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Status and Trends of Resources Below Glen Canyon Dam Update—2009

The protection of resources found in Glen Canyon National Recreation Area and Grand Canyon National Park, Arizona, emerged as a significant public concern in the decades following the completion of Glen Canyon Dam in 1963. The dam, which lies about 15 miles upstream from the park, altered the Colorado River's flow, temperature, and sediment-carrying capacity, resulting over time in beach erosion, expansion of nonnative species, and losses of native fish. During the 1990s, in response to public concern, Congress and the Department of the Interior embarked on an ongoing effort to reduce and address the effects of dam operations on downstream resources.

In 2005, the U.S. Geological Survey produced a comprehensive report entitled "The State of the Colorado River Ecosystem in Grand Canyon," which documented the condition and trends of resources downstream of Glen Canyon Dam from 1991 to 2004. This fact sheet updates the 2005 report to extend its findings to include data published through April 2009 for key resources.

*A view of Marble Canyon (top) in Grand Canyon National Park, Arizona. Grand Canyon is home to a diverse range of wildlife, including the endangered humpback chub (*Gila cypha*; lower left), and is a premier whitewater rafting (lower right) destination. The flow of Colorado River through the canyon is controlled by Glen Canyon Dam. Federal efforts to protect natural, cultural, and recreational resources affected by the dam are ongoing.*

Background

Congress passed the Grand Canyon Protection Act of 1992, which directs the Secretary of the Interior to operate the dam "to protect, mitigate adverse impacts to, and improve values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established …."

In response to the 1992 legislation and an extensive environmental review, the Secretary of the Interior signed a formal decision in 1996 that altered historical flows from the dam and established the Glen Canyon Dam Adaptive Management Program (GCDAMP). Adaptive management, also known as "learning by doing," is a process for evaluating and revising management actions as new information becomes available. The U.S. Geological Survey (USGS) Grand Canyon Monitoring and Research Center is responsible for the scientific monitoring and research efforts of the program.

During the past 13 years, the modified low fluctuating flow (MLFF) alternative has governed dam operations. Under MLFF operations, the historical range of daily flow fluctuations and peak releases associated with hydropower production from the dam have been reduced. Additionally, in keeping with the precepts of adaptive management, the Department of the Interior implemented a series of flow and nonflow experiments intended to improve downstream resource conditions. After more than a decade, two questions remain: What are the effects of Glen Canyon Dam operations on those resources of concern? Are desired outcomes being achieved? The current condition of each key resource is summarized below and in the table on the following pages.

Water Quality

Because the water-intake structures of Glen Canyon Dam are well below the surface of Lake Powell, where the warmth of the sun cannot penetrate, water released from the dam is cold, with an average temperature of about 48°F (9°C) for the period from 1988 to 2005. Warming occurs as the water moves downstream, reaching an average annual high of about 64°F (18°C) at Diamond Creek between 1990 and 2002. Low temperatures have threatened the survival of endangered humpback chub (*Gila cypha*). Beginning in 2003, an ongoing drought in the upper Colorado River Basin has reduced the water level in Lake Powell, meaning releases are drawn from closer to the surface of the reservoir where the water is warmer. As a result, water temperatures have increased substantially, reaching an annual high of 70°F (21°C) in 2005 at Diamond Creek. The warmer releases may be playing a role in recent increases in native fish, including humpback chub in Grand Canyon (see below).

Specific-conductance data are collected as a cost-effective method for estimating salinity, or salt inputs, which affect ecosystem functioning as well as municipal, industrial, and agricultural water users. Drought conditions, prevalent since 1999, generally result in an increase in specific conductance in Lake Powell and water released downstream, owing in part to the decrease in the volume of water in the reservoir.

Sediment

Throughout Grand Canyon National Park, sandbars create habitat for native plants and animals, provide camping beaches for river runners and hikers, and act as the source of sediment needed to protect archeological resources. Sandbars in the park have been significantly eroded because Glen Canyon Dam traps all of the upstream sediment supply and eliminates natural flooding.

Today, Colorado River tributaries below the dam are the only sources of sediment available to maintain the park's sandbars, providing just 16% of the sand supply available before the dam's construction. In 1996, 2004, and 2008, short-duration high-flow experimental water releases, which simulate mild natural floods, were tested for their ability to maintain sandbars with this post-dam sand supply. High-flow releases are required to transfer sand from the riverbed and low-elevation parts of sandbars to higher-elevation environments that are only inundated during higher than normal releases.

The 1996 high-flow experiment resulted in limited areas of sandbar building at the expense of larger areas of erosion, whereas the 2004 release produced net sandbar building in the upper reaches of the 277-mile-long river system. As a result of the 2004 high-flow experiment, scientists confirmed that increases in total sandbar area and volume can occur when high-flow releases follow tributary floods that enrich sand supplies in the main channel below the dam. In 2008, when sand supplies in the main channel of the Colorado River were approximately three times larger than in 2004, a high-flow experiment was done to determine whether the conditions of greater sand enrichment would result in more sandbar building than occurred in 2004.

Building on what has been learned through experimentation, scientists have concluded sandbars can be potentially rebuilt using short-duration high flows following each average to above-average input of sand from tributaries; this approach would move sand from the riverbed to sandbars before it can be carried downstream. The effectiveness of this strategy rests on minimizing sand export and sandbar erosion during periods between high flows. Export and erosion rates are strongly dependent on water release volume and daily release patterns. For a given annual volume of water to be released from Glen Canyon Dam, the optimal dam operation for accumulating tributary-supplied sand is a constant, steady flow over the entire year.

Aquatic Food Web

Aquatic food resources play an important role in the distribution, population density, and growth of native and nonnative fish. Found in Lakes Mead and Havasu in January 2007, the nonnative quagga mussel (*Dreissena bugensis*) will in all likelihood make its way to Lake Powell. Introductions of invasive quagga and zebra mussels (*Dreissena polymorpha*) into lakes and rivers in the Eastern United States have caused broad ecosystem-scale changes, including shifts in the location of aquatic food resources.

A risk assessment by the USGS found that it is likely that the mussel will establish in moderate densities at Lees Ferry. A moderate presence of quagga mussels in Lees Ferry might actually increase food availability for fish by stimulating algae and invertebrate production. High suspended-sediment concentrations and other conditions make it unlikely that quagga mussels will become well established in the mainstem Colorado River below Lees Ferry or its tributaries.

Native Fish

The humpback chub is an endangered freshwater fish found only in the Colorado River Basin. Humpback chub have been affected not only by changes in hydrology since the construction of the dam but also by predation by and competition with nonnative fish.

The USGS has developed and used a computer model to assess the Grand Canyon humpback chub population status and trends from 1989 to 2008. Reproductively mature humpback chub, those 4 years old and older, appear to have decreased from 1989 to about 2001, when the population stabilized at about 5,000 adults. From 2001 to 2008, the adult population increased by approximately 50%. When possible model error is considered, the estimated number of adult chub in the Grand Canyon population is between 6,000 and 10,000. The most likely number is estimated at 7,650 individuals.

The factors driving the estimated increase in adult humpback chub numbers in Grand Canyon are not easy to determine. Between 2000 and 2008, both human-caused and natural events have occurred that could be independently or in combination contributing to the increase. Scientists hypothesize that humpback chub may have benefited from experimental water releases from Glen Canyon Dam, removal of nonnative fish, and drought-induced warming of dam releases since 2002, particularly during late summer and fall of 2005.

Grand Canyon populations of the flannelmouth sucker (*Catostomus latipinnis*) and bluehead sucker (*Catostomus discobolus*) are stable, and both species may have increased in the reach of the Colorado River upstream and downstream from the mouth of the Little Colorado River. In this reach, scientists have found juvenile, young, and adult fish of both species, which suggests that more successful reproduction is occurring.

Nonnative Fish

The number of nonnative rainbow trout (*Oncorhynchus mykiss*) found in Lees Ferry, which is immediately downstream from the Glen Canyon Dam and supports a recreational fishing industry, began declining about 2002. Research to better understand

Update of key downstream natural, cultural, and recreational resources affected by Glen Canyon Dam, summarizing data published through April 2009.

[The goals presented were established by the Glen Canyon Dam Adaptive Management Program (GCDAMP; http://www.usbr.gov/uc/rm/amp/strategic_plan.html). Predictions are drawn from the 1995 Operation of Glen Canyon Final Environmental Impact Statement (EIS) on how key resources would respond to the selected flow alternative]

Resource and GCDAMP Goal	1995 EIS Prediction	2009 Summary
Natural resources		
Water quality (water temperature) (Goal: Establish water temperature, quality, and flow dynamics to achieve GCDAMP ecosystem goals)	No effect	Since 2003, downstream water temperatures have increased in response to drought conditions (see http://pubs.usgs.gov/ds/2007/251/).
Specific conductance (salinity)	No effect	Drought conditions, prevalent since 1999, generally result in increases in specific conductance (see http://pubs.usgs.gov/ds/364/).
Sediment (sandbars and related physical habitats) (Goal: Maintain or attain levels of sediment storage within the main channel and along shorelines)	Modest improvement	Sandbars erode during periods between high flows. Increases in total sandbar area and volume are only possible when high-flow releases follow large tributary floods that enrich sand supplies in the main channel (see http://pubs.usgs.gov/fs/2007/3020/).
Aquatic food web (Goal: Protect or improve the aquatic food base)	Potential major increase	Increases were apparent in Glen Canyon Dam tailwater reach, but the trend is unclear along downstream reaches. Unlikely that quagga mussels (*Dreissena bugensis*) will become well established in the mainstem Colorado River below Lees Ferry or its tributaries (see http://pubs.usgs.gov/of/2007/1085/).
Native fish (humpback chub) (Goal: Maintain or attain viable populations of existing native fish)	Potential minor increase	The population of adult humpback chub (*Gila cypha*) decreased between 1989 and 2001; however, adult abundance has increased more than 50% since 2001 (see http://pubs.usgs.gov/of/2009/1075/).
Trout (Goal: Maintain a naturally reproducing population of rainbow trout above the Paria River)	Increased growth potential, dependent on stocking	Rainbow trout (*Oncorhynchus mykiss*) numbers have decreased in the Lees Ferry reach.
Riparian vegetation (Goal: Protect or improve the biotic riparian and spring communities)	Modest increase	Native and nonnative woody vegetation continues to expand in the river corridor. Nonnative tamarisk (*Tamarix ramosissima*) is the dominant species, making up 24% of vegetation (see http://pubs.usgs.gov/of/2008/1216/).
Kanab ambersnail (Goal: Maintain or attain viable populations of Kanab ambersnail)	Some incidental take	Snail habitat increased since 1998 (see chapter 6 at http://www.gcmrc.gov/products/score/2005/).
Cultural resources		
Archeological sites affected (Goal: Preserve, protect, manage, and treat cultural resources)	Moderate degradation (less than 157 sites affected)	Archeological site condition continues to decline because of a combination of factors including erosion, gravity, visitor impacts, and insufficient sediment (see chapter 11 at http://www.gcmrc.gov/products/score/2005/).
Traditional cultural resources affected (Goal: Preserve, protect, manage, and treat cultural resources)	Increased protection	Tribes have developed protocols for monitoring the condition of cultural resources in accordance with tribal values.
Recreation resources		
Whitewater boating camping beaches (average area at normal peak stage) (Goal: Maintain or improve the quality of recreational experiences)	Minor increase	Areas suitable for camping have decreased on average 15% per year between 1998 and 2003 (see chapter 12 at http://www.gcmrc.gov/products/score/2005/).

Scientists with the USGS Grand Canyon Monitoring and Research Center collecting water samples during the 2008 high-flow experiment (USGS photo by Paul Alley).

the early life-history dynamics of rainbow trout in Lees Ferry showed that hourly flow fluctuations do affect the neashore habitat use and growth of young trout (less than 1 year old). For example, nearshore catch rates increased two to four times at the daily minimum flow compared to the daily maximum. The effects of winter experimental fluctuating flows of 2003–2005, flows designed to disrupt spawning activity to reduce trout numbers and increase their size, were also evaluated for Lees Ferry. Survival rates increased as egg deposition decreased, meaning that incubation mortality rates owing to experimental flows were insufficient to reduce the numbers of young fish. In 2006, for example, early survival rates posted a six-fold increase despite a ten-fold decrease in egg deposition.

In early 2003, a major effort was begun by the GCDAMP to remove nonnative fish, particularly rainbow and brown trout (*Salmo trutta*), from the Colorado River near the confluence of the Little Colroado River, which is considered important habitat for the humpback chub. Not only do trout rely on the same food sources—aquatic and terrestrial invertebrates, algae, and small fish—trout are also thought to prey on juvenile humpback chub. Between 2003 and 2006 the rainbow trout population in the Colorado River near the Little Colorado River was reduced by more than 80%.

Riparian Vegetation

Historically, the flow of the Colorado River varied greatly by season, swelling with snowmelt in the spring and slowing to a relative trickle by winter. Today, the regulation of the river by Glen Canyon Dam has reduced disturbance to vegetation caused by predam floods, and MLFF operations provide a constant source of water for riparian plants (plants living near a waterway). These conditions have resulted in the expansion of woody and herbaceous vegetation, both native and nonnative species, immediately along the river channel.

A limited study of vegetation change between 1992 and 2002 indicated that vegetation expansion appears to be the greatest along shorelines. Additionally, monitoring of existing vegetation showed an increase in diameter, suggesting that individual woody plants are increasing in size. Increases in both the number and size of riparian plants may contribute to campsite area loss.

Recent vegetation mapping efforts indicate that tamarisk (*Tamarix ramosissima*) is the dominant nonnative species, representing 24% of the vegetation community. The 2008 high-flow experiment was timed for early spring to decrease the likelihood of spreading tamarisk seeds, which would result in increased tamarisk colonization.

Riparin habitat for the endangered Kanab ambersnail has increased since 1998; habitat is used as a surrogate for snail numbers because they fluctuate widely by season. The snail, which is associated with wetland and spring vegetation, is currently found at three locations, including two in Grand Canyon National Park (Vaseys Paradise and Elves Chasm). Vaseys Paradise is a small patch of spring-fed vegetation that is surveyed by the USGS in cooperation with the Arizona Game and Fish Department.

Archeological Sites

Grand Canyon has been used by humans for at least 13,000 years. Today, more than nine contemporary Native American tribes have cultural ties to the area. Grand Canyon National Park contains more than 2,600 documented prehistoric sites; 336 sites are within the area potentially affected by Glen Canyon Dam operations.

Cultural resource monitoring suggests that archeological resources are affected both by erosion and recreational visitors. Natural erosion patterns would happen whether the dam existed or not; however, the dam and its operations have limited the sediment available within the river corridor. The diminished sediment supply appears to be exacerbating the rate and amount of erosion affecting cultural resources.

Sandbars created by a 2004 high-flow experimental release from Glen Canyon Dam increased the windborne transport of new river deposited sand toward some archeological sites found near the Colorado River in Grand Canyon. Increasing the availability of sand that can be transported by the wind to archeological sites in the river corridor, following sandbar building high flows (as described above) may reduce erosion and improve the condition of some archeological sites.

Camping Beaches

Camping area above the maximum water level permitted under MLFF dam operations (the water level at a flow rate of 25,000 cubic feet per second) decreased by 55% between 1998 and 2003, which is an average annual decline of 15% per year. Relative to total sandbar area, area suitable for camping continues to decline, indicating that factors other than sandbar erosion—particularly vegetation encroachment—contribute to loss of campable area.

Conclusion

The regulated Colorado River below Glen Canyon Dam is a dynamic system affected by a range of factors such as dam operations and other conditions, including drought. The timely and high-quality scientific monitoring and research provided by USGS scientists and their cooperators about the effects of dam operations and other natural and human-caused actions on downstream resources provides information essential to effective adaptive management of Colorado River resources below Glen Canyon Dam.

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This Fact Sheet and any updates to it are available online at
http://pubs.usgs.gov/fs/2009/3033/