Environment and Ecology of the Colorado River Basin

By Natalie Triedman

Key Findings:

-Human needs have historically taken precedence over environmental concerns when managing Colorado River water and other natural resources.

-The diversity of local habitats and the demand for unique management approaches complicates how we manage environmental concerns on the Colorado.

-The riparian zone is deteriorating, which is negatively impacting native plant and animal species that rely on this unique habitat.

-To this day, no specific water quantity on the main stem of the Colorado River is designated for environmental needs. The threat of endangered species and degraded water quality are both amplified by the fact that we do not allocate a significant quantity of water exclusively for environmental needs.

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The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

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"Ultimately, the condition of our forests, and the ability of these forests to respond to climate change, disease, development, and wild fires will help to shape the future of the Colorado River, and its role as the lifeblood of the arid Southwest...Our ability to protect this incredible green infrastructure is every bit as important as our ability to build dams, canals, waste treatment plants, and other bricks-and-mortar type of solutions."

-Harris Sherman, the Undersecretary for Natural Resources and the Environment for the U.S. Department of Agriculture, speaking at the Colorado College, on February 6th, 2012 as part of the State of the Rockies Project Speakers Series

Introduction

The Colorado River Basin is an environmental treasure that is an increasingly fragile system due to complex and diverse pressures. Human needs have historically taken precedence over environmental concerns when managing water and other natural resources. Natural organisms do not follow political boundaries, so laws and other policy actions are not always aligned with the specific needs of plants, animals, and water. The diversity of local habitats and the demand for unique management approaches also complicates how we manage such environmental concerns.

How do we assess the health of the Colorado River Basin? Biodiversity, water quality, and water quantity are key indicators of a river system's health.[1] The zone adjacent to a river, called the riparian zone, is critical for river health and biodiversity. The good news is that the banks lining the Colorado foster impressive ecological diversity, supporting 65% of the species in the West, even though it comprises a mere 5% of actual land area.[2] The concern is that the riparian zone is deteriorating, which is negatively impacting the plants and animals that rely on this unique habitat. Equally concerning, as populations of some plant and animal species decline, are the implications of why these populations are being threatened. Species declines are indicators that we should not ignore because they tell a story about the deteriorating environmental conditions that may affect other species.

It is easy to overlook these environmental threats considering the ecological beauty throughout the Colorado River Basin, which includes some spectacular natural wonders ranging from the Rocky Mountain National Park to the Grand Canyon. People who live and visit the region may be deceived by the array of colorful flora and impressive wildlife, potentially obscuring environmental threats not apparent to the casual observer. Not only are a number of species at risk rising and the natural habitat becoming degraded, but the quality of water is also threatened. The factors affecting water quality along the 1,450 miles of the river are varied and cause many different types of complications for species and the environment. Primary among these water quality issues are salinity, sediment, and metals.

The threat of endangered species and degraded water quality are both amplified by the fact that we do not allocate a significant quantity of water exclusively for environmental needs. For many decades water quantity along the river has been determined by legal mechanisms, which have consistently prioritized human needs over natural requirements. Dams are one example of a policy intervention that causes myriad changes that upset the natural habitat along the river; by regulating the quantity of flows, dams threaten water quality and native species. Dams and diversions cause a reduction of downstream flows on the Colorado River, transforming riparian habitats that are essential for plant and animal development. Dams also trap sediment and nutrients essential to downstream ecology and release water that is colder than waters upstream. Deprived of adequate flows and water quality, species are then faced with the challenge of quickly adapting to a new habitat, and some do not survive.

The Colorado River Basin is threatened. To this day, no specific water quantity on the main stem of the Colorado River is designated for environmental needs. Environmental issues, such as water quantity and quality, are also linked to important economic and social issues. By taking initiative to create a healthy river ecosystem, we will be addressing human needs in this expansive region as well. We are all stakeholders, and the stakes are high.


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Ecology of the Basin: Diversity in Geography

The 242,000 square miles of the Colorado River extend across many different eco-regions with distinct environmental profiles. Despite the variation in climate, hydrology and ecology, these diverse habitats are united by the fact that they all rely on a healthy riparian environment- the transition zone between land and river, as seen in **Figure 1**.[3] As natural buffer zones, riparian areas support flora and fauna native to both upland and wetland habitats.[4] This explains why the riparian environment throughout the Colorado River Basin is home to a high percentage of plants and wildlife, despite the small percentage of land that actually comprises the riparian zone.[5] The powerful and erratic river flows that are characteristic of riparian environments also contribute to the health and diversity of the ecosystem by transporting nutrients and sediment during flood events.[6] Plants and animals in the Colorado River Basin are dependent on this resource-rich buffer zone, which is becoming increasingly threatened by dams and diversions, invasive species, pollution, and water depletion.[7]

Figure 1: Image of a Riparian Environment

Natalie Triedman

The Colorado River Basin is an impressive landscape replete with diverse flora and fauna that draws millions of tourists to the region every year. However, assessing the region with too broad a brush can obscure the reality of numerous environmental threats. Development projects have altered natural processes related to the hydrology, ecology, and climate of the basin, which has interfered with ecological stability and contributed to population declines among many different plant and animal species. The specific environmental impacts vary with each eco-region in the basin, challenging conservation groups and environmental lawyers to create flexible management strategies that consider the diversity of habitats. This diversity is seen as one that follows the course of the river through the basin from its source high in the Rockies to the Colorado River Delta.

Ecological Overview of the Basin from Source to Sea

From the snowcapped Rocky Mountains to the dry delta where the river no longer reaches the sea, the Colorado River flows 1,450 miles through seven U.S. states and areas in northern Mexico.[8] It encompasses a range of habitats, each with unique ecological profiles and threats that are specific to that region. Thus, it is impossible to summarize the biological makeup of the basin as a whole. It is helpful to have an overview of this diversity as a context for understanding the environmental challenges in more detail.

The Colorado River starts at the headwaters on the continental divide, the geological boundary separating the Atlantic and Pacific watersheds. At an elevation of over 10,000 feet, the river flows down La Poudre Pass and through the Rocky Mountains as it is fed by melting snowpack that contributes 85% of the river's water.[9] Flora and fauna native to this section of the Colorado River have adapted to the variability and intensity of the high elevation weather patterns, as well as the rugged topography characteristic of the steepest habitat in the United States.[10] In spite of more than 3.1 million visitors annually to Rocky Mountain National Park, water quality is adequate to support the growth and survival of plants and wildlife.[11] Alpine plants, such as the columbine, bloom in April and color the landscape through September. An impressive 139 confirmed butterfly species make the park a popular location for butterfly research. This area is home to large mammals such as elk, black bears, and bighorn sheep that reap the benefits of this healthy Rocky Mountain ecosystem alongside many smaller inhabitants such as marmots, snowshoe hares, ground squirrels, and pika. However, not all animals have been able to thrive in this highly visited park; the yellow-billed cuckoo was once native to the National Park but can no longer be found in the region.[12]

Rushing down the western slope of the state of Colorado, the river meets its fifth largest tributary, the Gunnison River. Prior to meeting at their confluence in Grand Junction, Colorado, the Gunnison winds through the Black Canyon of the Gunnison National Park, a unique area for flora and fauna alike. Over the course of two million years the river's flows have carved through the Precambrian rock to form the Painted Wall, the highest cliff in the state of Colorado standing at 2,250 feet (**see Figure 2**). A wide range of ecosystems exist within the 30,045 acres of land that comprise the National Park.[13 14] "Pygmy forests" are sparsely decorated with pinyon pines and juniper trees, typical of the southern sections of the upper rim of the canyon. This type of desert woodland is distinct from areas further along the rim of the canyon where oak flats dominate the landscape, providing an abundance of habitat and food selection for animals. Large mammals such as coyotes, elk, and mule deer take advantage of this rich environment along the highest points of the canyon. Below the rim in the inner canyon, many different plant species can be seen strategically tucked away in recesses of the steep rock wall of the canyon. Resilient Douglas firs and aspen trees also cling on to these vertical slopes, subsisting on water from pockets of snow preserved late into the spring. The bighorn sheep is one of the few animals that can maneuver this unforgiving terrain. Many feet below, at the base of the canyon, vegetation such as chokeberry, boxelder, and narrowleaf cottonwoods shelter native birds and provide food for beavers and other small mammals. An abundance of insects and other invertebrates in this region make it an ideal habitat for birds like the American Dipper, which will often be seen scanning the river for food before diving down into the deeper waters.[15] Rainbow and brown trout are among the fish species that brave the cold waters of the Gunnison, which average about 50° Fahrenheit.[16 17]

Figure 2: The Painted Wall in Black Canyon of the Gunnison National Park


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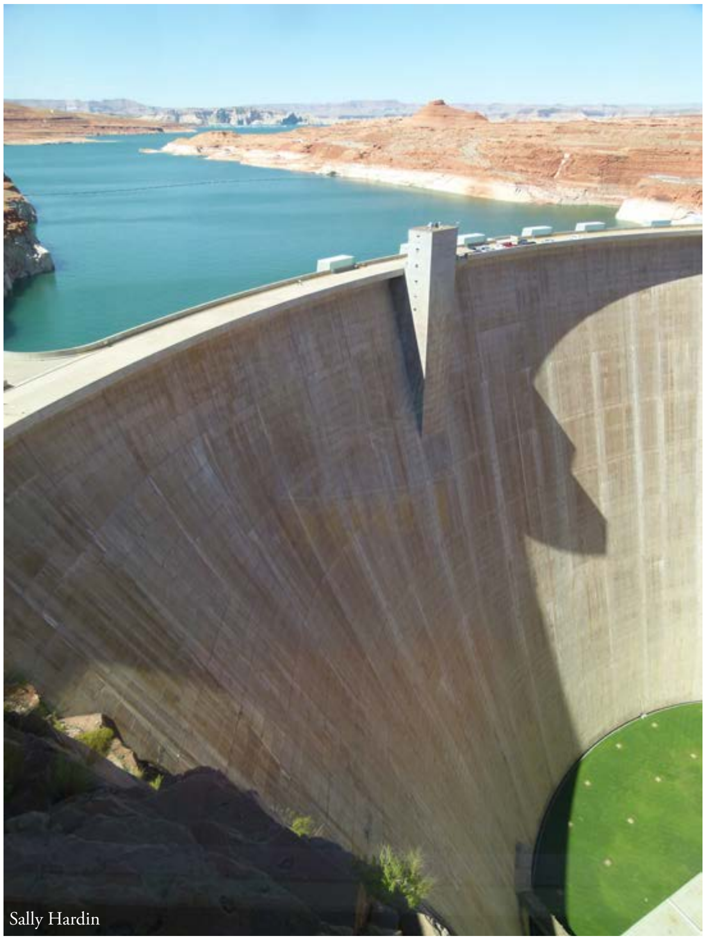
As it winds further south, the Colorado River unfolds into the unique high desert environment of Utah's canyon country. After cutting through Moab, a city highly dependent on the river's flows for its recreation industry, the Colorado enters Canyonlands National Park.[18] In the heart of the Canyonlands, the Colorado merges with its main tributary, the Green River. Much of the landscape in this region is still undeveloped, although a recent increase in human impacts, such as water pollution and the introduction of nonnative species, have taken a toll on native flora and fauna. Lining the river are two notorious invasive species, the tamarisk and Russian olive, which often outcompete the low-elevation native plants such as the Fremont cottonwood, seepwillow, water birch, and boxelder. The riparian corridor in the Canyonlands still attracts an abundance of wildlife because it is one of the few areas with water in this desert environment. Animals such as desert bighorn sheep and mule deer have evolved so that they can survive for days without water while other mammals such as beavers, muskrats, raccoons, ringtails, and skunks depend on the river daily. Mountain lions and other predators are attracted to the habitat not only because it is a source of water, but also due to the abundance of prey. Insects such as caddis flies, black flies, mayflies, diving beetles, and water boatmen inhabit areas along this section of the river as well. Some avian species such as songbirds feed on these insects exclusively, while others such as ducks and Canada geese prefer to feed on the abundance of riparian vegetation. Carnivorous birds such as ospreys, great blue herons, and bald eagles can also be found in this region, feeding primarily on fish. In the Canyonlands the peregrine falcon sits at the top of the avian food chain, feeding on songbirds and ducks.[19]

Flows continue to cut across the desert in the southeast corner of Utah until reaching Lake Powell, the second largest artificial lake in the country. Glen Canyon Dam created the reservoir, which is located just south of the Utah-Arizona border. The biological makeup within the 1.2 million acres of the Glen Canyon National Recreation Area is extremely different from the way it was prior to the construction of the dam in 1963. Since the completion of the dam, some species have begun to adapt to the new hydrologic patterns; over 300 species of birds have been identified in this region since the completion of the dam, even though the landscape is not ideal for breeding.[20] Adaptation to the changing landscape is more challenging for other plants and animals. The Copper Canyon milkvetch, alcove rock-daisy, and kachina daisy are all rare plants that are federally recognized as threatened


Sally Hardin

species. Nonnative species introduction has been a major challenge for these plants; invasive species such as the tamarisk, Russian olive, and Ravenna grass now make up 11% of the vegetation in the recreation area, and threaten native species by outcompeting them for habitat.[21]

The river then carves through the distinguished World Heritage Site, Grand Canyon National Park, home to seven different life zones with over 1,500 species of plants, 355 species of birds, and 89 species of mammals. This impressive diversity should not be taken for granted; the Grand Canyon is also experiencing endemic, threatened, and endangered species, as seen in **Figure 3**. There are currently many laws and regulations in place that aim to protect these natural resources from further threats. The creation of Glen Canyon Dam in 1966 had a lasting impact on the ecological makeup in the Grand Canyon. Once a vital transport system for silt and sediment, flows now discharge the sediment behind Glen Canyon Dam, changing the hydrologic condition that fish and other aquatic life have adapted to over many years. Similar to other impoundment projects throughout the basin, the dam discharges water from the bottom of the reservoir, leading to unnaturally clear and cold flows downstream. These new conditions facilitated the proliferation of nonnative species at the expense of native species adapted to the natural flows of the river.

After crossing into Arizona and through the Grand Canyon, the Colorado River curves westward toward Lake Mead National Recreation Area, located in the Mojave Desert 30 miles southeast of Las Vegas, Nevada. Similar to Glen Canyon Dam, the construction of Hoover Dam resulted in a rise of bird populations due to plentiful still water and the subsequent increase in vegetation. Lake Mead is also a convenient stop for migratory birds because it is located in a typical north-south migration route. While the calm waters of the artificial lake can be an ideal habitat for birds, its aquatic inhabitants may not be so fortunate. The endangered razorback sucker, typically found in this area of the Lower Basin, has sharply declined in population during the past two decades.[22] Like many other areas throughout the basin, Lake Mead is also faced with the challenge of invasive species. There are current efforts underway in the Lake Mead National Recreation Area to eradicate fountaingrass, a noxious weed that lines the shores of Lake Mojave. The flatworm larva parasite, commonly known as “swimmer’s itch,” is another environmental management challenge in the recreation area.[23]

As the river continues its path toward the delta, it passes east of the Salton Sea, one of the lowest inland seas at an elevation of 227 feet below sea level.[24] It was created unintentionally in 1905 when high spring floods took down floodgates leading up to Imperial Valley, forcing all contents of the Colorado River into the Salton Trough for the subsequent 18 months. The Whitewater, Alamo, and New Rivers now support the Salton Sea, along with the agricultural return flows from the Imperial, Coachella and Mexicali Valleys.[25] After the California Department of Fish and Game stocked the Salton Sea with sport fish in the 1950s, it has been a popular destination for anglers. Tilapia is the primary fish caught in this region due to their high salt tolerance.[26 27] Evaporative losses in the sea have affected the dilution factor for dissolved salts and caused increasingly saline waters, which threaten plants and animals that are less tolerant of high salinity. Many species will be forced to adapt or die if concentrations

Figure 3: Grand Canyon Endangered Species

Fish	Federal	State
Humpback Chub	E	WSCA
Razorback Sucker	E	WSCA
Flannelmouth Sucker	SC	-
Reptiles and Amphibians		
Relict Leopard Frog	C	WSCA
Northern Leopard Frog	-	WSCA
Desert Tortoise	SC	WSCA
Birds		
California Brown Pelican	E	-
California Condor	XN	WSCA
Northern Goshawk	SC	WSCA
Bald Eagle	T	WSCA
American Peregrine Falcon	-	WSCA
Yuma Clapper Rail	E	-
Mexican Spotted Owl	T	WSCA
Southwestern Willowfly-catcher	E	WSCA
Yellow-billed Cuckoo	C	WSCA
Mammals		
Long-legged Myotis	SC	-
Western Red Bat	-	WSCA
Spotted Bat	SC	WSCA
Pale Townsend’s Big-eared Bat	SC	-
Allen’s Big-eared Bat	SC	-
Greater Western Mastiff Bat	SC	-
Southwest River Otter	SC	WSCA
Bighorn Sheep	-	-

KEY

Federal Status:
E: Endangered, in danger of extinction
T: Threatened, severely depleted
C: Candidate for listing as threatened or endangered
XN: Experimental non-essential population
SC: Species of Concern. Some information showing vulnerability or threat, but not enough to support listing

State Status:
WSCA: Wildlife of Special Concern in Arizona

Source: National Park Service, http://www.nps.gov/grca/naturescience/upload/threat-endanger.pdf.

continue to increase, as projected.[28] The New and the Alamo Rivers contribute a dangerous pollutant called selenium, which builds up in agricultural drainage and becomes concentrated in small organisms living in the Salton Sea before contaminating larger organisms higher up on the food chain.[29]

Natural resources do not adhere to national borders, and this holds true for the Colorado. The Colorado River Delta was once a massive wetland environment, sustained by the interaction between 10-20 million acre-feet of freshwater from the Colorado and the salty ocean tide from the Sea of Cortez. This ecological haven that supported two million acres of plants and wildlife native to freshwater, brackish water, and saltwater environments was compromised when the Colorado River stopped flowing to the delta due to dams, diversions, and water depletion.[30] More than 30 years ago, brackish agricultural drainage from the Wellton-Mohawk Irrigation and Drainage District (WMID) in southern Arizona began emptying into a dry mudflat, which evolved remarkably into Mexico's Ciénega de Santa Clara, a 400,000-acre artificial wetland on the Colorado River Delta. This drainage system now sustains an impressive amount of wildlife and is home to many threatened and endangered species. Thousands of birds, both migratory and resident, rely on this habitat for food and shelter year-round. As the largest remaining wetland in the Colorado River Delta, the Ciénega acts as a migration corridor for over 75% of North America's birds, including a number of endangered species such as the Yuma clapper rail.[31]

Having followed the full length of the river and seen its varying ecosystems and habitats, some natural to the river, others engineered by the hand of man, the diversity of the basin's ecology is apparent. However, that diversity is threatened by alterations made to the traditional flow of the river for the beneficial use of the region's human inhabitants. Thus, an ecological investigation of the basin would be incomplete without highlighting some of the most threatened species of the larger system.

Endangered Species: Victims of Diversion and Development

Humans have contributed to the degradation of natural ecosystems throughout the Colorado River Basin in many ways. As it flows through seven U.S. states and parts of northern Mexico, the Colorado extends across many different habitats, each with a distinct ecological profile and challenges unique to that region. Even on the micro-level, within a single habitat, there is an interconnected system where any modification may benefit one species while threatening another. River systems cannot be simply labeled "healthy" or "unhealthy" because the health of a riparian ecosystem rests upon a variety of complex factors that may even have opposing needs. Indicators such as plant and animal population trends can give clues about the stream health and environmental impacts that result from changes made to the river. Relying on these types of indicators is not ideal because it is a reactive strategy and by the time population declines become apparent, the species is already threatened. The alternative is to target the specific causes of environmental degradation first. Historically, this proactive approach to conservation has not been the norm in the Colorado River Basin. This oversight is rooted in the Homestead Acts of the late 1800s, which set a precedent for water use in the West, an area dominated by arid conditions and a desert landscape. Ever since, urban and agricultural expansion in and around the basin states, society's primary objective in managing the river, has put a strain on natural resources and interrupted environmental processes that plants and animals in the basin rely on.

The prevalence of dams and diversions on the Colorado River allows for regulation of stream flows and water allocation but threatens wildlife in the basin. Plants and animals native to this region depend on hydrologic patterns that have existed for thousands of years, up until the creation of dams. The strong flows that were characteristic of the Colorado have historically carried high levels of sediment and nutrients throughout the river system. Once carrying about 160 million metric tons of sediment to the delta, the Colorado River deposits almost none today.[32] Changes like this are a major threat to plants and animals that rely on sediment-rich waters and strong flows for providing habitat and transporting nutrients.

The changing climate has also had a significant impact on the river hydrology. Temperatures have been steadily increasing in the western United States since the 1970s and the Colorado River Basin has experienced more warming than any other region in the country.[33] Increasing mean annual temperatures have caused a shift in the timing of peak annual runoff so that high flows are consistently occurring earlier in the year. Another manifestation of warming temperatures has been increased evaporation from snowpack, which has resulted in less runoff overall.[34] Plants and animals are dependent on the specific hydrologic patterns typical of the Colorado River for habitat, migratory patterns, food distribution, and development and growth. Species are currently faced with the challenge of adapting to new flow patterns in a short period of time.

Invasive species also exacerbate the threat of extinction for endangered plants and animals by acting as competitors and predators to the native species. Invasive species are nonnative organisms that have been introduced, either intentionally or unintentionally, to a new geographic location that has conditions that foster its proliferation. On the Colorado, invasive species threaten ecological well-being on many levels. Invasive animals threaten native species because of

"The 'Ten Percent Rule' is a general rule of thumb that says of all non-native species that are released into new ecosystems, about 10% survive at all, and of these survivors, about 10% (or 1% of the original number of species released) become invasive."
- Environmental Protection Agency

Source: Environmental Protection Agency, Invasive Non-Native Species, http://www.epa.gov/owow/watershed/wacademy/acad2000/invasive2.html.

their competitive potential and their threat as predators. There are four endangered fish in the basin that have to compete with over forty nonnative fish for food and habitat, and must also face the additional threat of predation from nonnative species such as the northern pike, smallmouth bass, and channel catfish.[35] Politicians are confronted with the ethical implications of prioritizing the survival of a native fish over one that is nonnative. Current legislation typically advocates for the removal of nonnative species in the basin even if it requires forceful strategies. Though there is some debate with regards to the ethics of targeted species removal, there is a widespread recognition of the threat of invasive species and the urgency to address the issue.

Dams and diversions, climate change, and invasive species are three causes of environmental degradation that have threatened native species in the basin. Plants and animals are affected by changing conditions on different levels, depending on many factors such as the developmental needs of a particular species. In the Colorado River, four of the fourteen native fish species are federally recognized as endangered species. Habitat depletion and invasive species competition have been major challenges for these four fish, the bonytail chub, humpback chub, Colorado pikeminnow, and razorback sucker. A closer look at the ecological and legal history of these fish helps us understand their population decline and indicates potential solutions for these and many other endangered species in the basin.

The Four Endangered Fish

Shown in **Figure 4**, the Colorado pikeminnow (*Ptychocheilus lucius*), bonytail chub (*Gila elegans*), humpback chub (*Gila cypha*), and razorback sucker (*Xyrauchen texanus*) are the four federally listed endangered fish species in the Upper Colorado River. These warm water fish are threatened by years of human manipulations to the river that have jeopardized stream flow patterns, water quantity, water quality, and fish habitats.

Figure 4: Colorado River Endangered Fish

Source: Bureau of Reclamation

***Bonytail Chub* (*Gila elegans*)**

The bonytail is a large minnow, with a maximum length of approximately 22 inches. It is named for its bone-like tail that narrows drastically towards its posterior end. Its tail works in conjunction with its exceptionally large fins to help the bonytail navigate the rough flows of the Colorado.

With no known reproducing populations in the wild to date, the bonytail is considered one of North America's most endangered fish species, and is the most threatened of the four endangered fish in the Colorado. The natural habitat of the bonytail remains unknown to scientists because fish populations were already so depleted by the time restoration efforts began. Despite this species' severe vulnerability, it was not granted full protection under the Endangered Species Act until 1980. The Upper Colorado River Endangered Fish Recovery Program recommends that the bonytail should not be downlisted from its status as an endangered species until instream flows are granted, potential threats are eliminated, and genetically varied self-sustaining populations exist throughout the Green and Colorado Rivers. To accomplish these goals, the program focuses on reestablishing and conserving floodplain habitat, creating fish screens at major dams, providing instream flow rights, managing nonnative species and raising genetically diverse populations in hatcheries.

***Humpback Chub* (*Gila cypha*)**

The humpback chub is one of the larger fish in the minnow family, with a maximum weight of about two and a half pounds and length of twenty inches. The prominent hump behind its head, for which the species is named, helps with stabilization in the fast whitewaters it inhabits. When the humpback chub can avoid threatening anthropogenic factors they can live up to thirty years in the wild.[36]

This species was first identified in the Colorado River in 1946, though it inhabited Colorado River waters for millions of years prior to its official discovery. The humpback chub is more prevalent in the Lower Colorado waters, near the confluence with the Little Colorado River. First listed as an endangered species in 1967, it was not until the Endangered Species Act of 1973 that it was given full protection. In addition to ongoing population monitoring, recovery strategies include: legal battles for instream flow rights, creation of fish screens at major dams, and management of nonnative species. With the help of management and restoration projects, there are currently five self-sustaining humpback chub populations in the Upper Basin, only one less than the project goal. Recovery goals incorporate habitat restoration and elimination of threats to the species' survival.[37]

***Colorado Pikeminnow* (*Ptychochelius lucius*)**

Growing up to three feet long, the Colorado pikeminnow is the largest minnow in all of North America. It is renowned for its remarkable spawning habits that take it as far as 200 miles for a single migration. Three million years of adaptation to the specific hydrologic patterns that characterize the Colorado River have made this fish susceptible to dams and diversions that alter its native habitat and cause population fragmentation. Once an abundant species in this region, there are currently only two populations of Colorado Pikeminnow in the Upper Colorado River. It was added to the list of endangered species in 1967 and given full legal protection from the Endangered Species Act (ESA) in 1973.

Current restoration efforts include nonnative fish management, the creation of fish screens at major dams, the legal granting of instream flows, and the creation of backwater habitats to allow for early fish development.[38]

***Razorback Sucker* (*Xyrauchen texanus*)**

At three feet long, this species of sucker is one of the largest of its kind. Razorback sucker spawning patterns are sensitive to the changing temperatures of both air and water throughout the basin and depend on hydrologic patterns such as heavy spring flows, which have been drastically altered by dams and diversions. Razorback sucker larvae require quiet and warm backwaters for maturation, another habitat that has been depleted. These habitat challenges primarily affect young fish, causing there to be a disproportionately high percentage of adults in razorback sucker populations, which threatens the next generation.[39] Restoration projects under the Upper Colorado Endangered Fish Recovery Program have focused on protecting the habitats and stream flows necessary for spawning, fish maturation, and migration.

Other restoration efforts have used propagation and stocking methods, while keeping mindful of the importance to raise genetically diverse populations. These fish are then stocked in the Upper Colorado, Green, and Gunnison Rivers. With only one wild population of razorback suckers left in the basin, these propagation and stocking programs are essential for the maintenance of this species. Fish stocks have consistently developed to sexual maturity, proving restoration efforts successful.

The Future of the Endangered Fish

Various conservation programs have been launched throughout the basin in an effort to preserve its ecological diversity. The Upper Colorado River Endangered Fish Recovery Program is a key player in the conservation efforts, especially in the Upper River system. This organization arose in 1988 after the four native fish species had been listed as endangered.[40] The project aims to restore endangered fish populations in the Colorado River and its tributaries in Colorado, Utah, and Wyoming. This effort was initiated because local and state governments, federal agencies, and environmental groups all agreed that further depletion of natural resources would jeopardize the survival of these species, especially because they are not found anywhere outside of this region.[41] Legal backing to the recovery program was rooted in a new condition of the ESA that sets forth requirements for all federal water projects that have the potential to impact any endangered fish species. Following this mandate, the U.S. Fish and Wildlife Service stepped up in 1983 to advise against any additional water removal in the Colorado River because of the vulnerability of the four fish.[42] In the early 1980s, the Colorado Water Congress (CWC) jumpstarted various projects aimed at balancing needs between development and restoration efforts. By 1985, the CWC presented an official proposal to the Upper Colorado River Coordinating Committee that outlined threats to the four fish and suggested solutions to improve their endangered status. Since the establishment of the Upper Colorado River Endangered Fish Recovery Program in 1988, the goals have remained in accordance with the initial goals of the CWC proposal.[43]

The Upper Colorado River Endangered Species Recovery Program should be commended for its successes, but many of the problems affecting these fish remain as threats for other plants and animals. It is necessary to transition from projects with reactive restoration strategies to those with proactive strategies, which preemptively introduce holistic solutions that benefit overall stream health. Otherwise, we will simply be forced to continue creating additional restoration programs as habitat degradation forces new plants and animals onto the list of endangered species. The constant expansion of the endangered species list is a symptom of damaged ecosystems. This deterioration will continue until environmental policies are implemented and acted upon with urgency.


Ryan Schumacher

Case Study: The Tamarisk

The tamarisk, more commonly referred to as the salt-cedar, is a nonnative invasive shrub that threatens an already fragile ecosystem along the Colorado River. Introduced in the 1800s, eight species of tamarisk were intentionally brought over to North America from southern Europe, central Asia, and the eastern Mediterranean region.[44 45] Because of the tamarisk's extensive root system, it was initially sold by plant nurseries so that it could be used as a tool to control erosion in the western United States.[46] Since its introduction to the Colorado River in the 1800s, many natural and anthropogenic factors such as the adaptability of the tamarisk and the high salinity content in the Colorado River have facilitated the uncontrollable population growth of the invasive shrub in the desert southwest, as seen in **Figure 5**. Ecological hazards associated with the tamarisk include its large water consumption and secretion of a highly saline waste product.[47 48]

Figure 5: Aerial Spraying of Tamarisk

Source: Bureau of Land Management, Aerial Spraying of Tamarisk, http://www.blm.gov/ca/st/en/info/newsbytes/2011/500_extra-aerial_spraying.html.

Biology and Adaptability

As a facultative phreatophyte, the tamarisk has deep roots that are able to reach down to the water table in order to utilize moisture from groundwater to satisfy some of its water needs.[49] But unlike the native cottonwoods and willows, the tamarisk can survive in habitats with limited or even no groundwater.[50] Ideal growing conditions include bare substrates in areas with high water availability, such as those created by floods, heavy rainfall, and irrigation.[51] In one of these favorable habitats and without human disturbance, a tamarisk plant will typically have a 75-100 year lifespan.[52]

Mature tamarisk trees can produce up to 500,000 seedlings annually and can bloom year-round, creating a favorable environment for germination and colonization.[53] The small and lightweight tamarisk seeds are easily dispersed by way of wind and water.[54] Part of what makes the tamarisk so successful is that it can germinate in highly saline soils that are unsuitable for most native plant species. In order for seeds to survive, they need to find a suitable environment within approximately five weeks and the location that they find must be wet for at least two to four of those weeks in order for the seeds to survive.[55] The seeds can endure extreme desiccation and inundation, making them even more competitive against native plants.[56] Once a tamarisk seed finds an ideal location and begins to germinate, the plant will grow three to four meters annually.[57] Adult plants are resilient to stress conditions such as fluctuations in temperature and water availability, high levels of salinity, and human disruption.[58]

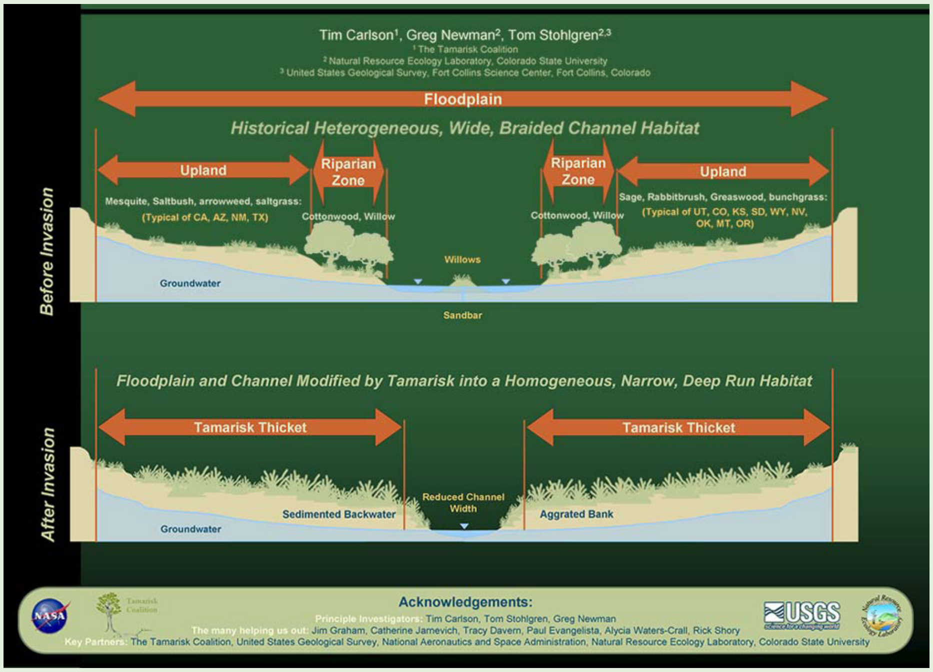
There are many anthropogenic factors that stimulate tamarisk growth. Infrastructure created to manage water along the river can interrupt natural flows that are essential for native species, but not as important for the tamarisk. Dams and water diversions have reduced spring floods so drastically that the diminished flows have created alluvial bars where there were once heavy flows. These sediment deposits are ideal conditions for the tamarisk and unfavorable for native species.[59] Irrigation also facilitates tamarisk growth because the saline return-flows are tolerable for the tamarisk but restrict recruitment of native species that are not accustomed to such saline waters.[60]

Environmental Impact

The tamarisk has a dramatic impact on the natural hydrology and ecology along the Colorado River. Its extraordinary rates of evapotranspiration lead to patterns of water consumption that are enough to actually deplete stream flows throughout the Colorado River. Despite this reduction of stream flows, many areas that are densely populated with tamarisk experience an increase in flood events. **Figure 6** illustrates how the tamarisk's extensive root system increases bank rigidity, which causes the channel to narrow from the sediment buildup, thereby increasing the power of the flows and the frequency of flood events.[61] Outside of the river, the tamarisk impacts the surrounding ecosystem by increasing the salinity. The tamarisk is able to withstand highly saline waters because it has a mechanism for extruding salts from its leaves and depositing these salts back into the river system.[62] Due to the large amounts of leaf litter, the tamarisk also increases the frequency and scale of forest fires throughout the Colorado River Basin.[63] The tamarisk can actually benefit from fires because it is more efficient at post-fire re-vegetation than other native species.[64]

Because tamarisk invasion impacts many different elements of its ecosystem, its co-inhabitants experience the effects in a variety of ways. As insectivores, most birds in the Colorado River are drawn to vegetation that is hospitable to a range of insects. Studies indicate that the tamarisk supports just as many, if not more, insect populations when compared with native plant species.[65] However, the insects that are attracted to the tamarisk are of less nutritional value than those that live on native plants.[66] A study was completed in the Lower Colorado River Basin that showed a significant increase in bird diversity after tamarisk was cleared from a 20 hectare area.[67] The southwestern willow flycatcher, a federally listed endangered species since 1995, relies on the tamarisk for its breeding habitat; 25 percent of willow flycatchers choose to breed in areas dominated by tamarisk. Studies have shown that, while the breeding habitats and diets of willow

Figure 6: Tamarisk Induced Changes in Channel Structure and Associated Habitats



Source: The Tamarisk Coalition, *Colorado Tamarisk Mapping & Inventory Summary Report*, http://www.tamariskcoalition.org/PDF/Colorado%27s%20Inventory%20&%20Mapping%20summary%20REVISED%202-08.pdf.

flycatchers that utilize the tamarisk are different from those that do not, the use of tamarisk has no detrimental effects on bird health or reproductive success.[68]

Fewer studies and conclusions have been made regarding the impact of tamarisk on other animals. Of the few studies that have been completed, none have demonstrated any impacts of tamarisk on small mammals. Some studies show that reptile densities and diversity decrease in areas dominated by tamarisk.[69] Others have suggested that the tamarisk may have detrimental impacts on the Colorado pikeminnow and the razorback sucker, two of the four endangered species in the Colorado River, because it reduces the abundance of preferable habitat.[70]

Restoration Efforts

Since the 1960s, restoration efforts have focused on reestablishing riparian ecosystems that have been destroyed by the tamarisk.[71] Control methods are numerous and varied. Mechanical controls are effective, with 97%-99% mortality rates, and consist of bulldozing, root removal, and controlled burns. The one problem with this approach is the cutting of tamarisk has actually proven to stimulate growth.[72] Plants can also be controlled chemically by spraying herbicides; however, this method is costly ($4,000-$6,200 per hectare) and is not as effective with a 60%-80% mortality rate. In order to increase effectiveness to 93%-95%, chemicals can be sprayed from an aircraft to reduce monocultures during late summer. This is also one of the cheaper control methods, costing only $240-$280 per hectare.[73]

The tamarisk leaf beetle was first introduced in 1999 and has been used in a number of other locations across the basin ever since. The beetle feeds exclusively on the tamarisk; studies were completed before the beetle's introduction that demonstrated that the beetle would starve in the absence of tamarisk, rather than resort to other native species. Therefore, when tamarisk populations begin to subside, so will beetle populations.[74] The way that the tamarisk leaf beetle works is that it defoliates the tamarisk until the plant can no longer photosynthesize. Without being able to store nutrients in its roots, the once extensive root system begins to shrink until it is too small to provide for the plant.[75] **Figure 7** illustrates the shocking contrast of land before and after beetle introduction.

The tamarisk leaf beetle is by far the most controversial approach to tamarisk control. The controversy is two-fold:

1. The beetle is a nonnative species, and there is inevitably controversy whenever an alien species is introduced to control another nonnative species.
2. The defoliation caused by the beetle can have a detrimental impact on the willow flycatcher populations that rely on the tamarisk for breeding.[76] Defoliation occurs during peak breeding season.

In the summer of 2010, the U.S. Department of Agriculture put a hold on tamarisk leaf beetle control in the majority of areas throughout the West due to the degradation of nesting habitats for the endangered willow flycatcher.[77]

Despite the fact that the tamarisk has undeniably harmful impacts on riparian communities throughout the Colorado River Basin, there is significant controversy surrounding tamarisk removal. Scientists, conservationists, and farmers need to continue to assess the economic and ecological outcomes of tamarisk removal in order to decide whether these outcomes justify its removal.[78] They will have to evaluate where and how the tamarisk should be controlled by completing a cost-benefit analysis that encompasses both economic and ecological factors.

Figure 7: Effects of Tamarisk Beetle Introduction

Source: Tamarisk Coalition, *The Tamarisk Leaf Beetle- Monitoring Efforts in the Colorado River Basin*, http://www.lcrmscp.gov/crtr/presentations/2011/100005.pdf.

Water Quality: Affecting All

The Colorado River Compact of 1922 explores water quantity in great detail but fails to address the equally important concern of water quality, setting a dangerous precedent for subsequent legislation. Water quantity remained the legislative and environmental focus in the basin for many years after the Compact was signed, whereas water quality has just recently emerged as a part of political and legal agendas. The delayed recognition of water quality as a priority in the basin has widespread implications because Colorado River water has environmental, economic, and social value that is dependent on high-quality water. Now that water quality is recognized as a main concern in the basin, significant regulatory and legislative actions are necessary to secure the resources that come from the Colorado River, some of which are irreplaceable.

The quality of water is measured by physical, chemical, and biological characteristics that evaluate the suitability of water for a particular use.[79] Indicators such as turbidity, pH, and bacteria are tools that help detect changes in water quality and evaluate the suitability of water conditions for environmental and human needs. The interconnectedness of surface water, groundwater, landscape geology, stream health, and human land use means that water quality is sensitive to modifications made to the river and the surrounding environment, and can be affected by remote nonpoint sources.[80] Changes in water composition cannot be assumed to be good or bad because different water uses have distinct water quality needs. The range of water uses and the interconnectedness of the river system present management challenges because water quality standards must be comprehensive, dynamic, and flexible.

Water quality has to be monitored and regulated because if the quality of Colorado River water were to become threatened, it could jeopardize life in the basin for humans and wildlife alike. Colorado River water quality standards are legally guided by state and federal regulations that help to maintain and restore the condition of surface waters by identifying areas of concern and examining the causes of poor quality. The Water Quality Act of 1965 initially set the stage for water legislation in the basin by requiring states to adhere to numeric standards for interstate waters within state borders. Following the Water Quality Act came an amendment to the Federal Water Pollution Control Act, known as the Clean Water Act (CWA) of 1972. This amendment authorized the Environmental Protection Agency (EPA) to regulate the quality of U.S. surface waters and to limit pollutant discharging into U.S. water systems. The environmental legislation that sets water quality standards is faced with the challenge of establishing criteria for a dynamic river system.

The composition of Colorado River water is constantly in flux. As previously discussed, water quality issues are complex and a river system cannot simply be said to have "good" or "bad" water because different uses require different standards. With this said, there are still particular contaminants that have a generally threatening impact on the river ecology. Many pollutants have the potential to influence water quality in the basin, but for the purpose of this report the following issues have been identified as the most relevant because of the environmental, social, and economic risks:

1. Salinity
2. Sediment
3. Metals (selenium)

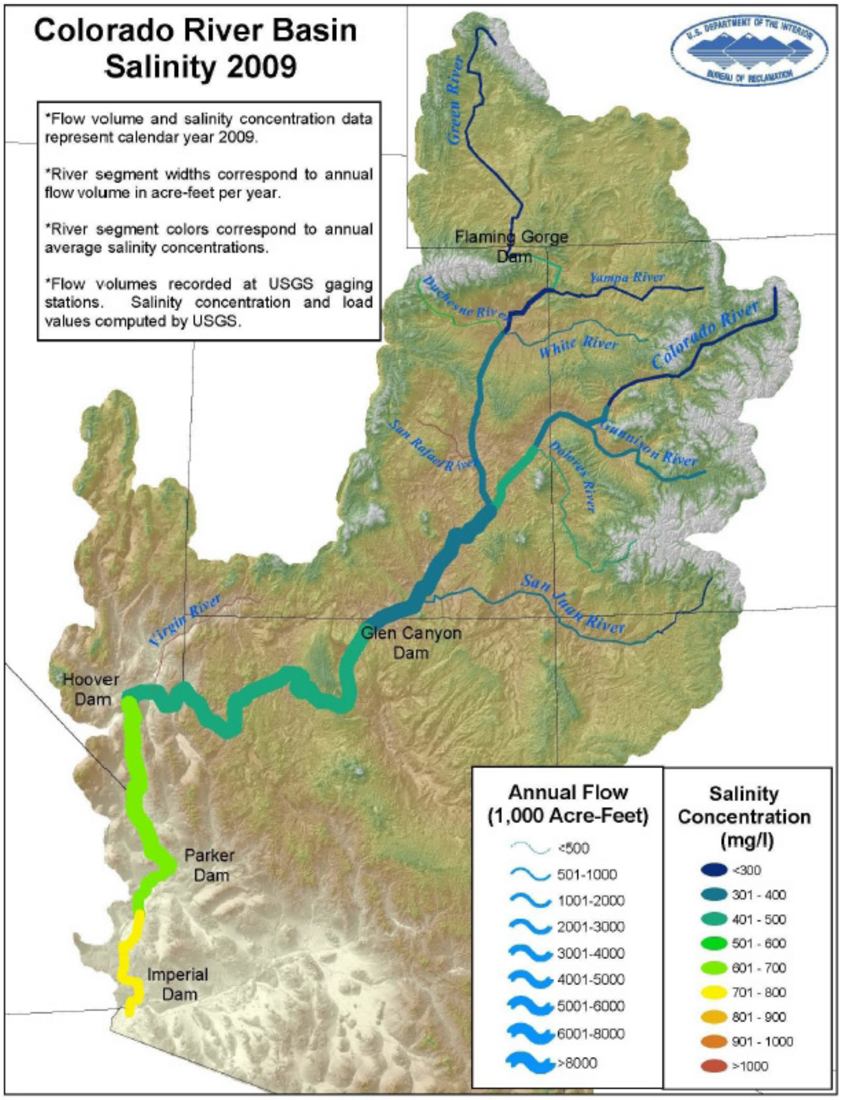
Salinity

Salinity is the most discussed water quality issue in the basin. The Colorado River currently carries an estimated salt load of nine million tons annually past Hoover Dam.[81] Almost half of the salt content in the Colorado River comes from natural sources such as saline springs, natural runoff, evaporation and transpiration, and the erosion of saline geologic formations. Salinity levels are intrinsically linked to flow patterns, which dilute concentrations during heavy flows and increase salt concentrations during low flows. These natural factors that influence salinity levels are so dominant that they can cause concentrations to double or halve in one year.[82]

Human activities account for the other half of the salt load in the Colorado. With 80% of Colorado River water diverted for agricultural use, it is no surprise that irrigated agriculture is the most significant contributor to salinity levels, accounting for approximately 37%.[83] Return flows from irrigated agriculture increase salt concentrations because water is lost to evaporation and evapotranspiration and dissolved salts are transported from the saline soils and geologic formations (such as mancos shale) to surface waters. Groundwater is susceptible to salt contamination because farmers often recycle the saline return flows. When groundwater salt concentrations rise, so do the levels in surface water because the tail waters empty back into the main stem of the river. Energy exploration and development projects also exacerbate the problem by transporting saline waters that were previously contained and allowing saline runoff to accumulate and feed into the system. Municipal and industrial contributions to the salt load are limited to water softeners and saline wastewater from treatment plants and account for less than 1% of the overall salt load.[84] All consumptive uses, whether they are municipal, industrial, or agricultural, also inevitably increase salinity concentrations by lowering the dilution factor of the water.

Whether the motive is environmental, social, or economic, salinity management deserves to be a high priority in the basin because the unnaturally high salt load can affect municipal, industrial, and agricultural users, as well as fish and wildlife. Until the 1960s, very little had been done to address salinity levels in the Colorado River. The first salinity improvements were instigated by Mexico's dissatisfaction with the quality of the water they were receiving from the U.S., who was required by the 1944 U.S.-Mexico treaty to deliver 1.5 maf to Mexico annually. The treaty never defined a water quality standard until 1961 when excess flows diminished and the Wellton-Mohawk Irrigation and Drainage District (WMIDD) began operating their drainage wells, putting saline water back into the Colorado River. This nearly doubled salinity levels, with drainage water reaching as high as 6,000 parts per million (ppm).[85] In December of 1961, the water quality of the deliveries became so poor that Mexico

Figure 8: Map of Salinity Levels throughout the Basin



Source: Bureau of Reclamation, *Quality of Water- Colorado River Basin*, Progress Report No. 23, 2011.

filed a formal complaint that the U.S. was violating the treaty agreement. This led to the creation of Minute No. 242, which holds the U.S. responsible for delivering water that is no more than 115 plus or minus 30 ppm greater than the salinity levels at Imperial Dam, the last water quality checkpoint in the U.S. There has never been a violation of Minute No. 242; however, the Lower Colorado River still receives water several times more saline than the water at the Colorado River headwaters, as shown in **Figure 8**.

Various political and legal changes were made in the years following the creation of Minute No. 242 in order to meet the terms of these new salinity standards (**see Figure 9)**. Amendments to the Water Quality Act and the Clean Water Act both included salinity requirements for Colorado River surface water, which prompted the creation of the Colorado River Basin Salinity Control Forum in 1973. This forum helped establish water quality standards and a viable basin-wide implementation plan. The Salinity Control Act of 1974 was passed soon after, authorizing a range of projects that were intended to improve salinity levels so that water deliveries to Mexico would be within the numeric criteria.[86] Title I of the Salinity Control Act authorized the construction of the Yuma Desalting Plant in Arizona, as well as the lining of the first 49 miles of the Coachella Canal, while Title II endorsed the creation of the Salinity Control Program and allowed the Secretary of the Interior and the Secretary of Agriculture to use federal funds to implement

Figure 9: Colorado River Basin Salinity Timeline

1961- Mexico filed a formal complaint about the quality of the water they were receiving from the Colorado River, arguing that it violated the 1944 treaty.

1972- Federal Water Pollution Control Act was passed establishing numeric criteria in the Basin - Water Quality Standards for Salinity, Including Numeric Criteria and Plan of Implementation for Salinity Control, Colorado River System.

1974- Colorado River Basin Salinity Control Act, Public Law 93-320 was passed. This authorized the construction and operation of various forms of salinity control in order to ensure that water delivery requirements to Mexico could be met (including permission to build the Yuma Desalting Plant).

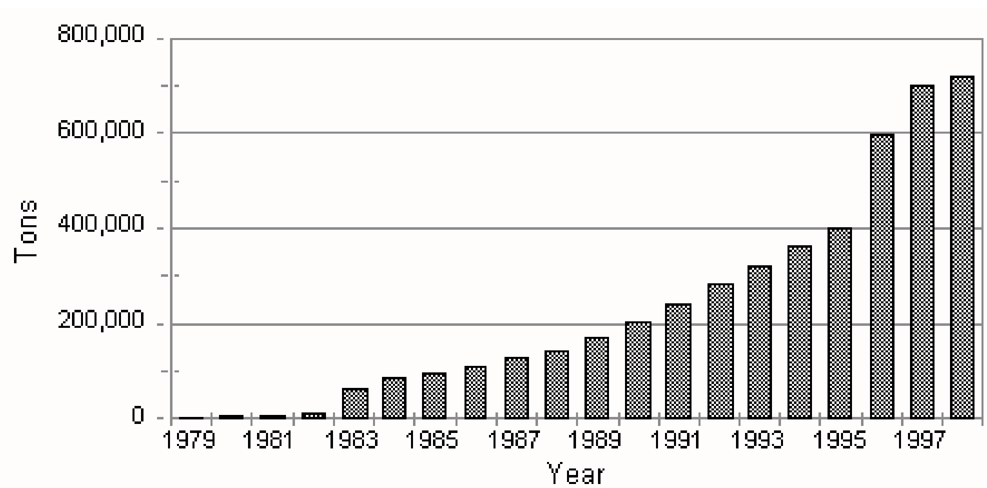
1960 1970 1980

1973- Minute 242 setting numerical requirements for the salinity of water delivery to Mexico

1974- Colorado River Basin Salinity Control Act prompted the creation of the Salinity Control Program, which allowed the BOR and USDA to work together to create new salinity control projects. It also placed responsibility on the Department of the Interior, the Department of Agriculture, and the EPA to manage salinity.

future projects or programs to help control salinity levels. The Title I projects were both approved under the supposition that they would enable U.S. compliance with the salinity standards for water deliveries to Mexico. The Yuma Desalting Plant was specifically constructed with the purpose of recovering saline drainage waters from the WMIDD so that they would adhere to the legal salinity standard.[87] This project cost $250 million and requires annual operating costs of over $25 million, even though it has never been operated regularly or at full capacity since its construction in 1992. The concrete lining of the Coachella Canal was completed in 1980 in an effort to conserve water previously lost through canal seepage. The achievement of these early salinity control projects is depicted in **Figure 10**.

Figure 10: Success of Salinity Control Programs in the Colorado River Basin



Source: Bureau of Reclamation, *Colorado River Basin Salinity Control Project*, http://www.usbr.gov/projects/Project.jsp?proj_Name=Colorado+River+Basin+Salinity+Control+Project.

Salinity management projects such as the lining of the Coachella Canal are expensive, but they lower the other costs that result from sustained saline waters. **Figure 11** depicts the current and projected economic damages resulting from salinity levels at Imperial Dam, the last water quality checkpoint before the Colorado River enters Mexico. High salinity increases water treatment costs and requires additional expenses for damaged plumbing, pump maintenance, and alternative drainage facilities. Currently an estimated $306-312 million per year are spent on salinity control alone, and the Bureau of Reclamation estimates that by the year 2025 the number will increase to $471 million if no additional Water Quality Improvement Projects are put in place by the government. New programs will be needed to implement an estimated 728,000 tons of salinity control in addition to the 1,072,000 tons that are already being taken care of by current programs.[88]

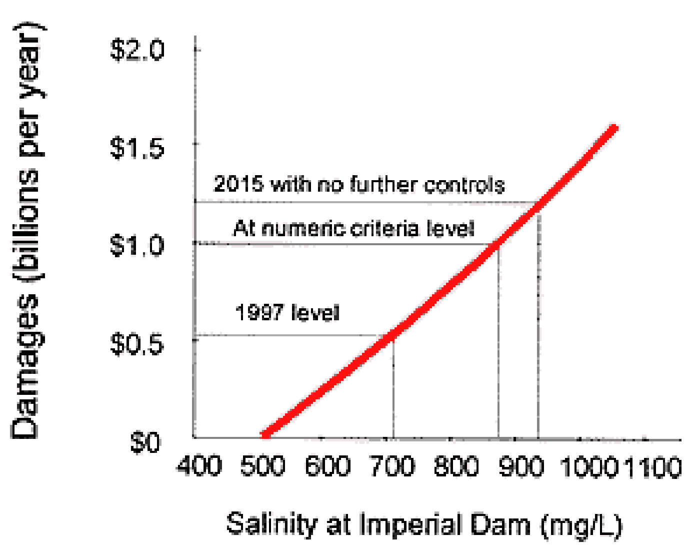
Ever since salinity emerged as a prominent issue in the 1960s, it has been a major environmental, political, and legal focus throughout the basin, which has led to decreased salinity levels despite the increasing water demand. The economic and political threats associated with high salinity levels have been the driving force for legal change regarding this issue, yet the legislative progress has benefited environmental needs in the basin as well. All plants have different salinity thresholds; specific salinity levels may be toxic for some species, while ideal for a different species that is able to withstand saline waters. The invasive tamarisk plant, which densely lines the riparian banks of the Colorado River, owes much of its invasive success to its high salt tolerance, which allows it to out-compete most native plants in the region. Native species such as the Fremont cottonwood did not historically require a high salt tolerance, and have been threatened for many years by the high salinity levels in the Colorado.[89] Salinity management can improve habitat conditions for native vegetation by restoring salt concentrations to levels that were historically preferable for native plants and animals.

Sediment

The Colorado is the most sediment-rich river in the nation.[90] The flow of sediment once facilitated the construction of natural sandbars that served as the foundation for a diverse riparian environment. The river transported sediment with essential nutrients, supporting wildlife populations along and within the Colorado.[91] Today there are some areas on the Colorado River that suffer from excess sediment, while other sections are crystal clear, deprived of typical sediment-rich flows.

Excess sediment generally comes from riverbank erosion, which has some natural causes but is accelerated by humans. Western development has increased the amount of agriculture, construction, and urban runoff throughout the basin, all factors that contribute to the high sediment load. Poorly managed agricultural areas facilitate the transportation of

Figure 11: Economic Damages vs. Salinity Levels



Source: Bureau of Reclamation, *Colorado River Basin Salinity Control Project*, http://www.usbr.gov/projects/Project.jsp?proj_Name=Colorado+River+Basin+Salinity+Control+Project.

sediment by causing soil erosion. Though livestock grazing does not occur beside the main stem of the Colorado, erosion due to grazing does occur along many of the river's tributaries, which eventually feed into the Colorado.[92] The urban runoff problem is exacerbated in highly developed areas because runoff cannot seep into the ground, forcing it to continue flowing while accumulating additional sediment until it reaches the river.

The riparian ecosystem throughout the basin can serve as a tool for reducing sediment in areas where there is excess. In a healthy system, riparian vegetation increases sediment deposition, which creates a beneficial buildup of organic material. In areas faced with threats of decreased vegetation density, the land is vulnerable to erosion that can lead to increased sediment loads within the waters. The Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) have developed criteria for monitoring the state of the riparian vegetation in an effort to manage the sediment load.[93]

While some areas along the river suffer from too much sediment, others have been deprived of the characteristic flow of sediment and nutrients throughout the river system. When a sediment-rich flow meets a dam, the sediment drops and begins to accumulate at the bottom of the reservoir. This inhibits the natural flow of sediment while also decreasing the reservoir storage capacity and the efficiency of the dam, issues that would require many billions of dollars to remedy.[94] Eighty-four tons of sediment enter Lake Powell every minute, causing Glen Canyon Dam to trap 95% of the river's sediment in the reservoir.[95] Today the waters below Glen Canyon Dam that run through the Grand Canyon are completely clear.[96] Though Glen Canyon Dam may be the extreme, most waters downstream of large dams are practically devoid of sediment, and the sediment that does make it passed the dams is inconsistently distributed due to reduced flows.[97] This phenomenon has drastically altered the ecosystem dynamics downstream, eliminating many natural sandbars that were once a vital habitat for riparian wildlife. The images in **Figure 12** were taken before and after a successful high flow experiment in the Grand Canyon that evaluated the feasibility of restoring natural sandbars.

Changes in natural sediment flows can drastically impact the health of an ecosystem. Excess sediment has a particularly harmful impact on fish; possible consequences include stunted growth, increased susceptibility to disease, increase of fatalities, interference with egg development, reduced food availability, and changes in migratory patterns. While many native species such as the endangered humpback chub rely on heavy sediment loads, other species such as rainbow trout benefit from clearer waters, creating an additional challenge for policy makers.[98] Aquatic plants can be affected by excess sediment because it limits the amount of sunlight available for photosynthesis.[99] Scientists are also finding that instead of being washed out to sea, there are some heavy metals and toxins getting trapped within sediment buildup throughout the basin, posing a potential wildlife and public health threat.

Sediment problems can also affect local economies. Sections of the river that contain excessive sediment are generally unappealing for water-based recreational use because of the threat of hidden hazards. If waters were to become too turbid, towns with recreation-based economies could suffer.[100] Economic losses due to agriculture are an additional threat because high sediment loads can inhibit crop photosynthesis by causing buildup on plant leaves, decreasing water percolation due to buildup on the soil, and decreasing soil aeration.

Metals (selenium)

All bodies of water contain some metals in the surface water, and many metal ions are biologically necessary for all forms of life. Artificial sources of metals, however, can threaten stream health, especially without natural stream flows flushing the toxins through the system. Human impacts from mining, agriculture, and landfills reach surface water on the Colorado by means of runoff, rain, leaching, and sewage. Metals have a tendency to buildup in aquatic systems over time because they cannot be broken down in nature.

Selenium

High levels of selenium affect a significant portion of the Colorado River. Agricultural drainage waters into both the Upper and Lower Basins have been determined to be selinferous.[101] The primary source of selenium in the basin is the seleniferous sedimentary rocks that can contaminate the water through natural weathering.[102] The combustion of seliniferous coal throughout the basin also adds to selenium levels in the river. Selenium is spread through ecosystems by accumulating in aquatic food chains. Animals exposed to selenium can experience a range of biological problems

Figure 12: Photograph before and after high flow experiment in the Grand Canyon

Source: USGS, *Science Activities Associated with Proposed 2008 High-Flow Experiment at Glen Canyon Dam,* http://pubs.usgs.gov/fs/2008/3011/.

such as reproductive failure and physiological deformities. Studies have suggested that some mammals and aquatic birds exposed to high levels of selenium in the wild are susceptible to congenital deformities and even death. The high solubility of selenium allows it to easily accumulate in fish tissues. Studies have shown that the presence of selenium has undesirable consequences for fish reproduction in the Colorado.[103] A study from 2005 demonstrates that even low selenium levels result in little or no survival of the endangered razorback sucker, and that larvae and young fish are the most sensitive to selenium contamination. The study suggests that the lack of recruitment in some areas in the basin may be due to selenium levels.[104] Some projects in the Upper Colorado River Basin have successfully flushed flows through affected areas, removing selenium from the water, sediments, plants, and animals.

Instream Flow Rights as a Legal Tool for Environmental Protection

> "Writing for the U.S. Supreme Court in the case *Jefferson City Public Utility District v. Ecology Dept. of Washington*, Justice Sandra Day O'Connor said that the separation of water quality from water quantity (or flow) was an artificial distinction that had no place in a law intended to give broad protection to the physical and biological integrity of water. Further, she claimed that reducing water quantity or flow was capable of destroying all designated uses for a given body of water, and that the Clean Water Act's definition of pollution was broad enough to encompass the effects of reduced water flow."[105]

For over one hundred years, the Colorado River has endured many forms of modification in the name of "development." This has caused diminished flows and interrupted hydrologic patterns that have shaped the physical, chemical, and biological composition of the native riparian environment. This short history reveals that human demand cannot serve as a justification for environmental degradation. To balance increasing human water demands with the environmental needs of the Colorado River will require collaboration between scientific and political leaders to determine how legal environmental protection can facilitate instream flow rights.

> "Instream flows are usually defined as the stream flows needed to protect and preserve instream resources and values, such as fish, wildlife and recreation."
>
> Source: State of Washington Department of Ecology, http://www.ecy.wa.gov/programs/wr/instream-flows/isfhm.html.

Western water law has historically functioned under the slogan "use it or lose it."[106] This outdated perception that water left in the river is water wasted has guided environmental policies with damaging outcomes and promoted full appropriation of Colorado River water. While the traditional view does not recognize a distinction between "beneficial use" and "consumptive use," instream flow rights do. These instream flows are considered beneficial simply because they maintain water in the river system for ecological and recreational use. Instream flow rights offer a legislative alternative by granting "the legal authority to use, within the stream channel, a flow of water sufficient for the purpose of preserving values and uses, such as wildlife, fish, recreation and aesthetics."[107 108]

Water law in the western United States is currently dictated by prior appropriation, a doctrine that grants water rights on a first-come-first-served basis by date of appropriation. This legal system fails to encourage efficiency by mandating that all water rights must be diverted or captured and put to beneficial use.[109] The current system requires states to individually establish water regulation standards, which has encouraged multiple interpretations of what constitutes a beneficial use. As seen in **Figure 13,** the seven states in the Colorado River Basin have gradually acknowledged different aspects of environmental health as a beneficial use.

To appropriate water for environmental use, an individual or group files an application with the state agency or non-governmental organization that is responsible for water acquisitions. New appropriations are done through state water courts, and the specific water acquisition process for instream flows varies by state depending on the different laws and non-governmental organizations involved. If the instream flows are granted, the application date becomes the priority date, causing the new appropriation to be junior to all preexisting

Figure 13: Instream Flow Rights in the Colorado River Basin

State	Ownership of Instream Flow Rights	Date	Environmental Beneficial Uses
Arizona	Public or Limited Private	1941	Wildlife; Fish; Recreation
California	Public or Private	1991	Wetland Habitat; Fish and Wildlife; Recreation; Water Quality
Colorado	Colorado Water Conservation Board	1973	"To preserve the natural environment"
Nevada	Public or Private	1988	Wildlife; Recreation
New Mexico	Public or Private	1988	Fish and Wildlife Habitat; Recreation (Note: Instream flows still not recognized as a beneficial use)
Utah	Division of Wildlife Resource and Parks and Recreation	1986	Propogation of Fish; Recreation; Preservation and Enhancement of Natural Stream Environment
Wyoming	State of Wyoming	1986	Fisheries

Source: Bureau of Land Management, *Western States Water Laws- State Summaries*, http://www.blm.gov/nstc/WaterLaws/abstract1.html.

water rights in the region. Some states, such as Colorado, authorize groups to obtain instream flows through lease, purchase, or donation. This progressive method of water acquisition makes it possible for instream flows to have senior water rights, making them a more effective legal tool.[110]

Additional Strategies for Obtaining Instream Flow Rights

Federal laws often facilitate protection of environmental flows, although no federal laws directly grant instream flow rights. The federal reserved water rights doctrine was established in 1908 as a product of the *Winters v. United States*, U.S. Supreme Court Case. The case found that Indian reservations possess implied water rights with priority from the year the reservation was established for the amount of water necessary to carry out the purpose of the reservation.[111] Since the initiation of this doctrine, a number of court cases have returned some power to states while limiting the power of federal reserved water rights. The McCarran Amendment of 1952 requires federal agencies to participate in state general adjudication processes to establish federal water rights.[112] The 1976 *Cappaert v. United States* court case found that federal reserved water rights would only grant the minimum amount of water needed to fulfill the primary purpose of the reservation. Federal reserved water rights have since been expanded as a result of the *Arizona v. California* court case to include a wide range of federally managed lands. Today, federal reserved water rights are powerful tools that can override many state water laws. Similar to instream flow rights granted at the state levels, federal reserved water rights take priority over the state requirement of water being put to beneficial use, permitting water to remain in the river.[113]

The 1968 Wild and Scenic Rivers Act is an additional legislative tool for protecting flows. Under this Act, Congress or the Secretary of the Interior can individually designate rivers that are highly valued due to their natural, cultural, and recreational assets, and selected rivers are granted completely free-flowing conditions.[114] The Virgin River and the Verde River are the two tributaries to the Colorado that are protected by the Wild and Scenic Rivers Act.[115]

Legal pressure for government abidance to the 1973 Endangered Species Act has been a major tool in the creation of instream flow rights. The ESA caters to plants or animals that require the presence of instream flows for survival. If diminished flows are partially responsible for a species' endangered status, this Act has the power to override other legal water rights to provide the necessary instream flows. Low flows are one of the major threats to the four endangered fish species in the Colorado River and the Upper Colorado River Endangered Fish Restoration Program recommends that none of the fish should be downlisted from their status as endangered until legal granting of instream flow rights.[116] These fish have evolved such that they depend on the characteristic patterns of flows, depths, velocities, and substrate composition of the water in the Colorado, which have now been interrupted by dams and diversions. This goal will be realized through water leases and contracts, coordinated water releases from upstream reservoirs, participation in reservoir enlargements, efficiency improvements to irrigation systems, and reoperation of federal dams and reservoirs.[117]

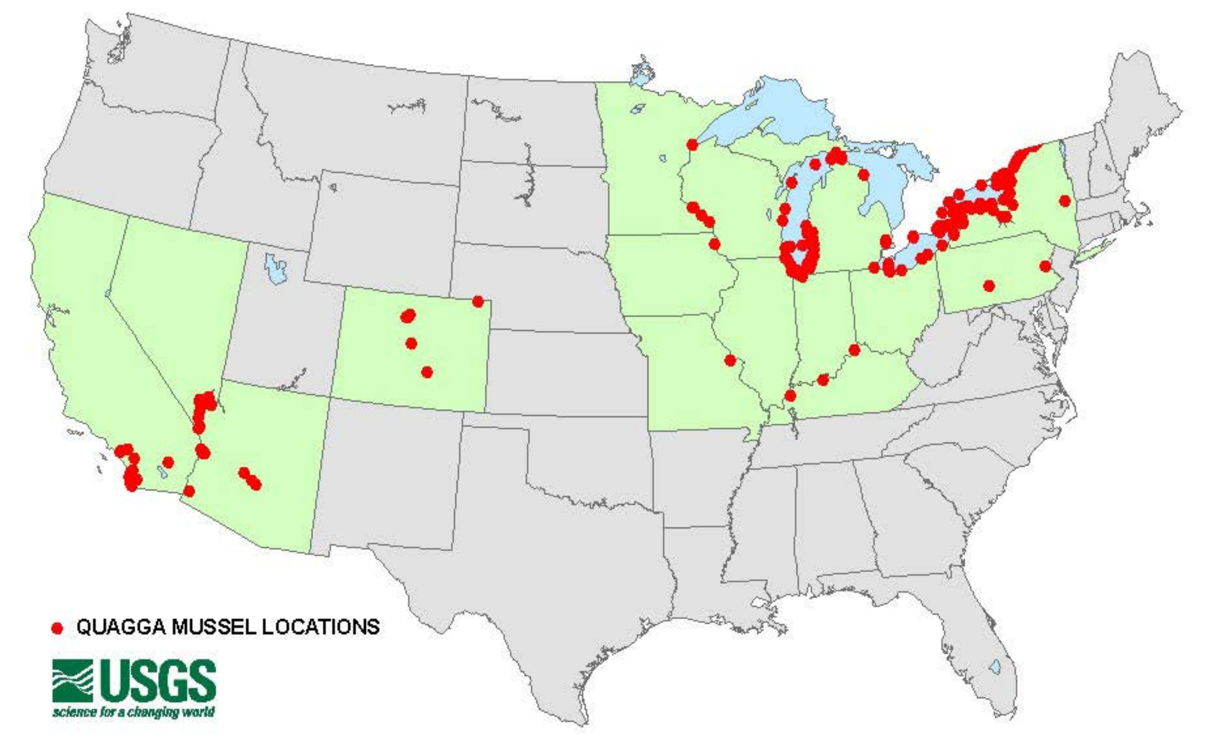
Conclusion: Nature Needs A Voice and an Assured Share of Water in the Basin

Diversions on the Colorado River currently send water to urban, agricultural, and industrial areas across the western United States to serve social and economic needs at the expense of stream flows.[118] The result has been changes in the timing, duration, variation, and magnitude of hydrologic conditions, modifications that have had devastating consequences for the water quality and native ecology of the river. Political and public recognition of these issues is gradually increasing, but to simply put these concerns on the political radar is not enough. It is time that we test the flexibility of western water law. The current legal structure, based on prior appropriation and a limited hierarchy of "beneficial uses," is outdated and requires reform. Economic and ecological threats to the Colorado River Basin urge us to improve the water acquisition and use processes so that water remains for nature under constructs that make instream flow rights legally defensible in all basin states.

It is imperative that we avoid the traditional inclination to solve shortages with further development. In addition to the huge financial burden of any remaining water projects that might be technically and financially feasible, the extraction and transportation of additional water supplies out of the basin would place enormous stresses on an already vulnerable ecosystem. The current situation of decreasing water supply and increasing water demand in the Colorado River Basin requires a fundamental shift in our discourse that provides new ways of thinking about water supply strategies that do not jeopardize environmental needs.

As representatives of today's youth, with a vested interest in the future of the Colorado River Basin, we remain guardedly optimistic that the daunting challenges in the region can be solved while enhancing the role of nature in a healthy region. Past pressures to develop water have largely operated under the assumption that ample water existed to meet numerous, rather narrowly defined, "beneficial" uses. We call upon water experts and stakeholders alike to redefine benefits of water in the basin to give nature "equal standing" for river flows so that riparian ecosystems can be viable into the future. Our generation recognizes the difficult tradeoffs but remains confident compromise is possible. We repeat where we started this section: We are all stakeholders, and the stakes are high!

Figure 14: Quagga Mussel Locations in the U.S.



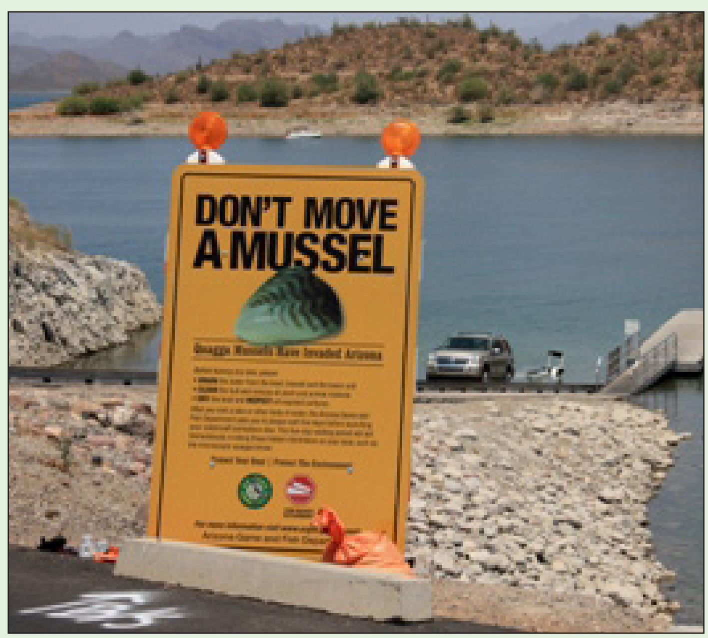
Case Study: Zebra and Quagga Mussels

Native to eastern Europe, the zebra mussel (*Dreissena polymorpha*) and the quagga mussel (*Dreissena rostiformis bugensis*) are two invasive species of freshwater bivalve mollusks that have taken a toll on the Colorado River system ever since they were first identified in Boulder Basin of Lake Mead in early 2007.[119] Originally brought over by transoceanic ships, these mussels will grow on just about any surface that they can find and can adapt to changing conditions and habitats contributing to their success as an invasive species.[120] After growing accustomed to the cold deep waters of the Great Lakes, *Dreissena* mussels quickly adapted to the warm shallow waters in the Colorado, conditions that have ultimately perpetuated population growth by allowing for yearlong breeding. This proliferation of the mussels can be seen in **Figure 14.** The microscopic larvae produced are small enough so that they can then float through the water column, unaffected by screens and barriers that are supposed to limit colony expansion. The mussels have also adapted to the calcium-rich waters of the Colorado River that have proven ideal for healthy shell formation.[121]

In addition to the impressive adaptation abilities of these mussels, anthropogenic influences have also enabled the proliferation of zebra and quagga mussels in the basin. The prevalence of recreational watercrafts has contributed to the rapid spread of these species because uneducated boaters acquire the hitchhikers and do not know to take proper precautionary measures such as properly rinsing boat equipment. **Figure 15** outlines ways that individuals recreating in the Colorado River can help to eliminate the spread of the invasive mussels.[122] Artificial sources of phosphorus and nitrogen can also facilitate phytoplankton growth by nurturing mussel populations while enabling the proliferation of these two species.[123]

Ecological Impact

Because the zebra and quagga mussels can colonize on both hard and soft surfaces, they pose as a threat to other freshwater organisms that could serve as substrates for colonization. Additionally, Dreissena mussels are water



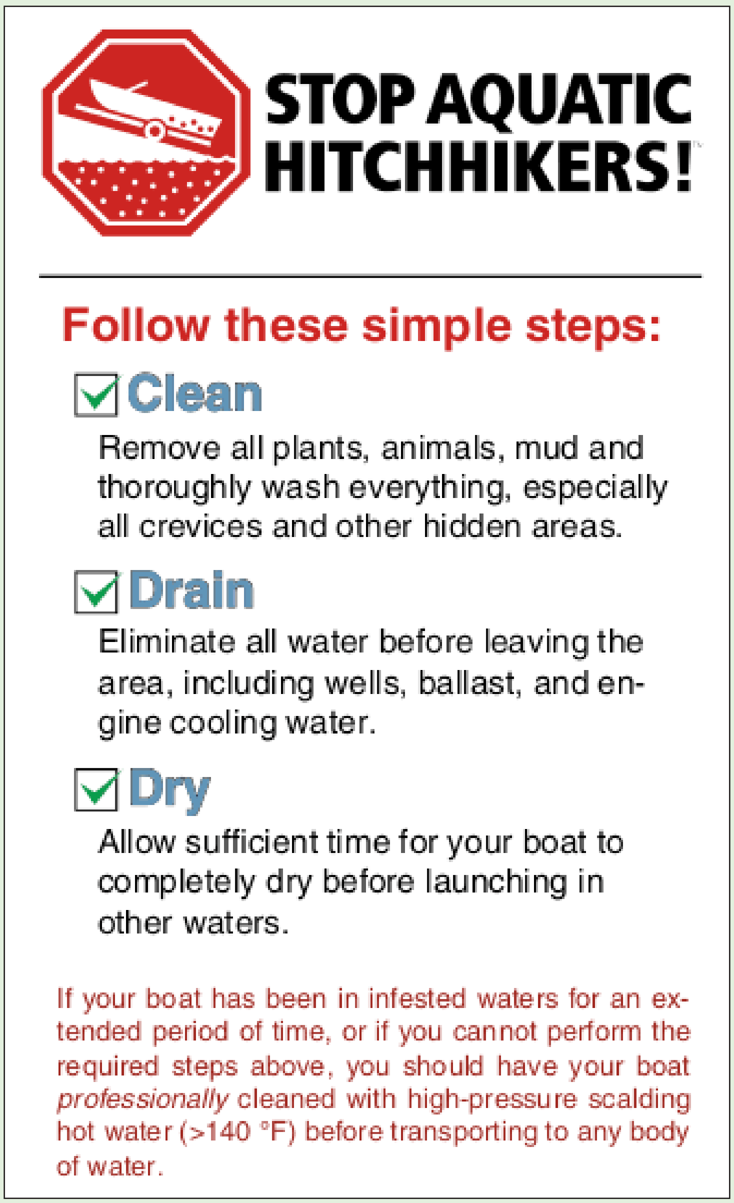
Source: Arizona Game and Fish Department, *AGFD Fishing Report,* http://www.azgfd.gov/artman/publish/printer_1123.shtml.

filterers whose survival relies upon the removal of phytoplankton and suspended particles from freshwater systems. Siphoning more than one liter per day, the mussels decrease food availability for zooplankton, an organism that anchors the food web. Excrement produced as a product of this filtration process then builds up and depletes oxygen levels in the river as the waste decomposes. Waste produced by these mussels also contains potentially toxic cyanobacteria that also deplete oxygen levels. Studies have shown that Dreissena mussels will often accumulate toxic levels of organic pollutants that are eventually passed up the food chain, posing a threat to ecosystem health.[124]

Figure 16: Quagga Colony on Pipe

Source: Arizona Game and Fish Department, *Quagga Mussels*, http://www.azgfd.gov/h_f/zebra_mussels.shtml.

Figure 15: Ways to Stop Aquatic Hitchhikers



Source: County of Lake, California, *Invasive Species Prevention Program*, http://hostwel.com/quagga/index.php.

Economic Impact

Dreissena species are able to colonize on practically any surface except for copper pipe, making them a huge economic threat. The millions of dollars spent on infrastructure repair and maintenance in the Lower Colorado River Basin, in areas where mussels have clogged water intake structures and decreased pumping capabilities for power and water treatment plants, have already been a major economic burden.[125 126] **Figure 16** illustrates the potentially catastrophic impact these mussels can have on infrastructure in the river. The recreation industry is also greatly impacted by *Dreissena*, which have colonized boats, docks, buoys, and beaches.

Management Strategies

Government response for management of these invasive mussels began promptly after the first sighting in 2007. The 100th Meridian Initiative took charge in the prevention of the westward expansion of *Dreissena* and remains an influential player. The governmental "Don't Move a Mussel" campaign has had success in educating individuals using the river for recreation about how they can prevent further spreading of this invasive species. There are also natural factors such as sediment-rich and high velocity waters that limit mussel growth; however, most sections of the Colorado River no longer possess these qualities due to dams and diversions.[127]

The potential impacts of *Dreissena* on the Colorado River are not entirely understood because previous research has focused on their presence in the Great Lakes system. Future research will aid in the creation of an effective management program for zebra and quagga mussels in the Colorado River Basin.

[1]Environmental Protection Agency, *Rivers and Streams*, accessed June 2011, http://www.epa.gov/bioiweb1/aquatic/rivers_and_streams.html.
[2]Western Resource Advocates, *Filling the Gap: Commonsense Solutions for Meeting Frontrange Water Needs*, accessed July 2011, http://www.westernresourceadvocates.org/gap/fillingthegap.pdf.
[3]Colorado River Salinity Control Forum, *Water Quality Standards for Salinity in the Colorado River System*, accessed June 2011, http://www.coloradoriversalinity.org/docs/2011 REVIEW-October.pdf.
[4]Indiana Division of Fish & Wildlife, *Riparian Zones*, accessed June 2011, http://www.in.gov/dnr/fishwild/files/riparian.pdf.
[5]Western Resource Advocates, *Filling the Gap: Commonsense Solutions for Meeting Frontrange Water Needs.*
[6]Ohio Division of Wildlife, *Riparian Habitat Management for Wildlife*, accessed June 2011, http://www.dnr.state.oh.us/portals/9/pdf/pub395.pdf.
[7]Colorado Plateau Land Use History of North America, *Biotic Communities of the Colorado Plateau*, accessed August 2011, http://cpluhna.nau.edu/Biota/riparian_communities.htm.
[8]Kammerer, J.C., *Largest Rivers in the United States*, accessed July 2011, http://pubs.usgs.gov/of/1987/ofr87-242/.
[9]Clean Colorado River Alliance, *Recommendations to Address Colorado River Water Quality*, accessed July 2011, http://www.azdeq.gov/environ/water/download/ccra06.pdf.
[10]United States National Park Service, *Rocky Mountain National Park: Environment and Landscape*, accessed August 2011, http://www.nps.gov/romo/naturescience/environment_and_landscape.htm.
[11]United States National Park Service, *Rocky Mountain National Park: Park Statistics*, accessed July 2011, http://www.nps.gov/romo/parkmgmt/statistics.htm.
[12]United States National Park Service, *Rocky Mountain National Park: Endangered and Threatened Animal Species*, accessed July 2011, http://www.nps.gov/romo/naturescience/endangered_threatened_animals.htm.
[13]United States National Park Service, *Black Canyon of the Gunnison National Park: Life Zones*, accessed July 2011, http://www.nps.gov/blca/naturescience/lifezones.htm.
[14]United States National Park Service, *Black Canyon of the Gunnison National Park*, accessed August 2011, http://science.nature.nps.gov/im/units/ncpn/link_library/park_descriptions/blca_description.pdf.
[15]United States National Park Service, *Black Canyon of the Gunnison National Park: Life Zones.*
[16]Ibid.
[17]United States National Park Service, *Black Canyon of the Gunnison National Park: Hiking the Inner Canyon*, accessed July 2011, http://www.nps.gov/blca/planyourvisit/hikinginner-canyon.htm.
[18]United States National Park Service, *Canyonlands National Park: Nature and Science*, accessed July 2011, http://www.nps.gov/cany/naturescience/index.htm.
[19]United States National Park Service, *Canyonlands National Park: Rivers and Streams*, accessed July 2011, http://www.nps.gov/cany/naturescience/rivers.htm.
[20]United States National Park Service, *Glen Canyon National Recreation Area: Nature and Science*, accessed July 2011, http://www.nps.gov/glca/naturescience/index.htm.
[21]United States National Park Service, *Glen Canyon National Area: Plants*, accessed July 2011, http://www.nps.gov/glca/naturescience/plants.htm.
[22]United States National Park Service, *Lake Mead National Recreation Area: Fish*, accessed July 2011, http://www.nps.gov/lake/naturescience/fish.htm.
[23]United States National Park Service, *Lake Mead National Recreation Area: Invasive Species*, accessed July 2011, http://www.nps.gov/lake/naturescience/invasivespecies.htm.
[24]California Department of Parks and Recreation, *Salton Sea State Recreation Area*, accessed December 2011, http://www.parks.ca.gov/?page_id=639.
[25]The Salton Sea Authority, The Salton Sea: A Brief Description of its Current Conditions, and Potential Remediation Projects, accessed January 2012, http://www.sci.sdsu.edu/salton/Salton%20Sea%20Description.html.
[26]Southern Regional Aquaculture Center, Tilapia: Life History and Biology, accessed December 2011, https://srac.tamu.edu/index.cfm/event/getFactSheet/whichfactsheet/53/.
[27]California Department of Parks and Recreation, *Salton Sea State Recreation Area*.
[28]California Department of Water Resources, *Salton Sea Ecosystem Restoration Program*, accessed January 2012, http://www.water.ca.gov/saltonsea/.
[29]California Regional Water Quality Control Board, *Salton Sea Water Quality*, accessed December 2011, http://www.sci.sdsu.edu/salton/SaltonSeaWaterQuality.htm.
[30]D. Larry Anderson, *Utah's Perspective: The Colorado River*, accessed December 2011, http://www.water.utah.gov/interstate/thecoloradoriverart.pdf.
[31]Jennifer Pitt, *Yuma Desalinization Plant and the Ciénega de Santa Clara*, accessed November 2011, http://www.sonoranjv.org/news/action_items/YDP_whitepaper.pdf.
[32]Karl Flessa et al., *Since the Dams Historical Ecology of the Colorado River Delta*, accessed July 2011, http://www.geo.arizona.edu/ceam/Hecold/hecolcd.htm.
[33]The Committee on the Scientific Bases of Colorado River Basin Water Management United States and The National Resource Council, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*, (Washington D.C.: National Academies Press, 2007), 83, http://www.nap.edu/openbook.php?record_id=11857&page=83.
[34]Ibid.
[35]Upper Colorado River Endangered Fish Recovery Program, *Nonnative Fish Management Policy*, accessed January 2012, http://www.coloradoriverrecovery.org/general-information/program-elements/nna/FinalNonnativeFishPolicy020404.pdf.
[36]Upper Colorado River Endangered Fish Recovery Program, *Humpback Chub*, accessed July 2011, http://www.coloradoriverrecovery.org/general-information/the-fish/humpback-chub.html.
[37]Ibid.
[38]Upper Colorado River Endangered Fish Recovery Program, *Colorado Pikeminnow*, accessed July 2011, http://www.coloradoriverrecovery.org/general-information/the-fish/colorado-pikeminnow.html.
[39]Upper Colorado River Endangered Fish Recovery Program, *Endangered Fish*, accessed August 2011, http://www.coloradoriverrecovery.org/general-information/general-publications/fish-fact-sheets/endangeredfishfacts.pdf.
[40]Jana Mohrman, *Upper Colorado River Endangered Fish Recovery Program*, accessed December 2011, www.waterrights.utah.gov/meetinfo/m20090930/jana1.ppt.
[41]Upper Colorado River Endangered Fish Recovery Program, *About the Upper Colorado River Endangered Species Recovery Program*, accessed July 2011, http://www.coloradoriver-recovery.org/.
[42]Tom Pitts, *The Upper Colorado River Endangered Fish Recovery Program*, accessed July 2011, http://www.cowatercongress.org/AnnualConvention/Archived/2011/Presentations/Tom%20Pitts%20-%2011-01-26%20CWC%20Annual%20Convention.pdf?id...A-74A14B2EE6A2.
[43]Ibid.
[44]Joseph M. Di Tomaso, *Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States*, Weed Technology 12, no. 2 (1998), accessed July 2011, http://www.jstor.org/stable/pdfplus/2269492.pdf, 326.
[45]Tamarisk Coalition, *Tamarisk*, accessed June 2011, http://www.tamariskcoalition.org/Tamarisk.html.
[46]J.B. Shafroth et al., *Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration*, accessed July 2011, http://www.fort.usgs.gov/Products/Publications/21653/21653.pdf.
[47]Joseph M. Di Tomaso, *Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States*, Weed Technology 12, no. 2 (1998), accessed July 2011, http://www.jstor.org/stable/pdfplus/2269492.pdf.
[48]Ibid., p. 327.
[49]Ibid., p. 330.
[50]Ibid., p. 326.
[51]Tamarisk Coalition, *Colorado River Basin Tamarisk and Russian Olive Assessment*, accessed August 2011, http://www.tamariskcoalition.org/PDF/TRO%20Assessment%20with%20Appendices%20FINAL%2012-22-09.pdf.

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[52]Joseph M. Di Tomaso, *Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States*, 330.
[53]Tamarisk Coalition, *Colorado River Basin Tamarisk and Russian Olive Assessment*.
[54]Dale A. Devitt, Anna Sala, and Stanley D. Smith, Water Use by Tamarix Ramosissima and Associated Phreaotypes in a Mojave Desert Floodplain," *Ecological Applications* 6, no. 3 (1996), accessed July 2011, http://www.jstor.org/stable/pdfplus/2269492.pdf, 888.
[55]Tamarisk Coalition, *Colorado River Basin Tamarisk and Russian Olive Assessment.*
[56]Dale A. Devitt, Anna Sala, and Stanley D. Smith, "Water Use by *Tamarix Ramosissima* and Associated Phreaotypes in a Mojave Desert Floodplain, 888.
[57]Tamarisk Coalition, *Colorado River Basin Tamarisk and Russian Olive Assessment*.
[58]Joseph M. Di Tomaso, "Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States," 326.
[59]Dale A. Devitt, Anna Sala, and Stanley D. Smith, "Water Use by *Tamarix Ramosissima* and Associated Phreaotypes in a Mojave Desert Floodplain," 889.
[60]Ibid.
[61]Peter B. Shafroth et al., *Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration*.
[62]Patrick B. Shafroth, Jonathan M. Friedman, and Lee S. Ischinger, "Effects of Salinity on Establishment of Populus Fremontii (Cottonwood) and Tamarix Ramosissima (Saltcedar) in the Southwestern United States," *Great Basin Naturalist* 55, no. 1, accessed August 2011, https://ojs.lib.byu.edu/ojs/index.php/wnan/article/viewFile/527/1476.
[63]P.B. Shafroth et al., *Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration*.
[64]Ibid.
[65]Mark K. Sogge, Susan J. Sferra, and Eben H. Paxton, "Tamarix as Habitat for Birds: Implication for Riparian Restoration in the Southwestern United States," *Restoration Ecology* 16, no. 1 (2008), accessed July 2011, http://sbsc.wr.usgs.gov/cprs/research/projects/swwf/Reports/Sogge%20et%20al%202008%20-%20Restoration%20Ecology%20paper%20-%20offprint%20version.pdf.
[66]W. D. Wiesenborn and S. L. Heydon, "Diet of Southwestern Willow Flycatcher compared among breeding populations in different habitats." *Wilson Journal of Ornithology* 119, no. 4 (2004): 547–557, http://www.jstor.org/stable/20456057.
[67]Joseph M. Di Tomaso, "Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States," 330.
[68]Mark K. Sogge, Eben H. Paxton, and April Tudor, *Saltcedar and Southwestern Flycatchers: Lessons from Long-term Studies in Central Arizona*, accessed August 2011, http://sbsc.wr.usgs.gov/cprs/research/projects/swwf/Reports/Sogge_et_al_Saltcedar_and_SWWF_proceedings_with_cover.pdf.
[69]K. Bruce Jones, *Comparison of Hepterofaunas of a Natural and Altered Riparian Ecosystem*, accessed August 2011, http://www.fs.fed.us/rm/pubs_rm/rm_gtr166/rm_gtr166_222_227.pdf.
[70]David Hanni and Jason Beason, *Colorado Plateau Cooperative Ecosystem Studies Unit (Cooperative Agreement #H1200-09-0005)*, accessed July 2011, https://docs.google.com/viewer?a=v&q=cache:kf1N9ciexKwJ:www.cefns.nau.edu/Orgs/CPCESU/current/documents/DINO_RMBO_ProjectAbstract-Final.doc+Colorado+pikeminnow+%2B+razorback+sucker+%2B+reduce+habitat+%2B+tamarisk&hl=en&gl=us&pid=bl&srcid=ADGEESi2GmaF6R6RSKXfD1RZqP4clIQTZqI8SEGVZ_9TneQQud8TtinFpEbz7MfHLWf97MIENj0uNkHO-5afXvXvyHmh3KGrtXIWzU7oKsro-Vq_itmkUjlemdnx1gqoxEYlwaVyw2ln&sig=AHIEtbSaiYpbxeYcQODxD-hiT46fn-gWIA.
[71]Joseph M. Di Tomaso, "Impact, Biology, and Ecology of the Saltcedar in the Southwestern United States," 327.
[72]Ibid., p. 330.
[73]P.B. Shafroth et al., *Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration*, 238.
[74]Tamarisk Coalition, *Bio-Control*, accessed August 2011, http://www.tamariskcoalition.org/BioControl.html
[75]Ibid.
[76]Mary Anne Macleod, *Effects of Tamarisk Beetles on Southwestern Willow Flycatchers and their Habitats*, accessed August 2011, http://www.tamariskcoalition.org/PDF/2011ConferenceAbstracts/McLeod.pdf.
[77]Kirk Johnson, "In a Battle of Bug vs. Shrub, Score One for the Bird," *New York Times*, June 22, 2010, sec A, http://www.nytimes.com/2010/06/23/us/23beetle.html.
[78]P.B. Shafroth et al., *Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration*, 232.
[79]United States Geological Survey, *A Primer on Water Quality*, accessed December 2011, http://pubs.usgs.gov/fs/fs-027-01/.
[80]United States Geological Survey, *Water Quality*, accessed January 2012, http://ga.water.usgs.gov/edu/waterquality.html.
[81]Colorado River Salinity Control Forum, *Water Quality Standards for Salinity Colorado River System*.
[82]Bureau of Reclamation, *Quality of Water Colorado River Basin Progress Report No. 22*, accessed June 2011, http://www.usbr.gov/uc/progact/salinity/pdfs/PR22.pdf.
[83]United States Bureau of Reclamation, *Quality of Water Colorado River Basin Progress Report No. 22*.
[84]Clean Colorado River Alliance, *Recommendations to Address Colorado River Water Quality*.
[85]Hebert Brownwell and Samuel D. Eaton, *The Colorado River Salinity Problem with Mexico*, accessed July 2011, http://www.jstor.org/stable/pdfplus/2200267.pdf?acceptTC=true.
[86]United States Bureau of Reclamation, *Quality of Water Colorado River Basin Progress Report No. 23*, accessed June 2011, http://www.usbr.gov/uc/progact/salinity/pdfs/PR23.pdf.
[87]United States Bureau of Reclamation, *Yuma Desalting Plant*, accessed July 2011, http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp.html.
[88]Bureau of Reclamation, *Quality of Water Colorado River Basin Progress Report No. 22*.
[89]United States Department of Agriculture. United States Forest Service. *Tamarix spp.*, accessed July 2011, http://www.fs.fed.us/database/feis/plants/tree/tamspp/all.html.
[90]Living Rivers, *One Dam Solution*, accessed January 2012, http://livingrivers.org/pdfs/TheOne-DamSolution.pdf.
[91]Glen Canyon Dam Adaptive Management Program, *Sediment and River Sandbars in the Grand Canyon*, accessed January 2012, http://www.gcdamp.gov/keyresc/sediment.html.
[92]Clean Colorado River Alliance, *Recommendations to Address Colorado River Water Quality.*
[93]Ibid.
[94]Living Rivers, *One Dam Solution*.
[95]Ibid.
[96]Glen Canyon Dam Adaptive Management Program, *Sediment and River Sandbars in the Grand Canyon.*
[97]Kenyon College, *Ecological Impact of the Dam*, accessed July 2011, http://www2.kenyon.edu/projects/Dams/gbe03hol.html.
[98]Clean Colorado River Alliance, *Recommendations to Address Colorado River Water Quality.*
[99]Ibid.
[100]Ibid.
[101]Steven J. Hamilton, "Hypothesis of Historical Effects from Selenium on Endangered Fish in the Colorado River Basin," *Human and Ecological Risk Assessment* 5, no. 6 (1999): 1153-1180, http://www.mendeley.com/research/hypothesis-historical-effects-selenium-endangered-fish-colorado-river-basin-2/.
[102]Jaqueline García-Hernández, *Water Quality in the Colorado River Delta*, accessed July 2011, http://www.swhydro.arizona.edu/archive/V3_N1/feature4.pdf.
[103]Steven J. Hamilton et al., "Reduced Growth and Survival of Larval Razorback Sucker Fed Selenium-Laden Zooplankton," *Ecotoxicology and Environmental Safety* 61 (2005): 190-208, http://wwwrcamnl.wr.usgs.gov/Selenium/Library_articles/razorbackgreen.pdf.
[104]Ibid.
[105]The Environmental Protection Agency, *Protecting Instream Flows: How much does a river need?* Accessed July 2011, http://www.epa.gov/owow/watershed/wacademy/acad2000/river/river2.html.
[106]Sandra B. Zellmer, *Instream Flow Legislation*, accessed December 2011, http://water-center.unl.edu/Downloads/ResearchInBrief/ZellmerIinstreamFlows.pdf.
[107]L. Kulakowski and B. Tellman, "Instream Flow Rights: A Strategy to Protect Arizona's Streams (University of Arizona: Water Resources Research Center 1990).
[108]Yvonne Resendez Young, *Enhancing the Understanding and Importance of Instream Flow Water Rights in Arizona*, accessed December 2011, http://wsp.arizona.edu/sites/wsp.arizona.edu/files/YYoung.pdf.
[109]Anne Jinicki and Dan Merriman, *Colorado's Instream Flow Program: How it works and why it's good for Colorado*, accessed December 2011, http://cwcb.state.co.us/environment/instream-flow-program/Documents/WhyISFProgramWorksGoodForCOpdf.pdf.
[110]United States Bureau of Land Management, *Western States Water Laws: Colorado*, accessed December 2011, http://www.blm.gov/nstc/WaterLaws/colorado.html.
[111]United States Bureau of Land Management, *Federal Reserved Water Rights*, accessed December 2011, http://www.blm.gov/nstc/WaterLaws/fedreservedwater.html.
[112]The United States Department of Justice, *The McCarran Amendment*, accessed December 2011, http://www.justice.gov/enrd/3248.htm.
[113]United States Bureau of Land Management, *Federal Reserved Water Rights*.
[114]United States Department of Agriculture. Farm Service Agency, *Wild and Scenic Rivers Act*, accessed December 2011, http://www.fsa.usda.gov/Internet/FSA_File/wsr_act.pdf.
[115]United States National Wild and Scenic Rivers, accessed December 2011, http://www.rivers.gov/maps/zoom/conus/conus.html.
[116]Upper Colorado Endangered Fish Recovery Program, *About the Endangered Fish*, accessed July 2011, http://www.coloradoriverrecovery.org/general-information/about-fish.html.
[117]Upper Colorado Endangered Fish Recovery Program, *Instream Flow Identification and Protection*, accessed July 2011, http://www.coloradoriverrecovery.org/general-information/program-elements/instream-flow-protection.html.
[118]Western Resource Advocates, *Filling the Gap: Commonsense Solutions for Meeting Frontrange Water Needs.*
[119]Aquatic Nuissance Species Task Force, *Quagga and Zebra Mussel Control Strategies Workshop*, accessed October 2011, http://www.anstaskforce.gov/Documents/Quagga%20and%20Zebra%20Mussel%20Control%20Strategies%20Workshop%20(Final).pdf.
[120]United States Geological Survey, *Nonindigenous Aquatic Species*, accessed October 2011, http://nas.er.usgs.gov/queries/FactSheet.aspx?speciesID=95.
[121]Colorado River Regional Sewer Coalition, *Quagga Mussels and their Effects on the Aquatic System*, accessed October 2011, http://www.crrsco.org/Quagga%20mussels%20and%20their%20affects%20on%20the%20aquatic%20system.pdf.
[122]United States Geological Survey, *Nonindigenous Aquatic Species*.
[123]Colorado River Regional Sewer Coalition, *Quagga Mussels and their Effect on Lower Colorado River Aquatic Ecology*.
[124]Ibid.
[125]Ibid.
[126]Erik Stokstad, "Feared Quagga Mussel Turns up in Western United States," *Science* 315, no. 5811 (2007): 453, http://www.sciencemag.org/content/315/5811/453.full.
[127]Theodore A. Kenney, *A Dreissena Risk Assessment for the Colorado River Ecosystem*, accessed October 2011, http://www.usbr.gov/lc/region/programs/quagga/docs/USGSRiskAssessment.pdf.