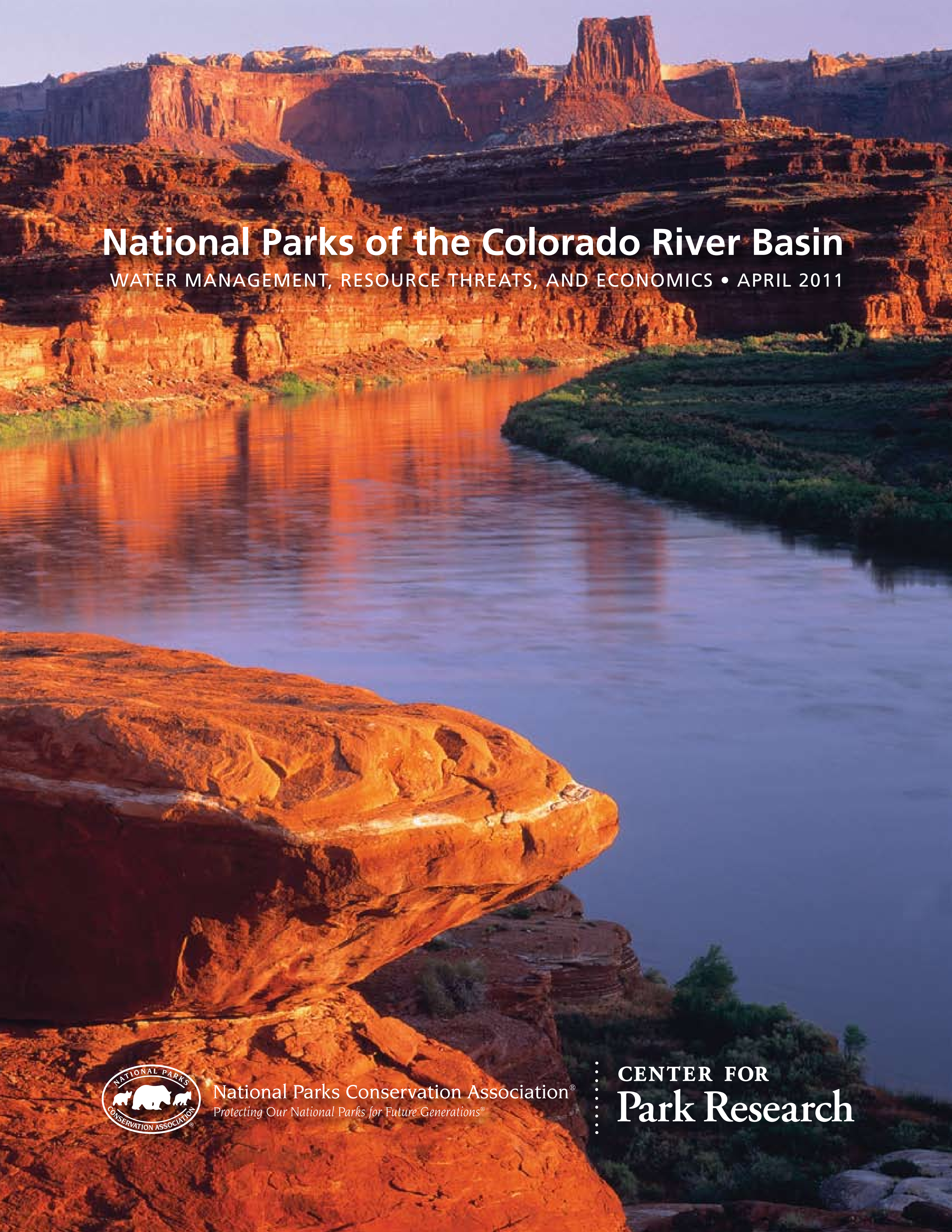

National Parks of the Colorado River Basin

WATER MANAGEMENT, RESOURCE THREATS, AND ECONOMICS • APRIL 2011

National Parks Conservation Association®
Protecting Our National Parks for Future Generations®

CENTER FOR
Park Research

National Parks Conservation Association®
Protecting Our National Parks for Future Generations®

SINCE 1919, NPCA has been the leading voice of the American people in protecting and enhancing our National Park System. NPCA, its members, and partners work together to protect the park system and preserve our nation's natural, historical, and cultural heritage for generations to come.

- More than 325,000 members
- Twenty-three regional and field offices
- More than 120,000 activists

CENTER FOR Park Research

More than a century ago, Congress established Yellowstone as the world's first national park. That single act was the beginning of a remarkable and ongoing effort to protect this nation's natural, historical, and cultural heritage.

Today, Americans are learning that national park designation alone cannot provide full resource protection. Many parks are compromised by development of adjacent lands, air and water pollution, invasive plants and animals, and increases in motorized recreation. Park officials often lack adequate information on the condition of critical resources within their parks, and knowledge about system-wide issues is also incomplete.

The National Parks Conservation Association initiated the State of the Parks program in 2000 to assess the condition of natural and cultural resources in individual national parks. To date, 80 parks have been studied. Recently, the Center for State of the Parks (CSOTP) turned its attention to issues affecting the National Park System as a whole. Because of this change in focus, CSOTP changed its name to the Center for Park Research (CPR). The Center for Park Research will deliver scientific information on systemic issues affecting national parks and their solutions. The goal of the new center remains the same: Provide information that will help policymakers, the public, and the National Park Service improve conditions in national parks, celebrate successes, and ensure a lasting legacy for future generations.

To learn more about the Center for Park Research, visit **www.npca.org/cpr** or contact:

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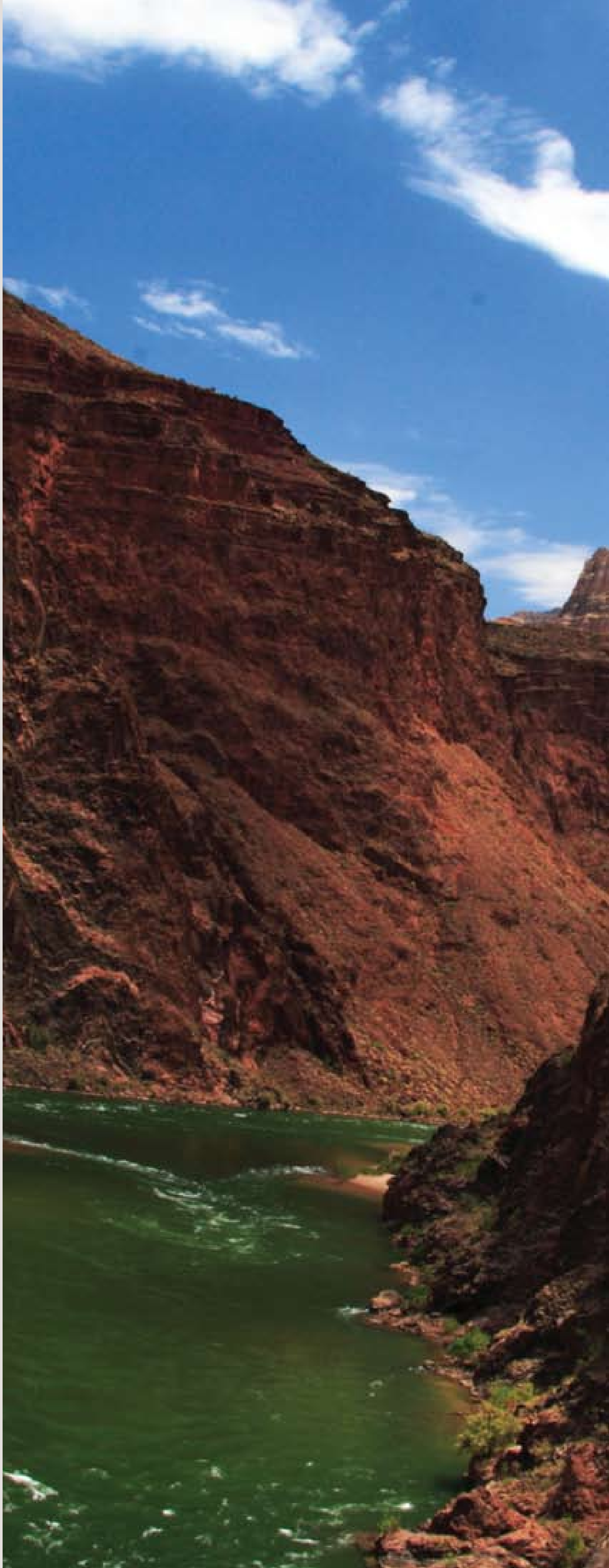

Cover: Colorado River in Canyonlands National Park. ©Tom Till.
Right: Colorado River in Grand Canyon National Park. ©maridav/123RF.

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A special note of appreciation goes to the Walton Family Foundation, whose generous support made this report possible. The project was also supported by a grant from the George S. and Dolores Doré Eccles Foundation.

Introduction

This report focuses on the ways in which management of the dams along the Colorado River and its major tributaries affects resources in five national parks in the Colorado River Basin. Dinosaur National Monument, Black Canyon of the Gunnison National Park, Canyonlands National Park, Glen Canyon National Recreation Area, and Grand Canyon National Park are case studies indicative of the effects that water management, specifically construction of large dams, has on natural and cultural resources throughout the basin, even in areas that should be receiving the highest protection available on public lands—units of our National Park System.

The National Park System of the United States includes 394 special places that were set aside in recognition of their abundant, ecologically or historically significant, and often unique resources. The National Park Service's mandate, according to the congressional act that established the agency in 1916, is to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

The National Parks Conservation Association's mission is to protect and enhance America's national parks for present and future generations. Fulfilling that mission includes ensuring the National Park Service is abiding by its own mandate, as well as examining cases where national park resources are being affected by human activities and taking action on behalf of parks.

Within the southwestern United States, nine national park units lie along the Colorado River and its major tributaries: Rocky Mountain National Park, Dinosaur National Monument, Black Canyon of the Gunnison National Park, Curecanti National Recreation Area (managed jointly with Black Canyon of the Gunnison), Arches National Park, Canyonlands National Park, Glen Canyon National Recreation Area, Grand Canyon National Park, and Lake Mead National Recreation Area. (Rainbow Bridge National Monument is managed jointly with Glen Canyon National Recreation Area and is accessible from Lake Powell, though it is located several miles from where the Colorado River ran through Glen Canyon prior to construction of Glen Canyon Dam.)

Left: Nine national parks lie along the Colorado River and major tributaries. Grand Canyon is shown at left. ©Scott Prokop/123RF.

THE COLORADO RIVER BASIN

MAP HERO

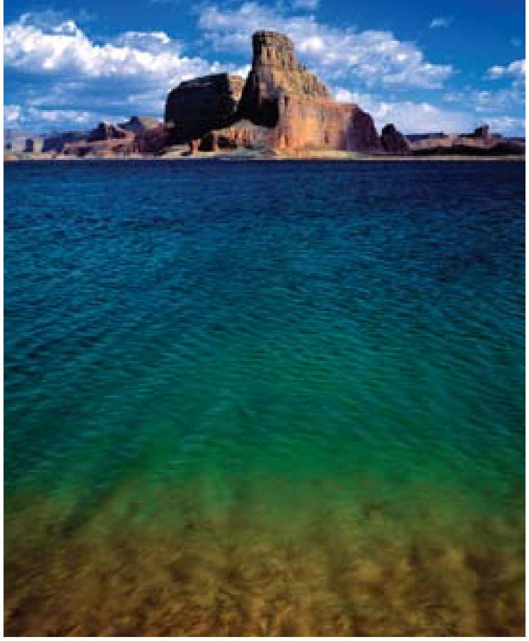
Fulfilling its mandate to conserve resources in these parks is a nearly impossible challenge for the Park Service due to water management activities in the Colorado River Basin that aim to provide a reliable supply of water to this arid but rapidly growing region of the country.

In particular, dams within the Colorado River Basin have fundamentally changed ecological and environmental processes by inundating and destroying natural habitats in some areas, creating highly unnatural flow regimes, trapping sediments that are critical for building and maintaining aquatic and riparian habitats, and altering natural water temperatures that foster native fish communities. As a result of dam operations, spring floods no longer occur as they once did, peak river flows have decreased while flows during non-peak periods (i.e., baseflows) have increased, and water temperatures are generally colder and no longer follow seasonal variations. Cultural resources have also suffered due to dams: Some resources were inundated as reservoirs filled, while others are affected by the same changes in flows and sediment supplies that harm natural resources.

Along with an accounting of how dam management strategies currently affect natural and cultural resources in five national parks, this report includes recommendations for ways to alter management strategies to ensure the preservation of park resources. It also includes information on the economic value of national parks in terms of recreation and passive-use values, as well as data on the economic value of hydropower and how changes to dam operations could affect power revenues.

This report includes recommendations for ways to alter management strategies to ensure the preservation of park resources; information on the economic value of national parks; and data on the economic value of hydropower and how changes to dam operations could affect power revenues.

Below: Dams and diversions affect flows of the Gunnison River in Black Canyon of the Gunnison National Park. ©Ron Wolf.



Key Findings

- **Dams have extensive and far-reaching impacts on national park resources.** Large dams in the Colorado River Basin have had and continue to have significant and far-reaching impacts on natural and cultural resources in national parks along the Colorado River and its tributaries. Because of these dams, rivers are now characterized by highly unnatural flow regimes rather than natural hydrological cycles. National parks that are included in this report and that are located directly downstream of dams—Dinosaur National Monument, Black Canyon of the Gunnison National Park, Grand Canyon National Park, and a portion of Glen Canyon National Recreation Area—experience reduced peak flows, enhanced baseflows, and the absence of consistent and predominant spring floods. Such effects and their consequences are also observed hundreds of miles downstream of dams, though often to a lesser degree, as information from Canyonlands National Park shows. The implications of these flow changes are far-reaching, affecting processes that shape landforms and plant communities along the river, wildlife and fish survival, and more.

- **Dams fragment the Colorado River system and interfere with natural ecological processes in national parks.** Before the dams were built, snowmelt from the Rocky Mountains thundered downhill, collected sediment and nutrients along the way, and deposited that sediment load throughout the river system and in the delta at the Gulf of California. Within the river, native fishes traveled upstream to spawn, and the larvae drifted back downstream to nursery grounds. Now, however, the dams around the basin have pinched off these pathways. Water is held behind dams until released. Sediment is trapped in upstream reservoirs and cannot be used to maintain important river and riparian habitats. The migratory ranges of native fishes are truncated. In effect, processes that in the past connected one end of the river to the other now are constrained to a few hundred river miles.

- **Dams and reservoirs have profoundly changed the appearance and sounds of the Colorado River and several of its major tributaries as they flow through national parks.** Glen Canyon and the upper portion of Black Canyon of the Gunnison are no longer recognizable as canyons carved by the river, now that they are filled by reservoirs. The deafening roar of the spring flood through the Canyon of Lodore in Dinosaur National Monument is subdued to the point that the sound no longer conveys a sense of the power that created this very place.

- **Changes in river temperatures and habitats wrought by dams have contributed significantly to declines in native fish populations.** Several species of endemic fish in the Colorado River Basin evolved to thrive in the relatively warm, sediment-rich waters present prior to the construction of major dams. The colder waters, changes in timing and quantity of water flows, loss of backwaters and floodplains, and other habitat-changing effects that have resulted from dams are primary factors in the decline of these fish species, as are other factors such as competition with and predation by non-native fishes and habitat loss due to non-native riparian plants. Declining populations of Colorado River Basin fishes provided much of the impetus for river managers to rethink dam operations. While the dams were initially operated to benefit power production and power revenues, the plight of endangered basin fishes focused public and scientific attention on dam operations. The Endangered Species Act has provided the strongest leverage to prompt research on river flows and consideration of ways to alter dam operations to benefit endangered fishes and, by extension, other resources. The ways in which resulting experimental changes to dam operations are affecting endangered fish populations are still unclear.

- **Non-native fishes pose problems for native species in national parks.** Non-native fish species (e.g., trout) have been introduced to the Colorado River Basin to create recreational fishing opportunities and to serve as bait fish; some of these fish spread beyond where they were initially introduced. Historical conditions in the Colorado River and the main stems of several tributaries were not suitable for cold-water fishes, but the cold, clear waters released from Glen Canyon Dam, Flaming Gorge Dam, and the Aspinall Unit have provided suitable habitat for trout. State wildlife agencies generally stocked and maintained these tailwater (i.e., immediately downstream of a dam or power-generation structure) fisheries with rainbow trout and

brown trout, and many are now world-renowned fisheries. In some cases, such as below Glen Canyon Dam, fish emigrating downstream from this location can seriously affect native fish populations by preying on them and competing with them for resources.

- **Non-native tamarisk alters the river channel, further restricting river flows.** The native vegetation that used to characterize the riparian habitats of the southern Colorado Plateau (e.g., cottonwoods and willows) has been replaced over large areas by invasive riparian plants, including tamarisk. At Dinosaur National Monument, resource managers are concerned that tamarisk could invade river cobble bars, further stabilizing these habitats and leading to river channel changes that could affect the breeding habitats of endangered fishes. River channel narrowing at Canyonlands National Park and just upstream, due in part to tamarisk invasion, has already been documented. Narrowing occurred prior to the construction of upstream dams, and channels continued to narrow after dams were built, indicating that changes to the river channel in Canyonlands are likely a complex product of the dams and the invasive tamarisk.

- **Incomplete or inadequate information is available at some national parks.** Some national parks within the Colorado River Basin have participated in research on the ways dam operations affect natural and cultural resources, while scientific understanding of such impacts is much more limited in other parks, due to a lack of financial resources and programs. Much of the current understanding of dam impacts comes from the extensive research and monitoring program focused on Grand Canyon National Park. All the national parks along the river have unique resources. Spreading attention across those parks and encouraging information sharing among them, which currently does not regularly happen, would deepen the understanding of dam impacts basin-wide and could lead to the development of effective management strategies.

- **Dams affect prehistoric and historic cultural resources within national parks.** Sediment trapped behind dams is no longer available to replenish what erodes from riverbanks, leading to the exposure of archaeological sites. Increased erosion of riverbanks downstream of dams can undermine terraces that support historic structures, causing them to collapse. Regulation of river flows and the creation of reservoirs have made historic cabins, archaeological sites, rock art panels, and other cultural resource sites, which were once remote and difficult to access, into routine destinations for recreational boaters. Such visitors may inadvertently or deliberately harm the resources. In addition, changing water levels in reservoirs periodically inundate or expose cultural resources, leaving them open to damage from the elements and vandals. It isn't clear which agency—the Bureau of Reclamation or the National Park Service—should be responsible for managing newly exposed cultural resources at places such as Lake Powell.

- **The economic value of national parks must be recognized when decisions are made that affect park resource health and the visitor experience.** Examinations of park visitation, estimates of visitor spending, models that represent the movement of dollars through the economy, and surveys of park visitors and supporters all provide evidence of the value of national parks to local economies and American citizens throughout the country. In the Colorado River Basin, spending estimates and estimates of total economic impacts of all park visitors indicate that the national parks of the Colorado River Basin contribute hundreds of millions of dollars to local economies.

- **Changes to dam operations to reduce impacts on endangered fishes and other resources would have relatively minimal effects on hydropower revenues.** Available data indicate that changes in dam operations that have been made, to date, in order to benefit national park resources have resulted in relatively small losses of hydropower revenue, and that proposed operational changes would also have relatively minor impacts on revenues.

Top (Far Left): Flaming Gorge Dam. ©R. Bruce Reed. **Middle Left:** Lake Powell and Gunsight Butte in Glen Canyon National Recreation Area. ©Tom Till. **Middle Right:** Hiker above the Colorado River near the beginning of the Grand Canyon. ©Amygdala Imagery (istockphoto). **Far Right:** Native Colorado River cutthroat trout. ©Bryan Gregson.

A Growing Need for Water

In the arid West, water is a precious and essential resource in high demand. Rainfall is not sufficient to irrigate crops or provide for the needs of growing urban populations. Other sources of water must be tapped. These include rivers fed by mountain snowmelt as well as groundwater that has accumulated and been stored over centuries. The Colorado River and its tributaries are primary water providers for western states with increasing water demands, including Wyoming, Colorado, Utah, New Mexico, Arizona, Nevada, and California. On average, these states of the Colorado River Basin receive just 14 inches of rain per year. As a result of the need to supplement this water supply to serve basin water consumers, the Colorado River system is one of the most heavily regulated and highly managed in North America.

The Colorado River Basin covers 242,900 square miles and portions of seven U.S. states and Mexico (see the map on page 4). People living in this region have long sought methods to control the availability of water to sustain their ways of life. Archaeological evidence indicates prehistoric peoples who lived in present-day Arizona practiced floodwater farming along the lower Colorado River, and possibly ditch irrigation in the Grand Canyon. Spanish missions practiced some irrigation in the 17th and 18th centuries, also mostly on the lower Colorado River along what is now the border between Arizona and California. Widespread water diversion throughout the Colorado River system began in the second half of the 19th century, when pioneers moved into the area and began to use water for mining operations, agricultural irrigation, and municipal water systems. Initially, most of these diversions were small-scale efforts by individuals. As time went on, water users began to band together to develop larger diversion projects. Farmers on the plains of northeastern Colorado diverted the headwaters of the Colorado River (then known as the Grand River in Colorado) east over the Continental Divide, and another project on the same river watered the Grand Valley, a fruit-growing region of western Colorado. Further downstream near the terminus of the river, plans to divert the river to irrigate California's Imperial Valley were being discussed in the 1870s, although it was several decades before canals were built and put into use.

Left: Las Vegas, Nevada, is one of the most rapidly growing urban areas in the Colorado River Basin. ©iofoto.

As water became more available as a result of irrigation projects, populations grew rapidly. Arizona, which is almost entirely within the Colorado River Basin, grew from 122,931 people in 1900 to nearly 6.4 million people in 2010.

Relatively speaking, the Colorado River Basin was sparsely settled during the 1800s. In order for the region to support a larger population and be suitable for producing food to feed that population, water supplies needed to be enhanced. As water became more available as a result of irrigation projects, populations grew rapidly. Arizona, which is almost entirely within the Colorado River Basin, grew from 122,931 people in 1900 to nearly 6.4 million people in 2010. Nevada grew from 42,335 people in 1900 to 2.7 million in 2010. These states, ranked as the top two states in terms of percent population change over the last ten years (between 2000 and 2010), are home to two of the largest and most rapidly growing urban areas in the Colorado River Basin: Phoenix and Las Vegas. Population growth within the Colorado River Basin and along the Front Range of Colorado led to increased demands for water, while water storage and delivery projects constructed during the 20th century allowed for further population growth. The self-perpetuating cycle of increased population growth, followed by increased water demands, and addressed by additional water storage projects and intense river management—which support further growth and fuel greater demand—continues today.

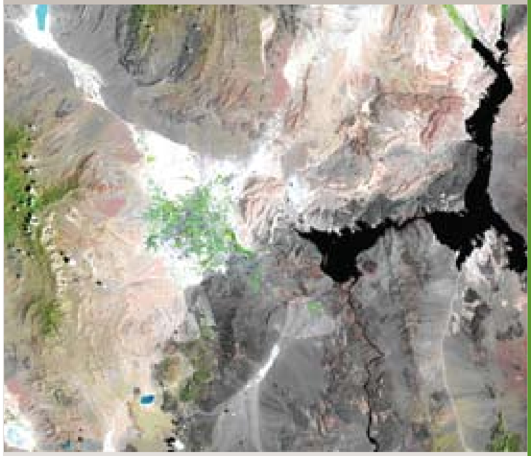
With so many acres of potential farmland to irrigate and households and industry to supply, it soon became clear that there was a need for rules governing how the Colorado River Basin's waters were allocated. By the early 20th century, California, Nevada, and Arizona were developing large-scale irrigation projects faster than upstream states. Those upstream states were concerned that downstream users would claim the majority of the river's water under prior apportionment, a system that allowed anyone to claim the waters flowing in a creek or river, with the priority of one user's right over another's based on the chronological order of claim and actual use of the water.

The seven basin states worked together to develop an agreement apportioning the water of the Colorado River Basin. Titled the Colorado River Compact, the agreement was signed by the states in 1922 and ratified by six of the states in 1929 (Arizona did not ratify the agreement until 1944 because of a conflict with California over apportionment of the water between those two states). The compact forms the core of the body of legislation, compacts, and judicial decisions known as the "Law of the River."

The compact divides the Colorado River Basin into upper and lower portions. Colorado, Wyoming, Utah, and New Mexico comprise the Upper Basin, and Arizona, Nevada, and California comprise the Lower Basin. The compact divides the waters of the Colorado River system between the Upper and Lower Basin states and is meant to eliminate water controversies among them, designate the relative importance of different uses of the water, and "secure the expeditious agricultural and industrial development of the Colorado River Basin, the storage of its waters, and the protection of life and property from floods" (Colorado River Compact, 1922). The compact allows for hydropower generation, but it makes this use subordinate to domestic and agricultural uses. The compact does not set a water right for each state, but rather it sets rights for the Upper Basin and the Lower Basin. Each basin is apportioned 7.5 million acre-feet (7.5 MAF) of water per year, based on the average flow of 16 MAF per year recorded during the 1910s (a period that history has shown to have been relatively wet). Excess flow above the designated apportionment is to be divided equally, provided it is needed for domestic and agricultural use. Any pre-existing water rights at the time the compact was signed are to be fulfilled out of each basin's apportionment. Both basins share the responsibility to fulfill a 1.5 MAF annual water delivery obligation to Mexico under international treaty.

To ensure these water needs could be met, dams and water storage projects were built along the Colorado River and its tributaries (see "Major Dams of the Colorado River Storage Project" on page 23). These dams radically altered the flow of the rivers, resulting in consequences for the diverse natural and cultural resources resident within much of the Colorado River Basin. Many of these resources—such as habitats formed by naturally occurring floods and low flows, diverse endemic fish species, prehistoric archaeological sites, and cultural landscapes, to name a few—are greatly influenced by flows in the Colorado River and its tributaries. In addition, many of these resources were supposed to be protected due to their inclusion within national parks that had been established either prior to the Colorado River Compact or prior to the construction of dams built as part of that agreement. Even so, designation as national parks has not prevented resource damage caused by dams.

Concerns about water scarcity due to increased consumer demands (e.g., new water diversion proposals), as well as uncertainty over changes in precipitation due to climate change, will make water management even more complicated in the decades to come. Determining how current water management strategies, primarily the operation of large dams, have affected and continue to affect national park resources provides an important baseline of information that will be critical as decisions pertaining to water allocation, supply, flow management, and hydropower generation are made. This report contributes to that baseline information by identifying and examining the consequences of dam management strategies on national park resources.



Opposite Page: Aerial view of a Colorado River aqueduct supplying water to agricultural areas. ©iofoto (istockphoto). **Above:** Landsat views of Las Vegas and Lake Mead, the reservoir created by Hoover Dam, from 1984 **(top)** and 2007 **(bottom)** show the increasing urban sprawl of Las Vegas, Nevada, and the shrinking of the reservoir. ©Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey, compiled by Ralph Mayer.

National Parks of the Colorado River Basin

This report focuses on the ways in which management of the dams along the Colorado River and its major tributaries affects resources in Dinosaur National Monument, Black Canyon of the Gunnison National Park, Canyonlands National Park, Glen Canyon National Recreation Area, and Grand Canyon National Park (see pages 14-21 for maps of each park). These parks exemplify the effects that water management, specifically construction of large dams, has on natural and cultural resources throughout the national parks within the basin—areas that should be receiving the highest protection available on public lands.

Dinosaur National Monument

In summer 1909, paleontologist Earl Douglass from the Carnegie Museum made an exciting discovery in the northeastern corner of Utah. Exploring the Uintah Range for fossils, Douglass found eight vertebrae of *Apatosaurus,* a dinosaur that lived in the Late Jurassic epoch (146-157 million years ago). The bones were part of the entire skeleton of a 65-foot-long, 16-foot-tall plant eater (formerly *Brontosaurus*). This was just the beginning of what turned out to be the discovery of an extraordinarily rich fossil deposit in the hillside above the Green River. Douglass and the Carnegie Museum spent the next 13 years excavating the site, which became a popular attraction for the local community and schoolchildren.

In October 1915, President Woodrow Wilson used his authority under the Antiquities Act of 1906 to proclaim 80 acres of the area as Dinosaur National Monument. On the recommendation of the National Park Service, President Herbert Hoover expanded the monument by approximately 8,000 acres in 1931, to include Split Mountain Gorge and the portion of the Green River therein, as well as nearby areas containing prehistoric rock art, in order to protect their scenic and geologic values. The expansion order noted that a portion of the new addition had already been claimed by the federal government for reclamation and hydropower purposes, although no dams had yet been built.

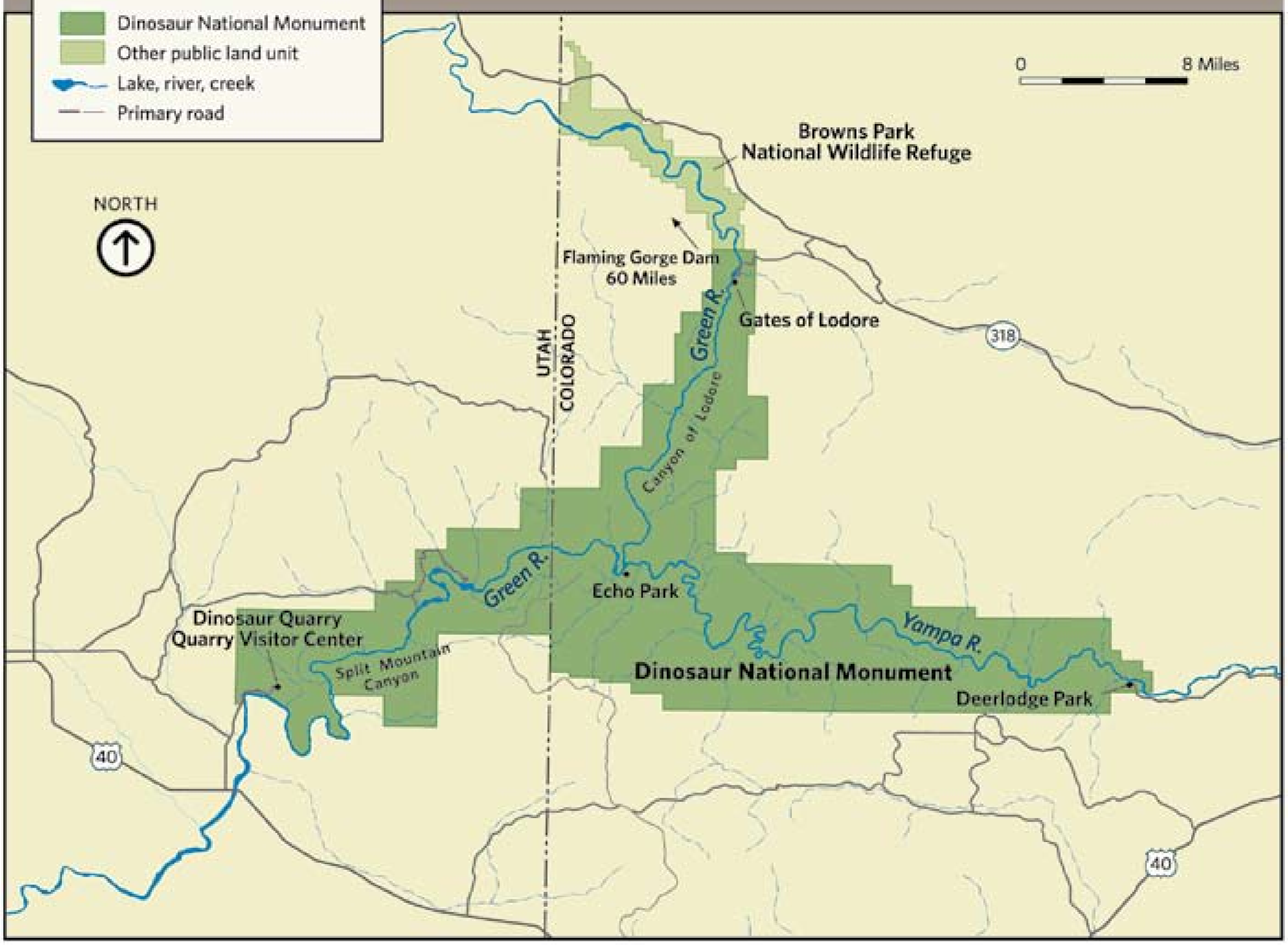
Left: The Green River (pictured) and Yampa River flow through Dinosaur National Monument. ©John and Lisa Merrill.

Through the 1930s, river runners publicized the grandeur of the river canyons, and support grew for expanding the monument or creating a national park that would encompass the canyons. Meanwhile, the Bureau of Reclamation (formerly called the Reclamation Service) had been considering dam sites along the Green River since early in the century, for flood control, hydropower, and water storage purposes. Three potential dam sites had been identified: Flaming Gorge on the Green River upstream of the national monument, Echo Park at the confluence of the Green and Yampa Rivers, and Split Mountain, on the Green River below the confluence.

Dinosaur National Monument's resources include fossils, interesting geological formations, stunning scenery, 10,000 years of cultural history, and more.

In July 1938, President Franklin Roosevelt signed an executive order incorporating the canyon country along the Green and Yampa Rivers into Dinosaur National Monument in recognition of the scenic and geologic values of the river canyons, expanding the monument to more than 200,000 acres straddling the border between Utah and Colorado. Technically, the order was subject to the existing hydropower and reclamation claims on the river and surrounding lands, but precedent at the time led the National Park Service to believe no dams would be built in the newly expanded monument. However, in the 1950s the Bureau of Reclamation moved forward with plans to build dams at all three previously identified locations, two of which, Echo Park and Split Mountain, were within the boundaries of the monument. A massive

DINOSAUR NATIONAL MONUMENT



MAP HERO

public outcry against the destruction of the protected scenic canyons at Echo Park and Split Mountain eventually led to the dismissal of plans for those two dams, and only the dam at Flaming Gorge was built, 45 miles upstream of Dinosaur National Monument on the Green River.

Dinosaur National Monument's resources extend beyond fossils, interesting geological formations, and stunning scenery, encompassing 10,000 years of cultural history evidenced by prehistoric rock art and a historic log cabin as well as habitats supporting more than 1,000 native species of plants and animals. Scenic drives, hiking trails, river rafting trips, guided tours, and more give visitors many choices for exploring the park's resources. In 2010, nearly 198,000 people visited the park.

Black Canyon of the Gunnison National Park

The Gunnison River originates in the central Rocky Mountains of Colorado and flows west to its confluence with the Colorado River at Grand Junction in western Colorado. It drains a high-altitude basin of approximately 4,200 square miles on the eastern edge of the Colorado Plateau through a single outlet, the Black Canyon of the Gunnison. Fifty-three miles long, more than 2,000 feet deep in some places, and as narrow as 40 feet across at the river, the Black Canyon of the Gunnison is an astonishing testament to the river's power to shape the landscape.

Residents of western Colorado began advocating for designation of the Black Canyon of the Gunnison as a national monument in the 1920s, seeing its scenic qualities as a potential tourism draw for the region. In 1930, the local Lions Club constructed a road to and along the canyon's south rim, opening the area for automobile travel. Congressman Ed Taylor contacted the National Park Service to inquire about designation as a national monument, but the National Park Service initially had no interest, due to lack of funds, concerns about private ownership of some of the lands, and a possible treaty obligation to pay the Ute Indians for a portion of the land. It was not until Roger Toll, superintendent of Yellowstone National Park and the agency's chief investigator of new park areas, visited the Black Canyon area in 1932 and wrote a favorable report that the National Park Service took an interest in the area.

In 1933, President Herbert Hoover used his authority under the Antiquities Act to designate about 17,600 acres as Black Canyon of the Gunnison National Monument, to preserve the scenic, scientific, and educational value of the gorges as well as the wild character of the river. Part of the land had already been selected by the Bureau of Reclamation as a potential dam site; designation as a national monument did not preclude future development for hydropower and for water storage and use.

In the 1960s and 1970s, the Aspinall Unit of the Colorado River Storage Project was built on the Gunnison River immediately upstream of Black Canyon of the Gunnison in what is now Curecanti National Recreation Area. The three dams of the Aspinall Unit affect the flow of the river through Black Canyon of the Gunnison, but because the dams are upstream and the reservoirs did not flood the main part of the canyon in the national monument, there was no significant public opposition to these dams at the time they were built. The Bureau of Reclamation manages the dams. Another water project that affects flow in the Gunnison River is the 30,650-foot-long Gunnison Tunnel, just upstream of the boundary of Black Canyon of the Gunnison National Park. It was dedicated in 1909 and diverts water from the Gunnison River to support agriculture within the Uncompahgre Valley to the southwest.

Above: The scenic quality of the Black Canyon of the Gunnison contributed to its designation as a national monument and then a national park. ©Bart Everett.

Fifty-three miles long, more than 2,000 feet deep in some places, and as narrow as 40 feet across at the river, the Black Canyon of the Gunnison is an astonishing testament to the river's power to shape the landscape.

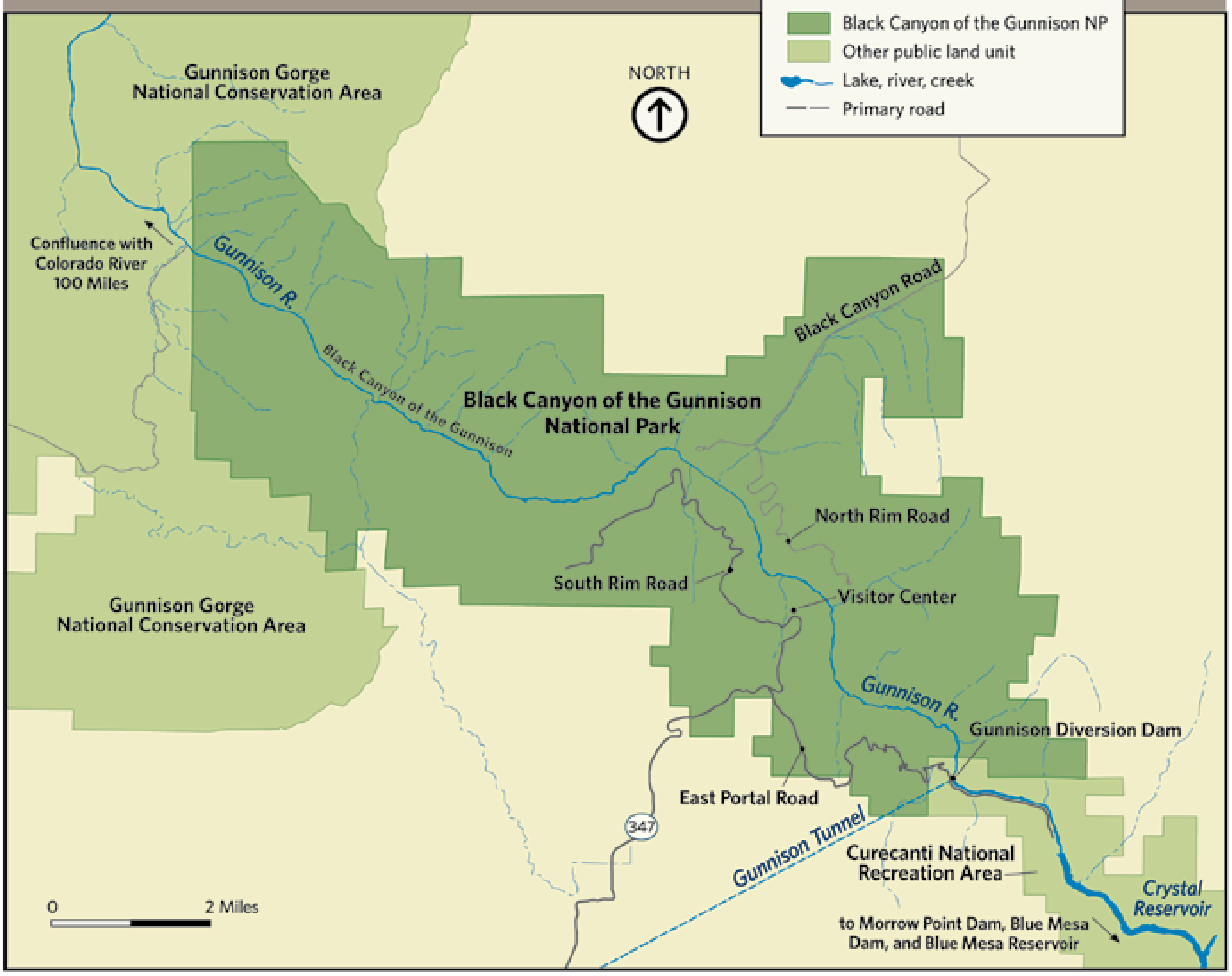
Black Canyon of the Gunnison National Monument gradually increased in size over the years as the result of several boundary changes. In 1976, a portion of the monument was designated wilderness, including about 12 miles of the river and its immediate corridor. In 1999, Congress changed Black Canyon of the Gunnison's designation from a national monument to a national park. The park currently encompasses 32,950 acres, including 14 miles of the canyon and adjacent uplands along the north and south rims. The 40,000-acre Curecanti National Recreation Area, which borders the park to the east and encompasses the Aspinall Unit dams and reservoirs, is managed jointly with Black Canyon of the Gunnison National Park.

The 40,000-acre Curecanti National Recreation Area, which encompasses the Aspinall Unit dams and reservoirs, is managed jointly with Black Canyon of the Gunnison National Park.

Black Canyon of the Gunnison supports habitats that change as one travels from the canyon's rim down to the river's edge—going from pinyon-juniper forests to boxelder and narrowleaf cottonwood stands, with many habitat transitions in between. Each habitat hosts a different wildlife community.

Although there are no known cultural resources within the deep and narrow river gorge in Black Canyon of the Gunnison National Park, the upper reaches of the canyon

BLACK CANYON OF THE GUNNISON NATIONAL PARK



MAP HERO

itself, now within the boundaries of Curecanti National Recreation Area, have a rich human history. This history includes stories of 18th- and 19th-century explorers, an early 20th-century water diversion tunnel that continues to supply water from the Gunnison River to the agricultural fields of the Uncompahgre Valley, railroads, mining, ranching, and tourism. In addition, the views of the canyon and the sound of the river from scenic overlooks along the rim have been important parts of the cultural heritage of the region since the late 19th century.

Visitors to Black Canyon of the Gunnison National Park can take advantage of opportunities to hike, camp, watch wildlife, or fish for trout. The Gunnison River within the park is designated by the Colorado state wildlife commission as a Gold Medal Water & Wild Trout Water, which means there are excellent opportunities to catch large trout. In 2010, more than 176,000 people visited the park.

Canyonlands National Park

Formal interest in protecting the scenic values of the canyon country surrounding the confluence of the Green and Colorado Rivers in southeast Utah began in the 1930s, when Secretary of the Interior Harold Ickes recommended to President Franklin Roosevelt that a national monument be established incorporating most of what is now Canyonlands National Park and Glen Canyon National Recreation Area. His recommendation was opposed by local residents who feared the loss of ranching lands, mining claims, and potential hydropower generated by the river—activities and development that would be prohibited in a national monument. As a result, nothing came of Ickes's recommendation at that time.

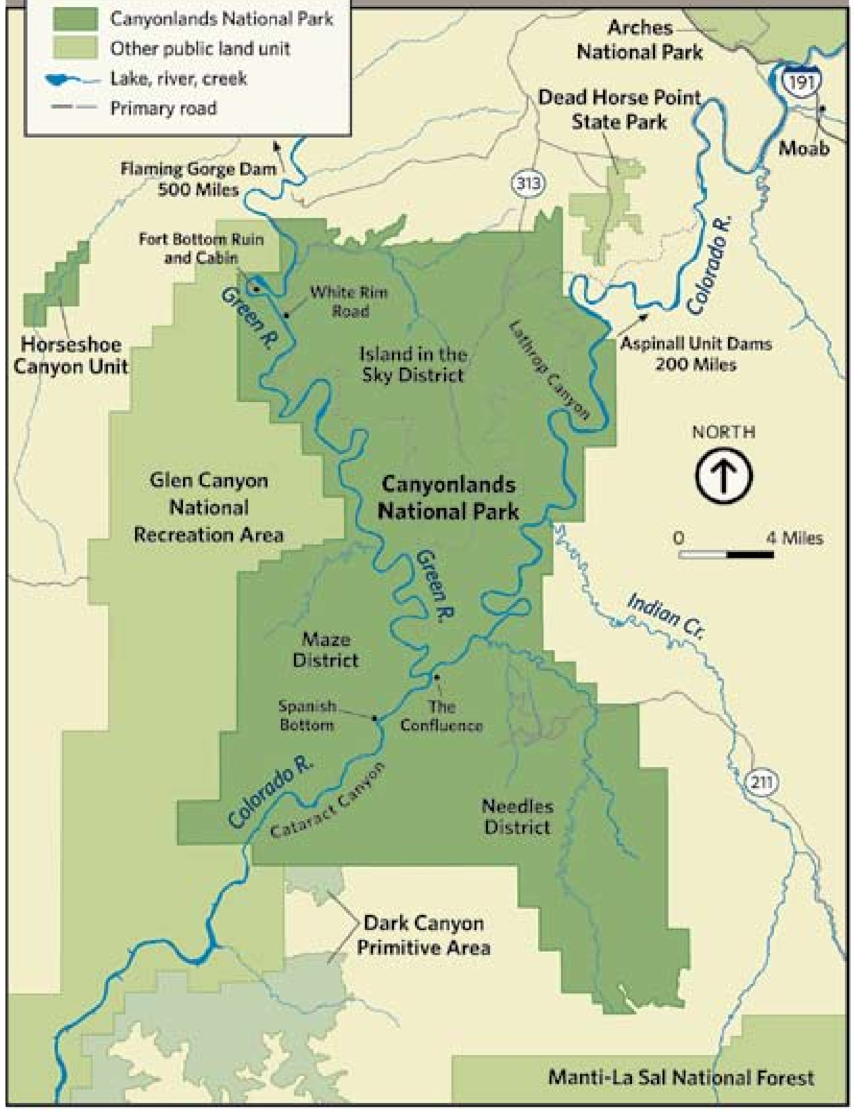
Yet support for federal protection of the area did not die. In the 1950s, Bates Wilson, superintendent of Arches National Monument, began advocating for a new park in this region. Secretary of the Interior Stewart Udall visited the area in 1961 and began lobbying on Capitol Hill for the creation of a park of approximately 600,000 acres comprised of lands managed by the Bureau of Land Management. Members of Utah's congressional delegation and many Utah residents remained opposed to the idea of a national park that would preclude commercial use, especially ranching and mineral development. Since the beginning of the Cold War nuclear era after World War II, uranium reserves in the mountains of southeastern Utah offered the promise of economic riches to this remote and underdeveloped region. In an attempt to compromise, proposals were floated to create a state park, or a national park that allowed multiple commercial uses. Utah Senator Frank "Ted" Moss authored legislation designating a smaller park. This idea eventually gained the support of other members of Congress after three years of wrangling over mineral rights, commercial access, and the economic benefits of the park to rural southeastern Utah. On September 12, 1964, President Lyndon B. Johnson officially created Canyonlands National Park. The original area of the park was 257,640 acres, considerably smaller than Udall's original plan. It was expanded in 1971 to its current size of 337,598 acres.

Canyonlands National Park encompasses the spectacular plateaus, mesas, and river canyons of the Colorado and the Green Rivers where they meet in southeastern Utah. The park includes 47 miles of the Green River as it meanders to its meeting with the Colorado River, and more than 50 miles of the Colorado River. The park was established to preserve the unique landscape and the extensive prehistoric rock art found throughout the canyons. In addition to rock art, the remains of camps used by cowboys who tended livestock in the canyons are evidence of the region's past

Above: Desert bighorn sheep in Canyonlands National Park. ©Mike Puchreiter. **Below:** Prehistoric pictographs in Canyonlands National Park. ©James Margolis.

Bighorn sheep, a species that once inhabited much of the United States but declined precipitously due to hunting, habitat changes from livestock grazing, and disease passed from domestic sheep, found refuge in part of Canyonlands National Park.

CANYONLANDS NATIONAL PARK



MAP HERO

inhabitants. Throughout the park, fragile biological soil crusts—assemblages of cyanobacteria, green algae, mosses, fungi, liverworts, and lichens—help stabilize underlying soils, prevent erosion, alter water infiltration, and benefit the germination and growth of some native plants. Bighorn sheep, a species that once inhabited much of the United States but declined precipitously due to hunting, habitat changes from livestock grazing, and disease passed from domestic sheep, found refuge in part of Canyonlands National Park. After the park was created, some of those animals were used to repopulate other national parks where the species had been extirpated. Hiking, backpacking, kayaking, rafting, mountain biking, and stargazing are just a few of the recreational experiences the park offers visitors. In 2010, nearly 436,000 people visited the park.

There are no dams or diversions within Canyonlands National Park; the nearest major dams upstream are the Aspinall Unit on the Gunnison River in Curecanti National Recreation Area and Flaming Gorge Dam on the Green River, both more than 200 river miles upstream from Canyonlands National Park.

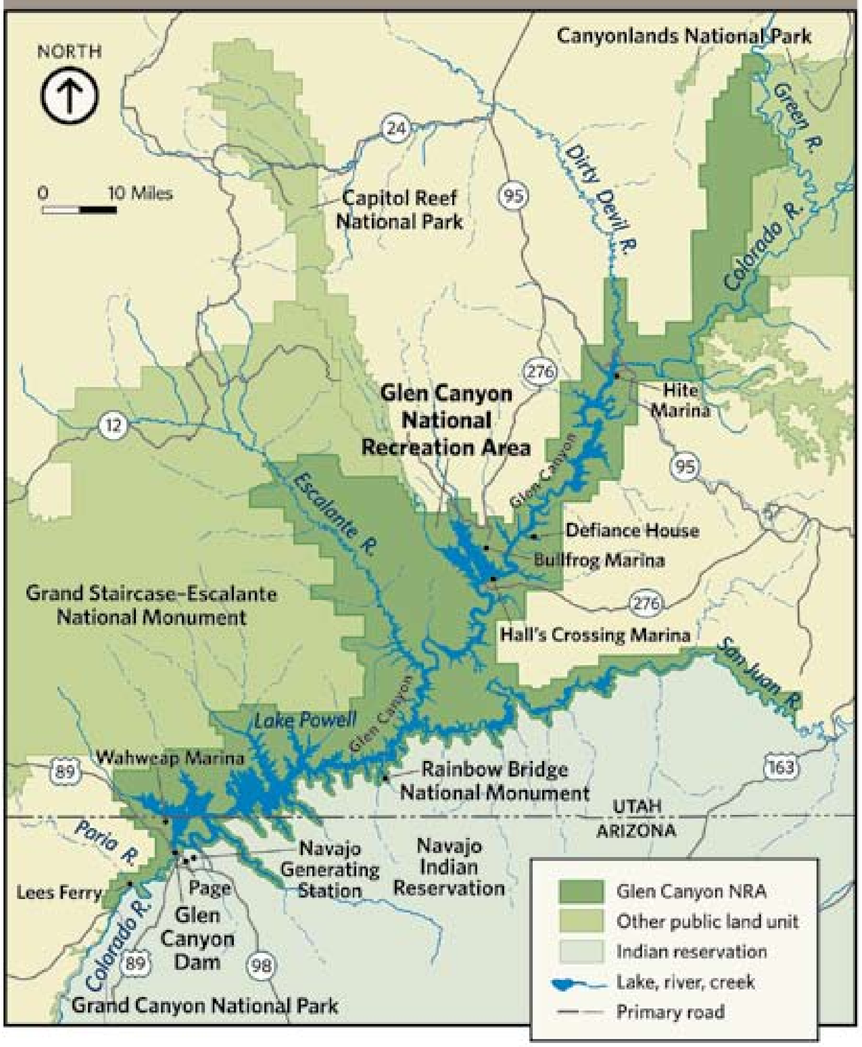
Glen Canyon National Recreation Area

Glen Canyon National Recreational Area is best known for its reservoir, Lake Powell, which was formed by the completion of the Glen Canyon Dam on the Colorado River in 1963. The recreation area was established in 1972 and covers more than 1.25 million acres. According to the legislation that established the national recreation area, it was created both to provide outdoor recreational opportunities and to preserve scenic, scientific, and historic features.

The Colorado River flows into Lake Powell at the northeast end of the lake. Other major tributaries that flow directly into the reservoir include the San Juan, Dirty Devil, and Escalante Rivers. Below the dam, the Colorado River travels 15 miles within Glen Canyon National Recreation Area before entering Grand Canyon National Park.

Glen Canyon National Recreation Area is one of several units in the National Park System created to take advantage of the recreational opportunities in and around a major reservoir. There are four major boat marinas on the lake (Wahweap, Bullfrog, Hall's Crossing and Antelope Point). In addition to enjoying water-based activities

GLEN CANYON NATIONAL RECREATION AREA



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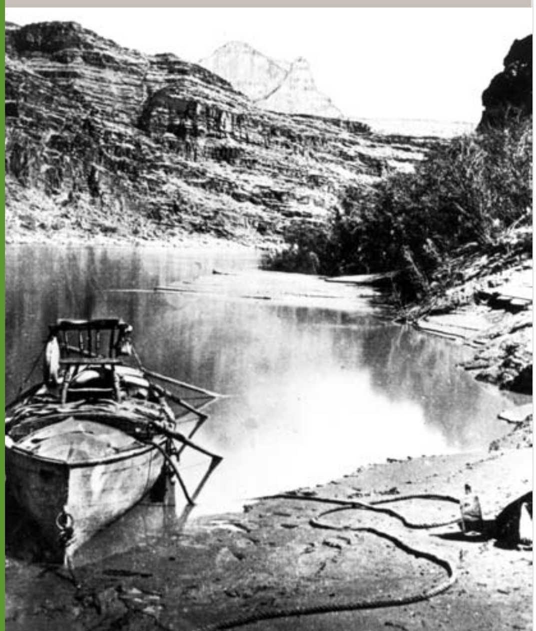
Above: Lake Powell in Glen Canyon National Recreation Area. ©Hugh Caton (istockphoto).

such as boating, fishing, and swimming, visitors to Glen Canyon National Recreation Area can mountain bike along primitive roads, hike some of the park's many miles of trails, and camp in its scenic backcountry. The park also features scenic vistas, geologic formations, and archaeological resources of national significance, such as the Ancestral Puebloan structure known as Defiance House and the pictograph panels at Davis Gulch. In 2010, more than 2.1 million people visited the park.

Grand Canyon National Park

It was explorer John Wesley Powell who first drew attention to the Grand Canyon's scenic wonders, decades before Arizona became a state. Newspaper accounts of his 1869 expedition down the Colorado River and through the Grand Canyon, and later publication of his expedition reports, attracted adventurous tourists to the region, and railroads and amenities followed in the 1890s. As tourism to the area increased, it matched a growing movement in the nation to protect its resources. The Grand Canyon, once considered a geographic impediment to settlement of the West, had become a nationally known tourist destination worthy of protection.

Many of the area's residents clamored to have the canyon declared a national park to increase its status and fame as a tourist destination. In 1887, U.S. Senator Benjamin Harrison introduced a bill in Congress to declare the Grand Canyon a national park, but it was unsuccessful. In 1893, when he was president of the United States, Harrison took the opportunity to provide initial protection for the canyon by designating it as a forest reserve.



Above: Major John Wesley Powell's boat the *Emma Dean* moored on a bank of the Colorado River in the Grand Canyon, 1871/2. U.S. Geographical and Geological Survey of the Rocky Mountain Region (Powell Survey). ©J.K. Hillers, U.S. Geological Survey.

After a visit to the Grand Canyon in 1903, President Theodore Roosevelt expressed a belief that more was needed to ensure the future preservation of this natural wonder. Following passage of the Antiquities Act in 1906, Roosevelt used his authority under the act to issue a presidential proclamation in 1908 that established an area of about 600,000 acres as Grand Canyon National Monument, based on its value as an object of scientific interest.

The monument was upgraded to national park status in 1919. An adjoining area was designated Grand Canyon National Monument in 1932, and Marble Canyon National Monument was designated immediately upstream of Grand Canyon National Park in 1969. In 1975, President Gerald Ford signed legislation that incorporated those monuments into Grand Canyon National Park, doubling its size to 1.2 million acres. The Grand Canyon itself is 277 miles long, stretching (from North Rim to South Rim) an average of ten miles across, with an average depth of one mile. At its widest, the Grand Canyon stretches 18 miles rim to rim; at its narrowest, it is 600 feet at Marble Canyon. The park includes the canyon, the Colorado River running through it, and acreage at the top of the canyon on both sides of the rim.

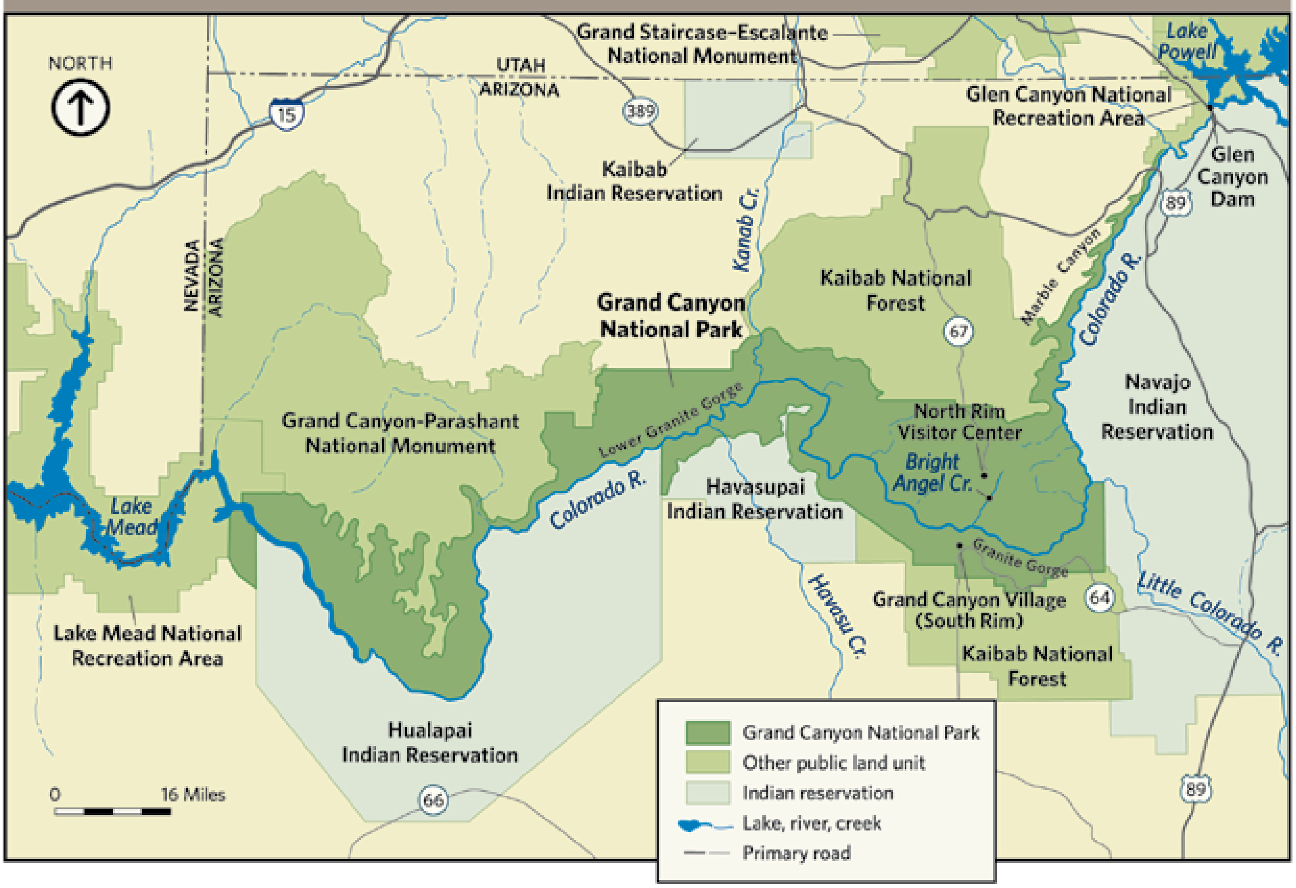
Three of the four desert systems in North America—Great Basin, Sonoran, and Mojave—are represented within Grand Canyon National Park, and the park is home to nine plant and animal species found nowhere else on Earth. Twenty-three more regionally endemic species also inhabit the park. Evidence of the Grand Canyon's human history spans nearly 12,000 years. The canyon and nearby features are sacred locations for the Hopi, Zuni, and Pai peoples. Europeans first began to explore the region in the 16th century, with Spanish missionaries arriving in the 18th century, expeditions by John Wesley Powell in the 19th century, mining and other pioneer settlement in the 19th century, and then a growing tourism movement in the 20th century. Thousands of archaeological sites, nearly 900 historic structures, and 889,000 museum and archival items document the Grand Canyon's human history.

In the 1960s, the federal government seriously considered plans to build dams in Grand Canyon at Marble Canyon just below Lees Ferry in the northern end of the park, and at Bridge Canyon in Lower Granite Gorge. Grand Canyon's status as a national park did not protect it from consideration as a dam site, although it played a significant role in the strong public opposition to the dams. The plans were abandoned, and no further attempts to dam the river within the park have been made. In the 1970s and 1980s, public concern mounted about the effects that Glen Canyon Dam, located 15 miles upstream of Grand Canyon National Park, were having on the park. This concern led to the passage of the Grand Canyon Protection Act of 1992, which mandates the Bureau of Reclamation to operate Glen Canyon Dam so that the resources of Grand Canyon National Park are not harmed. This goal has not been achieved, as detailed in "Effects of Dams on Natural and Cultural Resources in National Parks within the Colorado River Basin" on page 29.

In 2010, nearly 4.4 million people visited Grand Canyon National Park. River rafting trips, mule trips into the canyon, hikes along the rim or into the canyon, and ranger programs are some of the ways visitors enjoy the scenic splendor and multitude of learning opportunities Grand Canyon National Park offers.

Grand Canyon National Park is home to nine plant and animal species found nowhere else on Earth.

GRAND CANYON NATIONAL PARK



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Major Dams of the Colorado River Storage Project

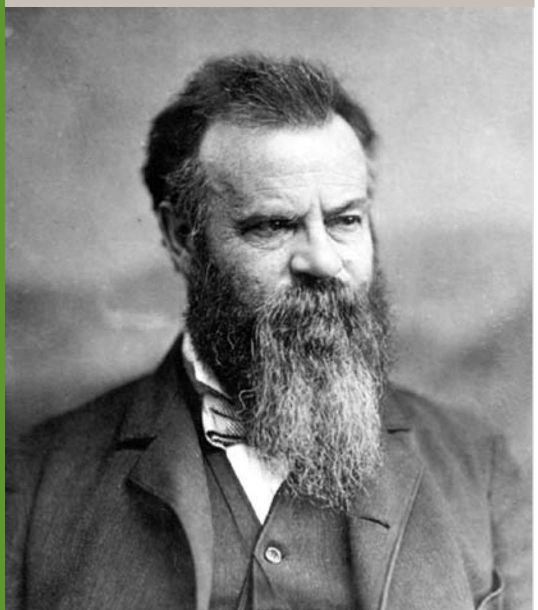
As described above, three of the five national parks examined in this report are located immediately downstream of major dams, one is further downstream of several dams, and one was created largely to recognize the recreational opportunities provided by the reservoir created by a dam. The dams affecting or associated with these national parks were built to help satisfy water delivery obligations outlined in the Colorado River Compact, as described in "A Growing Need for Water" on page 9. Under the compact, the Upper Basin states (Colorado, Wyoming, Utah, and New Mexico) are required to ensure 75 million acre-feet (MAF) of water are delivered to the Lower Basin states (Arizona, Nevada, and California) in every rolling 10-year period. During the past 90 years, annual flow in the Colorado River has varied widely, from as little as 4 MAF to as much as 22 MAF. After the compact was signed, there were several periods of successive years of lower-than-average flow, straining the Upper Basin's ability to deliver the agreed-upon allocation of water to the Lower Basin. In the 1930s, the Upper Basin states began conferring with the Bureau of Reclamation to plan water developments that would provide a way to store water in excess of the annual allocation in wet years, in order to provide the full allocation in dry years without having to reduce consumption in the Upper Basin. Investigation and planning studies continued into the 1940s.

The ultimate result was the Colorado River Storage Project, a system of dams and reservoirs on the main stem of the Colorado and its major tributaries, designed to store enough water to allow the Upper Basin to meet its delivery commitment. The Colorado River Storage Project included power plants for hydropower generation at the major dams, the revenue from which would repay the construction costs over a 50-year period. Additional smaller elements of the project provided for irrigation needs throughout the Upper Basin. Not all of the elements included in the Colorado River Storage Project were built. The four major units eventually constructed as part of the project are Flaming Gorge Dam, the three dams of the Aspinall Unit, Navajo Dam on the San Juan River in northern New Mexico, and Glen Canyon Dam, each with its corresponding reservoir (see the map on page 4). Although part of the

Left: Glen Canyon Dam. ©Derek DeVries.

Colorado River Storage Project, Navajo Dam is not included in this report, since it does not directly affect any of the national parks included in this study.

Other dams have been built in the Colorado River Basin, in addition to those built as part of the Colorado River Storage Project (e.g., Hoover Dam on the Colorado River, on the border between Arizona and Nevada). These other dams either do not directly affect the parks considered in this report, or their impacts on the parks covered are dwarfed by one of the large dams addressed in this report.



Above: John Wesley Powell, explorer and second director of the U.S. Geological Survey. Served 1881-1894. ©Portraits Collection, USGS. **Opposite Page:** Flaming Gorge Dam. ©Darlene Cutshall.

The reservoir created by Glen Canyon Dam is named Lake Powell in honor of the 19th-century explorer John Wesley Powell.

Glen Canyon Dam

In 1956, dam construction began in Glen Canyon, 15 miles upstream of Lees Ferry, on the border between Utah and Arizona. The reservoir behind the dam, named Lake Powell in honor of the 19th-century explorer John Wesley Powell, began filling in 1963, and reached full pool in 1980. Capacity of the reservoir at full pool is 27 MAF, and at full capacity, the reservoir inundates 186 miles of the Colorado River and covers about 163,000 acres. It has nearly 2,000 miles of shoreline due to the complex side channels and irregular landforms that characterize this part of the Colorado Plateau.

The power plant that is part of the Glen Canyon Dam began generating electricity in 1963. It has a maximum power capacity of 1,304 megawatts (Mw) or millions of watts, which constitutes about 75 percent of the total generation capacity for all Colorado River Storage Project dams. When electricity generation began, the dam was operated to maximize power generation revenue. Through the 1970s and 1980s, this was the primary operating philosophy.

Before Glen Canyon Dam was built, there was public outcry about the archaeological resources and canyons that would be inundated. After the dam was built, attention regarding dam operations shifted to the downstream impacts, especially in Grand Canyon National Park. As previously mentioned, President George H.W. Bush addressed these concerns by signing into law the Grand Canyon Protection Act in 1992, which required the Secretary of the Interior to complete an environmental impact statement evaluating different operating criteria to select an alternative management strategy that would protect resources as well as fulfill the other purposes of the dam. The management strategy selected in 1996 has not adequately provided for the protection of resources, as will be discussed throughout this report. The Glen Canyon Adaptive Management Work Group was established in 1997 as a federal advisory committee to the Secretary of the Interior. The U.S. Geological Survey's Grand Canyon Monitoring and Research Center provides scientific information to the Glen Canyon Dam Adaptive Management Work Group.

Because of the presence of the national park and the associated National Park Service mandate to protect and preserve resources, the Colorado River within the Grand Canyon is one of the most intensely scrutinized rivers in the world. Extensive study and monitoring, as well as experimental flows done to evaluate the impacts of different dam operations on Grand Canyon resources, have been conducted. For more information on changes to dam operations meant to benefit resources, see "Addressing Natural and Cultural Resource Concerns Through Dam Management" on page 53.

Flaming Gorge Dam

Flaming Gorge Dam is located in Red Canyon on the Green River in northeastern Utah, 32 miles downstream of the Wyoming border. Although dam construction was not completed until early 1964, the diversion tunnel was closed in late 1962, and the river's flow was controlled by the dam beginning at that time. Flaming Gorge Reservoir, which extends 91 miles upstream from the dam through Red Canyon, Horseshoe Canyon, and Flaming Gorge Canyon, reached full pool in 1974. It has a total capacity of just under 3.8 MAF. The dam has the capacity to produce 86 Mw of electricity, or about 8.5 percent of the capacity of all the dams in the project. It has the same production capacity as the Morrow Point Dam of the Aspinall Unit in Colorado.

Since its construction, Flaming Gorge Dam has been operated largely to maximize power generation and revenue. Only twice before 1984 were the flows coming from Flaming Gorge Dam revised, in both cases to benefit the introduced recreational trout fishery just downstream of the dam. These modifications included higher minimum flows and releases of slightly warmer water in summer. By 1985, concern over the decline of native Colorado River Basin fishes led to constrained operations for Flaming Gorge Dam while researchers studied ways to modify dam operations to benefit the native fishes in the Green River. Constrained operations included reducing the variations in flows that were used to respond to power generation demands. See "Addressing Natural and Cultural Resource Concerns Through Dam Management" on page 53 for more information on changes to Flaming Gorge Dam operations.

Only twice before 1984 were the flows coming from Flaming Gorge Dam revised, in both cases to benefit the introduced recreational trout fishery just downstream of the dam.

Aspinall Unit

The Wayne N. Aspinall Unit consists of three dams and reservoirs stretching along 40 miles of the Gunnison River in west-central Colorado, immediately upstream of Black Canyon of the Gunnison National Park. Construction on the most upstream dam, Blue Mesa, began in 1962 and was completed in 1966. At full flood-control capacity, Blue Mesa Reservoir holds more than 900,000 acre-feet of water. Water storage and power are the primary roles of the Aspinall Unit, with the majority of the storage for flood control being managed through Blue Mesa Dam and Reservoir.

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Construction on the second dam, Morrow Point, began in 1963 and was completed in 1968. Work on the third and final dam in the unit, Crystal Dam, began in 1973 and was completed in 1976. The Morrow Point and Crystal Reservoirs are intended for short-term storage only. Maximum capacity of Morrow Point Reservoir is approximately 117,000 acre-feet, but the active capacity is approximately 42,000 acre-feet. Capacity of Crystal Reservoir is 25,000 acre-feet, but it is normally operated at approximately 13,000 acre-feet capacity. The Aspinall Unit produces about 290 Mw, or about 17 percent of the hydropower capacity of the Colorado River Storage Project.

After completion of the Aspinall Unit, the main focus of operation was to store water and generate hydropower. The operating plan for this unit called for minimum discharges to support downstream water rights. In 1966, the minimum discharge was

100 cubic feet per second (cfs); in 1976, the minimum was increased to 200 cfs (in dry years) and 400 cfs in wet years. In 1985, the minimum flow was slightly increased in order to protect the Gold Medal Water & Wild Trout Water fishery below the Aspinall Unit. In 1992, concern over the status of Colorado River Basin endangered fishes increased, and dam operators began to modify water releases to evaluate the impact to them. Over the next decade, dam releases reflected a little more closely the natural hydrograph (a plot of flow rates over time).

In 2001, the question of Black Canyon of the Gunnison National Park's right to Gunnison River water, and the timing of the flow of that water, came before the courts. The Bush Administration was willing to cede the park's right to all but minimum flows and allow the State of Colorado to control the amount of water flowing through the park and the timing of those water flows. The National Parks Conservation Association, Trout Unlimited, and Western Resource Advocates led a group of conservationists in opposition to the administration's position, contending that only Congress could authorize giving away the park's federal property right to the water, and that the National Park Service could not delegate its responsibilities under the Organic Act to protect the park's resources. The federal district court judge found in favor of the conservationists.

The case then went to the Colorado water court for resolution. Three-hundred and eighty-three parties participated in mediation for the case. These parties represented a wide variety of viewpoints: environmentalists and conservationists interested in preserving the park and its resources; domestic users; municipal, county, and state government agencies; industrial users; hydropower interests, including the Western Area Power Administration and the Bureau of Reclamation; fishermen and hunters; and recreation interests. Flood control and capacity in the reservoirs were also of critical concern. The National Parks Conservation Association and its partners hired experts who demonstrated that a more natural hydrograph, which benefits the park, would actually result in little disruption of most existing users. The water right for the park was issued in 2008 and ended more than 30 years of dispute. The right is senior to the Aspinall Unit and the Colorado River Storage Project but not the Uncompahgre Project/Gunnison Tunnel, which is senior to both the rights of both Black Canyon of the Gunnison National Park and the Aspinall Unit. For the last three years, the park has benefitted from the water available under the water rights decree.

Opposite Page: Blue Mesa Reservoir in Curecanti National Recreation Area. ©Lisa Lynch, National Park Service. **Above:** The Gunnison River carved this gorge over millennia. ©Benjamin Hayes. **Below:** Historical photo of the Gunnison Tunnel. ©Bureau of Reclamation, Department of Interior.

Effects of Dams on Natural and Cultural Resources in National Parks Within the Colorado River Basin

Dams along the Colorado River and its tributaries have had and continue to have significant and far-reaching impacts on natural and cultural resources along these waterways, including areas within national parks. They have fundamentally changed ecological and environmental processes by subjecting rivers and their surroundings to novel and highly unnatural flow regimes, rather than natural hydrological cycles. Examples of these changes include reduced peak flows, enhanced baseflows, altered temperature extremes and patterns, and the absence of consistent and predominant spring floods. The implications of these flow and temperature changes affect processes that shape the landforms along the river, riverbank plant communities, native fish reproduction, and more.

In addition to altering natural flows and temperature regimes, dams within the Colorado River Basin have fragmented the continuous nature of the Colorado River and its tributaries. Before the dams were built, snowmelt from the Rocky Mountains thundered downhill, collected sediment and nutrients along the way, and deposited much of that sediment load in the delta at the Gulf of California. Within the river, native fishes traveled upstream to spawn, and the larvae drifted back downstream to nursery grounds. Now, however, the dams around the basin have pinched off these pathways. The migratory ranges of native fishes are truncated. Water is held behind dams until released. Sediment is trapped in upstream reservoirs, altering sandbars, other in-stream habitats, and riparian habitats. In effect, processes that used to connect one end of the Colorado River Basin to the other are able to act only within separate segments of river bounded by dams.

Cultural resources within national parks are not immune to the consequences of dams and dam operations. Sediment trapped behind dams is no longer available to replenish that which erodes, leading to the exposure of archaeological sites, while increased erosion of riverbanks that occurs downstream of dams can undermine terraces that support historic structures, causing them to collapse. Regulation of river flows has made historic cabins, archaeological sites, rock art panels, and other cultural resource sites, which were once remote and difficult to access, into routine destinations

Left: Shinumo Creek waterfall in Grand Canyon National Park. ©Alan English.

for recreational boaters. Such visitors may inadvertently or deliberately harm the resources. In addition, changing water levels in reservoirs periodically inundate or expose cultural resources, leaving them open to damage from the elements and visitors. And it isn't clear which agency—the Bureau of Reclamation or the National Park Service—should be responsible for managing newly exposed cultural resources at reservoirs like Lake Powell.

Changing water levels in reservoirs periodically inundate or expose cultural resources, leaving them open to damage from the elements and visitors.

The following sections describe how the consequences of dams and dam operations—changes in river flows, sediment transport, water temperatures, and reservoir water levels—act individually or in concert to affect various natural and cultural resources in five national parks within the Colorado River Basin. The discussion of dam impacts is followed by a chapter titled "Addressing Natural and Cultural Resource Concerns Through Dam Management," which describes ways dam operations have been altered in an attempt to benefit resources.

Changes in Flow Dynamics and Consequences

For millennia, the Colorado River has flowed from its headwaters in the Rocky Mountains of Colorado, through present-day Utah, Nevada, California, Arizona, and Mexico, out into the Gulf of California. Along this path, snowmelt contributes water to the river and its tributaries with seasonal regularity and year-to-year variability,

WATER FLOWS BEFORE & AFTER DAM CONSTRUCTION

LOCATION	FLOW TYPE	PRE-DAM	POST-DAM
Gunnison River, Black Black Canyon of the Gunnison	Peak flows	More than 9,400 cfs	3,900 cfs
	Baseflows	500 cfs	About 1,000 cfs
Green River, upstream of Dinosaur National Monument and downstream of Flaming Gorge Dam	Peak flows	10,900-12,700 cfs	5,300 cfs
	Baseflows	About 880 cfs	1,700-2,600 cfs
Green River, upstream of Canyonlands National Park	Peak flows	32,000 cfs	22,400 cfs
	Baseflows	1,500-2,700 cfs	2,800-3,500 cfs
Colorado River, upstream of Canyonlands National Park	Peak flows	42,000 cfs	28,000 cfs
	Baseflows	2,500-3,700 cfs	3,700-4,400 cfs
Colorado River near Grand Canyon National Park, downstream of Glen Canyon Dam	Peak flows	79,000 cfs	30,800 cfs
	Baseflows	Less than 3,000 cfs	Sometimes 10 times historical levels; since 1996, they can be no greater than 25,000 cfs

resulting in changes to the amount of water in the river and the speeds at which it flows. Riparian communities and in-stream habitats may be fostered or destroyed, depending on the amount of water flowing in the river. Droughts periodically affect snowpack and the amount of water that enters the river. The Colorado River is shaped by natural processes, and in turn, the river shapes the landscape through which it flows, as is magnificently evidenced by the canyons of the Colorado Plateau.

Placement of dams along the Colorado River and its tributaries has changed the way water flows in the rivers and the ways in which the rivers shape their environments. The timing of flows and the quantity of water in the Colorado River and major tributaries are now controlled by dams rather than natural processes. In most instances, peak flows have decreased and they rarely follow their historical seasonal pattern. In addition, baseflows have generally increased, resulting in a flattening of the river's hydrograph. The following highlights the consequences of these changes on the conditions of resources in Dinosaur National Monument, Black Canyon of the Gunnison National Park, Canyonlands National Park, Glen Canyon National Recreation Area, and Grand Canyon National Park.

Dams have changed the amount of water flowing and the seasonal variability of those flows in the Colorado River and several of its tributaries. Before Flaming Gorge Dam was built upstream of Dinosaur National Monument, the annual discharge (total amount of flowing water) of the Green River averaged nearly 1.5 MAF, and its mean annual peak flow corresponded to spring floods of snowmelt. Since the construction of Flaming Gorge Dam in 1962, the total amount of water that flows through the river within the course of a year has not changed, but the dam's operating plan has decreased the annual peak flow by 59 percent and it no longer corresponds to seasonal inputs of snowmelt. To achieve the same annual discharge in the Green River as historical levels, baseflows in the river were increased through manipulation of dam releases.

A similar story to that of the Green River—a story of changes in the quantity and timing of water delivery—is told in the Gunnison River due to operations of the three dams of the Aspinall Unit, though this river's flow had already been altered by the Uncompahgre Project and a dam on the Taylor River, a tributary of the Gunnison River, prior to construction of the Aspinall dams.

The Gunnison River within Black Canyon of the Gunnison National Park was once wild and dominated by disturbances. Floods were the dominant ecological processes; they scoured the river channel, adjacent banks, and riparian zones with high flows and moved large cobble and boulders downstream. Spring floods usually peaked in May and June and then tapered off to summer and fall baseflows. The dams of the Aspinall Unit have changed natural conditions. While the quantity of water that passes through the Black Canyon each year has not changed since about 1930, seasonal variability in water flows and timing of peak flows have changed. As a result of the upstream dams, the average annual peak flows of the Gunnison River (as measured just downstream of the Gunnison Tunnel) have diminished nearly 60 percent from pre-dam levels. Furthermore, the timing of peak flows has been less consistent. From 1906 to 1965, the peak flow was always in the spring. More recently, the timing of the peak flow has been spread across the year.

Above: Flaming Gorge Reservoir. ©David B. Gleason.

As a result of the upstream dams, the average annual peak flows of the Gunnison River have diminished nearly 60 percent from pre-dam levels.

At Canyonlands National Park, the major upstream water impoundment projects are quite distant, so changes in the character of the Green and Colorado Rivers have been more modest relative to pre-dam conditions.

Not only have the annual peak flows changed, but baseflows observed outside of the flooding period are now much higher as a result of dam operations. Water is released through turbines to generate power; the operating plan for the Aspinall Unit allows for higher flows during the non-flooding period than would have been seen historically in order to generate power. In effect, the operating plan has created artificially high baseflows, instead of the sometimes very low baseflows that have historically occurred in this river.

At Canyonlands National Park, the major upstream water impoundment projects—Flaming Gorge Dam on the Green River and the Aspinall Unit dams on the Gunnison River, which flows into the Colorado River—are quite distant, so changes in the character of the Green and Colorado Rivers have been more modest relative to pre-dam conditions. For example, since Flaming Gorge Dam was constructed, peak flows in the Green River, as measured about 100 river miles upstream of its confluence with the Colorado River, have decreased approximately 30 percent. This decline in the annual peak flow is much less than occurs in Dinosaur National Monument, which is much closer to Flaming Gorge Dam, where peak flows were reduced by 59 percent after the dam was built. Furthermore, these peak flows still consistently occur during the spring in Canyonlands National Park because of spring floods from other tributaries.

The annual peak flow in the Colorado River as it flows towards Canyonlands, as measured about 97 miles upstream of the confluence with the Green River, has also decreased since dams were built upstream. Since 1962, the peak flow has declined nearly 33 percent. Again, this is a large change, although smaller than the nearly 60 percent decrease seen directly below the Aspinall Unit dams. The timing of the spring flood remains similar to the historical period.

The Glen Canyon Dam has transformed both the upstream and the downstream character of the Colorado River within national parks, affecting conditions within Glen Canyon National Recreation Area and downstream within Grand Canyon National Park. The natural rhythm of the Colorado River is very similar to the other major tributaries described previously—it experiences spring floods and variability in flows throughout the course of a year. Glen Canyon Dam has changed those natural dynamics. Upstream of the dam, what was once a seasonally variable, sediment-laden river flowing through a canyon has been transformed into a lake. Downstream of the dam, the quantity and seasonality of water flows have changed.

Prior to dam construction, annual peak flows ranged from 25,000 cfs to more than 120,000 cfs and corresponded to the spring flood. Since Glen Canyon Dam was built, the average annual peak flow is 30,800 cfs, and the timing of peak flows has changed so that spring floods no longer govern peak flows; instead, dam operations determine peak flows.

The changes to the Colorado River hydrograph include not only a reduction in and changes in timing of peak flows but also a higher baseflow and major fluctuations in flows over a daily time frame. In the late 1980s, researchers reported that the Colorado River exhibited tidal characteristics, with regular fluctuations in flows going between 10,000 and 20,000 cfs over the course of a single day, to accommodate power production needs. A change like this could affect the river's water level 5 to 10 feet within the course of a day. For the sake of comparison, day-to-day changes in flows were examined for May 1944 (spring flood period) and February and October 1944 (baseflow periods). During the spring flood before the dam was built, flow changes from one day to the next were often high. For example, discharge at Lees Ferry increased more than 10,000 cfs from May 9 to May 10 in 1944. Peak discharge occurred a few days later on May 19. However, during periods of baseflow, the absolute changes in discharge from one day to the next were much smaller. In February 1944, the highest change in discharge was 440 cfs. In October 1944, the highest discharge change from one day to the next was 800 cfs. These daily changes are much smaller than the 10,000 to 20,000 cfs daily changes documented in the late 1980s.

The impacts resulting from changes in the river's hydrograph degraded natural resources in the park, as described in the following section. The adaptive management approach to Glen Canyon Dam operations outlined in 1996 as a result of the Grand Canyon Protection Act has since attempted to ameliorate those resource conditions by changing the dam operating plan, including conducting temporary experiments to evaluate the impacts of different flow programs. The 1996 Record of Decision adopted "modified low fluctuating flows" (MLFF) as the basis of dam operations. The MLFF dictated that, under normal conditions, dam releases could not exceed 25,000 cfs in a day unless there were some special conditions (e.g., high flow periods, experimental flows, etc.) and could fluctuate no more than 8,000 cfs in a day. While the MLFF plan addressed the daily tides reported on in the late 1980s, it did not address the larger issue of unnaturally high baseflows. The most current environmental assessment by the Bureau of Reclamation, completed in 2008, incorporated low flows in the late summer and early fall. Other times of the year, baseflows remained unnaturally high.

Opposite Page: Camping along the Colorado River in Cataract Canyon, Canyonlands National Park. ©rchefas (istockphoto). **Above:** Colorado River downstream of the Glen Canyon Dam; view from Glen Canyon Bridge. ©pmphoto (istockphoto).

Since Glen Canyon Dam was built, spring floods no longer govern peak flows in the Colorado River in the Grand Canyon; instead, dam operations determine peak flows.

Changing the timing and quantity of water flows in the Colorado River and its tributaries has ramifications for natural resources, particularly vegetation. Dams have modified the natural rhythm of the river (i.e., the timing and the size of natural floods). Not only do dams alter the big flows, but historical dam management in the Colorado River Basin has changed the small flows as well. Water releases in the non-flooding season have typically been higher than the natural flows that occurred historically. Ecological research indicates that river ecology depends on flow variability, from the natural lows to the natural highs. Unfortunately, past dam management practices have minimized variability, often focusing on average flows downstream of dams. Upstream of dams, river environments have been dramatically changed from flowing systems to lake systems.

Above: Non-native tamarisk along the riverbank in Grand Canyon National Park. ©National Park Service. **Below:** Cottonwood trees in Canyonlands National Park. ©Amygdala Imagery.

Since the early 1960s, with the completion of most major dams in the Upper Basin, the floods that once played a major role in the Colorado River Basin have been largely eliminated. Large floods in 1983, 1984, and 1995 were a glimpse of what once was a common occurrence in this basin. By curtailing the flooding, dam management efforts have cut off the adjacent floodplain habitats from the river. These adjacent habitats would routinely flood during the spring; by reducing the magnitude of the spring flood as well as preventing off-season floods due to climatic events (e.g., big rainstorms), nutrient transport between the river and floodplains has been reduced and valuable habitat for young fish, migratory waterfowl, and resident wildlife has been eliminated.

Historically, the low-elevation riparian forests along the Colorado River and its tributaries were dominated by Fremont cottonwood (*Populus deltoides wislizenii*), as well as willow (*Salix* spp.) and box elder (*Acer negundo*). Cottonwoods, in particular, provided the forest structure and biomass, and some of the critical wildlife habitat along the river. Riparian areas have changed over the past century, partly due to land management practices (including the introduction and subsequent invasion of tamarisk [*Tamarix ramosissima*] and hybrids of several tamarisk species) and partly due to dam management and regulation.

Before Flaming Gorge Dam was built, the riparian vegetation within Dinosaur National Monument was characterized by herbaceous plants that lived closer to the water and woody vegetation that lived farther from the water. Flooding along the Green River was too frequent to allow woody vegetation to establish close to the river; seedlings would routinely be washed away by the next big flood. After Flaming Gorge Dam was built, flows were regulated, and low-elevation riparian areas near the river's channel, which normally would have flooded too frequently for woody vegetation to establish, were now more stable habitats. The result at Browns Park, just upstream of Dinosaur National Monument, is a novel riparian plant association that includes species adapted to wet conditions all the time (because of the constant baseflow released from the dam) and species that are intolerant of flooding (which can establish due to a dam-regulated lack of regular floods).

Before dams were built on the Gunnison River, snowmelt-derived water raged through the narrow Black Canyon, moving large cobbles and boulders in the river channel and sweeping away riparian vegetation. In fact, prior to dam construction there was little if any riparian vegetation within the Black Canyon because of the frequent floods that occurred there. Researchers conducted a study in the 1990s, several decades after the Aspinall Unit dams were built, to quantify the riparian zone vegetation at

Roiling Waters Shaped the Character of the Canyons

The canyons all along the Colorado River and its major tributaries were formed by the enormous, inexorable power of water rushing down from the mountains to the sea, carving its way through millions of years of history in the canyon walls. The appearance and sound of the river are important elements in the experiences of people who visit the parks for their scenic and educational values, to help them understand and appreciate the forces that shaped the landscape before them. The creation of reservoirs and the regulation of the water's flow through dams profoundly affect the appearance and sound of the river. Glen Canyon and the upper portion of Black Canyon of the Gunnison are no longer recognizable as canyons carved by rivers, now that they are filled by reservoirs. The furious roar of the spring flood through the Canyon of Lodore in Dinosaur National Monument and Cataract Canyon in Canyonlands National Park is subdued to the point that the sound no longer conveys a sense of the power that created those very places.

At Black Canyon of the Gunnison National Park, the Park Service has formally recognized that the viewshed and soundscape of the river are among the elements that contribute significantly to the visitor experience and significance of the park. This acknowledgment is stated in the park's 1997 general management plan. Maintaining sufficient water flow in the river through the park has been a challenge in the past, because the park had no control over the amount of water released through the Aspinall Unit dams. As noted previously, the average annual peak flow in the river below the dams decreased by nearly 60 percent after the dams were built. A 2008 water rights decree gives the park some influence over decisions regarding water management on the Gunnison River, which should help park staff maintain the viewshed and soundscape resources associated with the river. Monitoring to assess the impact of any future changes in dam operations made under the water rights decree should include visitor surveys to ascertain whether river flows are sufficient to convey the historic soundscape to visitors.

Below: Black Canyon of the Gunnison National Park. ©Lance Long.

Tamarisk was introduced to the Colorado River Basin as a means to stabilize riverbanks and reduce sediment erosion. However, this highly invasive riparian tree spread rapidly and, in some cases, seemed to drive changes in the riparian communities and the river channel.

Warner Point Reach in Black Canyon of the Gunnison National Park. In a canyon not known historically for extensively developed riparian areas, these researchers documented a riparian community dominated by grasses and herbs as well as a few trees (box elder, tamarisk, and willow). This riparian community was more developed than would be expected to occur under natural flow conditions.

In the past, springtime floods would have swept clear any vegetation, and the low flows common during the remainder of the year might have allowed some colonization. Under the flow management strategy following the construction of the Aspinall dams, both aspects of this natural dynamic changed. Floods are now smaller and scarcer; low flows are now higher and constant. This research highlights the importance of the changing flow regime on vegetation: While it might have been predicted that diversion and damming would have resulted in a shift towards dry communities, the data show that the shift has been towards more mesic or even wetland-type communities. It is too soon to know if the 2008 decree that established Black Canyon of the Gunnison National Park's water rights will affect this vegetation shift.

At Canyonlands National Park, changes to the river channel are likely a complex product of the dams and invasive tamarisk. This woody plant was introduced to the Colorado River Basin in the early 20th century as a means to stabilize riverbanks and reduce sediment erosion. This highly invasive riparian tree spread rapidly and, in

some cases, seemed to drive changes in the riparian communities and the river channel. Tamarisk was documented in Canyonlands and the surrounding area by the late 1930s, two decades before major water regulation projects, and it caused channel narrowing at several locations along the Green River, as a result of its ability to stabilize riverbanks and reduce erosion. For example, by the early 1950s there was channel narrowing in response to tamarisk invasion that averaged 27 percent at Bowknot Bend, a stretch of the Green River within Labyrinth Canyon just upstream of the Canyonlands boundary. Channels continued to narrow after the dams were closed. Although the impacts on riparian habitats are better described for the Green River within Canyonlands, similar changes along the Colorado River are probable. Research done in the mid-1990s showed that the disturbance-prone island habitats that were common in the river channel in the pre-dam era have generally been stabilized by vegetation and even become attached to the riverbank with the modest decline in historical flooding. These vegetated stretches trap sediment and these habitats get larger and higher. While the benefits or consequences of these changes to the riparian habitat are not currently known, data demonstrate that these are real changes that could have implications for wildlife or other valued resources.

Glen Canyon National Recreation Area presents a story of vegetation change that differs in a major way from the other parks included in this report. When Glen Canyon Dam was built, it didn't simply affect the species composition and structure of riparian habitats, it inundated 186 miles of the Colorado River and destroyed the riparian habitat, a habitat known in arid regions to provide critical food and shelter for wildlife, food and fiber for people, and organic matter that fuels the adjacent aquatic ecosystem. (Similar flooding and resource destruction occurs upstream of all dams; the other dams considered in this report, as well as the reservoirs they created, are upstream of the national parks addressed here, so that resource damage is not described.)

Surveys of Glen Canyon prior to dam construction had documented 485 species of plants from 47 families. Once Glen Canyon Dam flooded all surveyed riparian habitat, 17 species from 12 families were locally extirpated—they have not been documented within Glen Canyon since that time. In some cases, destroying the riparian habitat required the birds using that habitat to relocate. For example, there was a breeding colony of great blue herons (*Ardea herodias*) that used the chokecherry (*Prunus virginiana*) riparian habitat at the upper end of Halls Creek. When Lake Powell flooded, the chokecherry habitat was destroyed (chokecherry is considered locally extirpated). Great blue herons are common in other parts of Glen Canyon now, but they can no longer use this one-time favorite habitat.

While there is no evidence that flooding Glen Canyon extinguished any plant species, it is likely that some rare or endemic plants were lost. Pre-dam surveys concentrated on the main corridor channel, but there was no systematic survey work done in the many side canyons that were also flooded when the dam was closed. The unsurveyed area certainly contained more species, and some of those plants might have been rare or had a very limited spatial distribution. Furthermore, the survey did not document many of the spring, seep, and hanging garden habitats that characterize the Colorado Plateau region and are associated with high levels of endemism. In Glen Canyon National Recreation Area today, there are currently a total of 40 known endemic plant species. Of these 40, ten are found only in hanging gardens. While undocumented, there were most certainly hanging gardens on the canyon

continues on page 40…

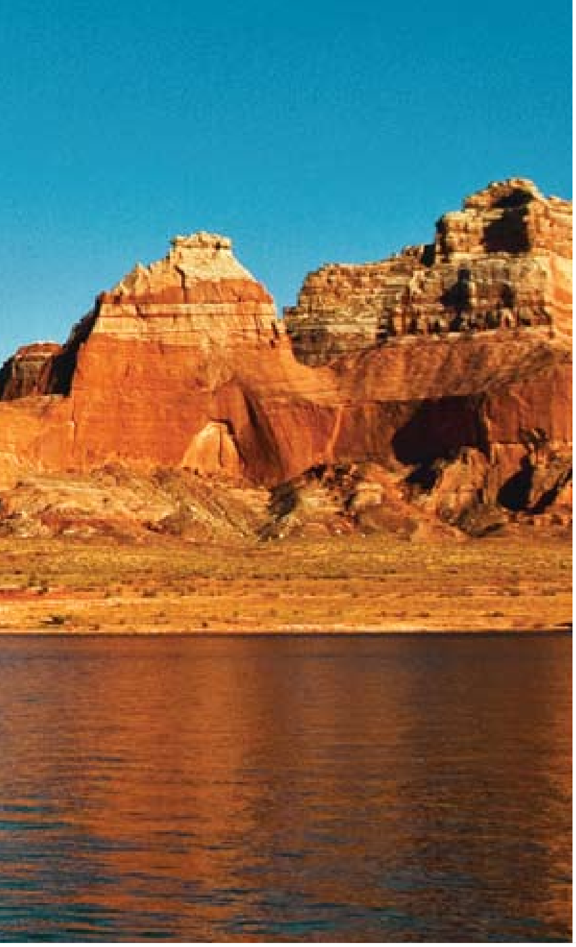
Opposite Page: National Park Service fire management personnel conduct a controlled burn of non-native tamarisk in Lake Mead National Recreation Area. ©David Horne, National Park Service. **Above:** Cutting and collecting tamarisk by hand is one way to control the plant. ©National Park Service. **Below:** Hanging garden in Glen Canyon National Recreation Area. ©Nancy Nehring (istockphoto).

Changing Water Levels in Lake Powell Affect Cultural Resources

Once Glen Canyon Dam impeded the flow of the Colorado River, Lake Powell began to fill, inundating a host of cultural and natural resources. The reservoir took about 18 years to reach full pool. Water levels have fluctuated since that time, reflecting variations in the water coming in through the Colorado River, San Juan River, and other tributaries versus variations in the water going out to generate power or to supply Lake Mead, which provides water for agricultural, municipal, and commercial uses.

Regional climatic events such as floods and droughts also affect water levels in Lake Powell. During the late 1980s and then again in the early 2000s, the region underwent a significant drought. In those periods, river flows were much lower than the recorded average. For example, from April 2002 to July 2002 (typically the time of highest input, the spring flood period), the inflow to Lake Powell was about 84 percent lower than the long-term average. The regional drought resulted in a water deficit (i.e., more water is released than is replenished in a year) in Lake Powell that reached a maximum in 2005 and has persisted to this day. In 2005, the lake was 145 feet below full pool, its lowest level since reaching full pool in 1980; it is presently about 77 feet below full pool. Climate change scenarios that predict the western United States will become drier and warmer raise further concerns that storage levels in the reservoir lakes, including Lake Powell, may get dangerously low. Extremely low reservoir levels could affect the ability to meet water delivery obligations and, in an extreme situation (i.e., water levels below dam outlets), could perhaps preclude all water releases.

Cultural resources on the bank of the river or near the water's edge along the reservoirs are subject to effects caused by changing water levels. Structures, artifacts, and archaeological sites are inundated with water as levels rise, then they are exposed to air and dry out as water levels fall. They may go through this cycle again and again. The cycling causes accelerated deterioration of some artifacts and building materials, and may lead to loss of integrity of a site by changing or destroying factors such as



pollen grains, charcoal, or faunal remains, which can be used to identify and date sites. Different resources respond to inundation and exposure in different ways. Some archaeological resources, such as unmortared structures, are reasonably well preserved deep in the pool of the reservoir, while structures held together with mortar or those possessing wooden structural elements have suffered extreme deterioration. How deeply resources are inundated also has a bearing on their survival. A resource that would be well preserved in the cold, still water at the bottom of a reservoir may suffer negative impacts if it were instead located just below the surface of the water, where it would be subjected to wave action. Of the 2,500 documented archaeological sites at Glen Canyon National Recreation Area, about 10 percent are within the area affected by fluctuating lake levels.

The changing water levels in Lake Powell mean that the areas accessible to the public are continually changing. Due to the creation of Lake Powell and the changes in water levels that have occurred since then, visitors are able to access areas containing resources that used to be virtually inaccessible, either due to difficulty reaching them or the fact that they had been previously inundated with lake water. Visitation can lead to deliberate or unintended damage to resources (see "River Recreation in the Colorado River Basin's National Parks" on page 65).

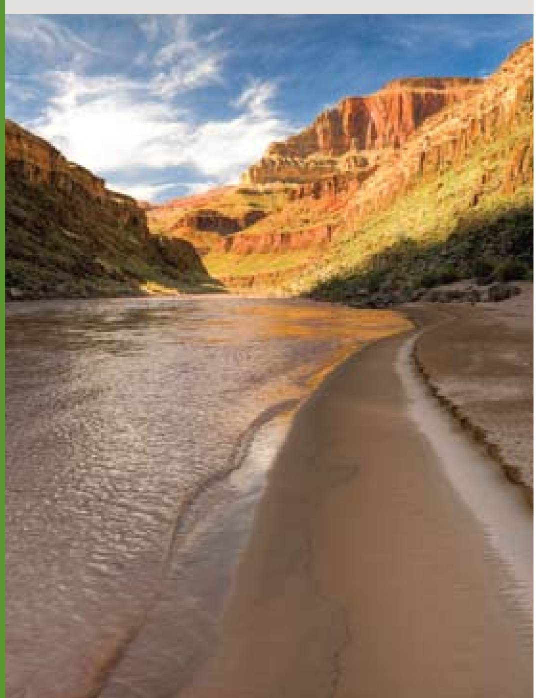
Glen Canyon Recreation Area does not have a formal policy that determines which federal agency, the National Park Service or the Bureau of Reclamation, is responsible for managing cultural resources exposed by changing lake levels. Predictions of future lake levels indicate recently exposed resources will remain as such. Without a determination of management responsibility, these resources, some of which may be nationally significant, are highly susceptible to erosion, wave action, and visitor impacts such as vandalism and soil erosion around sites. For example, Baker Ranch includes a ranch house, a storage building made of rock, a large log building, and a number of other structures dating to the first few decades of the 20th century. All were submerged under 20 feet of water when Lake Powell reached full pool. Due to lower lake levels, they are now exposed and popular with boaters, making them vulnerable to intentional or unintentional damage.

Top Left: Lake Powell in Glen Canyon National Recreation Area. ©Garo Kalaydjian.
Top Right: View of Hite Marina, which is now closed due to decreased water levels in Lake Powell. ©Ben Johnson.

walls in inaccessible areas that could not be surveyed in the pre-dam period. These rare habitats were destroyed when Lake Powell filled; with those habitats likely went uncataloged endemic plants.

Fortunately, many of the side canyon riparian habitats above 3,700 feet (the height of Lake Powell at full pool) are considered to be fairly healthy and somewhat intact. This is likely because the flooding dynamics that largely shaped the historical development of these riparian communities are still somewhat in play along the rivers and ephemeral streams in the side canyons. In these distant and somewhat inaccessible parts of the side canyons there are still representatives of a traditional healthy riparian habitat. Furthermore, these distant and isolated parts of the side canyons are home to rare and relict communities, such as several isolated stands of Douglas fir (*Pseudotsuga menziesii*). Normally, stands of Douglas fir are found at or above 7,500 feet, but if conditions are right, they can occur in protected alcoves along canyons as low as 5,500 feet. While the origin of these relict stands is unclear, they are a unique resource found within the park.

Above: Endangered southwestern willow flycatcher. ©Suzanne Langridge, U.S. Geological Survey. **Below:** Colorado River and beach in Grand Canyon National Park. ©Jason Corneveaux. **Opposite Page:** Vaseys Paradise in Grand Canyon National Park harbors endangered snails. ©Steven P. Chan.



Before construction of Glen Canyon Dam, the banks of the Colorado River through the Grand Canyon were frequently swept with powerful floods. The steep-sided canyons, such as Marble Canyon, contained little riparian vegetation. In contrast, the alluvial reaches of the river, where the river snakes across the area between the canyon walls, might have had some patchy vegetation, but this was composed mostly of annual grasses and species that are able to colonize a disturbance-prone habitat. In the upper bench habitats, above the usual reach of the spring floods, common vegetation included honey mesquite (*Prosopis glandulosa*), catclaw acacia (*Acacia greggii*), and non-native tamarisk. In this flood-prone riparian area, there was a natural gradient from the sparsely vegetated low benches and sandbars to the more mature, stable shrub and tree vegetation of the high benches.

After the dam closed and flows were first regulated, the riparian areas of the Grand Canyon began to change. Within Marble Canyon, the vegetated area nearly doubled. In areas that would typically flood during high-flow periods, there was an increase in vegetation, with dense stands of tamarisk, coyote willow, and some cottonwoods. The high bench areas were relatively stable. Over time, the vegetation encroached down towards the river, as the vegetation that had previously established was not flooded out and tended to stabilize the habitat. As the vegetation continued to expand, it moved into camping beaches and channel margins. Of the camping sites surveyed between 1983 and 1991, 41 percent were found to be unusable because there was too much vegetation. In general, the installation of the dam and the resulting changes to the flow regime of the Colorado River through the Grand Canyon has led to the development of significant riparian areas.

Riparian areas are valuable habitats for wildlife, including invertebrates, birds, mammals, and reptiles. Several species have benefitted from new or expanded riparian habitats that have formed in Grand Canyon National Park as a result of water management at Glen Canyon Dam. The Kanab ambersnail (*Oxyloma haydeni kanabensis*), a federally listed endangered snail, uses the spring-fed riparian area at Vaseys Paradise, which has expanded in recent years due to a combination of dam management and drought. The U.S. Fish and Wildlife Service designated this riparian area as critical habitat for the species. The newly created riparian area of the Grand Canyon is also proposed critical habitat for the federally listed endangered southwestern willow flycatcher (*Empidonax traillii extimus*). Surveys indicate that this bird was probably not found in the Grand Canyon before the dam was built, but it is able to live in the riparian area that has developed in the last 40 years. Both the snail and the flycatcher benefit from habitat that developed under highly manipulated conditions imposed by Glen Canyon Dam. Yet these manipulations have been detrimental to other wildlife, such as native fishes (see "Dam Operations and Endangered Fish of the Colorado River Basin" on page 48). Resource managers must determine how to address the needs of endangered fishes that thrive under natural river flows with those of endangered wildlife that benefit from the stable riparian habitat made possible by regulated flows.

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Sediment Trapping and Consequences

Given its name, which means "red" or "colored" in Spanish, the Colorado River conjures up images of a reddish, muddy torrent, carving through the sandstone of the Colorado Plateau. The river was once true to its name, known historically for its sediment-laden waters.

The loss of sediment in the Colorado River and its major tributaries due to sediment trapping by dams affects different parts of the river system in different ways. At the northern end of the Colorado River Basin, at locations such as Dinosaur National Monument, sediment inputs and transport do not play as major a role in river processes as they do toward the bottom of the river system at Grand Canyon National Park, which has historically been shaped by large inputs of sediment from upstream tributaries now separated from the canyon by Glen Canyon Dam. Because the lower part of the Colorado River Basin is more greatly affected by changes in sediment

Cultural resources at Glen Canyon National Recreation Area are primarily affected by changing water levels and visitor-related impacts, rather than by changes in sediment dynamics, though erosion in the portion of the park downstream of the dam could be affecting archaeological sites.

availability, Glen Canyon National Recreation Area and Grand Canyon National Park are the focus of this sediment discussion.

As for cultural resources, discussion of sediment-related effects of dam operations are focused on Grand Canyon National Park because it is the only park included in this report that has a cultural resources monitoring program along the river corridor. There are few known cultural resources in the river corridor at Dinosaur National Monument, as there has never been a thorough survey. Those that are known to exist are located either above the river corridor or downstream of the Yampa River, where park staff believe that sufficient sediment is transported to maintain pre-dam conditions for cultural resources; monitoring is needed to provide scientific support for this belief. There are no known tangible cultural resources in the canyon itself or along the river corridor at Black Canyon of the Gunnison National Park.

At Canyonlands National Park, there is no reliable documentation from the pre-dam period that would allow park staff to determine whether the upstream dams have changed the river levels, flows, sedimentation, or frequency of flooding dramatically enough to impact the cultural resources differently than did the natural flow of the river. Photos taken at the same point in the seasonal flow cycle in several years both before and after the building of the dams show little correlation between the dams and changes in the river.

Cultural resources at Glen Canyon National Recreation Area are primarily affected by changing water levels and visitor-related impacts, rather than by changes in sediment dynamics, though erosion in the portion of the park downstream of the dam could be affecting archaeological sites.

Dams have changed the movement and distribution of sediment in the Colorado River and several of its tributaries. In the beginning of the 18th century, the Colorado River transported more than 110 million tons of fine sediment per year to the Gulf of California. Most of the sediment came from the arid regions of the Colorado Plateau and was transported to the Colorado River via its tributaries, including the Dirty Devil, Escalante, San Juan, Paria, Little Colorado, and Virgin Rivers.

Today, much of the Colorado River no longer embodies the images evoked by its name. The large dams that have been built in the Colorado River Basin, and the reservoirs that form behind them, trap sediments and prevent them from washing downstream. This results in a profound alteration of the historical balance of sediment inputs and exports. Overall, the dams along the Colorado River and its tributaries have reduced sediment transport to the Gulf of California, the Colorado River's terminus, from more than 110 million tons each year to essentially nothing.

Changing the distribution of sediment in the Colorado River and its tributaries has ramifications for natural and cultural resources. Far less sediment comes into the Colorado River and its tributaries downstream of dams than would otherwise be present, and in turn, the sediment washing out is not being replaced. Erosion has become a driving force, and both the form and structure of the river and important river habitats (e.g., backwaters, sandbars) have changed. Before Glen Canyon Dam was built, sediment was carried into the Grand Canyon and deposited along the Colorado River's shorelines. The sediment created sandbars and backwaters, and it added complexity to the river channel, which was important for native fishes. Today the dam traps essentially all of the sediment carried by the Dirty Devil, Escalante, San Juan, and Colorado Rivers and about 84 percent of all the sediment that would have been delivered to Grand Canyon National Park. This sediment settles out in Lake Powell, the reservoir created by Glen Canyon Dam.

Dams release water that contains very little sediment, and this water collects all available sediment in rivers just downstream of the dams, leaving behind only the small boulders and large cobbles that are too heavy to be carried along by water flows. In general, the erosion of sediment from the river channel changes what was once a complex habitat, filled with backwaters, eddies, and side channels, to a simpler corridor that resembles a chute or flume. In 1965, after the closure (i.e., beginning of operation) of Glen Canyon Dam, the flows of water from the dam moved millions of tons of fine sediment and sand from not only below the dam, but also from Marble Canyon and the upper Grand Canyon. (This sediment was trapped by Hoover Dam downstream and has settled at the bottom of Lake Mead.) Between 1991 and 2004, sandbars within the Grand Canyon decreased in size by approximately 20 to 30 percent. Terraces along the river can also erode.

Changes in the amount of sediment available to build and maintain habitats have resulted in greater erosion of riparian environments, areas that were once well watered and contained rich soil. These areas were frequently chosen as agricultural sites by prehistoric and more recent peoples. Campsites and longer-term habitation sites were typically located on terraces above the river. Archaeological sites and historic cabins are often found in these locations, and they are subject to significant impacts from erosion. Where riverbanks are undercut and sediment is not replaced, the foundation of a structure can fail, leading to collapse of the structure and loss of integrity, if not complete destruction. Once-buried sites on beaches or sandbars can

Opposite Page: Prehistoric granaries above the Colorado River in Grand Canyon National Park. ©Mark Lellouch, National Park Service. **Above:** Dried mud along the shore of Lake Powell is evidence of decreased lake levels. ©Dave Hughes (istockphoto).

Before Glen Canyon Dam was built, the annual sediment load in the Colorado River upstream of Grand Canyon National Park was 140 million tons. Since the dam was installed, the annual sediment load upstream of the park and downstream of the dam has decreased to 20 million tons.

be exposed by the loss of sediment, causing accelerated deterioration of structural elements and artifacts, and loss of site integrity due to elements being moved or washed away by the water. The rich sediment is an important part of the context of an archaeological site that allows researchers to understand why a site exists in a particular location. If a site that was originally located on an alluvial fan or sediment-laden floodplain now sits on bedrock, that site has lost important contextual elements that would help explain site selection and lifeways of the people who built and occupied it.

Opposite Page: Boats crowd a marina at Lake Powell in Glen Canyon National Recreation Area. ©Chuck Schug Photography (istockphoto). **Above:** Researchers prepare to measure river velocity and depth in the Colorado River in the Grand Canyon. This photo was published in a 1969 U.S. Geological Survey paper. ©U.S. Geological Survey.

At Glen Canyon National Recreation Area, there are 54 documented archaeological sites within the 15-mile reach of the Colorado River below Glen Canyon Dam and within the park.

At Glen Canyon National Recreation Area, there are 54 documented archaeological sites within the 15-mile reach of the Colorado River below Glen Canyon Dam and within the park. The Park Service is responsible for monitoring 32 of these sites, and the Navajo Nation is responsible for monitoring the remaining 22 sites. The National Park Service sites were monitored in the 1990s but they have not been monitored since 2003, at which time the Grand Canyon park staff who had been monitoring them ceased to do so. Glen Canyon National Recreation Area does not have enough cultural resources staff to monitor these sites, and rangers patrolling this reach do not have the specialized archaeological training to recognize instances where erosion and changed sedimentation patterns have affected resources.

In contrast to Glen Canyon National Recreation Area and the other park units in this study, Grand Canyon National Park has a program in place to identify, document, and monitor the cultural resources in the Colorado River corridor that are vulnerable to impacts resulting from operation of the Glen Canyon Dam. In addition, the cultural resources staff from several of the park's affiliated tribal organizations conduct their own monitoring work.

At Grand Canyon National Park, most of the archaeological sites in the river corridor are on terraces or benches above the river channel and are not subject to direct water erosion from river flows, but they are affected by the loss of sediment that would have been carried by the river in pre-dam times and then blown onto the terraces and benches by the wind. Additionally, erosion from gullying and arroyo formation along the riverbanks where side canyons and tributaries enter the main channel is much more severe without the corresponding flood stage flows in the river and deposition of sediment from those flows.

Habitat and resource degradation due to erosion and a lack of sediment input are some of the downstream effects that result when sediments are trapped behind dams. Also of concern are the effects the sediments themselves could be having as they accumulate in reservoirs behind the dams. When sediments are trapped, so too are many chemical compounds that are adsorbed onto those sediments. In some cases, those compounds are nutrients such as phosphorus, which is important for the growth of phytoplankton, important photosynthesizing organisms and key components of the aquatic food chain. Research shows that up to 95 percent of all phosphorus reaching Lake Powell is associated with sediment or in particulate form; a majority settles out in Lake Powell and is not transported further downstream. As a result of this settling, reaches of river downstream of dams receive lower levels of certain nutrients than they received prior to dam construction.

In addition to trapping sediments and attached nutrients, dams trap sediments that are carrying chemical contaminants such as mercury and arsenic. As these sediments and associated contaminants collect in reservoirs, they could have implications for wildlife and humans that use the reservoir water. While the risk of exposure to contaminated sediment in Lake Powell has not been quantified, there is a growing concern among both park staff and staff from other federal agencies that contaminated sediments arriving in Lake Powell may have negative effects. Sediment contamination can reduce the species diversity or change the structure of invertebrate communities, and may even lead to changes in the kinds of fish species that feed on them. The only study that has been done to explore sediment contamination was conducted by the U.S. Geological Survey in 2001 and published in 2005. This study focused on sediments deposited in the delta in the area around Hite, Utah, where much of the deposition from the Colorado River has occurred. While analyses found varying concentrations of metals and organic contaminants, researchers concluded that the preliminary data do not indicate any sediment contamination concerns. However, continued monitoring is needed to detect any contaminants that could present future concerns for people or wildlife.

There is a growing concern that contaminated sediments in Lake Powell may have negative effects on species diversity, change the structure of invertebrate communities, and may even lead to changes in the kinds of fish species that feed on the invertebrates.

Temperature Changes and Consequences

Modern engineering skills have brought about dams that are hundreds of feet high, and water that is released from these dams is often from several hundred feet below the surface of the upstream reservoir. Because of its depth, the water is often very cold relative to the natural temperature of the river, and its temperature does not vary over the course of the year. In the Colorado River Basin, water management through the use of dams and regulated releases from those dams has resulted in thermal changes to the Colorado River and several major tributaries. These thermal changes have been one of the driving forces behind changes to downstream organisms, including native fishes that require relatively warm waters for survival and reproduction.

Water temperature is an important ecological factor that can alter patterns of river productivity and propagate up through the food web. Furthermore, the lower water temperatures wrought by dams have had a direct impact on the warm-water adapted native fishes of the Colorado River.

Dams have changed water temperatures in the Colorado River and several of its tributaries. Before Flaming Gorge Dam was built, temperatures in the Green River increased in the spring and then decreased in the fall. Daily temperatures ranged from 32°F to 79°F through the course of the year. The mean annual water temperature was 55°F. After the dam was built, the water temperature in the river was more consistent and less seasonally variable. Temperatures ranged from 41°F to 50°F over the course of the year and reached their peak in late fall instead of summer. An effort to restore the thermal character of the river to benefit the trout fishery located below the dam was undertaken in the 1970s. At that time, a selective water withdrawal structure was installed, which facilitated the release of warmer water (closer to the reservoir's surface) during summer to enhance trout growth. The effect of this structure was a modest return of the river's temperature to something that more closely approximated the historical temperature schedule. Winter temperatures were colder, and summer temperatures were warmer. Overall, though, water temperatures did not return to normal. This is the only example within the Colorado River system where water managers have used engineering solutions to attempt to ameliorate the effects of cold-water releases by modifying the dam penstocks to draw warmer, near-surface water. Even so, this was done to benefit the growth of introduced trout, not native fishes whose decline may be attributed, at least in part, to temperature decreases caused by dam operations.

As stated previously in this report, efforts to protect introduced trout fisheries below the Aspinall Unit and within Black Canyon of the Gunnison National Park have included increases in minimum flows, rather than dam modifications to release warmer waters. Water temperatures within Black Canyon of the Gunnison National Park are not as great a management concern because there are currently no native fishes residing in the Gunnison River as it flows through the park.

Water released from Glen Canyon Dam can travel through three outlets. Most of the time, water goes through the penstocks and then flows directly through the dam's turbines to generate power. The penstocks are located approximately 230 feet below the lake's surface, when Lake Powell is at full pool. This water is colder and usually higher in dissolved materials, including salts and nutrients, than water closer to the surface. Water can also pour out of the river outlets, which are nearly 100 feet below the penstocks. Water from this deep in Lake Powell is even colder and has higher concentrations of nitrogen and dissolved materials. This could create water quality issues such as algal blooms below the dam. Lastly, in an emergency overfill situation, water can go through the spillways, which are gated tunnels about 52 feet below full pool.

Historically, the Colorado River through the Grand Canyon exhibited seasonal temperature variation. While it could be close to 32°F and even have blocks of ice during winter, the water of the Colorado River warmed during the low flows of the late summer and could get up to 70°F and possibly as high as 80°F. Since the Glen Canyon Dam was built, water temperature does not exhibit seasonal variability; instead, the water released through the penstocks is sufficiently far below the surface of the lake that it has a much lower and more consistent temperature. Water released from the dam averages 50°F over the entire year and generally fluctuates between 44°F and 53°F. From 1973 to 2003, the mean temperature of the water released from Glen Canyon Dam reached its maximum not in late summer but instead in December. This occurred because the fall turnover of the lake (i.e., a seasonal mixing of surface and deep waters that is facilitated by air-temperature changes and wind) brought warmer surface waters down to mix with the colder water, and this mixed water was pulled through the penstocks and released downstream.

Across years, there has been some variation in the temperature of the water released from the dam, resulting most often from the fluctuating water levels of Lake Powell. While fluctuating lake levels can modify water temperatures slightly, Glen Canyon Dam has still modified the natural temperature regime of the river: Average water temperatures below Glen Canyon Dam have been reduced, seasonal variations have been eliminated, and maximum temperatures have shifted from late summer to late fall or even early winter.

Altered water temperatures in the Colorado River and its tributaries have ramifications for natural resources, especially fisheries. Water temperature is an important ecological factor that can alter patterns of river productivity and propagate up through the food web. Furthermore, the lower water temperatures wrought by dams have had a direct impact on the warm-water adapted native fishes of the Colorado River. (See "Dam Operations and Endangered Fish of the Colorado River Basin" on page 48 for more information on the four species of federally listed endangered fishes that inhabit parts of the Colorado River and its tributaries.)

In the stretches of river below each of the major dams discussed in this report, the temperature conditions created by constructing and operating these dams have been inhospitable to native warm-water fishes. For the most part, the waters released from the Flaming Gorge, Glen Canyon, and Aspinall Unit dams throughout the year are too cold for these fish to successfully reproduce. Without water temperatures increasing throughout the spring, adult fish do not receive the appropriate environmental signal to begin reproducing. When they do reproduce, colder water temperatures slow growth and development of the larval and juvenile fish, making them vulnerable to predators. Under these circumstances, native fishes declined significantly after the construction of the dams.

At the same time that cold temperatures have adversely affected native fishes, the new colder temperatures and elevated dissolved oxygen content below these dams have been a boon for introduced trout. The trout fishery below Flaming Gorge Dam, which includes self-sustaining brown trout and stocked rainbow trout, is widely considered one of the top sport fisheries in the United States. Similarly, the trout fishery in the Gunnison River flourished after the construction of the Aspinall Unit dams, and the river through Black Canyon of the Gunnison National Park is now recognized as a Gold Medal Water & Wild Trout Water.

Farther south, cold-water salmonid fishes (i.e., trout) are native to the chilly headwaters of many of the tributary rivers flowing into Lake Powell, but in the main stem of the Colorado River historical conditions were not conducive for cold-water fishes to thrive. Since the creation of Glen Canyon Dam, the cold, clear water released from the depths of Lake Powell creates a perfect habitat for trout. The trout fishery is an important recreational aspect downstream of the dam.

Above: Flaming Gorge Dam. ©Doug Nichols.
Below: Fly-fishing is a popular activity in Dinosaur National Monument. ©John and Lisa Merrill.

Dam Operations and Endangered Fish of the Colorado River Basin

The Colorado River Basin is home to many species of fish found nowhere else in the world. Of the approximately 35 species of native fish in the basin's rivers, more than 20 are endemic. These fish are well adapted to the warm temperatures and turbid conditions found in the main stems of the basin's unregulated rivers. The reduced water temperatures, reduced flow variability, and altered sediment transport associated with water flows controlled by dams have degraded the fishes' habitat and negatively affected their ability to survive and reproduce.

While water management through dam operations is not the sole cause of the population declines in endemic fishes—non-native fish stocked by state wildlife agencies have also harmed native fishes by eating them or competing with them for resources—there is an accepted link between water regulation and the loss of native fishes.

The U.S. Fish and Wildlife Service has listed four endemic native fishes as endangered, a status that requires agencies to take protective actions according to the Endangered Species Act: Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), bonytail chub (*Gila elegans*), and humpback chub (*Gila cypha*). The U.S. Fish and Wildlife Service has designated 7,128 miles of river shoreline as critical habitat for these four endangered fishes; the National Park Service administers 2,532 miles (nearly 36 percent) of this habitat. Additional efforts are under way to cooperatively manage the roundtail chub (*Gila robusta*), which is a candidate for listing under the Endangered Species Act, as well as two rare species, the bluehead sucker (*Catostomus discobolus*) and the flannelmouth sucker (*Catastomus latipinnis*), in order to conserve and recover these species in the Colorado River Basin.

Following are details on Colorado pikeminnow, razorback sucker, bonytail chub, and humpback chub within Dinosaur National Monument, Black Canyon of the Gunnison National Park, Canyonlands National Park, Glen Canyon National Recreation Area, and Grand Canyon National Park. Also included is information on how dam operations have affected the endangered fishes in these parks and efforts being made to benefit the fishes.

Dinosaur National Monument

Endangered fish species: Colorado pikeminnow, razorback sucker, and humpback chub

Important habitats: Colorado pikeminnow spawn in late spring/early

summer in the cobble and gravel habitats of the lower Yampa River in Yampa Canyon; larvae require downstream alluvial areas with good backwater habitats. Razorback suckers spawn in areas of cobble, gravel, and sand in the lower Yampa River and in Island Park, just below the confluence with the Green River; larvae drift downstream to quiet, off-channel, warm habitats, including inundated floodplains, which are typically warmer and have abundant vegetative cover. Humpback chub spawn in the cobble and gravel beds of the Yampa River, following peak flows in spring and early summer, when water temperatures are about 60-68°F. Habitats used by recently hatched chub include talus shorelines, backwaters, small eddies, secondary channels, and embayments. Before Flaming Gorge Dam, humpback chub were reported in Flaming Gorge and in Lodore, Whirlpool, and Split Mountain Canyons. These populations were virtually eliminated by regulated flows and cold waters released by the dam.

Concerns: The operation of Flaming Gorge Dam precludes big spring floods, a lack of which degrades breeding habitats, impairs backwater habitats, and prevents floodplains from flooding. The timing of the spring flood is also critical for signaling spawning in native fishes. In addition to damage done by a reduction in peak flows, many critical floodplain habitats have been eliminated by diking, done to minimize the risk of flooding. Subsequently, the floodplain habitats have changed from wetland habitats to infrequently flooded tree- and shrub-dominated habitats.

Also of concern are non-native fishes, including trout and smallmouth bass (*Micropterus dolomieu*), which eat native fishes and compete with them for resources.

What's being done: The Upper Colorado River Endangered Fish Recovery Program, a partnership of government agencies, water and power interests, and environmental groups, has implemented actions to remove or breach dikes and manage flows to reconnect floodplains to the main stem and reestablish some of the floodplain habitat. In addition, numerous research studies done over the years have resulted in the most recent directive for Flaming Gorge Dam management, which comes from an environmental impact statement and Record of Decision put forth in February 2006. The Record of Decision states that the Bureau of Reclamation would change "the operations of Flaming Gorge Dam, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper Colorado River Endangered Fish Recovery Program." These recommendations are designed to address the needs of all three endangered fish species.

Top: (Left): Flaming Gorge Reservoir. ©Michael Christensen. **Middle:** Humpback chub. ©Arizona Game and Fish Department. **Right:** A researcher monitors translocated humpback chub in Shinumo Creek, Grand Canyon National Park. ©Allyson Mathis, National Park Service.

Dam Operations and Endangered Fish (cont.)

Recently, numbers of Colorado pikeminnow and razorback sucker larvae have increased, which may indicate that various management actions could be helping to improve survival and recruitment of all native fishes.

Black Canyon of the Gunnison National Park

Endangered fish species: There are currently no native fishes residing in the Gunnison River as it flows through Black Canyon of the Gunnison National Park, although Colorado pikeminnow have been captured in the lower part of the Gunnison River, between Delta and Grand Junction, Colorado, and they may use a spawning ground within this reach. Razorback suckers have been captured just downstream of Delta, but the area with the highest concentration of these fish is near Grand Junction, where the Colorado River and Gunnison River merge.

Important habitats: In 1994, the U.S. Fish and Wildlife Service designated the river corridor from Delta, Colorado, at the confluence of the Gunnison and Uncompahgre Rivers down to the confluence with the Colorado River at Grand Junction as critical habitat for the pikeminnow. The agency designated the stretch of Gunnison River near Grand Junction as critical habitat for the razorback sucker. There is extensive overlap between the areas designated as critical habitat for the Colorado pikeminnow and the razorback sucker.

Concerns: Operation of the Aspinall Unit dams, resulting in changes to natural flow rates, affects downstream habitats used by endangered fish.

What's being done: The ways in which flows controlled by the Aspinall Unit dams upstream affect endangered fishes have been extensively studied. The *Draft Environmental Impact Statement, Aspinall Unit Operations* (January 2009) describes proposed flows through the Aspinall Unit dams for the benefit of endangered Colorado River fishes, particularly the pikeminnow and the razorback sucker, as these species are currently found in the section of the Gunnison River most likely to be affected by any changes to dam operations. Much of the information incorporated into the draft environmental impact statement comes from hydrology and geomorphology research done on the Gunnison and Colorado Rivers in the mid-1990s. Studies of river hydrology were synthesized with studies of fish biology, and a series of flow recommendations were developed based on habitat needs and what is currently known about the Colorado pikeminnow and the razorback sucker. Operating the dam in such a way to achieve these flow goals would create a more natural hydrograph, which would serve to maintain and even restore the riverine and riparian habitats, as well as potentially benefit the endangered fishes downstream. However, at the time of this writing, a new operating plan has not been finalized.

Canyonlands National Park

Endangered fish species: Colorado pikeminnow, razorback sucker, and humpback chub

Important habitats: These include floodplains and backwater habitats that form as a result of spring flooding and the sediment left behind after those spring floods. Floodplains are critical habitats for adult pikeminnow, which rest there before undertaking long spawning migrations and which serve as warm, productive habitats that help to accelerate maturation; juvenile razorback suckers grow up in these sheltered productive habitats before re-entering the main stem river. Backwater habitats are the low-velocity habitats created by chute channels on large sandbars or from side channels. Larvae of humpback chub and pikeminnow use backwater habitats to avoid predation while feeding and growing.

Concerns: Even though flows in the Green and Colorado Rivers have not changed dramatically in response to upstream dams, native fishes have declined in the major rivers of Canyonlands National Park. These declines reflect basin-wide changes (e.g., fragmentation of the river system) and impacts of those changes on native fish populations (e.g., altering migratory behavior of Colorado pikeminnow). Impacts to the native fishes might also be tied to subtle but significant habitat changes that result from slight changes in the rivers' flows. Sediment inputs from the Green and Colorado Rivers flowing through Canyonlands National Park are still relatively high, so backwater habitats are relatively common. However, the amount of floodplain habitat available to endangered fishes at the appropriate stage of their lives has decreased within the park, due to somewhat reduced flooding. The loss of floodplain habitat in Canyonlands National Park due to the operations of Flaming Gorge Dam, at least as operations were practiced in the 1990s, has had an unquantified (but likely negative) impact on the Colorado River's native fishes.

What's being done: A new operating plan for Flaming Gorge Dam was adopted in 2006, but it is not known if new dam operations have begun to restore lost habitats in Canyonlands.

Glen Canyon National Recreation Area

Endangered fish species: All four native fish species currently listed as endangered were found throughout the Glen Canyon region prior to the creation of Lake Powell. They do not inhabit the reservoir. Downstream of Glen Canyon Dam, the cold, clear water released from the depths of Lake Powell is not suitable for native fishes that require warmer temperatures to survive and reproduce.

Important habitats: There is evidence that some of the endangered native fishes still exist in the upper parts of the San Juan, Escalante, and Dirty Devil Rivers that flow into Lake Powell.

Concerns: The creation of Lake Powell destroyed a significant section of native fish habitat and also restricts movement for populations of fish remaining in the upstream parts of the San Juan, Escalante, and Dirty Devil Rivers. Since there is no immigration between isolated populations, those remaining populations would be more susceptible to local extinction.

What's being done: Some of the habitat in the upper side channels of Lake Powell may be useful for captive breeding or grow-out areas for these endangered fishes, which could then be stocked in other suitable habitats located around the basin. Such a project is planned to help bolster populations of bonytail chub.

Grand Canyon National Park

Endangered fish species: humpback chub

Important habitats: There is only one reproducing population of humpback chub in the Lower Basin of the Colorado River; it is centered at the confluence of the Little Colorado River and the Colorado River in Grand Canyon National Park.

Concerns: The Grand Canyon humpback chub population declined about 40 to 50 percent between 1989 and 2001. Glen Canyon Dam has changed the Colorado River from a warm, sediment-rich river with variable flows that corresponded to the seasons and climatic events to a cold, sediment-poor river with flows that are controlled by dam releases rather than by natural factors. The main stem of the Colorado River is too cold for native fish to spawn, and those that spawn in side streams are not well prepared to transition to the main stem. Those that survive seek low-velocity talus shorelines or backwater habitat to feed and grow, but a lack of sediment and ongoing erosion have made such habitats less common. Also of concern are non-native fish species (e.g., catfish, carp, trout) that compete for resources with and/or prey directly on the native fishes, fish parasites (e.g., Asian tapeworm), and changes in aquatic food webs due to dams and possibly other factors.

What's being done: Glen Canyon Dam managers implemented the modified low fluctuating flow regime in 1996 in an effort to improve river habitat and benefit endangered fish. Researchers do not know if this regime contributed to the humpback chub decline documented in the late 1990s, but it did not reverse the decline. Surveys and models based on more recent data show a 52 percent increase in the number of adult humpback chub, and best estimates now indicate the population is up to 7,650 adults. The park, in cooperation with other federal and state partners, recently translocated young humpback chub to Shinumo Creek, a perennial tributary downstream of the Little Colorado. They hope to establish another viable population of chub in Grand Canyon National Park.

Top (Left): Colorado pikeminnow. ©Paul Badame. **Right:** Glen Canyon Dam has affected habitats required by endangered fishes. ©Can Balcioglu (istockphoto).

Addressing Natural and Cultural Resource Concerns Through Dam Management

Flaming Gorge Dam, the Aspinall Unit dams, and Glen Canyon Dam have traditionally been operated to satisfy hydropower needs and to maximize hydropower revenues. The preceding sections of this report have demonstrated how such dam operations are affecting natural and cultural resources in national parks of the Colorado River Basin, largely through changes to water flows, sediment availability and movement, and water temperatures. Changes to dam operations could be made to restore ecosystems and natural processes and better protect cultural resources. These changes to protect resources would also ensure these parks continue to significantly contribute to the economies in their regions. Changing dam operations to benefit resources would not result in extensive economic losses for the hydropower industry, as is evidenced in "Examining the Economic Values of National Parks and Hydropower" on page 57. The following changes to dam operations have been made or proposed thus far, with varied results. In some cases, it is too soon to know if changes to dam operations will have the desired resource benefits.

The need to address the plight of endangered fishes that were suffering as a result of changes to river conditions caused by dams was a primary factor that prompted dam operators to explore changes to water-management strategies. Flaming Gorge Dam operators first began modifying releases in the mid-1980s in order to benefit native fishes in the Green River. Numerous research studies culminated in final biological opinions on the operation of Flaming Gorge Dam in late 1992. After 1993, the Bureau of Reclamation began operating Flaming Gorge Dam in order to meet the flow and temperature recommendations of that 1992 biological opinion. Further research after 1992 led to new flow and temperature recommendations in 2000. This comprehensive report formed the foundation of the environmental impact statement (EIS) process that culminated in a final Record of Decision in February 2006, and a finalized EIS document. The Record of Decision states that the Bureau of Reclamation would change "the operations of Flaming Gorge Dam, to the extent possible, to achieve the flows and temperatures recommended by participants of the Upper

Left: Lonely Dell Ranch Historic District in Glen Canyon National Recreation Area. ©Alan English.

Colorado River Endangered Fish Recovery Program." The current operation of Flaming Gorge Dam reflects many of these recommendations, including baseflows and peak flows that somewhat better reflect historical conditions. It is too soon to know if resources have improved as a result of these changes in operation.

In 1992, operators of the Aspinall Unit dams began to conduct test releases to evaluate impacts on endangered fishes. In the decade that followed, dam releases reflected natural flow rates a little more closely. Investigations funded by the Upper Colorado River Endangered Fish Recovery Program culminated in flow recommendations for the Colorado and Gunnison Rivers in 2003. Since then, coordination and consultation have been occurring among the Bureau of Reclamation, U.S. Fish and Wildlife Service, and regional stakeholders in an effort to develop alternatives for the operation of the Aspinall Unit. The associated environmental impact statement is currently still in the draft stage.

Of the major dams of the Colorado River Storage Project, the most time, resources, and interest in modifications to dam operations have been focused on Glen Canyon Dam, due to its effects on the iconic Grand Canyon. In 1996, dam operators adopted the modified low fluctuating flow (MLFF) regime, which was meant to help restore damaged habitats (e.g., beaches and sandbars), aid in native fish recovery, and fulfill the other purposes of the dam (e.g., hydropower generation). The MLFF dictated that, under normal conditions, flows from dam releases could not exceed 25,000 cfs in a day unless there were some special conditions (e.g., high flow periods, experimental flows, etc.) and could fluctuate no more than 8,000 cfs in a day. The MLFF regime established minimum flows of 8,000 cfs during the day and 5,000 cfs at night. In general, the Glen Canyon Dam has been operated under the MLFF plan since 1996.

In 1996, Glen Canyon Dam operators adopted the modified low fluctuating flow (MLFF) regime, which was meant to help restore damaged habitats (e.g., beaches and sandbars), aid in native fish recovery, and fulfill the other purposes of the dam (e.g., hydropower generation).

As of this writing, there is no way to release the sediments trapped by Glen Canyon Dam and restore them to the river system, so dam managers must find ways to control dam-released water flows to achieve some of the same effects as natural flows. Controlled high flows have been used in attempts to rebuild or maintain certain habitats, including sandbars and backwaters, within Grand Canyon National Park by redistributing sediments contributed by the Paria River and other tributaries downstream of Glen Canyon Dam. Sediment inputs from the Paria River and other tributaries can be quite high. That sediment will accumulate in the river channel. With a controlled flood (where large quantities of water are released from the dam, through both the penstocks and the river outlets), this sediment can be redistributed within the canyon. Such an experiment took place in 1996 when a flood of 45,000 cfs moved sediment from the upper part of the canyon below the dam to rebuild downstream habitats. Unfortunately, the results of the experiment were temporary. The sand and fine sediments were moved downstream and deposited around bars, but when the sediment supply declined after the high-flow period, the sandbars that had been created or augmented eroded. Time-series photos of the 1996 flood illustrate that sandbars were immediately rebuilt and then lost over the next few years.

Other high-flow experiments at Glen Canyon Dam took place in 2004 and 2008. While both events resulted in sandbars being built initially, once the dam resumed its normal operations, the sandbars eroded. From the perspective of long-term sandbar maintenance and improvement, such experiments were failures.

High-flow experiments had mixed results for cultural resources downstream of the Glen Canyon Dam. Resources in the Glen Canyon reach between the dam and Lees Ferry were negatively affected by the loss of sediment due to the experimental high flows, while further downstream, sediment was deposited in the mouths of arroyos and on sandbars, where it temporarily alleviated erosion. However, prior to 2006, the data collected by the monitoring program did not include rates of erosion, only whether or not erosion was negatively affecting resources. Without information about the rate of change, the effects of the high-flow experiments could not be fully evaluated. Once sufficient data are collected under new monitoring protocols developed in 2006, Grand Canyon staff will be better able to assess the long-term effects of various flow regimes.

A fundamental question regarding the management and restoration of sediment-dependent resources in the Grand Canyon is this: Is it possible to manipulate water flows in order to rebuild and maintain sandbar habitats over decadal time scales? That is, since the dam traps the majority of the sediment, and only a relatively small fraction of sediment is brought in through the Paria and Little Colorado Rivers, is it possible to devise a flow-based management plan that will restore these important resources? Using previously collected data, researchers attempted to address this question and concluded that, under steady flow regimes, the amount of sand in Marble Canyon should exceed the amount exported, which would over time lead to a rebuilding of the eroded sandbars. They are careful to state that this does not mean that the sandbar resources will return to their pre-dam state; instead, they contend that the dam can be operated in such a way to use the available sediment to rebuild eroded beaches over a long time scale.

Efforts to find acceptable dam operations that will not damage the sediment-based resources of the Grand Canyon continue. Plans for dam operations from 2008 to 2013 originally included only one experimental flood—the one that occurred in March 2008—and also incorporated periods of low flows in late summer and early fall. There was controversy about the operating plan including only one scheduled high-flow event over the 5-year period. In response to these concerns, in December 2009 the Secretary of the Interior called for additional experimental floods following the one held in March 2008. In response, the Bureau of Reclamation just released its draft environmental analysis on high-flow events in Grand Canyon 2011-2020. This document proposes a series of high-flow events intended to mobilize available sediment and rebuild sandbar and backwater habitats. While these management strategies will likely benefit resources and will have short- to medium-term benefits for the sediment-based resources of Grand Canyon, the fundamental problem still exists—a basic imbalance between the sediment inputs and outputs because of the Glen Canyon Dam.

Above: High-flow experiment at Glen Canyon Dam in 2004. ©U.S. Geological Survey. **Below:** Deluge Shelter pictograph in Dinosaur National Monument. ©National Park Service.

Examining the Economic Values of National Parks and Hydropower

Determining the overall economic value of resources in national parks within the Colorado River Basin is important because this information can be used to guide strategies for important activities such as water management (e.g., dam operations). Dam operations greatly affect conditions of natural and cultural resources and can affect related recreational values in national parks within the Colorado River Basin. Resources along river corridors are especially susceptible to the ways dams have changed and continue to manipulate rivers. Quantifying the economic value of water-related resources within national parks allows for finer examination of the benefits of preserving resources.

Just as the economic value of national parks is an important component in discussions of water management in the Colorado River Basin, so too is the economic value of hydropower generated by dams in the basin. Dam operating plans in the Colorado River Basin have traditionally been structured to maximize hydropower generation and revenues. These operational strategies have been shown to negatively affect natural and cultural resources, necessitating a reevaluation of dam operations. The economic value of hydropower is relatively easily calculated, and will be discussed below as it pertains to proposed changes in dam operations to benefit park resources. Available data indicate that changes in dam operations to benefit national park resources have resulted in relatively small losses of hydropower revenue, and that proposed operational changes would also have only relatively minor impacts on revenues.

Determining the Economic Value of National Parks

A colorful sunset on the rim of the Grand Canyon, mist rising off Lake Powell on a chilly morning, elk browsing on streamside willows, the white waters of the Gunnison River crashing against boulders, an invigorating hike, an exhilarating rafting trip, or an informative guided tour—visitors hope to experience these sights, sounds, activities, and more during their stays in the national parks of the Colorado River Basin.

Left: Rafts along the Colorado River near Phantom Ranch in Grand Canyon National Park. ©Ann Kruetzkamp.

Above: Mules carry visitors into the Grand Canyon. ©Jane Norton (istockphoto). **Opposite Page:** Whitewater rafting through the Gates of Lodore section of the Green River in Dinosaur National Monument. ©Justin Bailie.

While most park visitors acknowledge the financial impact of park vacations on their own personal budgets—in terms of travel expenses, lodging, food, and park fees—few visitors would consider putting a price tag on the spectacular landscapes and cultural heritage preserved within parks or the enjoyment they offer to the public. Many would consider these special places and the lifelong memories created in them to be priceless. In addition, many U.S. citizens, some of whom will never have the opportunity to visit the national parks, assign value to the parks for what they represent about our nation and our shared heritage, and for their existence as repositories of natural and cultural treasures.

Even those people who would be hard-pressed to assign a dollar value to national parks might find it possible to consider how much a particular park experience is worth to them or what they would be willing to pay to protect specific areas, resources, or qualities. Using these and other techniques to quantify the economic value of national parks is useful because it provides further support to managers and decision-makers for protecting and preserving park resources, especially when competing economic values (e.g., value of logging or value of mining next to a park) threaten the health of national park resources. One useful way to quantify the economic value of national parks is to evaluate them in terms of the dollars they contribute to local economies and communities through visitation linked to the parks' resources, including recreational activities. Other approaches focus on the personal value of recreation and resource protection.

Studies have been done to quantify the economic value of national parks, though the data are far from comprehensive and additional work is needed. Most of the information below comes from an exhaustive review of economic studies pertaining to the value of national parks in the Colorado River Basin completed in 2007 by economists from the University of Montana, which described economic values provided by national park resources and identified the additional work needed to fill in data gaps.

Evaluating the economic value of national parks, and specifically the value of water-related resources, can be done by examining economic values associated with passive use of resources, direct use of resources, and regional economic impacts. Passive-use (also called non-use) values are related to the knowledge that park resources exist and will be preserved; they can be measured through surveys that ask individuals to place a monetary value on specific resources (e.g., native fish or cultural sites). Direct-use values are associated with the immediate use of park resources, such as participation in recreational activities, and can be measured by asking recreationists how much they would be willing to pay for certain recreational experiences beyond what they have already spent to have those experiences. Regional impacts relate to jobs, income, sales, and tax revenues generated by park resources; they can be measured using models that approximate how visitor dollars circulate through the local economy.

As noted above, although these three approaches can be used to evaluate the economic value of national park resources in the Colorado River Basin, only limited work has been done on this topic. Researchers at the University of Montana compiled existing data and determined that there is a significant shortfall in information needed to reliably measure the economic significance of water-related uses and values in these national parks. In fact, these researchers indicate that only about one-fifth of the information needed is available. Even so, initial findings point to the overall economic significance of national park resources, and to the significance of water-related resources specifically. The five Colorado River Basin parks examined in this report, as well as Curecanti National Recreation Area adjacent to Black Canyon of the Gunnison National Park, when taken together, received more than 8 million recreational visits in 2005. More than 2 million of these visits were related to water-based recreation activities. These visitors valued the parks for the recreational opportunities they provided, and they funneled money into local economies. The full economic impact of the 8 million annual visitors to these parks exceeds 16,000 jobs and $300 million in wages.

To date, the only study to focus specifically on passive-use values related to water resources along the Colorado River estimated willingness to pay to improve native vegetation, native and game fisheries, river recreation, and cultural sites through different proposed operating changes at Glen Canyon Dam. Researchers surveyed households within the marketing area for hydropower generated at Glen Canyon Dam, as well as across the entire United States. The survey revealed that people were willing to pay the most in increased electric power rates (in the western United States) or increased taxes (across the country) for the change in dam operating scenario that was described as being most beneficial to wildlife, beaches, and cultural sites. Nationally, passive-use values are as much as two orders of magnitude greater than the hydropower revenues that would be forgone due to the different operating scenarios. Even within the smaller geographic scope of the hydropower marketing area, passive-use values compared favorably with the forgone hydropower revenues.

The full economic impact of the 8 million annual visitors to the five parks included in this report—plus Curecanti National Recreation Area—exceeds 16,000 jobs and $300 million in wages.

Above: Kayaker camping along the Colorado River just below Glen Canyon Dam. ©scottspiker.com. **Opposite Page:** Glen Canyon Dam generators. ©Renee Howbert.

Many national parks, monuments, and recreation areas are an important part of the quality of life that makes nearby communities attractive to long-time and new residents, their businesses, and their retirement and investment income.

As explained above, the direct-use value of resources at national parks involves the value associated with the immediate use of park resources, such as participation in recreational activities. It can be measured by asking recreationists how much they would be willing to pay for certain recreational experiences beyond what they have already spent to have those experiences. Information on this parameter is generally incomplete; existing estimates vary widely but indicate that direct-use values for the Colorado River Basin national parks included in this report are in the hundreds of millions of dollars. More studies are needed to better quantify the direct-use value of national parks in general and water-based recreation resources in particular.

Regional impacts—also estimated in the hundreds of millions of dollars stemming from water-based recreation alone at the five national parks included in this report—are often narrowly construed as the effects of visitor spending on sales, jobs, and income. In a broader view, however, many national parks, monuments, and recreation areas are an important part of the quality of life that makes nearby communities attractive to long-time and new residents, their businesses, and their retirement and investment income. The economic benefit of proximity to these high-quality public lands has been established largely through comparative studies that illustrate rather than quantify the economic significance of these "quality of life" values. For example, an analysis of non-metropolitan counties in the western United States found that, between 1970 and 2003, counties that neighbor national parks outperformed their non-park peers by 43 percent in job growth, 37 percent in personal income growth, and an impressive 86 percent in population growth. A study of 90 metropolitan areas across the country found that, in urban areas, workers would take a 4 percent pay cut to live 100 miles closer to the nearest national park.

In sum, existing research shows that national park resources have important economic value. The National Park Service has proposed additional studies that continue the work by the University of Montana researchers and fill in data gaps, allowing for a comprehensive estimate of economic values provided by national park resources along the Colorado River and its tributaries. This economic information is an essential component of the parks' voice in discussions about water management. The additional proposed research should also evaluate the impact of different river operating scenarios on national park resources and compare the value of park resources to other economic uses. All of this information will be valuable as changes to dam operations for the benefit of national park resources are considered.

Dam Operations Tied to Hydropower Considerations

The dams in the upper Colorado River Basin were constructed largely to store water so that it could be apportioned according to the Colorado River Compact. The compact requires Upper Basin states to allow at least 75 million acre-feet (MAF) of water per decade to flow downstream to the Lower Basin states. An additional 1.5 MAF per year must be delivered to Mexico, with this obligation split between the Upper and Lower Basin states. The reservoirs in the Upper Basin, especially Lake Powell, act as a water savings account, where excess water from wet years can be stored in order to meet the delivery commitment in dry years.

In addition to their water-storage capacity, the dams supply hydropower to consumers in all of the basin states. For the first few decades after the dams were constructed, they were operated largely to maximize hydropower revenues. Part of the revenues generated is used to repay the federal government for the costs associated with building the dams, and part is used to pay dam operating costs. Because the cost of hydropower from federally owned dams is less than the regional marginal cost of electricity, sales of federal hydropower reduce power costs for consumers in the basin, who would otherwise have to purchase more expensive power from other sources. As the detrimental effects that revenue-maximizing management strategies are having on natural and cultural resources in the Colorado River Basin are becoming more widely recognized, dam operators, resource managers, and other stakeholders are considering ways to modify dam operations to ameliorate impacts on affected resources.

The Colorado River Compact does not preempt all, or even most, measures to protect environmental quality within the Colorado River or the riparian environment. Indeed, the compact and the various implementation agreements associated with it generally prescribe only annual or decadal quantities of water flows, and do not prescribe hourly, daily, weekly, or even monthly flow patterns.

Thus, there is a great deal of flexibility possible within the constraints of the compact, and efforts to protect national park resources can take advantage of that flexibility. For example, Glen Canyon National Recreation Area extends about 15 miles downstream of Glen Canyon Dam to the border of Grand Canyon National Park. As described extensively throughout this report, operations at Glen Canyon Dam substantially affect the downstream environment in this section of the river. To minimize negative effects on resources, Glen Canyon Dam can be operated to shift water releases between months in order to more closely approximate the pre-dam pattern of water flows, with large spring and early summer flows that mimic runoff from melting

To minimize negative effects on resources, Glen Canyon Dam can be operated to shift water releases between months in order to more closely approximate the pre-dam pattern of water flows.

winter snows. The dam can also be used to hold water releases constant during each day to mimic pre-dam flows, rather than varying releases during the day to match electrical generation with consumption. In addition, the dam can be used to make large releases for periods of several days to several weeks, which move sand around downstream and contribute to rebuilding beaches that are eroded by daily fluctuating flows. Each of those modes of operation has been used in the past or proposed for the future. Dams upstream of other national parks (e.g., Flaming Gorge Dam and the Aspinall Unit) can also be used to manipulate the intra-year timing of downstream releases to improve the environmental health of those parks (e.g., Dinosaur National Monument and Black Canyon of the Gunnison National Park).

While the Colorado River Compact imposes few constraints on dam-related environmental mitigation measures that may be undertaken to benefit national parks within the Colorado River Basin, there are economic costs associated with such measures. Environmental mitigation can affect both the timing and level of river flows, which each affect the value of the electricity produced at dams.

Minor Economic Costs Associated with Modified Dam Operations

Each of the large dams along the Colorado River and its tributaries generates electricity as water passes through the dam. The amount of electricity produced at any one time is measured in units of megawatts (Mw), or millions of watts, while the cumulative amount produced over a period of time is measured in kilowatt-hours (kwh), megawatt-hours (Mwh; 1,000 kwh), or gigawatt-hours (gwh; 1,000 Mwh or 1 million kwh). The economic value of a kilowatt-hour of electricity depends on when it is produced. On an annual scale, a kilowatt-hour produced in the spring is generally less valuable than one produced in the summer (when air conditioner loads are high) or winter (when electric space heating occurs and more lighting is needed during the longer nights). On a daily scale, a kilowatt-hour produced late at night is generally less valuable than one produced during the afternoon (in the summer, because of air-conditioning demand) or early evening (in the winter, because of heating and lighting uses).

The natural environment of the Colorado River before human intervention was generally characterized by large spring and early summer flows due to snowmelt, lower flows the rest of the year, and little change in flow rates on a daily basis. Year-to-year flows could vary substantially due to changes in annual rainfall and snowfall. The Colorado River Compact constrains any attempt to restore the full range of historical variability in annual flows, but it has no effect on the monthly or daily flow patterns. Thus, most proposals to change the flow regime of the Colorado River are almost entirely proposals to change the timing of flows, not their aggregate quantity. That means that the annual kilowatt-hour quantity generated by dams along the Colorado River is generally not significantly affected by environmental mitigation efforts.

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In the Grand Canyon, for example, a multiyear environmental impact statement on operational alternatives for Glen Canyon Dam found that six out of nine alternatives would have no impact at all on annual electricity generation from the dam, two would change output by less than one-quarter of 1 percent, and none would change generation by even as much as 2 percent. Similarly, in the Gunnison

River above Black Canyon of the Gunnison National Park, an environmental impact statement on dam operations found that four alternatives to current operations would each change flows through the Black Canyon of the Gunnison National Park by less than 0.1 percent. The impacts on electricity generation from the Gunnison River dams were less than 5 percent for all alternatives.

Changing the timing of water releases from dams has economic impacts even if there is no change in the annual amount of water released. Generally, the power-generating facilities associated with the large dams on the Colorado River were built and initially operated to maximize the value of their electricity generation. Thus, to the extent permitted by other constraints, water was released during the months of the year, the days of the week, and the hours of the day when it was most valuable. This resulted in major changes from the historical pattern of water flows, and much greater variability in water releases on short (hourly and weekly) time scales than historically occurred. Attempts to change dam release patterns towards pre-dam patterns generally involve steadier flows on these short time scales than those that prevailed when the dams were first operated.

The typical effect of changing dam operations toward steadier short-term flows is a reduction in the economic value of electricity generation from the dam. Smoothing out electricity generation on the daily scale will prevent generation from being concentrated into higher value "on-peak" hours of the day. Smoothing generation on a weekly scale will prevent generation from being concentrated into higher value weekdays, and require more generation on Sundays than would occur if power value were being maximized.

While changes in generation patterns for environmental purposes that are made on daily or weekly time scales generally result in a decrease in the net value of electricity, changes made on monthly time scales can either increase or decrease the net value of electricity generation. At the Grand Canyon, for example, the historical peak monthly flows occurred in June, due to snowmelt from the Rocky Mountains. June is also the beginning of summer, the season when electricity values, particularly on-peak values, tend to be highest. Changes in Glen Canyon releases to decrease winter releases and increase June releases, mimicking historical flow patterns, would thus increase the value of generation at Glen Canyon. Conversely, reducing late summer dam releases in order to increase May/June releases would shift generation in such a way as to reduce its economic value. Releasing water reduces the average amount of water stored in Lake Powell, and thus the average elevation of Lake Powell. When water levels are lower, the quantity of electricity that is generated per acre-foot is decreased due to decreased water pressure on the turbines.

There have been a variety of proposals to change flows on the Colorado River in ways that would affect national park environments. Operational changes at Colorado River Basin dams have been the subject of past, present, and prospective environmental impact statements for those proposals. Various efforts have been made to quantify the economic impacts on hydropower of changing river flows.

Over the past two decades, Glen Canyon Dam operations have been changed, or proposals for changes have been made, for environmental protection reasons. Each change or proposal for change had an economic cost by reducing the ability of the dam operators to maximize the hydropower value of releases from the dam. How-

Above: Power transmission lines at Glen Canyon Dam. ©Gary Whitton.

A multiyear environmental impact statement on operational alternatives for Glen Canyon Dam found that six out of nine alternatives would have no impact at all on annual electricity generation from the dam.

ever, studies have shown that none of these changes, actual or proposed, reduced the value of Glen Canyon Dam hydropower generation by more than $1-10 million per year, which is a fraction of the approximately $150 million in annual generation at this dam. Repeated analyses over a 20-year period have shown that environmentally driven modifications to the operations of Glen Canyon Dam can be made with annual economic cost impacts for electricity in the single digits of millions of dollars. Such costs are tiny compared to the approximately $350 million per year in total value of electricity produced from dams on the Colorado River and its major tributaries, or the $5.5 billion per year that residents of the Upper Basin states pay for electricity at the retail level, and are also tiny compared to the value of recreation and other non-power benefits produced by the Colorado River.

Proposed diversions of water from Colorado River Basin rivers and reservoirs to meet the needs of water consumers would result in equal or larger losses of hydropower generation revenues than would changes in dam operations to benefit national park resources. Proposed diversions include projects at Flaming Gorge Reservoir and at Lake Powell. The project at Flaming Gorge Reservoir would reduce flows through Dinosaur National Monument and Canyonlands National Park, and into Lake Powell in Glen Canyon National Recreation Area. With less water coming into Lake Powell, either releases from Glen Canyon Dam would have to be reduced in an attempt to maintain the level of Lake Powell, or the level of Lake Powell would start dropping. The diversion at Lake Powell would reduce the lake's level or result in decreased releases; certain circumstances could result in both outcomes. Both of these projects would result in decreased power generation, not to mention probable effects on national park resources.

Above: A proposed diversion from Flaming Gorge Reservoir would reduce flows through Dinosaur National Monument and Canyonlands National Park, and into Lake Powell. ©Jan Muehlhauser. **Below:** Hikers in Dinosaur National Monument. ©John and Lisa Merrill. **Opposite Page:** Whitewater rafting in Grand Canyon National Park. ©Justin Bailie/Aurora Photos.

What This Economic Analysis Means for National Park Resource Health

National parks, including those within the Colorado River Basin, have economic value that can be quantified in several ways. Initial studies have attempted to do by examining passive-use values, direct-use values, and regional economic impacts. Available data indicate that national parks and the resources they contain, including water-related resources, hold economic value in terms of the visitor dollars spent on recreational activities and in local communities, as well as value associated with many people's desire to reside near them. Even those who have not visited a particular national park often still assign value to the park for its role in preserving natural and cultural resources, and would be willing to pay to support management strategies that benefit those resources.

Water management strategies (i.e., dam operations) have generally been determined by the goal of maximizing hydropower revenues. This report has repeatedly demonstrated that such strategies harm natural and cultural resources in national parks. There is latitude for water managers to adopt strategies that reduce impacts on park resources while ensuring water delivery obligations are met. In addition, such strategies need not have significant effects on hydropower revenue, as exemplified above.

When the economic value of national park resources and the economic value of hydropower are considered together, it is clear that changing dam operations to benefit resources contributes to the continued high values of those resources with only a minimal impact on economic values related to hydropower.

River Recreation in the Colorado River Basin's National Parks

Rafting through the canyons of Dinosaur National Monument, Canyonlands National Park, and Grand Canyon National Park or spending summer vacations aboard a houseboat on Lake Powell are just two types of the water-based activities enjoyed each year by thousands of people who visit the Colorado River Basin's parks. Kayaking and canoeing are also popular on the lake as well as in some parts of the Green and Colorado Rivers. All in all, boating is the predominant form of recreation on the rivers and is one of the major visitor uses at Lake Powell.

Rafting trips in Dinosaur National Monument, Canyonlands National Park, and Grand Canyon National Park are usually multiday trips, and rafters camp along the riverbanks. Guides and trip leaders often plan periodic stops to take advantage of hikes to waterfalls, rock art and other archaeological sites, as well as good fishing spots.

Permits and fees are required for non-commercial trips, and a limited number of permits are issued each year. (Single-day boating trips usually do not require permits.) At Dinosaur and Grand Canyon, far more applications are submitted than there are permits available, and a lottery system is used to award the permits. At Canyonlands, there are currently enough non-commercial permits available to satisfy the number of requests. River trip permits cost $20-30 per trip at Canyonlands, $185 per trip at Dinosaur, and $100 per person at Grand Canyon (difference in cost correlates to the difficulty in obtaining a permit at each park). Rafting trips can also be arranged through a commercial guide with a concession permit for the park; spaces are limited, and the cost of the trip runs to hundreds or thousands of dollars per person, depending on the length of the trip. Permits and fees are required for launching motor boats at Lake Powell ($16 per week, $30 per year), but those in kayaks and canoes pay no launch fees at the lake. At Black Canyon, permits are required for kayakers but there is no fee.

Fishing done independently of boating trips is also popular at the river parks, but generally does not include overnight stays on the riverbanks. State fishing licenses are required, and some locations require free permits.

Dinosaur has 21 designated camping areas on the Green and Yampa Rivers, and rafters are required to camp in these areas only. At Canyonlands and Grand Canyon, beaches and sandbars are used for camping. The size of a group is limited at all three parks, and only one group should occupy each camping area. Camping is allowed along the lakeshore at Glen Canyon, and permits/fees are not required for camping within 100 feet of Lake Powell's full pool level. Beyond that point, backcountry permits are required.

River Recreation in the Colorado River Basin's National Parks (cont.)

For the 2009 high season at Dinosaur (May through August), there were 298 multiday non-commercial trips. Average length of stay for boaters was four to five days. Assuming not all trips had the maximum number of persons, there were probably 20,000 to 25,000 overnight visits. Commercial guided trips are in addition to this total. At Canyonlands, river trips range from two to 12 days in length. For the 2009 season, Canyonlands reported about 8,700 river visitors, and just under 35,000 overnight stays. Glen Canyon reported more than 1,750,000 overnight visits for the four lake districts for 2009. Grand Canyon reported more than 1,000 commercial and non-commercial river trips for 2009, with 205,000 user days/overnight visits.

With visitation of the Colorado, Green, and Gunnison River corridors comes the need for managers in parks along those corridors to address the effects visitors can have on natural and cultural resources. Operations of the dams along those rivers play a role in how visitors use the rivers and resulting reservoirs and the ways in which they might affect associated resources.

Regulation of the flow of water in the rivers, through the operation of dams, has made it possible for recreational boating to develop into a major industry throughout the Colorado River Basin. Regulation maintains consistent, predictable flows through the summer boating season, with high flow releases scheduled far enough in advance that boating outfitters and customers can plan trips to take advantage of these flows. River trips, both commercial and private, range from a few hours to several days, with multiple stops along the riverbanks. Lower water levels and slower flows make stops possible in places that were previously inaccessible due to the difficulty of beaching and mooring a boat. Stopping points are often located near historic properties that serve as attractions for guests, who create social trails that erode the riverbanks and undermine structure foundations, and who climb in and on the structures, damaging and destabilizing walls. Some river guides illegally collect archaeological and historic artifacts and place them in authentic or re-created sites along the river, in order for their guests to "discover" them, which destroys the integrity of sites and is prohibited. Impacts from visitation are related to dam operations not just because regulation of the river has allowed the rafting industry to flourish, but because when the river is flowing higher and faster, river visitors travel through areas more quickly, making fewer stops and causing less damage to cultural resources.

The creation of reservoirs in the river corridor, such as Lake Powell at Glen Canyon National Recreation Area, allows access by boat to places that were

once high above the river and virtually inaccessible, either due to steep canyon walls or the distance from the river. Prehistoric structures and artifacts that have survived hundreds of years undisturbed in relatively inaccessible areas have suffered accelerated deterioration due to increased human traffic to these locations. Boaters repeatedly use the same campsites, and if there are cultural sites nearby that are easily accessible, those sites will incur damage, both intentional and unintentional, from the influx of human visitors. Visitors climbing or leaning on ancient structures inexorably wear down those structures, while paths that are worn around them undermine their foundations, causing structural collapse. Careless use of campfires or smoking materials can destroy rare habitats and historic structures. Previous fires have destroyed rare stands of maple trees in side canyons; once these habitats are destroyed, they will not regenerate. Some visitors add their own inscriptions or graffiti to rock art panels; the skin oil of a few thousand reverent visitors tracing ancient inscriptions with their fingers can be equally destructive to the pigments and sandstone art. Collection of arrowheads and pottery shards from archaeological sites, or metal artifacts from historic cabins, add up to loss of integrity and eventual destruction of these sites. Visitor traffic can trample and destroy plants that have subsistence and ceremonial importance, and alter the trails and vegetation of a cultural landscape.

Rainbow Bridge National Monument, a separate unit of the National Park System managed by the staff of Glen Canyon National Recreation Area, lies in a side canyon of Lake Powell. The park's namesake is the world's largest known natural bridge. The National Park Service manages the site to respect and preserve the significance it holds for the American Indian tribes who consider it sacred. Before Glen Canyon Dam was built and Lake Powell formed, access to Rainbow Bridge required a rugged 7-mile hike from the river, and only a few dozen people visited it each year. At current lake levels, boaters can dock within half a mile of Rainbow Bridge, and 300,000 people visit each year. Not all visitors respect the traditional character of the resource; activities such as climbing the arch or picnicking beneath it may be offensive to the American Indian community. At full pool, water from Lake Powell extends under the bridge, in what was historically a dry gulch with no permanent water. Boaters are no longer allowed to navigate under the bridge, but the altered viewshed affects the traditional meaning of this place.

Top (Left): Rainbow Bridge National Monument, accessible from Glen Canyon National Recreation Area. ©Rian Houston. **Middle:** Water skier on Lake Powell. ©Greg Sargent (istockphoto). **Right:** Multiday river trip in Grand Canyon National Park. ©Justin Bailie.

Recommendations

National parks are special places that have been set aside for their abundant, ecologically or historically significant, and often unique resources. These resources are valuable not only for these reasons; in fact, it has been demonstrated that national parks have recreational value, they have value simply due to their existence and mission, they are attractive amenities to residents and investors, and they contribute dollars to local communities through visitor spending.

Dams within the Colorado River Basin have changed ecological and environmental processes—in many cases quite fundamentally—within Dinosaur National Monument, Black Canyon of the Gunnison National Park, Canyonlands National Park, Glen Canyon National Recreation Area, and Grand Canyon National Park by inundating and destroying natural habitats in some areas, creating highly unnatural flow regimes, trapping sediments that are critical for building and maintaining aquatic and riparian habitats, and altering natural water temperatures that fostered native fish communities. As a result of dam operations, spring floods no longer occur as they once did, peak river flows have decreased while flows during non-peak periods have increased, sediments no longer replenish riverbeds, and water temperatures are generally colder and no longer follow seasonal variations. Cultural resources have also suffered due to dams, with some resources being inundated as reservoirs filled, while others are affected by the same changes in flows and sediment supplies that harm natural resources. Analysis has indicated that changes to dam operations could be made to provide conditions more favorable for resource protection while having relatively small impacts on aspects of hydropower generation. Such changes could begin to repair the detrimental effects documented in this report that will eventually detract from the parks' economic value and their inherent value as symbols of America's unique heritage.

As populations served by the waters of the Colorado River Basin grow and their water demands increase, ways will be sought to satisfy these demands. Water diversions, new dams, and changes in current water management through alterations in operations of existing dams are all likely to be considered. Uncertainty about changes in precipitation due to climate change will further complicate matters. This report has identified and examined how current water management strategies, primarily the operation of large dams, have affected and continue to affect national park resources in the Colorado River Basin. This baseline information should be strongly considered in decision-making pertaining to water allocation, supply, flow management, and hydropower generation in the Colorado River Basin.

Left: Horseshoe Bend in Glen Canyon National Recreation Area.
©Galyna Andrushko/123RF.

Recommendations

There are a number of actions that should be taken to ameliorate damage done to the Colorado River Basin's national parks, to ensure the National Park Service can achieve its mandate to protect resources and to ensure the continued high economic value of the national parks. These actions include changes to dam operations, but they also encompass meeting the need for more information on national park resources, monitoring to assess the effects of changes to dam operations, and completing additional research on economic values associated with the national parks of the Colorado River Basin.

- **Dam operations should be modified to ensure the National Park Service can achieve its mandate to protect natural and cultural resources in the national parks of the Colorado River Basin.** Dams have fragmented the Colorado River system, changed river water temperatures to the detriment of native fish, disrupted water flows that were once governed by snowmelt inputs and climatic events, and robbed the river system of sediments needed to maintain important river and riparian habitats. As a result, natural and cultural resources in national parks have suffered. Modifying dam operations to restore disrupted natural conditions is critical for the health of the Colorado River system, and proposed modifications have been estimated to have negligible effects on energy production and hydropower revenues. Needed modifications include dam releases that more closely mimic the natural flows of the Colorado River and its major tributaries, including seasonal flow variability and spring floods. Spring floods are important both for shaping river habitats and for helping visitors understand how the canyons were carved by the rivers. Changes to dam operating plans should more aggressively emulate natural flow dynamics to benefit native fishes, and the effects of these changes should be regularly monitored to ensure they are achieving this goal.

- **Research and monitoring are needed to comprehensively understand natural and cultural resource conditions in the national parks within the Colorado River Basin.** The National Park Service is mandated to preserve and protect natural and cultural resources in national parks, yet the agency is hindered by a lack of information. Cultural resource monitoring programs need to be established at Dinosaur National Monument, Canyonlands National Park, and Glen Canyon National Recreation Area to gather data on the direct and indirect effects of water management activities on resources. These programs should be funded from the revenues generated by the dams of the Colorado River Storage Project. Natural resource monitoring should continue within the national parks of the Colorado River Basin. Good programs are in place in some parks (e.g., Grand Canyon) and should receive continued support, while the other parks that have been little studied should receive support for increased research and monitoring of resources. Information gained through research and monitoring should inform decisions pertaining to resource management and dam operations.

- **National parks need additional support to minimize vandalism and unintended resource damage within the Colorado, Green, and Gunnison River corridors.** Significant natural and cultural resources (e.g., archaeological artifacts, historic structures, rare plants) are found along the river corridors. River recreationists may intentionally or inadvertently damage these resources. Currently, none of the parks examined in this report have enough trained staff to monitor and protect resources. Additional staff and expanded efforts to educate park employees, visitors, concessionaires, and private river guides on proper treatment of park resources are important to ensure resources are protected.

- **Agencies must determine responsibility for management of cultural resources exposed when reservoir levels drop at Glen Canyon National Recreation Area.** Fluctuating water levels in Lake Powell periodically expose cultural resources that were inundated when the reservoir was at full pool. The National Park Service and the Bureau of Reclamation must determine which federal agency will assume responsibility for managing recently exposed resources to ensure they are not damaged by erosion, wave action, or visitor impacts such as looting, vandalism, and inadvertent damage from trampling artifacts or climbing on structures. Without a determination of management responsibility, no action is being taken to protect them.

- **Additional research is needed to comprehensively estimate the economic values provided by national parks along the Colorado River and its tributaries.** This economic information is an essential component of the parks' voice in discussions about water management. The additional proposed research should also evaluate the impact of different river operating scenarios on national park resources and compare the value of park resources to other economic uses. All of this information will be valuable as changes to dam operations for the benefit of national park resources are considered.

- **Dam operators, resource managers, and stakeholders basin-wide must adopt a broad perspective, commit to informed and adaptive decisions, and cooperate with one another to successfully address concerns and meet various needs for resource protection, water delivery, flood control, and hydropower generation.** The search for solutions to resource and water management issues in the Colorado River Basin must be approached holistically, instead of on a site-specific, dam-specific, or park-specific basis. Natural, cultural, and recreational resources must all be taken into account. Changes in dam operations affect both upstream and downstream resources, and especially for the largest dams considered in this report, effects can reach far beyond the immediately adjacent parks. The best hope for preserving resources throughout this fragmented landscape is a genuine commitment to the adaptive management approach by an extensive, cooperating group comprised of federal, state, and local entities, as well as private landholders and citizens.

Top (Left): Las Vegas, Nevada. ©Valerie Loiseleux. **Middle:** Houseboats on Lake Powell. ©Xiaodong Ye (istockphoto). **Right:** Water being released from Glen Canyon Dam. ©Joy Cooper.

Glossary of Terms and Concepts

Archaeological resources: the remains of human occupation and activity; they are important because they help us understand the lifeways and behaviors of groups of people. In the Colorado River Basin, common archaeological sites include rock art, storage structures such as granaries and dwelling structures built into cliff walls, and stone-lined hearths or firepits. Artifacts include butchered bones, ceramics, stone or metal tools, and twined or woven artifacts such as figurines, baskets, and sandals.

Baseflow: for the purposes of this report, baseflows are flows present during non-peak periods

Cultural landscapes: places on the land that have been altered by humans to create a setting for a particular activity or purpose, or that are assigned cultural meaning because of the features of the landscape. They are combinations of natural and man-made elements, and they may contain other cultural resources such as historic structures, ethnographic resources, or archaeological resources. Viewsheds and soundscapes can be important components of cultural landscapes. In the Colorado River Basin, cultural landscapes include the entire Grand Canyon; historic ranches such as the Lonely Dell Ranch at Glen Canyon National Recreation Area and the Josie Bassett Morris homesite at Dinosaur National Monument; and the Lathrop Canyon Mining District in Canyonlands National Park.

Ethnographic resources: tangible and intangible expressions of human culture; they include the cultural and natural elements of a park that have significance in the cultural system of a traditionally associated group. Ethnographic resources in the Colorado River Basin include plants used for food or ceremonial activities as well as sacred sites, such as Rainbow Bridge.

Geomorphology: the study of the characteristics, origin, and development of landforms

Historic structures: works constructed to serve some human activity; in the Colorado River corridor, historic structures include Fort Bottom Ruin in Canyonlands National Park and Defiance House in Glen Canyon National Recreation Area, both Ancestral Puebloan structures that are also archaeological resources; Bright Angel Trail at Grand Canyon National Park; the Gunnison Tunnel at Black Canyon of the Gunnison National Park; and the partially submerged remains of the *Charles H. Spencer* steamboat at Lees Ferry in Glen Canyon National Recreation Area.

Hydrograph: a plot of flow rates over time

Riparian zone: area along the bank of a river or other body of water

Sediment load: solid materials, such as sand, that are transported by a river

Tailwater: the part of a river or stream immediately downstream of a dam or power-generation structure

Above: Defiance House is a nationally significant Ancestral Puebloan structure within Glen Canyon National Recreation Area. ©G. Chase Maxfield.

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