populations throughout the Colorado River Basin. Kevin Bestgen of Colorado State University and Angela Kantola of the U.S. Fish and Wildlife Service reported significant declines in the endangered humpback chub in the Yampa River associated with dramatic increases in smallmouth bass (*Micropterus dolomieu*) populations in that same river. Michael Yard and others (U.S. Geological Survey, oral commun., 2008) reported that rainbow and brown trout (*Salmo trutta*) prey on endangered humpback chub in Grand Canyon and estimated that more than 20,000 chub would have been consumed by the trout removed as the result of their study. Lewis Coggins and Michael Yard (this volume) reported success in reducing rainbow trout populations in experimental reaches of the Colorado River in Grand Canyon by using intensive electrofishing during a 4-year period.

Robert Clarkson and Paul Marsh (this volume) concluded that segregating native and nonnative fish is the only viable tactic to conserve and recover imperiled warmwater native species in the Gila River Basin in Arizona. They described several projects involving the construction of instream barriers to prevent upstream fish migrations in conjunction with chemical eradication of nonnative fish that were effective at restoring native fish on several small streams. Unfortunately, the authors noted that this type of approach is not technically

Upper Colorado River Endangered Fish Recovery Program

Nonnative fish like the northern pike (*Esox lucius*), a voracious predator, are a threat to native fish populations throughout the Colorado River Basin.

or politically feasible in large drainage networks that also support nonnative sport fisheries.

A new invasive species, the quagga mussel (*Dreissena bugensis*) was found in Lake Mead in January 2007 and had spread to more than 30 Colorado River lakes and reservoirs by the end of 2008 (Nalepa, this volume). Quagga mussels are filter feeders, and when they attain high densities in an ecosystem they can dramatically alter water quality and food web structure, including reducing fish populations. Quagga mussels are not expected to attain high densities in riverine sections of the Colorado River Basin (Nalepa, this volume), but they are expected to attain high densities in reservoirs of the Colorado River Basin where important sport fisheries may be affected. Quagga mussels may impact downriver ecosystems by changing the water quality (that is, dissolved nutrients, phytoplankton, zooplankton) of water released from these reservoirs.

Other Resource Issues of Interest

John Schmidt (this volume), a geoscientist with long experience working throughout the basin, surveyed the highly varied range of geomorphic responses that have occurred following dam construction in reaches of the Colorado River and its tributaries, and noted that some reaches have developed significant sediment deficits while other reaches have experienced surpluses. His plea was for decisionmakers to think more strategically and at a more regional scale about the various restoration (or as he phrased it "rehabilitation") program objectives currently being pursued—at substantial cost and with varied successes—and consider in a more integrated way how costs and benefits might be reasonably and efficiently balanced. He asked two compelling questions:

1. What environmental management goals ought to be established for each part of the basin?

2. Should decisions about goals be made at a segment scale by local stakeholders or at a watershed scale by regional or national interests?

Schmidt's assessment suggested that there may be more "bang for the buck" by focusing rehabilitation efforts on the less perturbed parts of the upper basin but noted that currently most of the funding is being directed at efforts below Lees Ferry (Glen Canyon Dam Adaptive Management and Lower Colorado River Multi-Species Conservation Programs). As Schmidt pointed out, there is no regional process for the Colorado River Basin by which the goals of each rehabilitation program are compared nor is there consideration of the tradeoffs between rehabilitation efforts and the level of recovery.

Christopher Konrad's presentation (this volume) provided an overview of several site-based river restoration projects outside of the Colorado River Basin that are currently being evaluated by The Nature Conservancy in collaboration with the USGS. Konrad's presentation offered some perspectives and hope for moving from site-based to basin-scale river conservation on the basis of lessons from several projects he evaluated. One of Konrad's main observations and conclusions is that integrating dam operations with other types of river management, such as flood-plain land use and water quality throughout a basin, can better conserve river ecosystems and align conservation with human welfare. He acknowledged that basin-scale coordination is difficult, controversial, and time consuming to implement. He concluded that integrated management depends on an alliance of stakeholders with shared ecological goals who are willing to work together rather than simply to comply with the regulatory requirements applicable to their individual site.

In his talk titled "Changing the Law-Science Paradigm for Colorado River Restoration," University of Utah law professor Robert Adler questioned whether it is possible to meet the economic goals of water law and development and the environmental goals of the Endangered Species and Grand Canyon Protection Acts fully and simultaneously (Adler, this volume). He acknowledged that one possibility is that more time is needed to study and fine tune restoration programs until success is achieved. Another more sobering possibility is that the current "law-science paradigm" seeks impossible results. In other words, it is impossible to achieve the goals of each of the programs within the existing legal frameworks. Adler challenged the audience to consider a full range of possible alternatives to the existing "law-science paradigm" that underlies each of the current programs. One of his suggested alternatives included the idea for shifting dependence on large reservoirs for water storage to a variety of off-channel options, such as storing more of the river's flow in aquifers where underground storage might be available.

The barriers to effective Native American participation in Federal restoration programs were also discussed on the basis of the experience of Tribal participants active in the Glen Canyon Dam Adaptive Management Program (Dongoske and others, this volume). Kurt Dongoske, who represents the Zuni Tribe, and his co-presenters, members of the Hualapai and Southern Paiute Tribes, argued that heavy reliance on Western science has the unintended effect of

disenfranchising participating Native Americans. The authors concluded that within the Western science perspective, Native American perspectives of the ecosystem are delegitimized and marginalized in favor of scientific knowledge. Additionally, cultural differences in communication and differences in educational backgrounds between Tribal representatives and other stakeholders act as barriers to Tribal participation. For example, the sometimes argumentative nature of the exchanges that take place during meetings is uncomfortable for Tribal representatives and limits their participation. The authors assert that to achieve a program that integrates Native American perspectives, program leaders must embrace a paradigm shift that places traditional knowledge of ecosystems on an equal footing with Western science. The development of a stronger social science component of the Glen Canyon Dam Adaptive Management Program would be a first step toward this paradigm shift.

Kirk Emerson (this volume) wrapped up the symposium with her summary talk on "The Promise and Peril of Collaboration in the Colorado River Basin," addressing the potential values of collaboration and the difficult challenges associated with maintaining vital collaborative partnerships. One of the challenges highlighted was the peril of institutionalism for longstanding programs, which includes process fatigue and weakened commitment. Ms. Emerson noted that the jury is still out on large-scale ecosystem restoration programs, but concluded that adaptive management approaches are essential because there are no other alternatives for dealing with complex natural systems and the management challenges they face. Emerson urged the new Obama Administration to embrace the principles of environmental conflict resolution codified in a 2005 policy memorandum issued by the Office and Management and Budget and the Council of Environmental Quality.

Conclusion

The preceding discussion highlights the broader and perhaps more provocative topics that were discussed during the first Colorado River Science and Resource Management Symposium. In conclusion, it seems appropriate to return to the request from Ms. Onley to provide some thoughts on how science and restoration efforts might be enhanced collectively through better basinwide cooperation and integration.

From a coordination perspective, the hope was that the exchange of information that occurred at the 2008 symposium would improve the effectiveness of the programs both individually and collectively. Responses to the conference generally were very positive. The general conclusion was that the symposium provided an excellent forum for information exchange among individuals working on similar issues in different parts of the basin. As this document was being completed, preliminary plans to sponsor a second symposium in the fall of 2011 or winter of 2012 were underway as a means of promoting additional basinwide coordination and cooperation. The intent of the various program sponsors at the next symposium is to expand the scope and address environmental issues associated with the Colorado River in Mexico.

Determining the appropriate level of integration among the restoration programs is a more complicated question. All four programs have evolved independently, which probably has contributed to their current successes and broad agency and stakeholder support. In addition, the large geographic scope of the basin and the diversity of stakeholders warrant maintaining several distinct programs. As such, a suggestion to merge the current programs is not one of the outcomes of the first symposium. It is worth noting, however, that the combined annual cost of the four programs is about $40 million per year and is projected to be nearly $1 billion over the expected lives of the programs. The cost of the four programs, along with several significant basinwide challenges that transcend program boundaries such as climate change and invasive species, suggests that it is time to consider developing a broader framework to guide the overall effort. Although merging the four programs is not suggested, some form of an overarching framework and independent science organization would be useful to

- establish some fundamental science practices to guide overall restoration efforts throughout the basin,
- conduct regional-scale analyses and assessments of the status of important resources,
- establish indices of ecosystem health and develop the necessary database to monitor those indices, and
- serve as a clearing house for reports and information on the best available management practices.

Such a framework also would facilitate the kind of basinwide assessments that were advocated by Konrad and promote a more effective balance between environmental and water-supply objectives. An overarching framework also would allow for setting basinwide priorities and conducting basinwide tradeoff analyses to ensure limited funds are spent on the highest priority resources with the best potential for restoration, as advocated by Schmidt.

Some may argue that such a proposal goes beyond the compliance requirements of the ESA or GCPA, and that may be true; however, such steps may also lead in a direction toward what is needed—a more sustainable and effective science-based conservation effort throughout the Colorado River Basin. Examples exist where the current restoration programs have exceeded the minimum compliance requirements to head off future problems. Most notably, the goals of two of the upper basin recovery programs go beyond meeting basic Section-7 ESA requirements and seek instead to achieve full recovery of the endangered fish. The Lower Colorado River Multi-Species Conservation Program has an objective of avoiding the listing of a variety of candidate and sensitive

species. This same kind of forward-looking, broader-scale approach is now needed to ensure a more integrated, adaptable overall effort. With nine national park units and several national wildlife refuges in the area and large numbers of threatened and endangered or sensitive species dependent on the Colorado River, the importance of maintaining a healthy Colorado River ecosystem is unlikely to go away. As Emerson reminded us in her presentation, meeting the environmental challenges in the Colorado River Basin in the face of increasing water demands and decreasing water supplies will stress the existing restoration programs and demand new approaches. A long-term commitment to rely on consistent monitoring and sound science will be one of the keys to an effective, sustainable conservation effort throughout the basin.

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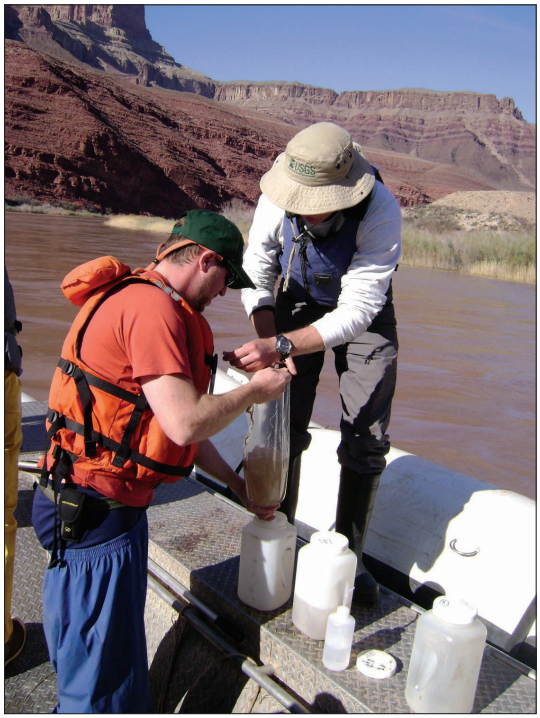

Paul Alley, USGS

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