The 2012

COLORADO COLLEGE

STATE OF THE ROCKIES REPORT CARD

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

An Outreach Initiative of Colorado College

Colorado College's Rocky Mountain Study Region

The Colorado College State of the Rockies Project is designed to provide a thoughtful, objective voice on regional issues by offering credible research on problems faced by the Rocky Mountain West, and by convening citizens and experts to discuss the future of our region. Each year, the State of the Rockies provides:

- Opportunities for collaborative student-faculty research partnerships;
- An annual *State of the Rockies Report Card*;
- A companion State of the Rockies Speaker Series and Conference.

Taken together, these arms of the State of the Rockies Project offer the tools, forum, and accessibility needed for Colorado College to foster a strong sense of citizenship for both our graduates and the broader regional community.

The Colorado College
State of the Rockies Project
An Outreach Initiative of
Colorado College

Cover Photo by:
Stephen G. Weaver

The 2012

COLORADO COLLEGE

STATE OF THE ROCKIES REPORT CARD

The Colorado River Basin:

Agenda for Use, Restoration, and Sustainability for the Next Generation

Edited By:

Walter E. Hecox, Ph.D.
Rockies Project Director

Brendan P. Boepple
Rockies Project Program Coordinator

Matthew C. Gottfried
GIS Technical Director

A publication of:
The Colorado College State of the Rockies Project
14 E. Cache La Poudre St.
Colorado Springs, CO 80903
www.coloradocollege.edu/stateoftherockies

ISBN: 978-0-935052-52-7

2011-2012 State of the Rockies Project Acknowledgements

The Colorado College State of the Rockies Project would like to thank the following individuals and groups for their generous contributions to help support summer research, publication of *Report Cards*, monthly speakers, and conference activities.

General Support

-Colorado College
-Michael B. Slade, Colorado College Class of 1979 and Trustee and Megan G. Slade
-John B. Troubh, Colorado College Class of 1979 and Louisa Troubh
-The Trinchera & Tercio Foundation
-The William and Flora Hewlett Foundation
-Western Conservation Foundation
-The David and Lucile Packard Foundation
-Charles H. "Chip" Collins, Colorado College Class of 1977 and Anne C. Childs, Colorado College Class of 1978
-Stephen B. Perry
-Jane E.S. Sokolow, Colorado College Class of 1972
-Walter E. and Ann E. Hecox, Colorado College Class of 1964
-James Collis, Parent Colorado College Class of 2013
-Anonymous (3)

Summer Research Support

-The Loewy Family Fund of the Denver Foundation
-The Grant Lyddon Foundation of the Silicon Valley Community Foundation

Monica Mueller

Table of Contents

Leah Lieber

The Colorado College State of the Rockies Project

Research, Report, Engage!

An Introduction from the President of Colorado College

The 2012 Colorado College State of the Rockies Report Card

As Colorado College's new president, I am excited to introduce my first Colorado College State of the Rockies *Report Card*. I view the Rockies Project as one of the college's signature programs and an important community, regional, even national resource. On behalf of the college community, welcome to this ninth annual report of vital student research on an iconic part of the college's Rockies backyard. The Colorado River Basin represents a world-renowned natural wonder in the American West. For decades our students and faculty have studied this region, even as they have rafted its rivers, climbed its cliffs and mountains, and hiked through its forests. Indeed, our environment in the Rockies region has fundamentally shaped our institution. Through the Rockies Project we continue to give back by studying critical aspects of the economy and environment that are so unique and yet fragile.

During summer 2011 and into this academic year, the Rockies Project has concentrated on a multi-faceted and ambitious evaluation and celebration of the Colorado River Basin. Student summer research, subsequently peer reviewed and edited, comprises the sections of this *Report Card* that focus on the law of the river basin, its infrastructure, associated agriculture and economies, recreation, and environmental challenges. In October 2011 to late January 2012, two recent CC graduates endured an epic 1,700-mile "source to sea" kayak trip from the head waters of the Green River in Wyoming to the delta in Mexico, documented in social media and blogs.

Monthly speakers have enriched our campus intellectual environment, bringing renowned experts to discuss Colorado River Basin exploration, law and management, climate, environmental challenges, healthy forests, and unheard voices of Mexico and Native American tribes. An April 2012 Rockies Conference, at which this *Report Card* was unveiled, continued the focus on the Colorado River Basin with sessions on federal Department of Interior management challenges, state of Colorado uses and claims on the river, and a portion of the basin we call the "western slope." A student photo contest displaying a Save the Colorado River Basin banner in each picture, enticed students, faculty, and alumni to explore and document favorite parts of the region. Associated with all of

Colorado College President Jill Tiefenthaler with her family on the Colorado River

About the author: **Jill Tiefenthaler** is the President of Colorado College

this, the Rockies Project for a second year has facilitated and hosted a unique Conservation in the West Survey of public opinion, garnering widespread publicity.

An additional, longer-term dimension of the Rockies Project is its yearly pool of student researchers, now totaling more than 40. I celebrate and underscore our commitment to maintaining and strengthening the Rockies Project's undergraduate leadership component. We are proud that increasing numbers of our graduates who participated in the Rockies Project have gone on to graduate school and careers in conservation.

Our college mission statement continues to guide us in our goals and highlights the importance of the Rockies region so important to our character:

At Colorado College our goal is to provide the finest liberal arts education in the country. Drawing upon the adventurous spirit of the Rocky Mountain West, we challenge students, one course at a time, to develop those habits of intellect and imagination that will prepare them for learning and leadership throughout their lives.

I invite you to explore the Rockies through the material in this *Report Card*, other aspects of the Rockies Project, and indeed the many dimensions of our uniquely located college. I am confident that you will be informed, challenged, and stimulated in your knowledge and thinking. At the same time I encourage you to reflect back on and celebrate the Rockies region so important to all of us. Thank you for caring enough to learn more about and contribute to protecting the unique features and character that make the Rockies region everyone's special backyard.


Colorado College President Jill Tiefenthaler

Jill Tiefenthaler
President
Colorado College


Colorado College Geology Department, A Geology Field Trip to Grand Canyon National Park

Colorado College, the Rocky Mountain West, and

The State of the Rockies Project

By Dr. Walter E. Hecox

The 2012 Colorado College State of the Rockies Report Card

Colorado College today, as for the past 138 years, is strongly defined by location and events of the 1800s. Pikes Peak abruptly rises out of the high plains that extend from the Mississippi and Missouri rivers towards the west. Peaking at 14,000 feet, this eastern-most sentinel of the Rocky Mountain chain first attracted early explorers and was later the focus of President Jefferson's call for the southern portion of the Louisiana Purchase to be mapped by Zebulon Pike in 1806. Gold seekers in 1858 spawned the start of the "Pikes Peak or Bust Gold Rush" of prospectors and all manner of suppliers to the mining towns. General William Jackson Palmer, while extending a rail line from Kansas City to Denver, in 1869 camped near what is now Old Colorado City and fell in love with the view of Pikes Peak and red rock formations now called the Garden of the Gods. An entrepreneur and adventurer, Palmer selected that site to found a new town with the dream that it would be a famous resort—complete with a college to bring education and culture to the region. Within five years, both Colorado Springs and Colorado College came into being in the Colorado Territory, preceding Colorado statehood in 1876.

Early pictures of present-day Cutler Hall, the first permanent building on campus that was completed in 1882, speak volumes to the magnificent scenery of Pikes Peak and the lonely plains. Katherine Lee Bates added an indelible image of the region. In 1893, she spent a summer teaching in Colorado Springs at a Colorado College summer program and on a trip up Pikes Peak was inspired to write her famous "America the Beautiful" poem. Her poem helped spread a celebration of the magnificent vistas and grandeur of Pikes Peak and the surrounding region, and provided bragging rights for Colorado College as "The America the Beautiful College."

The last quarter of the eighteenth century was challenging both for Colorado Springs and Colorado College. Attempts to locate financial support in the east and ease the travails of a struggling college were grounded on the unique role of Colorado College in then President Tenney's "New West" that encompassed the general Rocky Mountain region. His promotion of this small college spoke of Colorado College being on the "very verge of the frontier" with a mission to bring education and culture to a rugged land. Even then, Tenney saw the college as an ideal place to study anthropology and archeology, use the geology of the region as a natural laboratory, and serve the mining industry by teaching the science of mineralogy and metallurgy. In the early 1900s, a School of Engineering was established that offered degrees in electrical, mining, and civil engineering. General Palmer gave the college 13,000 acres of forest land at the top of Ute Pass, upon which a forestry school was built, the fifth forestry school created in the U.S. and the only one with a private forest.

Subsequent decades brought expansion of the institution, wider recognition as a liberal arts college of regional and national distinction, and creation of innovative courses, majors, and programs. The unique Block Plan, implemented in the 1970s, consists of one-at-a-time courses lasting three and one-half weeks each that facilitate extended course field study, ranging across the Rockies and throughout the Southwest.

About the author: **Walter E. Hecox** is professor of economics in the Colorado College Environmental Program and Project Director for the State of the Rockies Project.

Elyna Grapstein

Thus, CC has a rich history indelibly linked to the Rockies.

Today is no different: CC has new programs that meet evolving challenges in the Rockies, including environmental science and Southwest studies programs, the Rockies Project, and exciting fieldwork offered by a variety of disciplines. Students can thoroughly explore the Rockies through the Block Plan and block-break recreation.

The State of the Rockies Project

The Colorado College State of the Rockies Project is designed to provide a thoughtful, objective voice in regional issues by offering credible research on challenges and problems facing the Rocky Mountain West, and through convening citizens and experts to discuss the future of our region. Each year the Project seeks to:

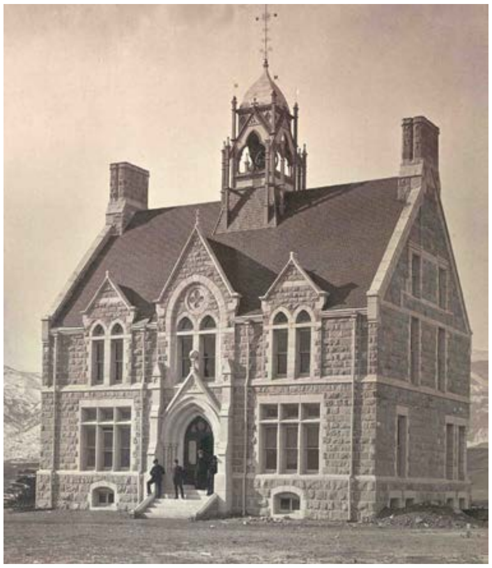
- **Research:** offering opportunities for collaborative student–faculty research partnerships
- **Report:** publishing an annual Colorado College State of the Rockies *Report Card*
- **Engage:** convening a companion State of the Rockies Conference and other sessions.

Taken together, these three arms of the State of the Rockies Project offer the tools, forum, and accessibility needed for Colorado College to foster a strong sense of citizenship among our students, graduates, and the broader regional community.

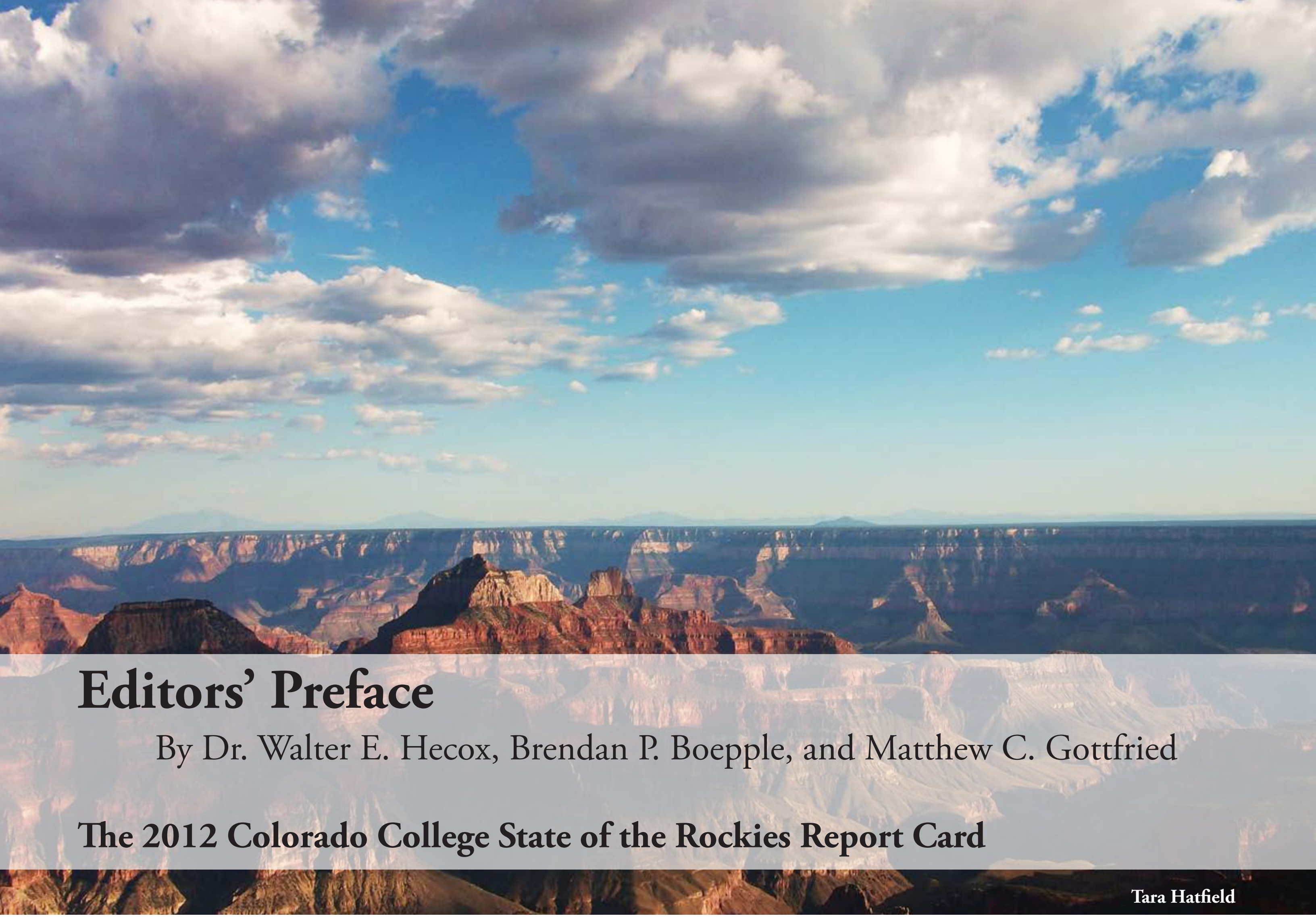
Walt Hecox, A 2011 Ecological Economics Field Trip

"An institution, like a person, is the product of a total environment. The whole setting of a college or university – climate, topography, material resources and the people – contribute to the formation of its character. Colorado College can best be understood through a knowledge of the West, of Colorado, and of Colorado Springs."
--Charlie Brown Hershey,
Colorado College president during World War II

Colorado College, A 1969 Geology and Ecology of Pikes Peak Field Trip



Colorado College, An early photo of Cutler Hall



Editors' Preface

By Dr. Walter E. Hecox, Brendan P. Boepple, and Matthew C. Gottfried

The 2012 Colorado College State of the Rockies Report Card

Tara Hatfield

The Colorado River Basin: A Unified Project Theme

The Colorado River Basin was the unified focus of all parts to the State of the Rockies Project during summer 2011 and the 2011-12 academic year. This basin encompasses portions of seven states in the American Southwest and continues into Mexico, supplying water to households, communities, businesses and farms, as well as natural ecosystems. Roughly 30 million people rely on the river for water, energy, food, and healthy ecosystems. Climate studies indicate the potential for inadequate water supplies throughout the 1,700-mile river system from the origins of the Green River high in Wyoming's Wind River Range to its historic outlet over the Colorado River Delta, emptying into the Sea of Cortez. Along its twisted path arise majestic mountains, deep canyons, tributaries, and a wealth of flora and fauna. The basin is indeed a natural treasure of world-class caliber, but heavily threatened. We dedicated our focus on the Colorado River Basin in order to help assure that the next generation inherits a natural and economic system as spectacular, diverse, and bountiful as has existed in the past, but is in transition today. The changes currently underway and those needed for the future must have new voices, especially those of today's youth, for they will live with the results.

The region's projected population growth means increased water demand on the Colorado River from municipalities, industry, agriculture, and recreation. Some expert studies predict that by 2050 climate change and burgeoning uses of the river system will result in inadequate water to meet all of its allocated shares two-thirds to nine-tenths of the time. A near century of sanctioned water management under the 1922 Colorado River Compact has largely catered to the traditional "beneficial uses" of water for agriculture, mining, manufacturing, and municipalities. Only in the last decade has society started to assess the needs of nature for water in the basin, sometimes called instream flows, able to nurture and sustain fish, riparian areas, and adjacent lands and vegetation.

Colorado College is grounded in the liberal arts, promoting a broad understanding of the world around us. Maddeningly "liberal" and complex is the Colorado River Basin! We have been challenged as student researchers, supporting river explorers, technical staff, and faculty to create in our own minds an understanding of a basin many experts spend an entire professional life appreciating and helping manage. Summer research, field trips, academic year speakers, and our sponsorship of a "source to sea" kayak trip have all been a

About the co-editors: **Walter E. Hecox** is professor of economics in the Colorado College Environmental Program and Project Director for the State of the Rockies Project.
Brendan P. Boepple is the 2011-12 Rockies Project Program Coordinator.
Matthew C. Gottfried is the college's GIS Technical Director and the 2011-12 Technical Liaison for the Rockies Project.

part of the process of exploration, reflection, and communication, which is the hallmark of the Rockies Project. What we have learned is partly reflected in the content of this *2012 Colorado College State of the Rockies Report Card*. Beyond these student research sections, we have also conducted a survey of college-age students' values and dreams for the iconic Colorado River Basin; extensive use of social-media from photo contests to You Tube, Facebook, and other media have amplified our audience in increasingly participatory ways.

Using A Proven Approach: Research-Report-Engage

Central to this year's activities, as in the past, are the three goals of the Colorado College State of the Rockies Project:

•RESEARCH: To involve Colorado College students as the main contributors to the *Report Card* and conferences.
•REPORT: To produce an annual research document on critical issues of community and environment in the Rocky Mountain West (the *Report Card*).
•ENGAGE: To host annual monthly speakers' series and conferences at Colorado College, bringing regional experts together with concerned citizens.

Research

Summer 2011 Field Trip Perspectives

Supplementing the intense work on campus of each Rockies student researcher during summer 2011, a two-week field exploration of the Colorado River Basin opened up key contacts with experts, provided for first-hand observation, and contributed to better understanding of the complexities of this huge natural and human system.

The State of the Rockies Project summer research team headed south in July 2011 with a tall task- to follow the Colorado River from its headwaters in the Rockies to the Mexican Delta where the river traditionally reached the sea. Covering over 3,400 miles, the trip reinforced the gravity of many issues the team had already been researching from afar at Colorado College.

From Colorado Springs the team crossed over the spine of the Rockies and passed from the Arkansas River Basin into the Colorado River Basin. They met up with the main stem of the Colorado and followed its course through Glenwood Canyon, first in the van on I-70 and then in a raft, viewing the river up close. The researchers then made their way to Aspen, Colorado, to meet with Aspen Skiing Company and continued on to Paonia, Colorado, where they learned about Western Slope agriculture and water issues. After a day spent hiking the Black Canyon of the Gunnison and learning about the issues of the National Park, the research team continued west into Utah.

Stopping in Moab, Utah, and Canyonlands National Park, the researchers met with national park service officials to hear about the difficulties of managing the Colorado River for both its ecological as well as recreational value. Further south the team travelled to Lake Powell and Glen Canyon Dam. A tour of the dam revealed the inner workings of hydroelectric generation and the operations of the Bureau of Reclamation. Following the course of the river, the researchers went to Lee's Ferry, the demarcation line between the Upper and Lower Basins of the Colorado River, and the starting point for all Grand Canyon rafting trips. The Rockies Project team then climbed up the Kaibab Plateau and found themselves on the remote North Rim of the Grand Canyon. After a six-hour drive, the team was in the desert metropolis of Las Vegas.

Meetings with the Southern Nevada Water Authority taught the researchers about the city's various water conserving initiatives and attempts to best utilize their share of Colorado River water. After experiencing Lake Mead and the massive Hoover Dam, the researchers met with Bureau of Reclamation officials in Boulder City, Nevada, to learn about the coordinated operations of the Lower Basin's various dams and diversions. Passing Lake Havasu and crossing Parker Dam, the team headed south to California's Imperial Valley.

Meeting with officials for the Imperial Irrigation District and touring their agricultural production, the research team learned the vital importance of the valley's role in the nation's food supply. On the following day, the team crossed into Mexico and met with members of the Mexican environmental group, ProNatura, to see first-hand Mexican uses of Colorado River water and the state of the dry Colorado River Delta. After touring the Cienega de Santa Clara, the student researchers returned to Yuma, Arizona, where they toured the Yuma Desalting Plant. The research trip then turned northward and back towards Colorado.

A quick stop to tour the Wellton-Mohawk Irrigation District provided another insight into the role of agriculture in the basin and its use of Colorado River water. Further north, the group stopped in Lake Havasu City, Arizona, to meet with Bureau of Land Management officials about regulating recreation in the area, both on the lake and in the surrounding

Brendan Boepple, Student Researchers touring the Cienega de Santa Clara wetlands with the environmental group ProNatura

Brendan Boepple, Rockies Project Student Researchers meeting with Navajo Nation officials

desert. The team travelled to the more popular area of the Grand Canyon, the South Rim. Crossing the Arizona-New Mexico border, the researchers made one final stop in the Navajo Nation to meet with tribal officials. Hearing from members of the nation's water management and rights divisions, the research team learned the issues of the traditionally under-recognized people. One final push across New Mexico and Colorado returned the researchers to Colorado Springs and Colorado College.

Report

The results of each 2011-12 Rockies student researcher reflect a summer of intensive research, the two-week field trip, fall 2011 re-writes, peer reviews, and editing in preparation for the publication of the following sections in this *Report Card*. In addition to sections devoted to each student researcher's topic, ranging from the Law of the River to the Environment and Ecology of the Basin, this year's *Report Card* is also supplemented with additional sections. The first, a basin overview, covers the key issues of the Colorado River Basin that will later be expanded upon more extensively in following sections. Next, a summary of the Rockies Project Source to Sea journey covers the trip of our two Project Field Researchers from the headwaters of the Green River in Wyoming to the Sea of Cortez and the threatened river delta. The last piece to supplement this year's student research is a call to action from our five student researchers through an open letter to Colorado River Basin water users, experts, and enthusiasts.

Will Stauffer-Norris and Zak Podmore: "Kayaking from Source to Sea on the Colorado River: The Basin Up-Close and Personal"

In addition to the traditional student-faculty collaborative research, the 2011-12 State of the Rockies Project also set its sight on another ambitious venture- to raise awareness of Colorado River issues through a Source to Sea journey across the full length of the basin. Starting in early October, high in Wyoming's Wind River Range, our two field researchers began the journey at the headwaters of the Green River. The ensuing 1,700-mile journey brought our researchers up close to many of the river's issues. From struggling to make progress on the river's large reservoirs to shooting rapids in the Grand Canyon, our researchers gained an insight into the whole basin that few others can understand. While their investigation of the various basin issues on a personal level led their concern over the future management of the basin to grow, a number of issues truly resonated with their growing love of the river system. Standing on the shores of Flaming Gorge Reservoir, they contemplated the value of pumping that water some 500 miles to the Front Range of Colorado. Equally as concerning was the delta they discovered at the end of the river. Once a mecca for North American wildlife, it was waterless and choked with invasive species. Setting out to raise awareness of such issues of the basin, this summary of their trip tells their story, as well as the story of the river.

Sally Hardin: "Demographics, Economy, and Agriculture Depend on Water Storage and Diversion: Is it a Zero Sum Game?"

The once wild Colorado River is dammed and diverted more than most other rivers in the entire world. The establishment of state-by-state apportionments in the early 20th century laid the groundwork for extensive development of infrastructure throughout the basin to store and divert every drop of available water. In laying this groundwork, the seeds of conflict were also sewn. The mounting pressures on the basin are coming to a head as municipalities and agriculture vie to secure what water they can for the future. The


Rockies Project Field Researchers paddling the Green River in southern Wyoming

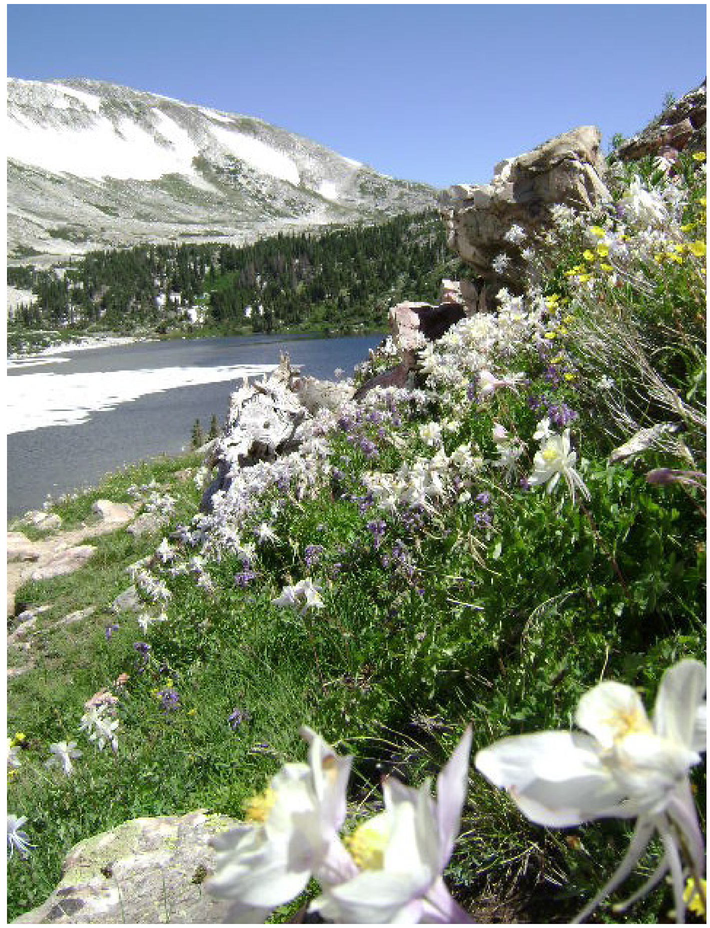
tradition of prior appropriation in Western Water Law looks to spell even more difficulties for an already over-allocated system. However, can a compromise be found between the agriculturalists with their "use it or lose it" doctrine and the ever-growing cities reliant on the basin's water supplies?

Warren King: "Laws of the Colorado River Basin: Obsolete or Flexible for a Sustainable Future?"

The Colorado River Basin is governed and litigated by a body of laws, compacts, trials, and treaties known as the Law of the River. The keystone of this body of law is the Colorado River Compact of 1922. The Compact apportioned water from the basin to the Upper and Lower Basin states following the recorded flows of the river from the decade prior to the signing of the Compact. However, as modern issues begin to put pressure on this ninety-year-old document, will the Colorado River Compact be able to bend under the stress or will it break as issues mount? Is a new document necessary to address the modern issues of the basin? Continued climate change, coupled with a failure to address key stakeholders in the basin such as Native American tribes, the Republic of Mexico, and the environment, would say yes. However, other stakeholders would say that the Compact allows for flexibility and compromise in the face of potential conflict.

Ben Taber: "Recreation in the Colorado River Basin: Is America's Playground Under Threat?"

The Colorado River Basin supports recreationists from around the world. From the ski areas high in the Rockies to the desert canyons that make the river famous for rafting, recreation is a basin-wide issue. While tradition has placed the "beneficial uses" of water well above its recreational value, an examination into the role that recreation plays in the basin's economy suggests a paradigm shift in the perception of the great pipeline of the Southwest. Furthermore, an investigation of people's values throughout the basin shows a high value placed on the continued access to the recreational playground that is the basin. However, instream flows have never been granted for recreational purposes and the other stresses on the basin continue to mount. From proposals to diminish the flow of the Green River through extensive diversions, to the manipulation of flows through the Grand Canyon by Glen Canyon Dam and its massive reservoir, Lake Powell, recreation in the basin needs a voice in the ongoing discussion of the river's future.



Maria Gades

Natalie Triedman: "Environment and Ecology of the Colorado River Basin"

From the majestic scenery of the Rockies to the treasure of biodiversity in the Colorado River Delta, the basin is home to a diverse collection of ecosystems that support a plethora of flora and fauna found nowhere else in the world. Following the river system from its headwaters to the sea helps one to understand the integral role that the riparian environments dependent on the river play in the larger basin-wide system. However, the history of the river stressed diversion and storage over the historical flow regime and left environmental values entirely absent from the basin's management. As municipalities and agricultural entities stake their claims in the face of projected diminished flows due to a changing climate, who will stand for the environment? The establishment of instream flows for environmental values has begun, but is piecemeal. What should be done to address the environment and ecology in the basin under these mounting pressures? Acknowledgement of the environment's key role in all aspects of the use of Colorado River water continues to gain

Carola Lovering, A fly-fisherman in Colorado's Gore Range momentum, but can something be done soon enough?

Carson McMurray: "The Colorado River Basin and Climate: Perfect Storm for the Twenty-First Century?"

The climate of the Colorado River Basin has always been unpredictable. From the headwaters high in the Rockies to the deserts of the Southwest, climatic volatility is more the norm than the outlier. A history of the region through paleoclimatology shows a pattern of drought accentuated by the rare wet years. The changes in our current climate point to only greater vicissitudes in the system as we enter the 21st century. With projections of substantially decreased flows and changing seasons, what should the basin expect in the coming years? Can the infrastructure from the basin's "Age of Construction" stand the test of the changing climate or must other solutions be sought? To start, projections of increased evapotranspiration threaten the large reservoirs, already losing substantial amounts of water to evaporation, but are drastic measures for augmentation necessary to divert disaster?

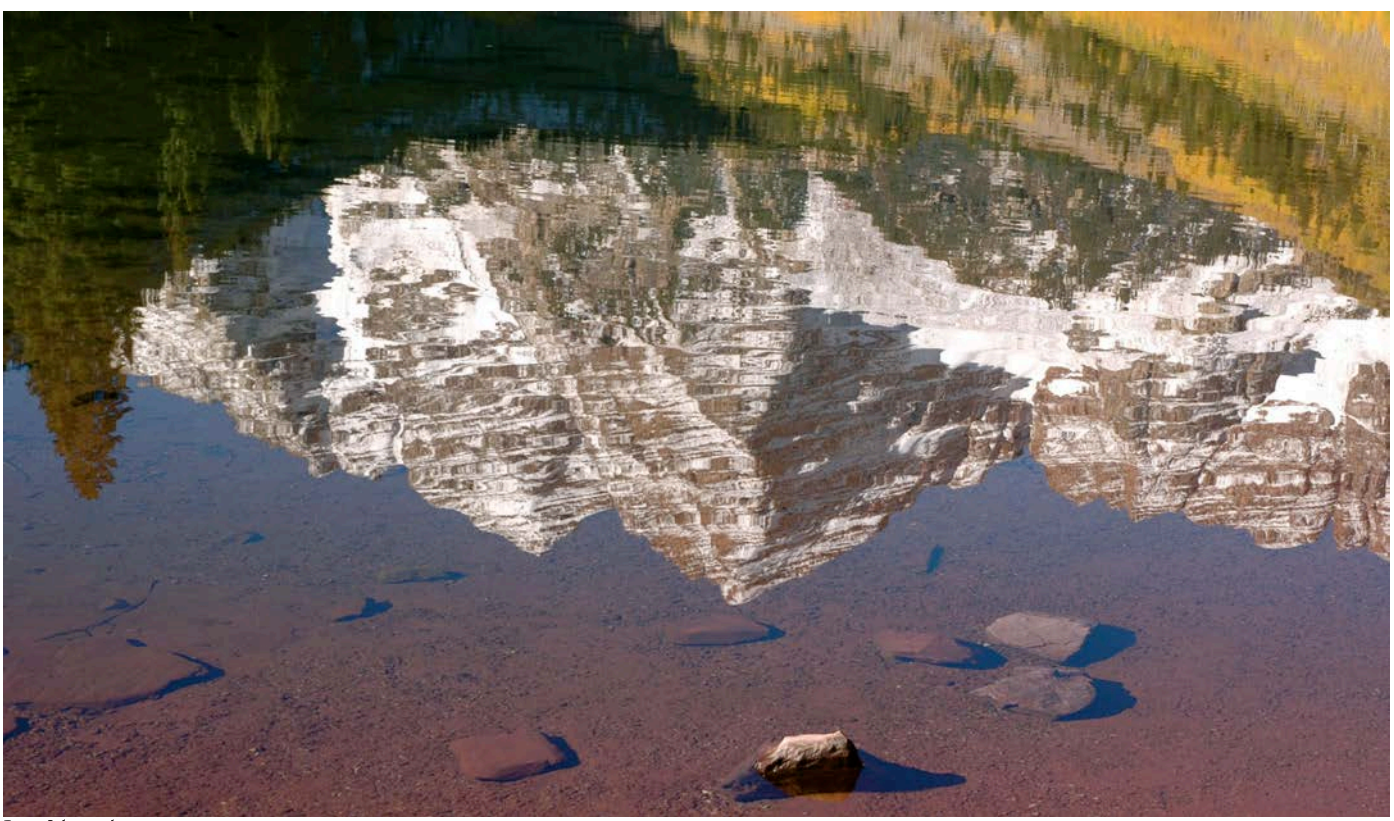
Student Research Team: "Managing the Colorado River Basin: An Agenda for Use, Restoration, and Sustainability-An Open Letter"

The "Five Actions" outlined in this section for the future management of the basin represent an accumulation of all the knowledge captured in this year's *Report Card*, coupled with a comparison of two public opinion surveys. The first survey, conducted by the Rockies Project, polled college-age students, the other survey, conducted by the Colorado River Governance Initiative, gauged the opinion of "water experts" already influencing decisions in the basin. This section, an open letter to those invested in the basin in one form or another, lays out suggestions for the future management of the basin from the next generation who will soon be working to manage the river system for use, restoration, and sustainability.

Engage

Monthly Speakers Series

Our understanding of the basin has been assisted by a stellar range of monthly speakers, drawn from a range of experts and authorities. Two widely-acclaimed explorers, naturalists, and National Geographic contributors Pete McBride and Jon Waterman provided a September, 2011 overview of the Colorado River "flowing through conflict" as a comprehensive introduction. Next we explored the Law of the Colorado River Basin in October, 2011 with Colorado Supreme Court Justice Gregory Hobbs and University of Wyoming Law School professor Larry MacDonnell. In November, 2011 environmental perspectives were initiated in a session featuring Bart Miller, water program director for Western Resource Advocates, Jennifer Pitt who manages the Environmental Defense Fund's initiatives on the Colorado River, and Tom Chart, involved in the endangered fish recovery efforts of the U.S. Fish and Wildlife Service. Sticking to environmental issues, in December, 2011 we organized a panel titled "The Colorado River Basin and Climate: Perfect Storm for the 21st Century?" with three speakers: Beth Conover, editor of *How the West Was Warmed* serving as moderator; Stephen Saunders, president of Rocky Mountain Climate Organization; and Jeff Lukas, Associate Scientist for Western Water Assessment run by the National Oceanic and Atmospheric Administration and the University of Colorado at Boulder. Switching directions, our January, 2012 session explored the "unheard voices" of Mexico and Native American Tribes in basin issues and management, featuring Bidtah Becker, Water Rights lawyer for the Navajo Nation Department of Justice, and Osvel Hinojosa, Director of Mexico's Pronatura Noroeste's Water and



Ryan Schumacher


John Barker, Sunset over Lake Powell

Wetland Program. Completing the wide-ranging series we featured "healthy forests" for the basin, presented by Harris Sherman, U.S. Department of Agriculture Undersecretary for Natural Resources and the Environment (overseeing both the U.S. Forest Service and the Natural Resources Conservation Service).

The combined perspectives from these six monthly talks about the basin represent an ambitious, comprehensive coverage of key basin dimensions and challenges, from complex hydrologic, environmental, and socio-economic dynamics to how the basin may be impacted by potential future climate scenarios and the burning issues of unmet water needs by underrepresented Native American and Mexican people. Alongside college and community attendees, the Rockies Project staff and students have benefitted immensely from the depth of each talk and the breadth of the different approaches.

April Rockies Conference

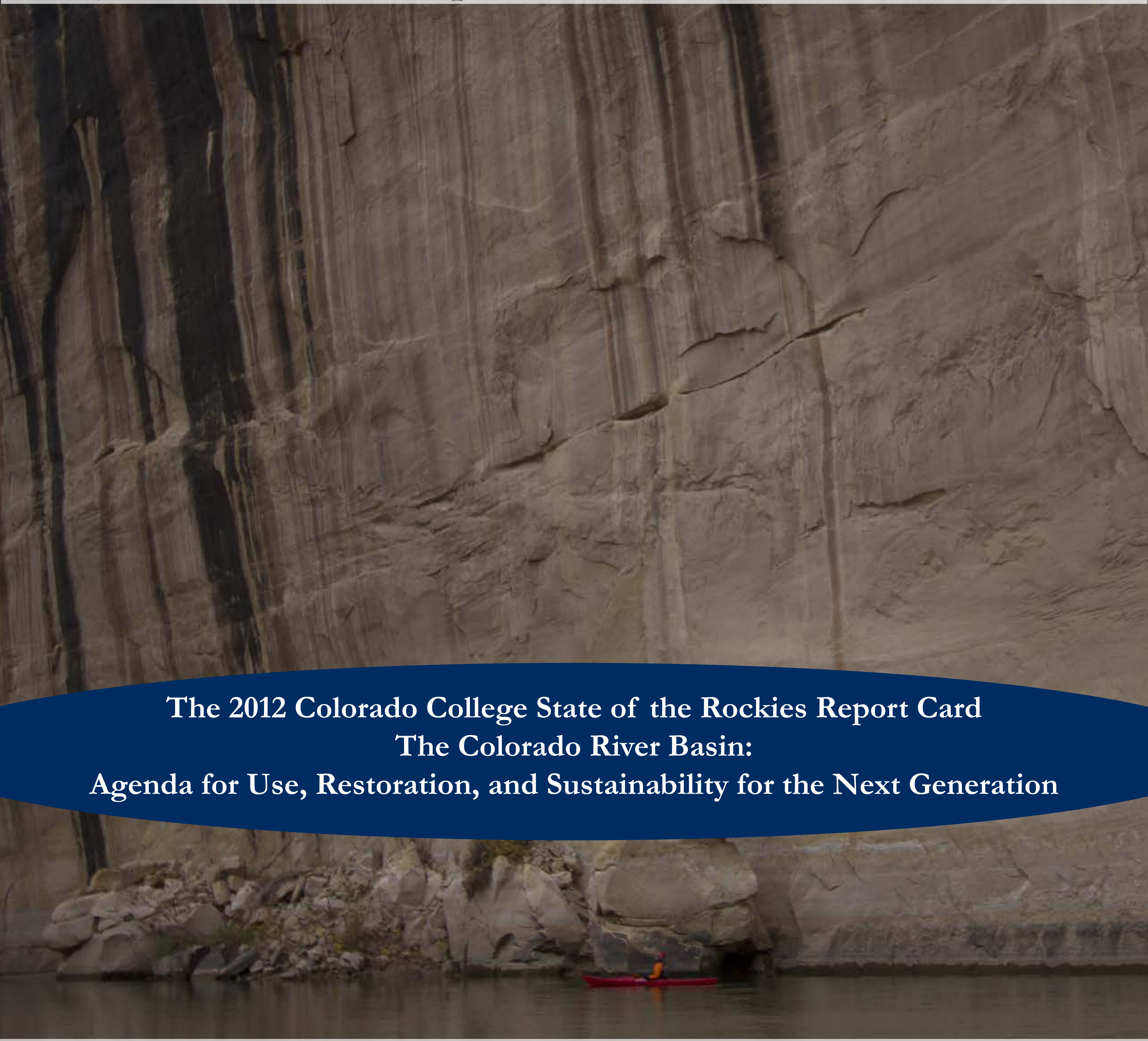
The unveiling of this *2012 State of the Rockies Report Card* once again offers us an opportunity to celebrate the Rockies region with an annual conference on April 9-10, 2012. Opening the conference on Monday, April 9th, our Rockies Project Field Researchers, Will Stauffer-Norris and Zak Podmore, will present a multimedia presentation of their trip, including the premiere of a film covering their entire trip from source to sea. Later that evening, the Colorado College community will welcome the Secretary of the Department of the Interior Ken Salazar, and the Director of the U.S. Geological Survey Marcia McNutt. The two Colorado College alumni, already heavily involved in the management of the Colorado River Basin, will address the future challenges for the Department of the Interior in managing the complex river system. Sessions on Tuesday, April 10th, will center on the state of Colorado's involvement in the future management of the basin. A noon-time session with Colorado Governor John Hickenlooper will focus on youth and the future of Colorado's water. The day will be enriched by an afternoon session with photographer, author, and teacher Stephen Trimble titled: "Bargaining for Eden: In Search of Visionary Conservation on the Colorado Plateau." The final session of the conference that evening, titled: "Colorado's Stake in the Colorado River Basin," will bring together water management officials from across the state to address the challenges for managing the Centennial State's water in the 21st century.

Saving the Colorado River Basin: Join In

For this, our ninth year of the Rockies Project, we have sought to take research-report-engage to new heights, mixing traditional dimensions with new social media, speaking to younger audiences in more visual and interactive ways. We have also "gotten off the fence" by taking a stand with our "Five Actions" that will help save the Colorado River Basin for the next generation. We urge you to be "active" in learning about, enjoying, and helping to protect the spectacular vistas and regions Colorado College is blessed to call "our backyard." Get out there and join each new class of CC students and many of our alumni and friends who seek solitude, recreation, and enrichment from these spectacular, but fragile, environments. Speak up for a Rockies region that can and must be healthy as a regional economy and environment. Your children and their children will thank you!

Kayaking from Source to Sea on the Colorado River: The Basin Up-Close and Personal

By Zak Podmore with photos from Will Stauffer-Norris



The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Authors:
Zak Podmore (Colorado College class of ‘11) is a 2011-12 Field Researcher for the State of the Rockies Project.
Will Stauffer-Norris (Colorado College class of ‘11) is a 2011-12 Field Researcher for the State of the Rockies Project.

Will Stauffer-Norris

Will and Zak near the “source” of the Green River in Wyoming’s Wind River Range

Bighorn sheep in Desolation Canyon

Zak paddles through an irrigation canal

The gulf of California

The messages on this map were transmitted from Will and Zak via GPS while they were on the river.

Between Mountains and Mexico

High in the Wind River Mountains of Wyoming, Mexico was a joke. A group of recent Colorado College grads floundered in two-and-a-half feet of freshly fallen October snow, our snowshoes leaving a winding track next to an iced-over creek. Breaking trail over mountain passes slowed us, our soaked boots chilled us, and fighting our way through slick boulder fields frustrated us as we made our way towards an alpine lake we were calling “the source.” The going was slow, but our jokes kept us amused as long as they stayed south of the border. Conversation revolved around tacos—and of lying stretched out on a beach in Baja, gratefully soaking in the desert sun.

We were amused because the idea was impossibly far away. The frozen creek beside us was to become the Green River. At 10,000 feet above sea level and over 1,700 miles of river from the Gulf of California, we were nearing the furthest upstream point in the entire Colorado River Basin. And the plan was to follow the river all the way to tacos and salt water.

By mid-January, the Colorado River had become a joke. Will Stauffer-Norris and I climbed out of a concrete irrigation canal somewhere in northern Mexico to meet a rapidly growing crowd of spectators. A pickup truck pulled up, a few bikes stopped, an old man in the process of setting a fishing line in the canal wandered towards us. They watched as we struggled to pull our overloaded, inflatable pack rafts out of the water and onto the road. We were bearded and dirty, feeling ridiculous in our life jackets and knee-high rubber boots. We had strange muscles protruding from behind our shoulder blades after months of forward paddling. Slightly embarrassed, we grinned at the crowd. Questions came pouring in. I attempted to explain how we arrived in my broken Spanish. “Four months,” I say, “on the Rio Colorado. In boat. 3,000 kilometers. All on the river.”

The fisherman smiled sadly at the confused gringo. “El Rio Colorado?” He shook his head and chuckled. “No hay agua en El Rio Colorado.” There’s no water in the Colorado River. Our story must be mistaken.

Beginnings

Will and I set out in the fall of 2011 to paddle the entire length of the Colorado River as field researchers for the State of the Rockies Project. The expedition, which would eventually take us through six states and into another country, was designed to better understand the river that supplies 30 million people in the Southwest with drinking water. The river, we knew, was endangered. We'd heard that it hadn't reached the sea since 1996, and we wanted to see for ourselves what that meant--eventually. But the fact that, between the source and the delta, the river also happened to take us through some of the most spectacular canyons in the world didn't exactly dissuade us from the expedition.

Zak preparing to hike to the source of the Green River in Wyoming's Wind River Range

Although nothing could have wholly prepared us for four months on the river, we both had the necessary skill sets: the ability to roll a kayak, a willingness to paddle forward for days on end, and the love of desert rivers. Will grew up in Blacksburg, Virginia, but he acquired these skills during his childhood summers in Idaho. He fell for the West and its water while learning to raft and kayak on the Salmon, the Snake, and Green Rivers. I was equally fortunate, having been taken by my parents on desert float trips starting at the age of one on the Colorado, Green, San Juan, and Dolores Rivers. Will and I met on an 18-day Ritt Kellogg Fund trip on the Nahanni River in the Northwest Territories of Canada. The next winter, I got a permit for the Grand Canyon and Will suggested we paddle the whole river. A year of convincing later, the expedition was born.

Will and Zak prepare to start kayaking after days of packrafting

The Green River

The Colorado River begins in Rocky Mountain National Park- 50 miles northwest of Denver; its headwaters lie about 1,450 miles from the sea. Our journey, however, began in the snowfields of a Wyoming mountain range. We'd decided early on that to traverse across the entire Colorado drainage basin it would be best to begin outside of the state of Colorado and on the Green River. This apparent contradiction often required explaining. Before 1921, the Colorado River officially began where it joins the Green in what is now Canyonlands National Park. From the headwaters to the confluence, it was known as the Grand River—hence the names of Grand Junction, Grand Lake, and Grand Mesa. Despite the fact that the Green River is about 250 miles longer than the Grand, it was renamed the Colorado for political reasons a year before the infamous 1922 Compact that would divvy up the flow of the river between eight southwestern states and Mexico. If measured by length, the headwaters of the Green River where we were snowshoeing that October day are the true source of the Colorado River.

But, of course, a river has many sources. We were quick to remind ourselves of this platitude when the first snowstorm of the year forced us to turn back about a mile from where the line on the map marked 'Green River' petered out in a near-vertical alpine valley. Will, myself, and three friends, who joined us for the first five days of hiking through the Wind Rivers, were slightly disappointed, but we were exhausted enough to spend the next 24 hours huddled in a tent without getting too restless. We listened as the wind howled and snow piled around the fly. Two days later, Will and I were on our own, blowing up our pack rafts on the shores of Green River Lakes. We paddled to the outlet and down the creek that was to take us to the sea. We quickly learned how many calories it is possible to burn when your feet are packed in frozen shoes, when your drysuit accumulates ice as soon as the sun ducks behind a ridge, and when you spend all day paddling against the wind with little current. Salami, mayonnaise, and peanut butter jars became our close friends. Fifteen hard-earned miles were about all we could squeeze out of a day's work.

Below Fontenelle Dam

After five days of packrafting, the river had gathered enough flow to switch over to kayaks. At 14.5 feet long, the boats were a lifesaver. The calories kept turning over as we paddled through ranch lands and gas fields, but our daily mileage more than doubled. The 15-mile-long Fontenelle Reservoir stood behind the first of 11 dams we'd cross before the sea. We paddled to the backside of the earthen dam and climbed out, expecting to be stopped by security. When nobody came, we hauled our 300 pounds of boats and gear to the top and lowered it down the steep front side with ropes.

The next reservoir, Flaming Gorge, was slightly more daunting. At 95 miles long, the threat of up-lake wind made us fear we'd miss our first permitted launch date in Dinosaur National Monument still at least a week's paddle downstream. Fortunately, my father and his friend, Jonathan Cooley, met up with us for several days, carrying plenty of fresh food that gave us a chance to refuel. Between sandwiches and breakfasts of bacon with butter-covered, deep fried toast, we learned from Jonathan, a geology professor at Colorado Mesa University, that the reservoir that was offering us a chance to fill ourselves back up with calories was in danger of being siphoned out of the basin. An estimated $9 billion pipeline from Flaming Gorge to Colorado's Front Range cities had just received funding to commence a feasibility study.[1] If funded, the project would spell not only a problem for the fisherman and jet boaters who come to use the reservoir for recreation, but would also have repercussions all the way to Mexico. The Green's yearly flow would be reduced by as much as one-fourth, and the wilderness canyons of Lodore and Desolation would often be unrunnable for rafters. The desiccated, but ecologically crucial, delta just north of the Gulf of California would suffer further damage in times of drought, and water related controversy in Nevada, California, Arizona, and Mexico would surely increase. Extending 560 miles in length, the project would be the most expensive water diversion in Colorado's history. And, to top it off, we read: "the majority of the water in Colorado's cities is used to keep lawns green for three months in the hot, dry summer."[2] Nine billion dollars and a series of incalculable negative effects downstream seemed a high price for green grass, but Jonathan encouraged us to learn more about the project.

We portaged Flaming Gorge Dam through the courtesy of the Daggett County Sheriff's department. Two patrol cars were waiting for us when we dragged our boats out of the reservoir, and we loaded one into the back of each car, the tails sticking six feet out beyond the bumper. Glad to be back on the flowing river, we made good time and met two friends who came to float through the Gates of Lodore with us.

Hitching a ride around Flaming Gorge Reservoir

The Wilderness River: The Gates of Lodore to Cataract Canyon

We went to the river in part to see what was threatened, going, or gone, but we also went to see the sections that have remained relatively healthy and intact. The 350 miles of wilderness canyons between Flaming Gorge and the confluence with the Colorado played no small role in the trip's attractiveness. As those who have spent any time floating between the monolithic sandstone walls of Utah's river canyons or made the effort to explore the secret wind-carved, water-sculpted folds of the Colorado Plateau know, this desert can take a hold on the mind which is slow to dissipate. The beauty of this place cannot be easily summarized. Its value refuses to be simply disclosed.

To an economist who can only see worth if it has a dollar sign in front of it, these canyons are near worthless. Protected from roads and diversions, recreation is about the only contribution the wild sections of the Green River make to "job creation" or "economic stimulation." Natural gas and uranium extraction has begun to draw roads along their outskirts. And the value of Colorado River water increases with each passing year as Colorado Springs, Denver, Phoenix, Las Vegas, San Diego, Los Angeles, and the other desert cities continue to grow. Unfortunately for the multitude of species that depend on a flowing river, water is more valuable out of the river than in it.

For three weeks, from the Gates of Lodore, through Desolation Canyon, under I-70, into Labyrinth and Stillwater Canyons, past the confluence with the Colorado, and through the rapids of Cataract Canyon, we saw no other boaters. The days were spent trying to understand why we'd agreed to float down these waters in late fall, and how, amidst the cold and the solitude, we were managing to enjoy it—and enjoy it immensely. The long November nights were spent reading John Wesley Powell, the first European to explore these canyons by boat, and Edward Abbey, the first anarchist to promote the violent sabotage of machinery in the name of the same canyons. Both writers loved the river and understood the critical role it would play as population grew in the West. We attempted to convey its value in our journals but only ended up paraphrasing our favorite parts of Powell's report and Abbey's essays--the parts that could only be understood from the floor of a remote canyon. When our attempts to explicate the river's value seemed to fall short, we wound up writing self-righteous lines such as: "Those who wish to understand what value water has in a free-flowing river must visit one. Float down it, if possible. Drink from it, if safe. Sleep on its banks for a week or a month, if prepared to be changed." Essentially, we said little that would convince the stubborn economist, but we said much to endorse our own river trip.

Sunrise breaks through the morning fog in Lodore Canyon

Lake Powell

Towards the end of Cataract Canyon, the current slowed and then stopped completely. Silt banks rose on either side until we were floating down a canyon of leg-eating mud. One foolish step onto what looked like solid bank kept us in our boats well past dark. We'd found Lake Powell, the largest and most controversial reservoir we'd pass on our journey, and we were still 165 miles from the Glen Canyon Dam.

The silt walls that made for such difficult camping had been dropped in the reservoir by the river at a rate of 30,000 dump truck loads per day ever since the Glen Canyon Dam was completed in 1962. Lake Powell, which formed behind it, holds 27 million acre feet of water when full,[3] generates electricity for Phoenix, and draws 2.4 million visitors annually.[4] The reservoir has been a focal point of heated environmental debate since it was built largely because the remote canyon it flooded is in one of the least accessible portions of the continental U.S. An estimated 500 people floated through the Glen Canyon between John Wesley Powell's exploratory 1869 trip and the filling of the reservoir. By comparison, about 20,000 people currently float the Grand Canyon each year—some waiting over a decade to obtain a private rafting permit—and over four million people visit the park annually.[5] It's not unthinkable that Glen Canyon might have drawn similar numbers had it remained intact. A collection of personal testimonies from those who had the chance to visit Glen Canyon before the dam and Eliot Porter's 1963 photography book *The Place That No One Knew*, speak for the stunning beauty of the place. Much of the seven days it took us to paddle our kayaks across the reservoir were spent trying to imagine the canyon that lay several hundred feet below us. Our Lake Powell Thanksgiving meal of turkey jerky and instant mashed potatoes left us feeling grateful that five more dams, which were once proposed for the Grand Canyon, had been stopped by concerned environmentalists in the 1960s.

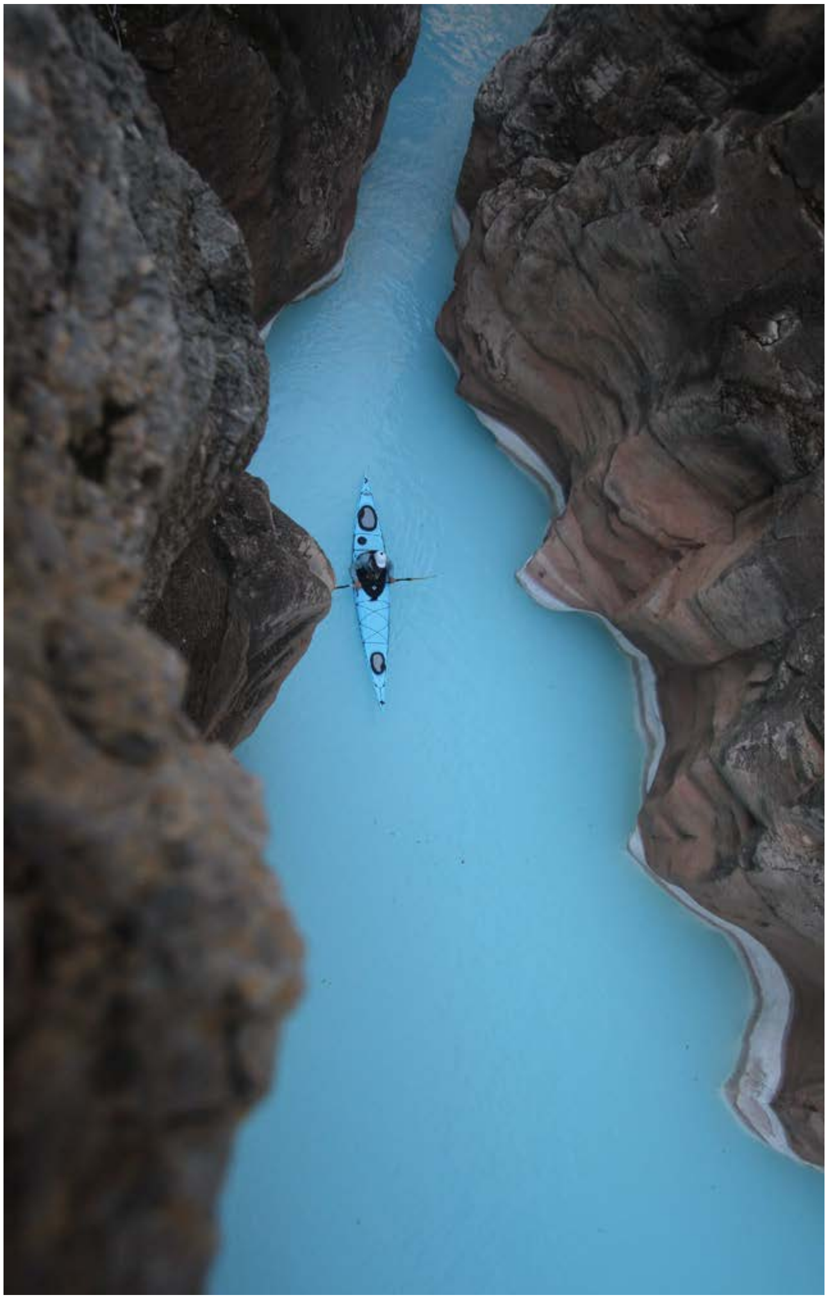
But we were well aware that our perspective might be different if we were equipped with motors like the other boats we passed on Powell, or if we fully understood the story about the reservoir's role in water storage. Since the dam's construction, there have been people calling for its decommissioning. We attempted to get caught up on some of the latest arguments for and against the dam. Unlike the series of reservoirs on the Arizona/California state line a few hundred miles downstream of the Glen Canyon Dam, Lake Powell provides no irrigation or municipal water except to the small towns built along its shores. Energy, recreation, and water storage are often cited as its uses. Advocates for the dam often claimed in the past that the reservoir was necessary to hold water in times of drought, but when a dry spell hit the Southwest in the late 1990s and continued until 2010, both Lake Mead and Lake Powell fell below half their capacities.[6] Since then, people have begun to question if the 860,000 acre feet of water that Lake Powell loses annually to evaporation and seepage outweigh the dam's benefits. The water lost is equivalent to six percent of the Colorado River's annual flow, and with evaporation comes increased salinity levels and decreased water quality. Both reservoirs have been substantially replenished thanks to heavy snowfall during the 2010-2011 winter in the Rockies, but with the current demands on the river, they are never expected to fill again. The debate has died a bit for now, but is sure to resume when the next drought hits.

On Lake Powell above the Glen Canyon Dam

The Grand Canyon

We'd structured the entire trip around one date—November 29, 2011—the day of our Grand Canyon launch, which was doled out to us by the National Park Service years earlier. Our willingness to brave the canyon in winter greatly increased our odds of winning a launch date in the yearly lottery. The notorious difficulty of obtaining a permit is a necessary restriction placed on the river corridor. Without strict measures limiting the number of rafters allowed in the canyon, the Grand would quickly lose the values that attract so many people—including the ability to find solitude and wonder in a wild, still largely untrammeled place. The trip is in such high demand that each year several people are jailed or heavily fined for violating the many restrictions in place. The growing number of rafters applying for the private permit lottery speaks to the benefits of keeping our rivers wild and free flowing. While the Grand Canyon isn't dangerously close to running dry, that is not the case for the rest of the river, which has numerous sections that are equally spectacular.

For Will and me, the Grand meant a chance to relax. After nearly two months of difficult paddling, the Lee's Ferry boat ramp provided the double relief of current and companions. There, we rejoined the clear, cold current being released from the bottom of Glen Canyon Dam, and met 11 of our friends who had come to float the canyon with us. Lake Powell was releasing a much higher volume of water than usual in an attempt to refill Lake Mead before next year's spring runoff. The current, flowing at an average of eight miles per hour, made it easy to meet our daily quota, and it gave our tired shoulders some much-needed rest. We spent our days lounging in camp, strolling up deserted side canyons to waterfalls draped in greenery, and exercising our underused vocal cords. For 25 days, we were lost to the outside world. Our drysuits saved us on multiple occasions when the 18-foot rafts were flipped effortlessly by the river's waves, hurling bodies through the air. In the evenings, we ate wonderful meals out of the Dutch oven and huddled next to the fire. When we emerged at the other end of the canyon, it wasn't easy to say goodbye to the group and the comforts of raft-supported camping. We reluctantly reduced our gear to what we could fit in our kayaks and paddled out to Lake Mead, the first of many reservoirs still between the sea and us.



Sophia Maravell, Will paddles through Havasu Creek

The Rockies researchers get some much needed raft support through the Grand Canyon

Mead to Mexico

Our families kayaked onto a deserted Lake Mead with us for Christmas, and helped us transition back away from the large group we'd grown used to. But at the Hoover Dam it was time to part ways again and head out on our own. We dropped into the Black Canyon below the dam expecting to find the wilderness solitude that had accompanied


The Rockies researchers begin the trek across Lake Mead with family

us since the source. Instead we found hikers, canoeists, rafters, jet skiers, and power boaters, flocking to the many hot springs tucked into the side canyons of the ten-mile stretch. Motors buzzed, voices shouted, firecrackers went off. We tried to enjoy ourselves but found crowds grating after so much time with the remote desert river to ourselves. Arriving late in the day to Arizona Hot Springs, we found the best campsites occupied and ended up sleeping on the edge of a busy trail. That night, we almost lost our kayaks as the river doubled in volume in less than half an hour.

It was clear we had some adjusting to do. The river changed character dramatically after Grand Canyon National Park. It was so heavily dammed, dredged, diked, and diverted that from the top of Mead to the sea, we permanently lost the illusion that we were floating on a river resembling its natural state. The flux of water that almost swept our gear onto Lake Mojave was an effect of the water demands of farmers or cities below, not a sudden influx of water into the river basin. Downstream of Lake Powell, flows in the river are determined by water and power demands as opposed to snow melt.

For the first time in the 1,300 miles we'd traversed since Wyoming, the river began to shrink in volume. Lake Mead was trying to recover from dropping hundreds of feet below its capacity in 2010, and the city of Las Vegas was dealing out crowds of people into the canyon in exchange for water. Sitting in the hot springs on December 30th we heard that there would be an estimated 500,000 people on the Vegas strip for New Year's Eve. The following afternoon, Will and I stashed our kayaks next to the river and hiked out to see the city where some of the water was going. We spent the next 24 hours wading through the overflowing streets of Vegas, staring into bubbling fountains, and gazing out on rows of palm trees and lawns. All these sights, which would have seemed so normal had we arrived onto the streets by car, felt dreadfully out of place in the middle of a landscape that receives about four inches of rain a year. What would John Wesley Powell, who finished his first Colorado River expedition in 1869 in the tiny hamlet of Las Vegas, have thought if somebody told him that in less than 150 years the mightiest river in the Southwest would be drained completely before reaching the sea?

Las Vegas represented only the first of many municipal diversion projects we'd pass in the coming weeks. Below Davis Dam, we passed a series of waterfront casinos, followed by rows and rows of riverside houses boldly asserting their faith in the ability of the Glen Canyon and Hoover Dams to prevent flooding. Past the London Bridge on Lake Havasu, we found the two largest straws sucking from the river yet. First, the Colorado River Aqueduct, which pumps water 242 miles through a series of canals and tunnels to Los Angeles and, second, the Central Arizona Project (CAP), the coal-powered, 336-mile long pumping and diversion project that takes water through Phoenix and eventually to Tucson. Within ten miles of each other on Lake Havasu, the two canals represent the first major trans-basin diversions since Colorado's Front Range. While irrigated farmlands next to the Colorado River return roughly half of the water used in irrigation to the river system and in-basin domestic use returns up to 90%, trans-basin projects mean 100% of the water that is diverted is gone from the river for good. With two substantial rivers worth of water being taken out of the Colorado River at Lake Havasu, it's no wonder that the river dries up.

Photographing the pumping station for the CAP, which immediately brings the water several hundred feet up a steep hillside to a tunnel system, Will and I had a disturbing thought. Which way does the river go from here? We chose to start our journey on the Green River instead of the Colorado, in part because it was the longer tributary by a couple


Lake Havasu and the pumping station for the Colorado River Aqueduct


Below Davis Dam

hundred miles. If we followed that logic now, then shouldn't we follow the longest continuous body of water? Tucson—at 336 miles away—was considerably further from us than the ocean. Does a river follow its water, or is the dry riverbed in Mexico still the true river? We debated these issues for some time, pondering biking alongside the CAP to Arizona's biggest cities. Perhaps they were the new sea. When we began paddling, we thought we had a firm grasp on what the term 'river' meant. Now, we weren't so certain. Eventually, we based our decision on less philosophical grounds and concluded that risking contaminated water and drug smugglers in Mexico was safer than risking arrest and endless flat tires in the Arizona desert.

We pushed on through five more reservoirs and past two more enormous irrigation canals—the Gila Gravity Main Canal and the All-American Canal. While some of the Gila water returns to the river as agricultural runoff, the All-American Canal greens the fields of the Imperial Valley in Southern California and drains into the near toxic Salton Sea. Alfalfa and a wintertime supply of produce are grown in this region thanks to Colorado River water. By the time the river reaches the Mexican border near Yuma, Ariz., 90% of the water has been diverted.

Below the Imperial Dam where these two canals depart, we left our kayaks and paddled our pack rafts down the Colorado River turned creek. We spent one final night next to the river, camped on the edge of a farm. It was the first night we'd had to spend on private property since we began. Across the border, we'd grow used to camping on farmland, but we never fully adjusted to the absence of the river that carried us 1,600 miles and across six states.

The next day, we paddled towards the Morelos Dam. We passed a tall fence on the bank and watched as the scenery suddenly changed. The left side of the small reservoir was lined with graded sand tracks and dotted with Border Patrol vehicles. From the right side, we heard dogs barking, tires screeching, and the forlorn horns of the local Norteño music blasting. The smell of burning plastic drifted through the air. At last, Mexico was in view.

We floated up to the dam, taking our boats out on the U.S. side. Border Patrol agents half-heartedly searched our bags and told us that if we'd set foot on the opposite bank, we'd be in handcuffs right now. We assured them that we'd cross in the proper location when the time came and walked around the Morelos Dam. On one side, the remnants of the Colorado River were still flowing and green. On the other side, there was a feeble trickle of water that was completely consumed by sand within a few miles. And we were still 90 miles from the sea.

The Delta

After two days of preparation in Yuma, we crossed into Mexico and feasted on the heavenly tacos that seemed so far away when the trip began. Those tacos, which had been laughable at the source, were now about the only certainty we had left—the rest we'd have to improvise. Although we'd speculated on the definition of a river back at the CAP, we didn't actually come that close to abandoning the river. Now we were face to face with the dry riverbed, and, for the first time in three and a half months, we had to make a decision about our route. We could either walk down the sand where the river once flowed, or attempt to navigate the complicated canal system in our pack rafts. Lugging our 100-pound backpacks the half-mile from the border crossing to the other from the border crossing to the other side of the Morelos Dam did the deciding for us. We inflated our tiny blue rafts and paddled out on the canal that was carrying the remaining water in the river to the Mexican cities of Tijuana and Mexicali, as well as hundreds of square miles of farmland. For the first several hours, we half expected to be stopped by a security

Imperial Dam

Morelos Dam and the end of the river

guard of some kind, but the cars alongside the canal only greeted us with double takes and blank stares. We spent our time learning how to awkwardly climb out of the concrete-lined canal to portage the many bridges and gates impeding our progress.

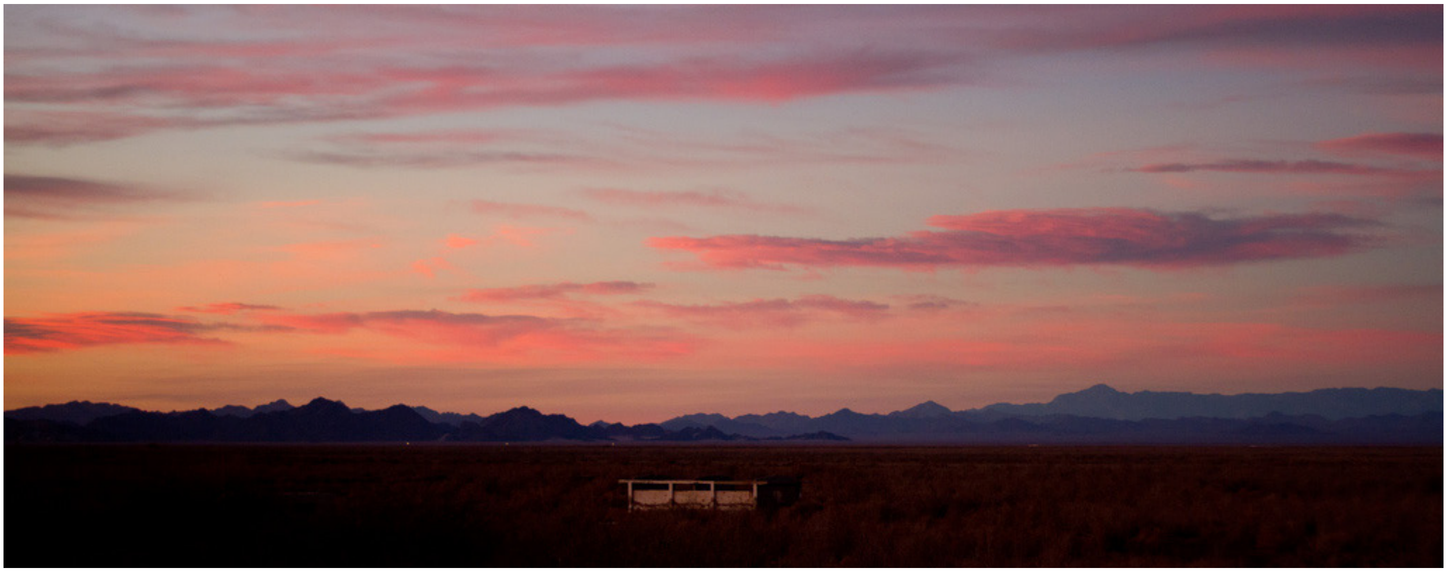
Several days later we'd grown used to the stares. I relearned enough Spanish to begin to explain what we were doing. Almost everybody asked if we were fishing and when we said no, the phrase "gringos locos" seemed to explain the rest. The thought of eating fish out of the canal water, that we were taking pains to avoid touching, made our stomachs churn, but we saw fishermen on several occasions. When the river still flowed, fishing was a large source of local income-now, it's farming.

The hospitality of the locals was endless. Security guards for the canal--instead of stopping us--gave us directions. Cars pulled over to offer us food. A kind woman in a store that only sold chips and sodas went to her home to bring a more hearty meal of beans, bread, and cheese and then refused payment for it. Crowds of children flocked out of their sheet metal homes to chase us, jaws agape, for a few hundred yards.

Mile after mile of farms floated past us, and the drone of crop dusting planes became familiar. The excitement of traveling by irrigation canal through a foreign country was almost enough to make us forget the dead river. But one day, while looking for a place to camp among a thick stand of invasive tamarisk trees, we stumbled across a pocket of water outside of the canal. We'd found a pool of agricultural runoff in the former riverbed. In the time it took us to paddle the several miles before it dried up, we saw a greater variety of bird species than we'd seen on the whole trip. The small wetland was a stark reminder of what the delta was losing.

The contrast was made sharper when canals finally dried the next day and we bushwhacked for ten miles through dying clumps of tamarisk. The thin line on the GPS marked "Colorado River" looked no different from the other ten miles of mud cracked desert we crossed that day. Our legs scratched from the brush and our throats parched from the January heat, we eventually found the Rio Hardy, another body of agricultural drain water that is keeping the delta from completely drying up. There, we rested at an "eco-camp" maintained by the Sonoran Institute, a nonprofit involved in restoration work in the delta. Among the native species, such as mesquite that had been planted on the Sonoran Institute land, we learned what the Colorado River delta once was.

When I heard, long ago, that the Colorado River dried up before reaching the sea, an image came to my mind. I pictured the river in the state of Colorado where it often flows at the bottom of boulder-choked canyons. If the river were to dry up there--as it often does for several miles in Glenwood Canyon at the Shoshone Hydroelectric Plant—what's left is the rocky canyon floor: only the width of the river is dried. I never questioned that image until Will and I arrived at the delta and understood what a different landscape we were dealing with. We were no longer between the narrow canyon walls of the upper river; we were standing on a great plain of Rocky Mountain and Colorado Plateau silt that had been steadily deposited for the last six million years as the river flowed into the Gulf of California and dropped Grand Canyons worth of sediment. The drying of the delta doesn't translate to a waterless, boulder-filled channel. The delta without water means the loss of the most biologically diverse area in the entire river basin—an enormous swath of land that once extended from the sea all the way into California's Imperial Valley, covering over 3,000 square miles.[7] The riverbed that we imagined we were crossing as we hiked to the Rio



Sunset over the Sonoran Institute's EcoCamp

Hardy was never as narrow and stable as the riverbed is in mountain canyons. Instead, the river on the delta poured out of a single channel into a vast network of wetlands, lagoons, and riparian areas that were replenished with yearly flooding events. The sediment being carried into the sea helped the fisheries to flourish for millions of years and provided a crucial habitat from millions of migrating birds.

Today, less than ten percent of the former delta remains, and the 380 species of birds still living in the area depend on wetlands formed by agricultural wastewater, particularly in the 40,000-acre Cienega de Santa Clara just north of the Gulf of California. But the amount of wildlife we encountered on the much smaller pockets of water we crossed was testament to the difference a minimal amount of water can make for restoring the delta. Edith Santiago and Francisco Zamora of the Sonoran Institute told us that their research indicates that if less than one percent of the total annual flow of the Colorado River could be obtained for the river corridor, a vital section of the riparian habitat could be restored and the river would once again flow into the sea. Fisheries would begin to be replenished along with bird populations and local economies dependent on ecotourism and fishing. But to make this happen, Mexico and the United States would need to collaborate to secure the necessary water. Suddenly, Colorado didn't seem so far away. The delta is drying due to the cumulative actions of the 30 million people who rely on the Colorado River. It's too easy to forget where the water comes from when you turn on a tap in Denver or L.A. Will and I left the eco-camp, vowing to help spread the word that the state of the delta is deeply connected with the state of the Rockies, even if they are over a thousand miles apart.

The Sea

The Rio Hardy carried us within several miles of the high tide mark before it grew too shallow to paddle. We packed up our rafts one final time, and slogged through a putrid swamp of mud and rotting brush. A few hours past nightfall, we were standing on a levee with salt water at our feet. We'd been dreaming of this moment for close to four months, and we both imagined that arriving at the sea would be similar to driving up to a beach. All of the sudden, we thought, we'd be standing at the edge of the ocean. Of course, the transition was more gradual than expected and we had 30 miles of intertidal zone ahead of us.

Zak searches for water in the Delta


Will and Zak rest on a beach after pulling themselves out of the Sea of Cortez

Unaccustomed to ocean travel, we misread our tide chart and when we awoke before dawn, it was a couple hours after high tide. The water that was lapping the levee the night before was now nowhere in sight, except for a shallow channel draining off the immense mud flats. Several hours were spent cursing and sinking up to our thighs into the saturated silt before we finally found enough water to float. Soon, the current was flowing more quickly than it had since the Grand Canyon, and we made good time until the tides switched and the current came rushing back towards us. We were forced back onto the mud until late evening when the current changed again. Running low on drinking water and still miles from the nearest town, we floated in the dark along the clay banks of the estuary.

The crescent moon shone on the surface of the water. The tidal river flowed quickly and deeply back towards the gulf. Exhausted from struggling in the mud and lulled by murmuring waters, I nearly fell asleep when a fin suddenly emerged a few feet from my pack raft. My first thought was "Shark!" and I instinctively began to race for shore. But before I could take more than a few strokes, the gleaming eye of a dolphin broke the surface and stared at me. Its mouth opened and clicked before it disappeared.

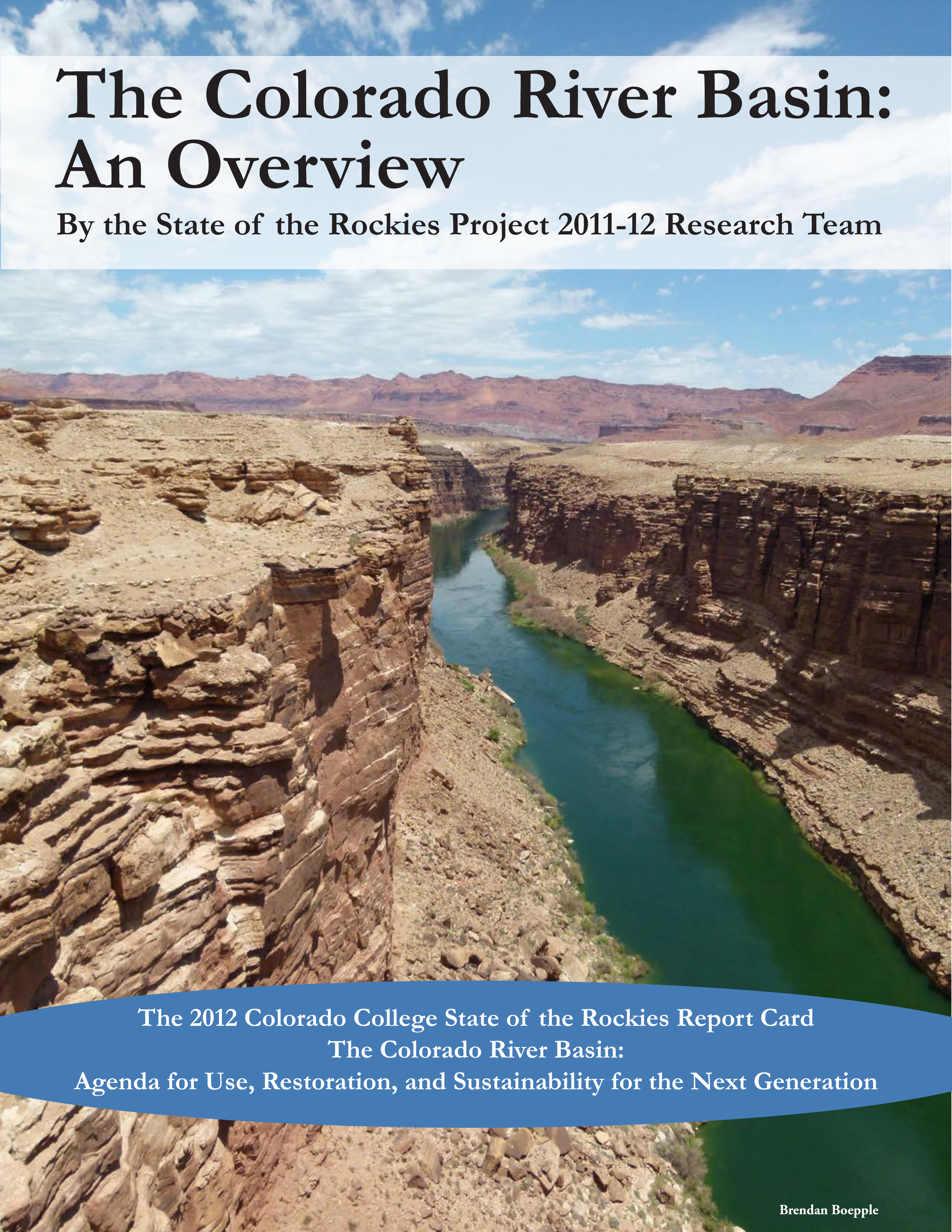
Will paddled up, not noticing the exchange. I started to explain my sudden movements when a tail flicked out of the water and sent water into both our rafts. Then more fins appeared--a pod of dolphins was swimming upstream towards the former mouth of the Colorado River, breaking the surface in steady rhythm. We watched the dark forms rise and fall until the whole pod had passed us. The tide carried us away from the moonlit mountains on the horizon. The smell of salt water hung thick on the air. "Dude," said Will, "I think we've found the sea."

[1]Information in this paragraph was found in: Gary Wockner and Alexandrea Cousteau, "$9 billion Flaming Gorge Pipeline Would Further Drain the Colorado River System," Huffington Post Denver, January 10, 2012, http://www.huffingtonpost.com/gary-wockner/flaming-gorge-pipeline_b_1195154.html.
[2]Earthjustice, "Colorado River Protection Coalition Intervenes Against Flaming Gorge Pipeline," December 15, 2011, http://earthjustice.org/news/press/2011/colorado-river-protection-coalition-intervenes-against-flaming-gorge-pipeline.
[3]Bureau of Reclamation, Glen Canyon Dam Statistics, accessed February 28, 2012, http://www.usbr.gov/projects/Facility.jsp?fac_Name=Glen+Canyon+Dam&groupName=Overview.
[4]Bureau of Reclamation, Lake Powell recreation area details, accessed February 28, 2012, http://www.recreation.gov/recAreaDetails.do?contractCode=NRSO&recAreaId=2002&contractCode=129.
[5]National Park Service Statistics, Grand Canyon NP user days, accessed February 28, 2012, http://www.nature.nps.gov/stats/viewReport.cfm.
[6]Information in this paragraph was found at: Glen Canyon Institute website, accessed February 28, 2012, glencanyon.org.
[7]Information in this and the following paragraph found in: Zamora-Arroyo, Francisco, Jennifer Pitt, Steve Cornelius, Edward Glenn, Osvel Hinojosa-Huerta, Marcia Moreno, Jaqueline García, Pamela Nagler, Meredith de la Garza, and Iván Parra, Conservation Priorities in the Colorado River Delta (Mexico and the United States, 2005) accessed online at sonoran.org.


The remnants of the delta and the Baja mountains

The Colorado River Basin: An Overview

By the State of the Rockies Project 2011-12 Research Team



The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

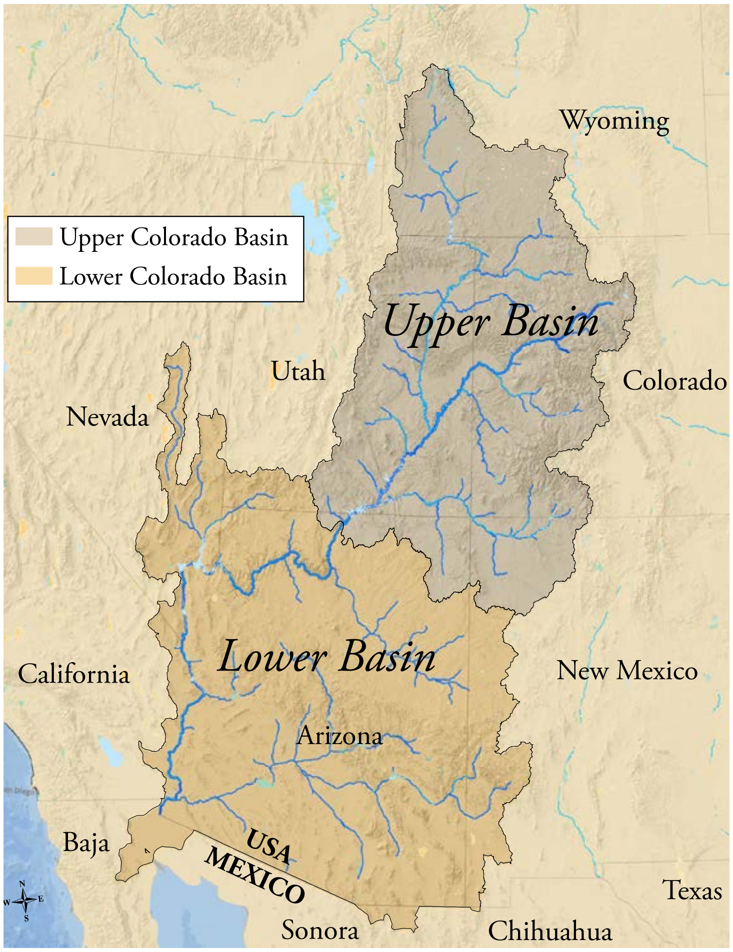
Brendan Boepple

The Colorado River Basin

The Colorado River is often referred to as the life-blood of the American Southwest. This legendary river begins both as snowmelt at its headwaters in mountainous northern Colorado, and as the origin of the Green River in the Wind River Range of Wyoming; then winds through seven states and approximately 1,400 miles of stunningly diverse ecosystems before it reaches the below-sea level desert expanses of Mexico. Thirty million Southwesterners, 20 Native American tribes, and Northern Mexico, as well as numerous species of flora and fauna, rely on its waters for their livelihoods and day-to-day survival.[1] The river supports major cities such as Denver, Los Angeles, Phoenix, and Las Vegas, through a carefully regulated dam, canal, and pipeline system. However, municipal uses pale in comparison to the nearly three million acres of farmland that utilize close to 80% of the river's annual flow.[2] Yet the flow is not what it once was, as drought, over-apportionment, and ever-expanding urban development have depleted the supplies of this cherished resource to the point where it no longer reaches the Gulf of Mexico. Its future has become increasingly contentious and uncertain.

Parts of the seven states of Wyoming, Colorado, Utah, New Mexico, Arizona, California, and Nevada form the U.S. portion of the 243,000 square-mile Colorado River Basin (8% of the contiguous U.S.)[3], with 2% of this area located internationally in Mexico's Sonoran Desert. The 1922 Colorado River Compact, created by these seven states, separated the basin into an upper and lower region with Lee's Ferry just below Glen Canyon Dam as the point of division. Wyoming, Colorado, Utah, New Mexico, and the northern portion of Arizona make up the 109,800 square-mile Upper Basin, while Arizona, California, and Nevada constitute the Lower Basin region as seen in **Figure 1**.[4]

Figure 1: Map of the Colorado River Basin divided into Upper and Lower Basin



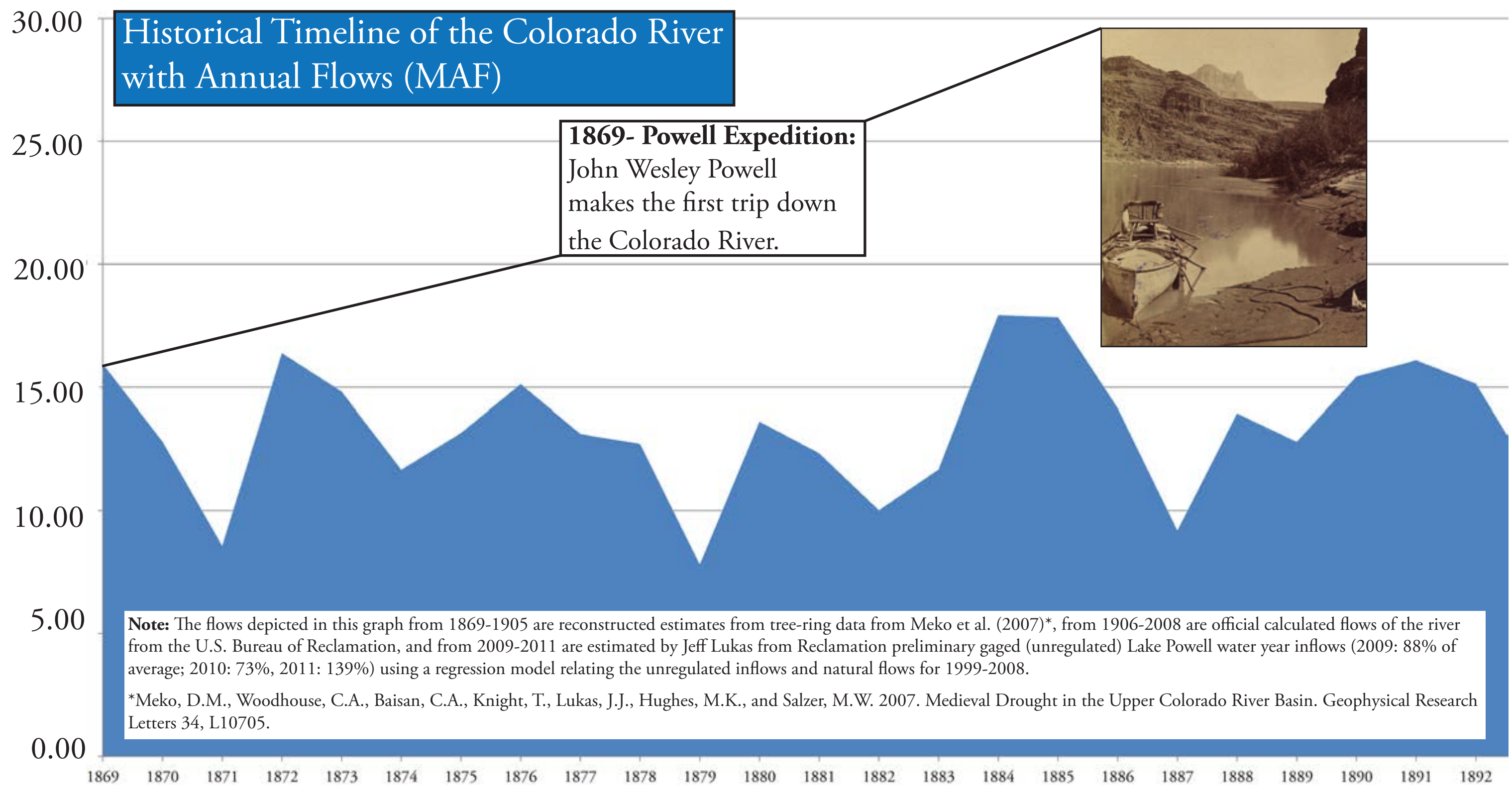


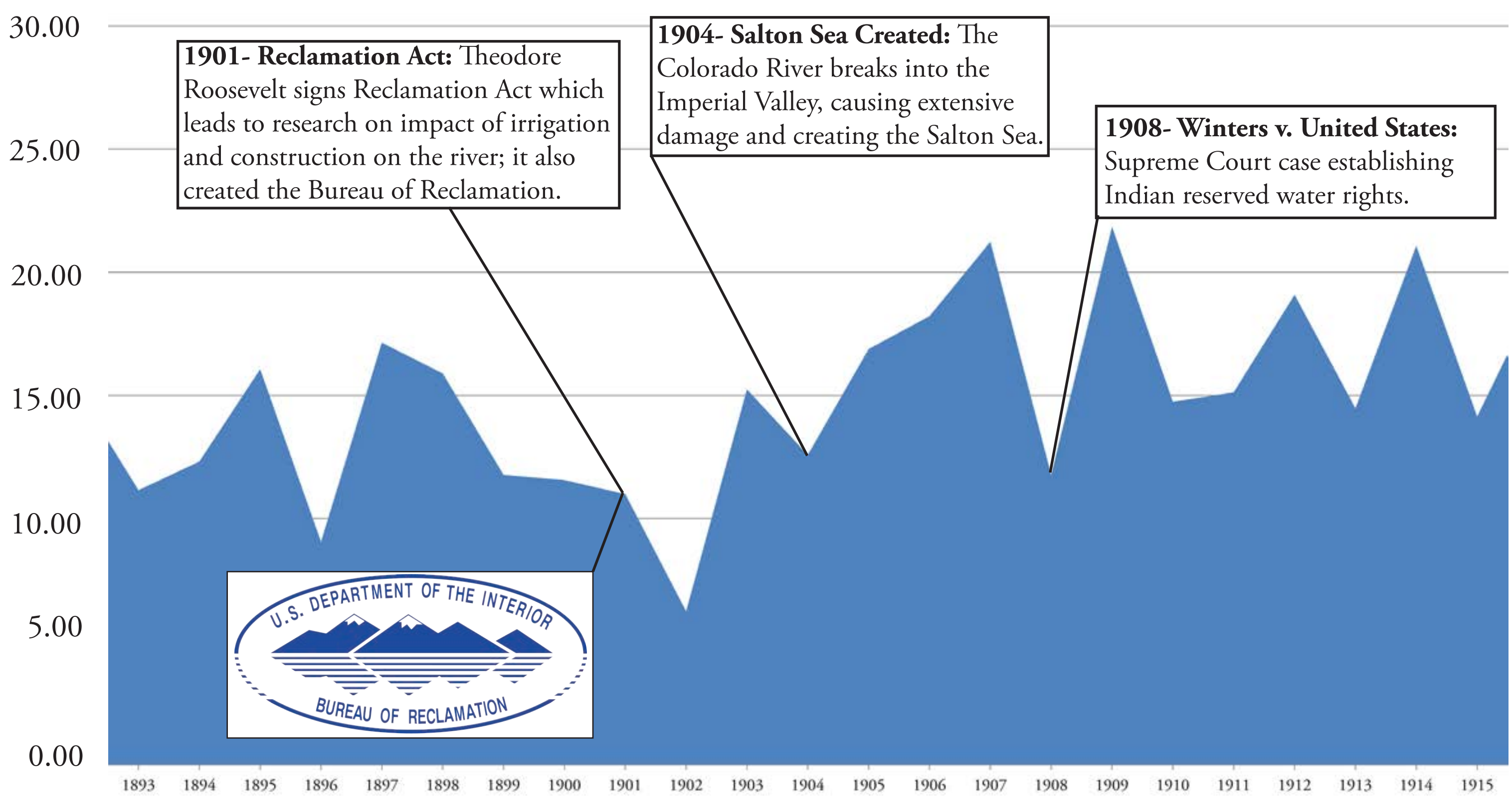
Figure 2: Colorado River Water Apportionments by State		
Upper Basin	**45.5%**	**7.5 maf**
Arizona	.3%	.05 maf
Colorado	23.4%	3.86 maf
New Mexico	5.1%	.84 maf
Utah	10.4%	1.71 maf
Wyoming	6.3%	1.04 maf
Lower Basin	**45.5%**	**7.5 maf**
Arizona	17.0%	2.80 maf
California	26.7%	4.40 maf
Nevada	1.8%	.30 maf
Total 7 States	**91.0%**	**15.0 maf**
Mexico	9.0%	1.50 maf
Total for Entire Basin	**100.0%**	**16.5 maf**

Major tributaries of the Upper Basin include the Green, San Juan, Escalante, Gunnison, and Dolores Rivers, and the Lower Basin is fed largely by the Paria, Virgin, Little Colorado, Bill Williams, and Gila rivers.[5] The basin, its water apportionment, and the protection of its environmental resources have long formed a complex combination of states' rights, federal agency involvement, and Native American tribal water rights, and as such, has often been a ground for both conflict and cooperation.

Laws and Apportionment

The Colorado River Basin is ruled by a compilation of decrees, rights, court decisions, and laws that together are referred to as the "Law of the River." The keystone of these "commandments" is the 1922 Colorado River Compact, an interstate agreement created by the seven basin states with provisions for general water allotments, including a 7.5 million acre feet (maf) annual delivery requirement from the Upper to the Lower Basin.[6] The 1928 Boulder Canyon Project Act (along with the 1963 Supreme Court decision in *Arizona v. California*) divided the Lower Basin's 7.5 maf—with an extra one maf in wet years—between Arizona, California, and Nevada.[7] The 1948 Upper Colorado River Basin Compact divided the Upper Basin's average allotment of 7.5 maf among the five states.[8] States allocate their individual shares of the waters of the Colorado River and ultimately have the highest authority after the Secretary of the Interior. The Secretary of the Interior is often called the "water master" of the Colorado River, as he/she has the final ruling on nearly every conflict, be it the definition of "beneficial use" or the creation of shortage guidelines.[9]

The Colorado River Compact of 1922, which set the annual average as 15.0 maf and divided this amount up between the basin states (**as seen in Figure 2**), was created in the wettest recorded ten-year period of the last 100 years. This was from 1914-1923, in which the annual average was 18.8 maf. In 2000, the Colorado River Basin entered a period of drought, accompanied by decreased precipitation and increased average temperatures, and continues today. Flows from 2001 to 2009 averaged around 12.1 maf at Lee's Ferry: roughly a 4-5 maf reduction from the 16-17 maf assumed average flows from the Compact.[10]



Federal, State, Native American, and Mexican Involvement

Native American involvement and tribal water rights

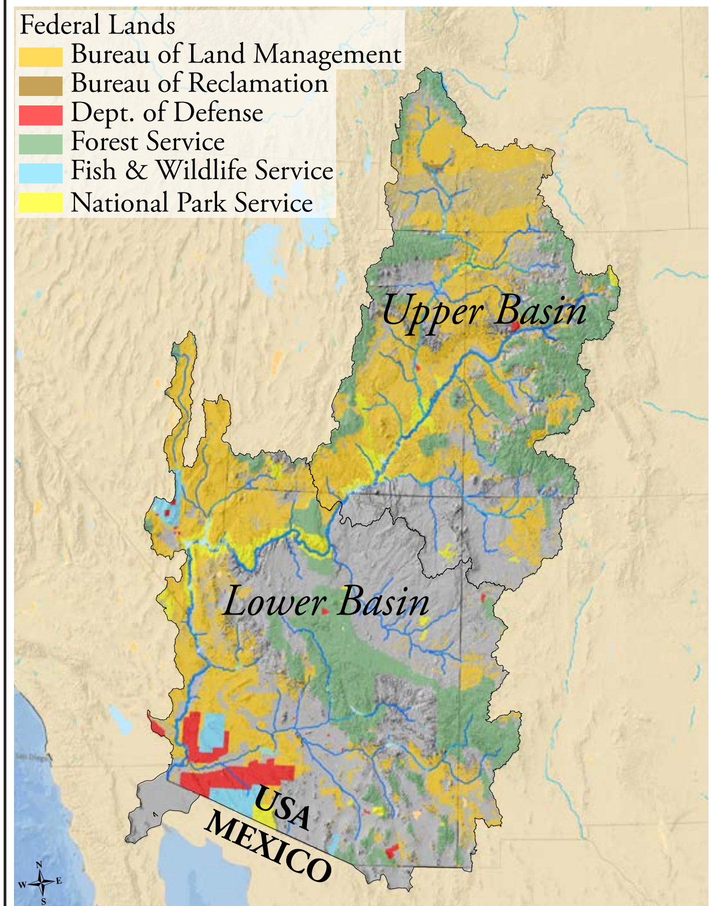
There are 34 established Native American reservations within the basin.[11] Reservations on paper have federally reserved implied water rights, but many reservations' inability to put their newly appropriated waters to beneficial use has resulted in subsequent conflicts between tribes and other stakeholders in the basin. The granting of new water rights to the tribes has led to a forced reduction of use by others.[12 13] In addition to these tribal lands, large areas of land in the basin are also owned by the federal government as seen in **Figure 3**.

Mexico's Role

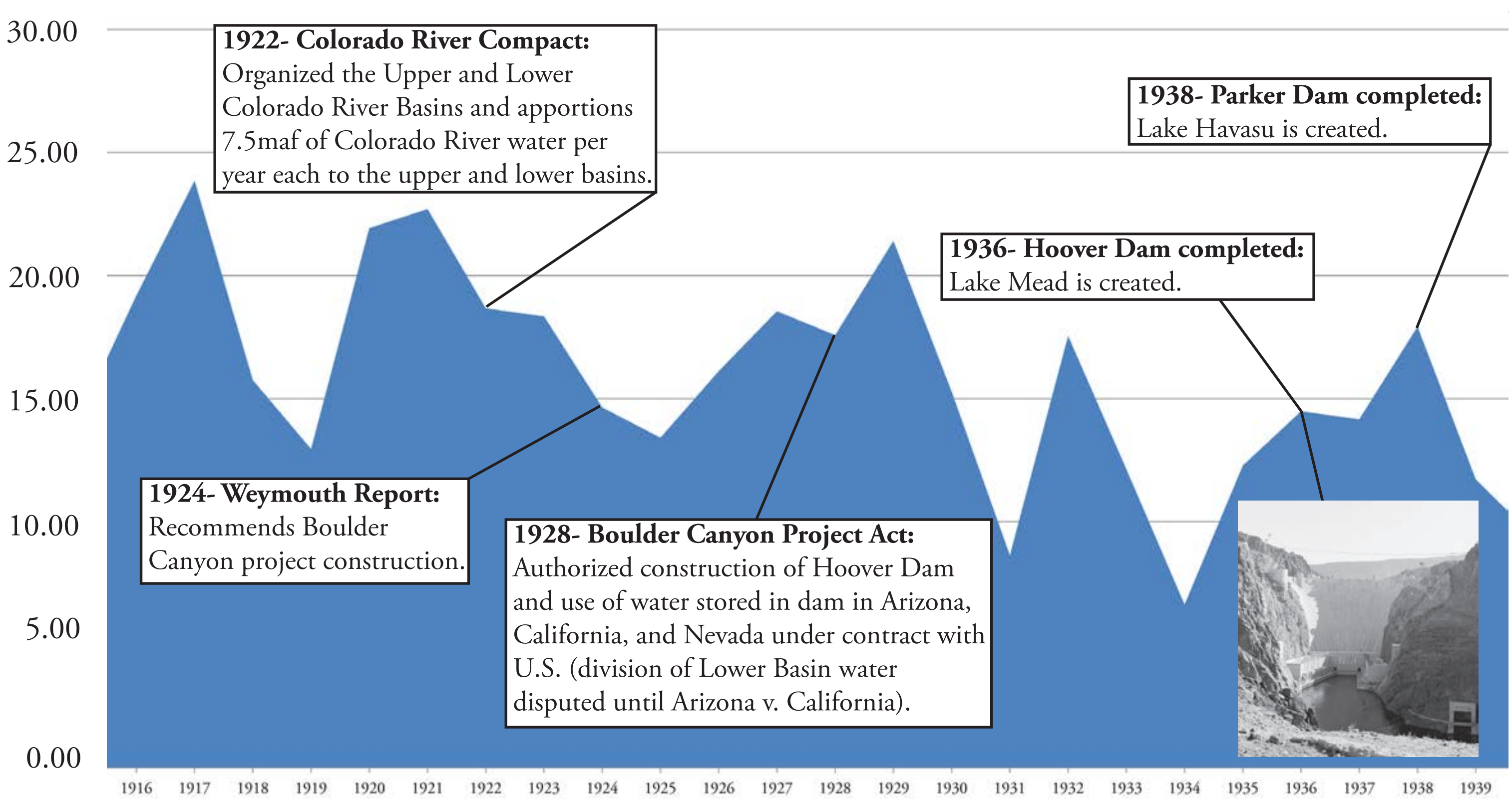
In 1944, a treaty facilitated by the International Boundary Water Commission (IBWC) was signed granting Mexico 1.5 maf annually. However, no water quality standards were established and as the river became increasingly developed, deliveries to Mexico were often diverted and/or had a near-toxic salinity level. In 1973, IBWC Minute Number 242 was signed mandating the U.S. to adopt measures to reduce the salinity of those waters delivered to Mexico. Issues such as the lack of water reaching the Colorado River Delta, the lining of the All-American Canal, and maintaining the Ciénega de Santa Clara continue to affect U.S.-Mexico relations.

Brendan Boepple, The dry Colorado River bed near San Luis Rio Colorado, Mexico

Figure 3: Federal Land Ownership in the Colorado River Basin



Source: U.S. National Land Atlas Federal and Indian Lands Areas



Uses of the Colorado River

Nearly all water in the Colorado River has been put to "beneficial use" both inside and outside of the basin. Human beneficial use does not generally include instream flows (leaving water in the river for environmental purposes), and has largely meant use for agriculture, municipal and industrial purposes, and recreation. Forty-five percent of Colorado River water is diverted out of the basin for both agricultural, municipal, and industrial use; many cities such as Denver, Los Angeles, and Salt Lake City already rely heavily on trans-basin diversions which disrupt surrounding ecosystems.[14] **Figure 4** illustrates the low and high flow of the river with many of these diversions.

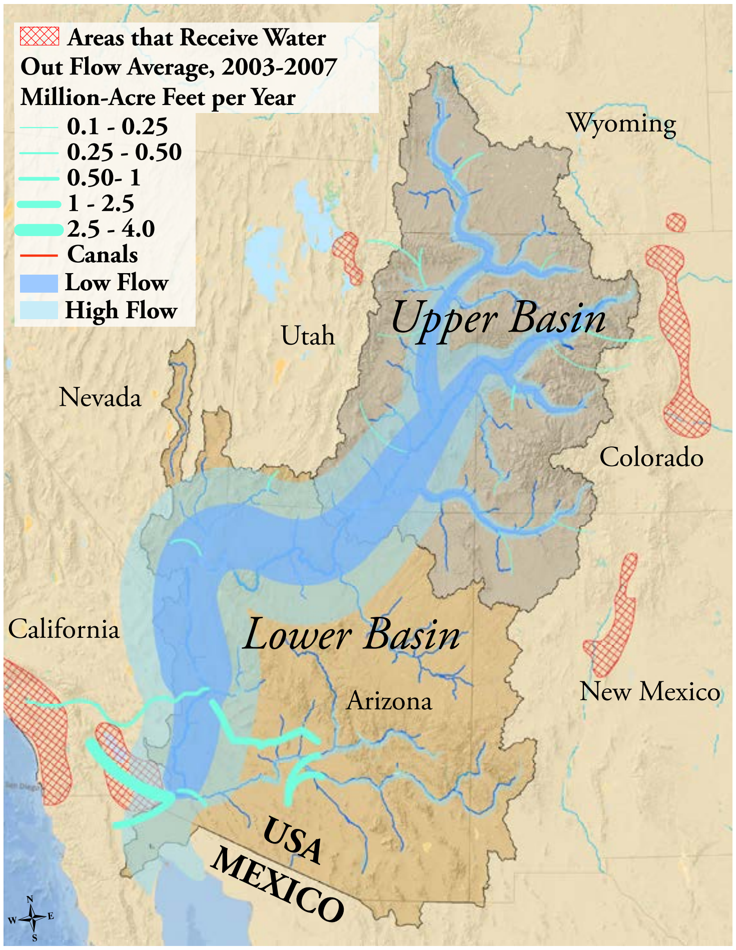
Agricultural Use

Areas in the West that use Colorado River water have proven to be agriculturally productive despite the arid climate, with a diverse crop yield that includes alfalfa, hay, wheat, cotton, and lettuce. Today, 78% of the water from the Colorado River is used for agricultural purposes. The concentrations of some of these minerals are now sufficiently high in some areas of the basin as to threaten the viability of agriculture there, as well as causing local water quality issues.[15]

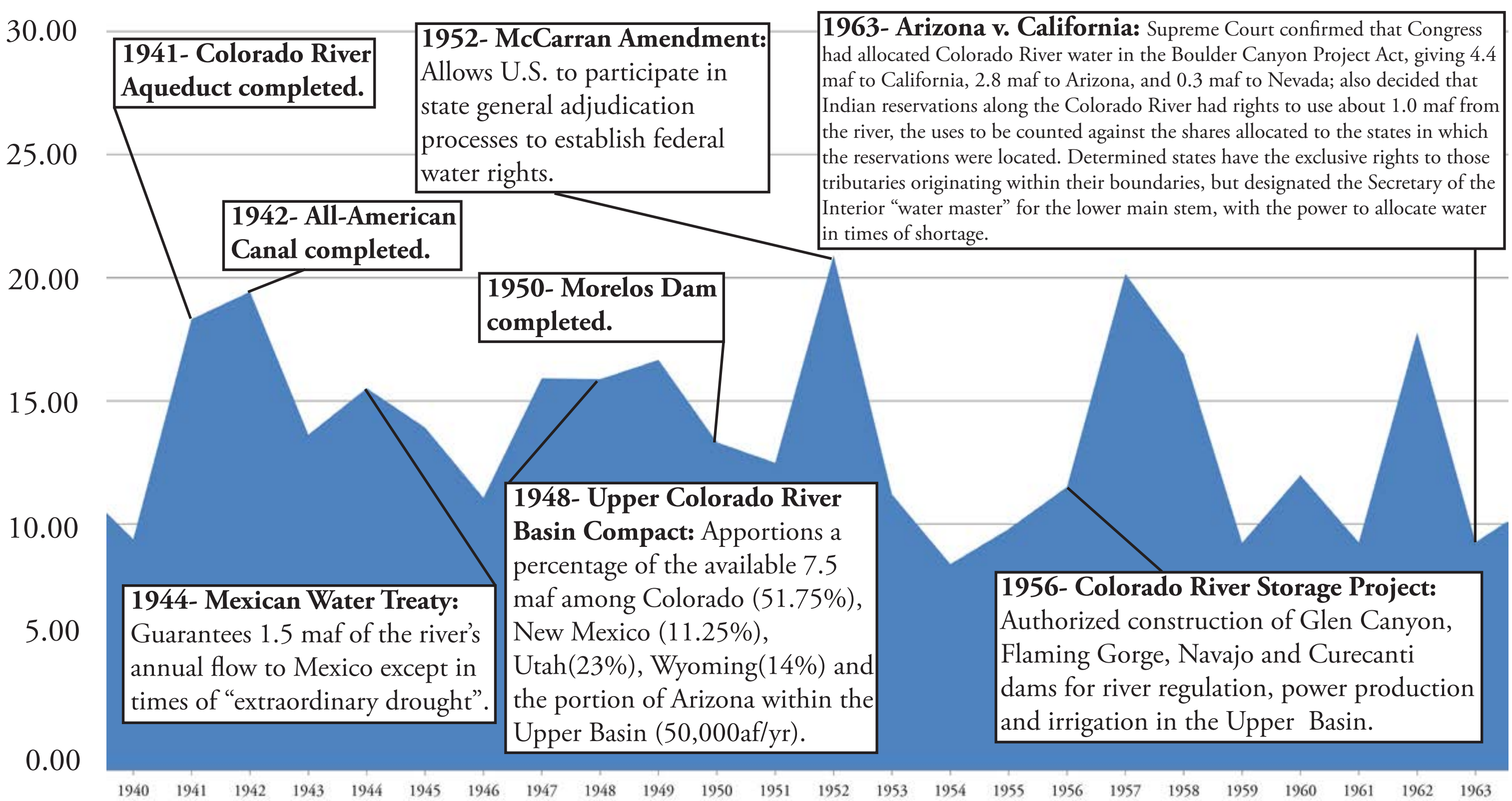
Recreational Use

The natural diversity and picturesque backdrop throughout the Colorado River Basin make it a popular destination for many outdoor recreation activities such as fishing, skiing, boating, camping, hiking, wildlife-viewing, hunting, and swimming. The multi-billion dollar industry relies on continued precipitation and flows in order to attract the tens of millions of people each year who support local economies and businesses.

Figure 4: Inflows and Outflows of the Colorado River



Source: Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, National Geographic Society, September 2010.



State of Nevada , The Lights of Las Vegas

Municipal and Industrial Use (M&I)

M&I water demand is increasing due to the rapid population growth in the arid West. Today, 30 million people in the U.S. depend on the Colorado River for some or all of their water, up from 23.5 million in 1990.[16] In years to come that statistic will continue to rise, as Nevada, Colorado, and Arizona alone are expected to add seven million residents to the basin population in the next 30 years.[17]

Water Supply and Demand

Constant development and manipulation of the Colorado River threaten the quality and quantity of the water supply. The demand for water has historically been greater in the Lower Basin, home to larger cities and agricultural operations with a more arid climate. As a result, prior to 2000 the Lower Basin was using more than its allotted 7.5 maf. In the past, the Upper Basin has under-used its allocation, partly for lack of adequate storage capacity and partly because it is a less populous region.[18] Overall, water use throughout the entire basin has been slowly overtaking supplies of the river, causing concern about over-allocation of future flows.

Shortages

In 2007, the Secretary of the Interior signed the Interim Shortage Guidelines created by the basin states as a continued drought began to put stress on delivery requirements. These guidelines designate three different decreased delivery requirement scenarios linked to the reservoir level of Lake Mead—and continue through 2026—allowing water managers to gather a better understanding of how to operate in times of shortage. This means that the Lower Basin's flows could be reduced from 7.5 maf to between 7.0 and 7.167 maf, depending on the intensity of the drought and resulting shortage.[19]

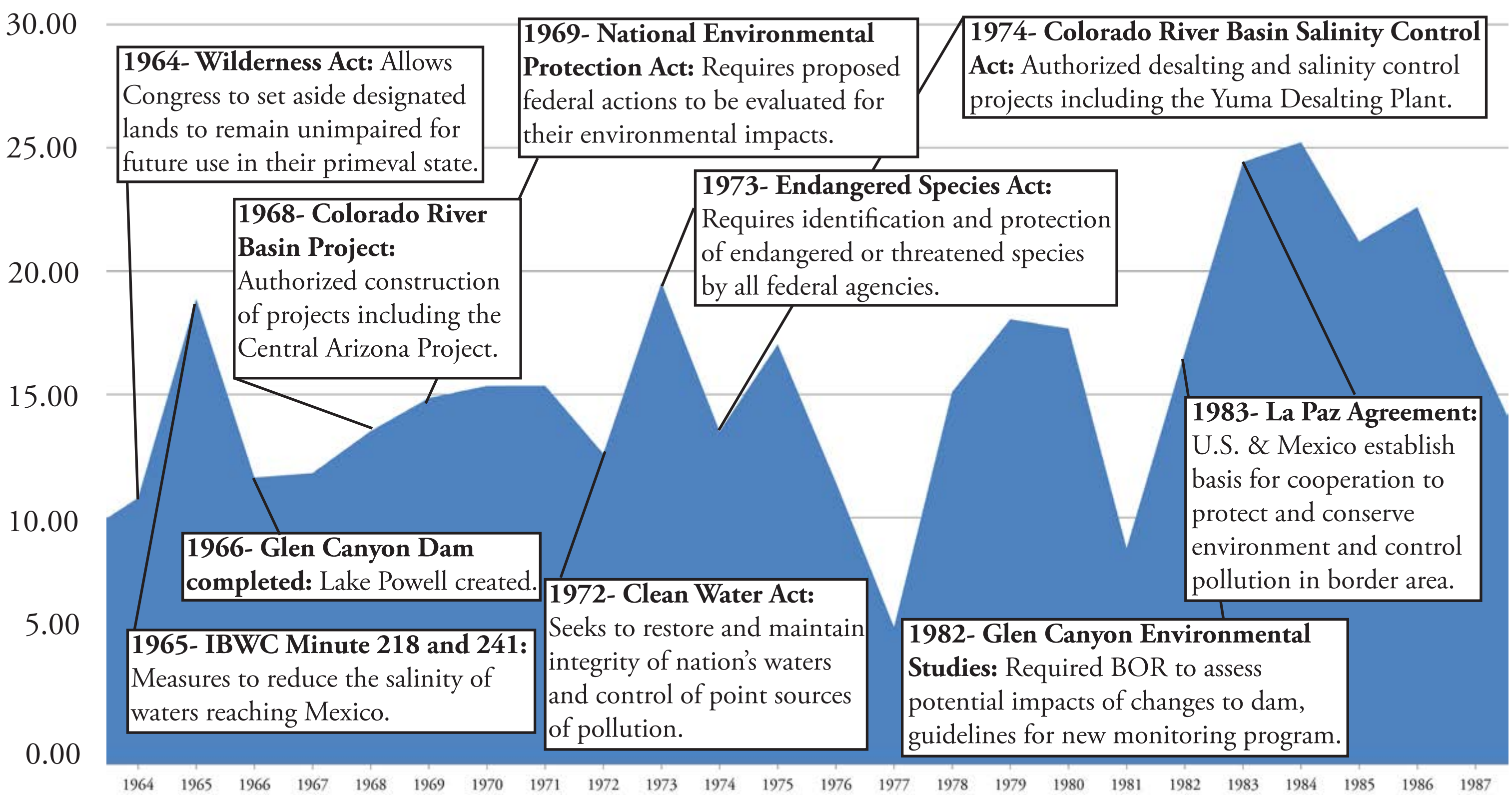
Dams and Reservoirs

Over 20 dams have been constructed on the Colorado River and its major tributaries in order to store and divert water. Reservoirs created by the Colorado River are used to generate electricity, increase storage capacity, and alter natural flows for human use. However, the basin reservoirs are considered by some to be inefficient; because of the susceptibility of still pools of water to evaporation, roughly two maf of the Colorado River's flow is lost annually to evaporation and seepage from its reservoirs.[20] Lake Powell alone averaged 378,500 acre feet of annual evaporative losses from 2006-2010.[21] Many environmental concerns have resulted from the manipulation of the Colorado River. However, without these dams and diversions the West would be unable to sustain the populations and development that it houses today.

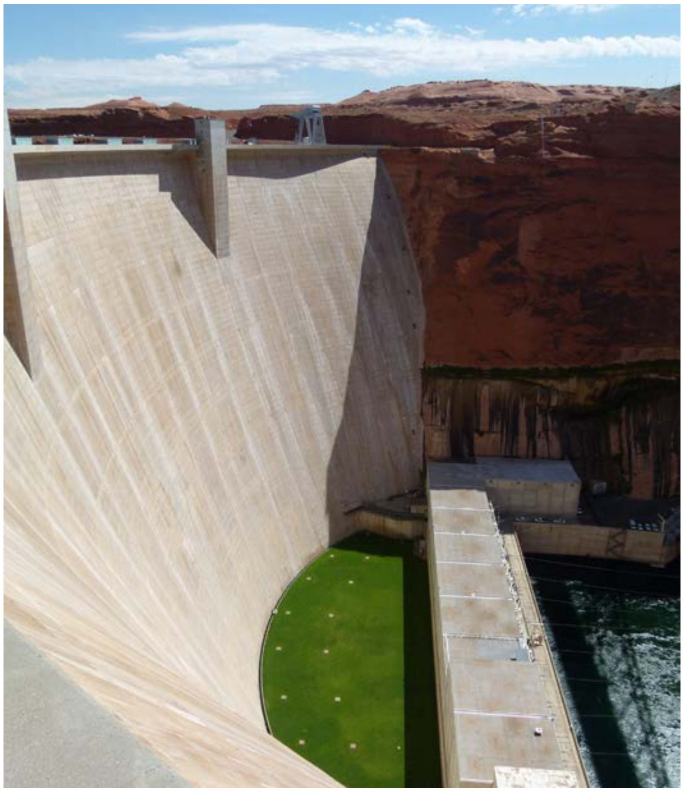
Environmental Concerns

Instream Flows

With a rising demand and a shrinking supply of water in the West, flows in the river system of the Colorado River are becoming increasingly depleted. When people think of our



dwindling water supply, the immediate concern is usually restricted to the threat that it could have on human consumptive needs. Because the 1922 Colorado River Compact designated water rights strictly in terms of human use, no water was ever legally reserved for the health of the stream. Through later legislation and management guidelines, however, stakeholders have begun to acknowledge the environmental and economic threats that will arise if environmental flows are not protected.


Brendan Boepple, The Glen Canyon Dam

Water Quality

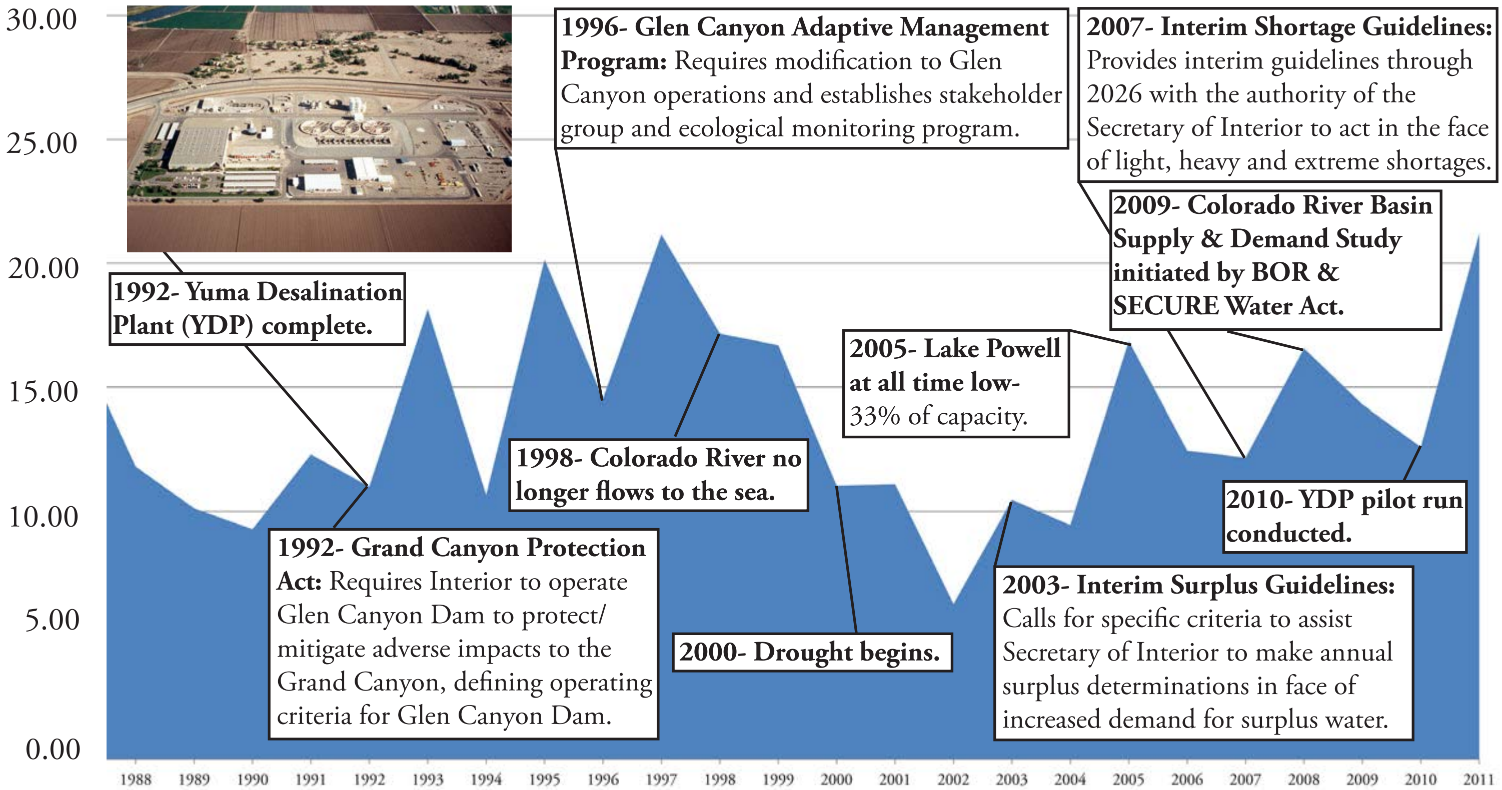
Contamination from agricultural and urban run-off, toxic leaching from mines, and the disruption of nutrient and sediment flow caused by dams are just a few examples of how current use and manipulation of the Colorado River can threaten ecosystems along the river through the deterioration of water quality.

Sediment

Historically, the flow of sediment in the free flowing Colorado River facilitated the construction of natural sandbars that served as the foundation for a diverse makeup of fish and wildlife. Many species evolved so that they could thrive in the sediment-rich environment of the free flowing river, a condition that no longer exists, as the construction of dams in the Colorado River Basin has disrupted the natural flow of sediment downstream.[22] Dams cause sediment to build up in the reservoirs, thus also decreasing the storage capacity and making the dam system less efficient for water storage and electricity generation.[23]

Salinity

In 1974, the Colorado River Basin Salinity Control Act was passed in an effort to control the salinity of the water being delivered to the Lower Basin and Mexico.[24] Today, increased salinity levels are a major water quality concern that threatens agricultural, municipal, and industrial users as well as the river's fish and wildlife populations. The Colorado River's salt content comes from a variety of sources; agriculture alone accounts for 37% of the river's salt. Natural sources such as stream flow, reservoir storage, climatic conditions, and natural runoff account for about 50% of the river's salt.[25] Currently, $306-312 million per year are spent on salinity control, and the Bureau of Reclamation estimates that by the year 2025 that number will increase to $471 million per year if no additional projects are put in place.[26]



Invasive and Endangered Species

Five percent of the Colorado River's native fauna are already extinct and 32% are currently endangered. Of the 14 native fish in the Colorado River, four species are currently endangered. They are threatened by stream flow regulation, habitat modification, poor water quality, and competition with nonnative species. If they are not addressed, these problems will continue to worsen due to a decrease in essential resources and increased interspecies competition. In addition to the ecological importance of species and habitat preservation, there are also legal requirements such as the Threatened and Endangered Species Act that mandate conservation.

Past, Present, and Future Climate

The climate of the Colorado River Basin has long been defined by high variability in both precipitation and temperature, but the constant nature of the system is a cold and humid climate in the relatively small headwaters regions where snowpack contributes to streamflow, but a semi-arid and arid climate throughout the rest of the basin. The average temperature in the basin is expected to increase; The SECURE Water Report noted a 2.16°F (1.2°C) increase in basin-wide temperatures in the 20th century. The Lower Basin alone saw a 3.06°F (1.7°C) increase, due to the dryer and hotter climate of the lower states. Findings also predict a 6-7°F (3.3-3.9°C) increase in Upper Basin average temperatures over the course of the 21st century, coupled with a 5-6°F (2.8-3.3°C) increase in Lower Basin temperatures over the same period.[27]

Impacts on Water Supply

Nearly all studies agree that the temperature increases predicted for a changing climate have a large probability of further reducing the water supply of the Colorado River. The Bureau of Reclamation has projected future changes in average annual runoff using an ensemble of 112 climate model runs; the ensemble mean is an 8.5% decrease by 2050. The climatic explanation for this flow reduction lies in a diminished accumulation of high elevation snow during the cool season due to higher average temperatures, which translates into a smaller snowpack and less snowmelt to sustain runoff during the warm season.[28] Expected changes in precipitation in the range of a 2.1% increase and a 1.6% decrease in the upper and lower basins, respectively, may also impact the supply of the river.

Impacts on Ecosystems

Increases in temperature will create additional stress on already sensitive fisheries, creating both ecological and economic strain in the region. A warmer climate also provides an optimal habitat for some invasive species, which will continue to threaten native flora and fauna. The hotter temperatures will likely be accompanied by increased wildfire potential and subsequent habitat destruction.[29]

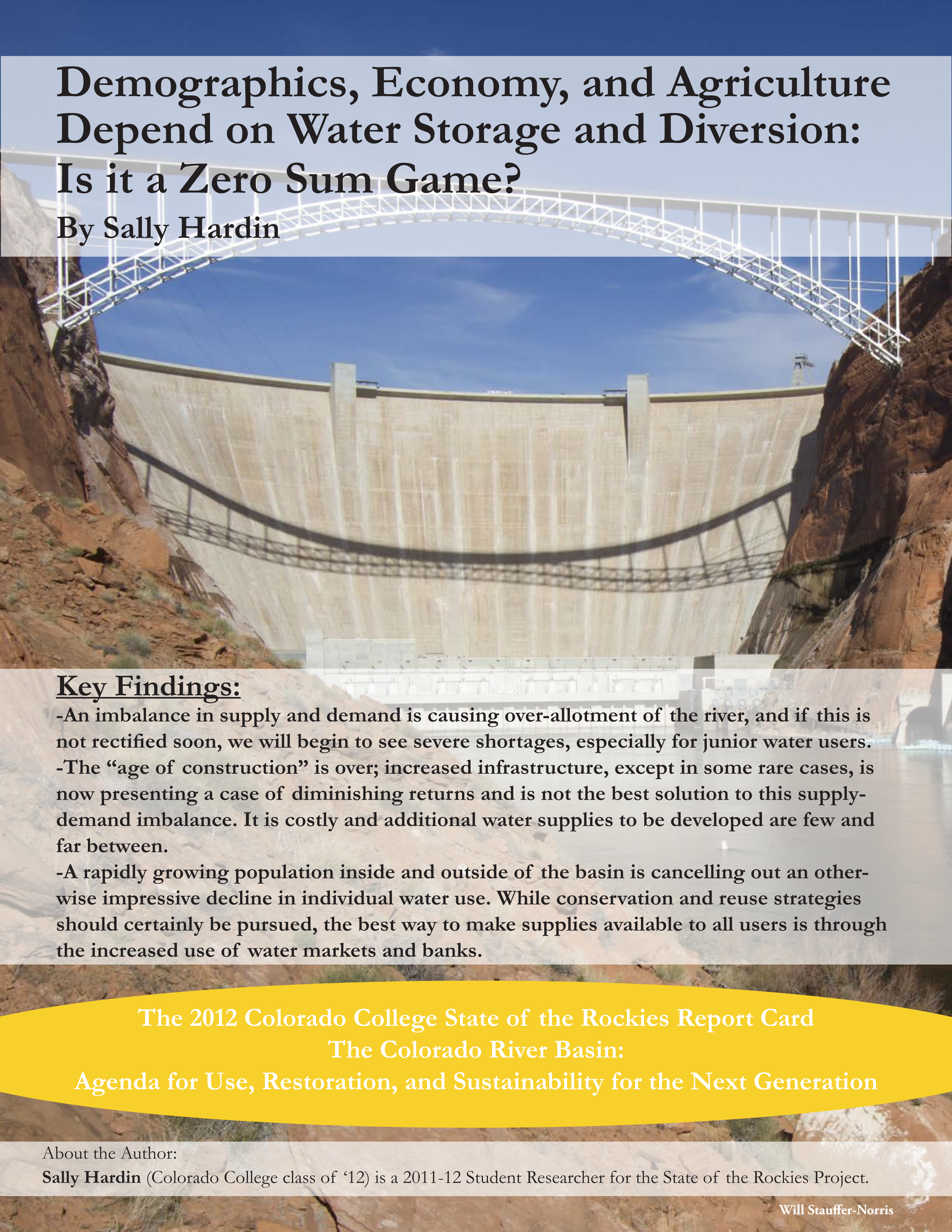
Conclusion

These issues are individually complex, and their relationships with one another are not fully understood. If efforts are not made to reach a careful balance between supply, demand, and competing uses, however, the negative impacts of each issue will become amplified, leading to drastic changes in the state of the Colorado River. While most matters of the river are currently in the hands of powerful stakeholders and politicians, what happens in the next decade largely dictates the future of the river for the next generation and beyond. It is time for the younger generation to become informed, involved, and engaged in making clear its desires, expectations, and solutions for the future of the Colorado River, before it is too late.

[1] Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, National Geographic Society, September 2010, http://maps.nationalgeographic.com/maps/print-collection/colorado-basin1-map.html.
[2] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," Report to the Western Water Policy Review Advisory Commission, 1997, 13.
[3] Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, http://maps.nationalgeographic.com/maps/print-collection/colorado-basin1-map.html.
[4] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," 2.
[5] Ibid., 5.
[6] Ibid.
[7] Colorado River Compact, 1922. Art. III Sec. (b).
[8] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," 15.
[9] Ibid., 21.
[10] Douglas Kenney, "An Introduction to Key Facts and Issues Regarding the Allocation and Use of the Colorado River" (conference primer for Hard Times on the Colorado River: Growth, Drought, and the Future of the Compact, Natural Resources Law Center, University of Colorado at Boulder, June 8-10, 2005), p. 9.
[11] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," 30.
[12] Congressional Budget Office, *Water Use Conflicts in the West: Implications of Reforming the Bureau of Reclamation's Water Supply Policies*, accessed January 24, 2012, http://www.cbo.gov/doc.cfm?index=46&type=0&sequence=3#N_7_ .
[13] Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, http://maps.nationalgeographic.com/maps/print-collection/colorado-basin1-map.html.
[14] Western Resource Advocates, "Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest," December 2003, p. 9.
[15] Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, http://maps.nationalgeographic.com/maps/print-collection/colorado-basin1-map.html.
[16] Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 36.
[17] Western Resource Advocates, "Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest," p. 9.
[18] US Bureau of Reclamation, "2. Basin Report: Colorado." In SECURE Water Act Section 9503(c): Reclamation Climate Change and Water, Report to Congress, 2011, 17-40.
[19] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," 22.
[20] US Bureau of Reclamation, "Colorado River System Consumptive Uses and Losses Report 1996-2000," accessed August 10, 2011, http://www.usbr.gov/uc/library/envdocs/reports/crs/pdfs/crs962000.pdf
[21] US Bureau of Reclamation, "Colorado River System Consumptive Uses and Losses Report 2006-2010," accessed July 13, 2011, http://www.usbr.gov/uc/library/envdocs/reports/crs/pdfs/cul2006-2010prov.pdf.
[22] Glen Canyon Dam Adaptive Management Program, "Sediment and River Sand Bars in the Grand Canyon," accessed June 26, 2011, http://www.gcdamp.gov/keyresc/sediment.html.
[23] International Rivers, "Sedimentation Problems with Dams," accessed June 26, 2011, http://www.internationalrivers.org/node/1476.
[24] US Bureau of Reclamation, "Colorado River Basin Salinity Control Act," accessed June 26, 2011, http://www.usbr.gov/uc/progact/salinity/.
[25] US Bureau of Reclamation, "Quality of Water: Colorado River Basin Progress Report No. 22," 2005, p. 13.
[26] Ibid., p. 23.
[27] US Bureau of Reclamation, "2. Basin Report: Colorado," p. 17-40.
[28] Ibid.
[29] Ibid.

Demographics, Economy, and Agriculture Depend on Water Storage and Diversion: Is it a Zero Sum Game?

By Sally Hardin



Key Findings:

-An imbalance in supply and demand is causing over-allotment of the river, and if this is not rectified soon, we will begin to see severe shortages, especially for junior water users.

-The "age of construction" is over; increased infrastructure, except in some rare cases, is now presenting a case of diminishing returns and is not the best solution to this supply-demand imbalance. It is costly and additional water supplies to be developed are few and far between.

-A rapidly growing population inside and outside of the basin is cancelling out an otherwise impressive decline in individual water use. While conservation and reuse strategies should certainly be pursued, the best way to make supplies available to all users is through the increased use of water markets and banks.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Author:
Sally Hardin (Colorado College class of '12) is a 2011-12 Student Researcher for the State of the Rockies Project.

Will Stauffer-Norris

"There is a growing recognition that we live in an age of limits, that water from the Colorado River is not endless, and we cannot keep just using more."

-Jennifer Pitt, head of the Environmental Defense Fund's efforts on the Colorado River, speaking at the Colorado College, November 7th, 2011 as part of the State of the Rockies Project Speakers Series

Introduction

The Colorado River is one of the most highly dammed, diverted, and otherwise regulated rivers in the world. Located in the southwest United States, it has long been a critical force sustaining life in the most arid region of the country. The Homestead Acts of the late 1800s set a precedent for water use in the West, bringing multitudes of settlers into what was previously considered a remote, inhospitable region. Population has boomed and development has raced ahead at lightning speed since these first pioneers settled in the West, so much so that the Colorado River is today over-allocated.

The "face" of the river has been drastically altered, for better and for worse, from its historical variability and wildness for use by our societies. Compounded with recent drought, this means that demand is dangerously close to overtaking supply on the river. Early 2011 brought a brief respite, with the most snow and subsequent highest flows of the river since the drought began in 2001, buying a little more time before shortages become severe.

Yet, as population and municipal demands for water continue to increase rapidly, future supplies of the river are under serious threat, even without the projected impacts of climate change. Competing users and interests are stretching supplies thin from many directions, while simultaneously looking for new and innovative ways to get more water. Now we face the question whether consumptive use of the Colorado River is a zero sum game, where one user impedes and cancels out another? Or can efforts from all sides be made to reduce total consumption, improve efficiency of use, and secure a sustainable future for both humans and the environment in the Colorado River Basin?

Hydrology for Human Use: Past, Present, and Future

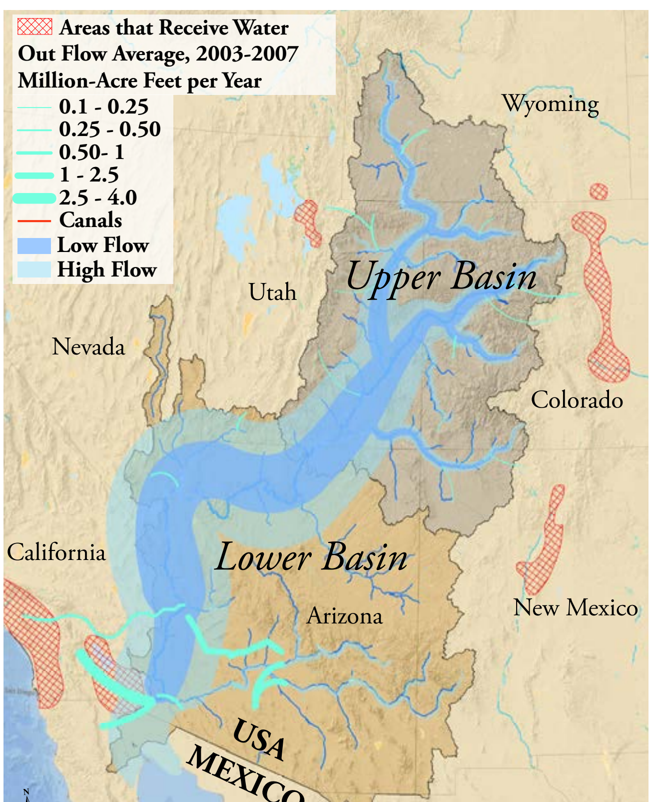
When John Wesley Powell first explored the Colorado River in 1869, the water ran fast, high, and muddy through pristine canyons such as the Grand. Today, many of these same stretches of river are clear and cold due to the construction of dams, and host lower flows because of upstream diversions. The river has changed immensely since Powell first charted its waters, in physical characteristics, environmental impacts, and its role in human society.

Once the Homestead Act was signed by Abraham Lincoln in 1862 and the West was opened up legally for further settlement by westward-migrating populations, land and water became more readily available. Following this was the General Mining Act of 1872, which allowed miners to stake a claim and, if valuable minerals were found, to purchase land for either $2.50 or $5.00 an acre. Because these two pieces of legislation also required water for their success, the system of prior appropriation and Western water law were born. Once all the best alluvial lands were claimed, the government passed the Enlarged Homestead Act in 1909 that was more conducive to dryland farming and gave homesteaders double the acreage because of lower land quality.[1] All of these acts only encouraged plentiful water use, as irrigation and small diversions became increasingly commonplace to support agriculture, and a precedent for western water consumption was set.

With the influx of people to the western U.S., population centers in and adjacent to the Colorado River Basin began to grow and transportation became increasingly key to a successful western economic system. Towns that became stops along the railroad often prospered disproportionately, Las Vegas being a perfect example. Established around 1905, the springs in Las Vegas allowed it to be a sort of oasis in the desert, one that settlers in small but growing numbers believed would become an agricultural paradise. The prior abundance of water in this now bone-dry city, which today survives entirely on water imported from the Colorado River, is what originally allowed it to grow into a booming metropolis.[2]

Figure 1 displays a comprehensive outline of the Colorado River Basin. The river and its tributaries are present,

Figure 1: Hydrology Map of the Colorado River with Infrastructure



Source: Jonathan Waterman, Samuel Velasco, and Robert E. Pratt, *Colorado River Basin: Lifeline for an Arid Land*, National Geographic Society, September 2010.

and the darker center and lighter outside shading surrounding the river line indicate periods of low and high flow, respectively. The major pipelines and canals are indicated by red lines, and major diversions, as well as amount of water diverted, are indicated by turquoise lines of varying thickness. Locations receiving diversions of water out of the basin, called transbasin diversions, are evidenced by red cross-hatching. This map provides a beginning idea of the layout of the river, as well as how and where Colorado River water is transported for use.

The Bureau of Reclamation was established in 1902, in part to begin what is today a legacy of damming, diverting, and otherwise managing the Colorado River. It dove right in to project creation in the basin, allowing for increased homesteading and western economic development.[3] Once it became clear that settlements in the West were not only permanent but also growing and demanding increasing water, the need for legal water allocations was recognized. In 1922, the Colorado River Compact was created, dividing the basin into Upper and Lower regions and creating water delivery requirements for each.

With delivery requirements now in place, it became necessary to create means by which to store and control water past minimal irrigation diversions. The Hoover Dam was constructed between 1931 and 1936 during the Great Depression, and was at the time the largest man-made structure after the Great Wall of China.[4] Its construction controlled floods, provided irrigation water, allowed for hydroelectric power production, and created Lake Mead, which increased water security by providing a more reliable source of multi-year water. Following the construction of Hoover Dam came many more large-scale projects to store and move water, especially the construction of Glen Canyon Dam and its corresponding reservoir, Lake Powell, in 1966. Glen Canyon Dam allowed for increased development of the Upper Basin, as Hoover had allowed for the Lower Basin. These projects were accompanied by the growing concept of "water buffaloes," those water managers who were adamant about obtaining increasing amounts of water in order to maintain a high rate of economic and human development in the West.

The 1922 Compact divided water use by Upper and Lower Basins, apportioning a flow of 15.0 million acre-feet (maf) that was assumed to be the Colorado River's average flow. Unfortunately, 1922 fell in the wettest ten-year period in the century of recorded Colorado River flow history (1914-1923), and as such may have greatly overestimated the actual average flows of the river over decades.[5] This over-estimation, coupled with the attitude of assumed abundance of western water based on historical rates of consumption, presents a difficulty today as regional populations grow and expected flows decrease. The Boulder Canyon Act of 1928 divided up the Lower Basin's apportionment by state, while the Upper Colorado River Basin Compact of 1948 designated apportionments for Upper Basin states. **Figure 2** shows a comparison of consumptive water use by states from 1970-1975 and from 1996-2000, indicating the consumption has increased nearly across the board.

In 2000, the Colorado River basin entered a period of severe drought in which the region experienced reduced precipitation and reduced river flows. Droughts are generally multi-year cycles, and this drought has continued through the present day.[6] This cycle mandated the creation of the Interim Shortage Guidelines in 2007 in order to guide re-apportionment in a time of severe decreased flows. All Lower Basin states, apart from California, will accept reduced deliveries pending severity of flow reduction if the guidelines are enforced, and California is being strictly held to its 4.4 maf apportionment (which has not always been the case in the past).[7] This roughly translates into cutbacks mostly in municipal water use, with a less severe decline (if any) in water available for irrigated agriculture based on seniority of water rights.

As this drought continues, water storage levels have been hard hit as users continue to withdraw water for various uses at rates faster than replenishment. In October 2010, Lake Mead reached an historic low of 1,083 feet above sea level; operations of the first intake station fail at a water elevation of 1,050 and below.[8] So far, 2011 has been the wettest year since the drought began in 2000, and Lake Mead has risen to 1,107 feet. One wet year does not end a drought, however, and the bottom line is that historic flows are changing. In retrospect, it is proving harmful to existing and promised future human uses, as well as environments dependent upon instream flows, that annual water in the basin was overesti-

Figure 2: Table of Consumptive Water Use by State, 1971-2010

Basin State	1971-1975 average per year	1996-2000 average per year	2006-2010 average per year
Arizona	5.18 maf	4.83 maf	No Data
California	5.19 maf	5.14 maf	No Data
Colorado	1.73 maf	2.06 maf	2.14 maf
Nevada	0.15 maf	0.39 maf	No Data
New Mexico	0.27 maf	0.41 maf	0.42 maf
Utah	0.80 maf	0.94 maf	0.84 maf
Wyoming	0.32 maf	0.43 maf	0.42 maf
Water to Mexico	1.63 maf	2.91 maf	No Data
Total	17.3 maf	19.1 maf	No Data

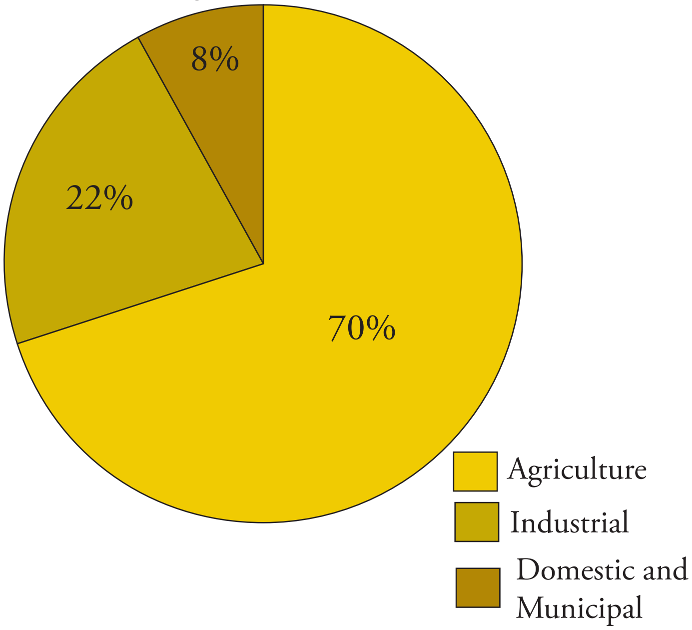
Source: U.S. Bureau of Reclamation, Colorado River System Consumptive Uses and Losses Reports, accessed December 12, 2011, http://www.usbr.gov/uc/library/envdocs/reports/crs/crsul.html mated when the Compact was created in 1922. The only consistent characteristic in flows of the Colorado River is variability, a phenomenon that Colorado River water users have historically tried to accommodate with multi-year storage, but to which humans and nature may soon be forced to adapt.

Water Supply and Demand: Trying to Make the Ends Meet

In order to understand the water supply of the basin, it is necessary to compare Colorado River supplies to those of other life-sustaining waters around the world. The Mississippi River is the fifth-largest river in the world by volume, with an average annual flow rate between 200,000 and 700,000 cubic feet per second (cfs). This is still only a fraction (usually around 9%) of the Amazon River, which experiences average annual flows around seven *million* cfs.[9] By contrast, the Colorado River had an average annual peak flow of 85,000 cfs before the construction of Hoover and Glen Canyon Dams, with tree ring analysis indicating a high of 250,000 cfs reached on a few occasions in the last 4,000 years. With the dams on the Colorado River in place today, average annual flows above Glen Canyon Dam are closer to 50,000 cfs, and sometimes as low as 30,000 cfs.[10]

The ways in which we use these limited flows in the southwest U.S. have varied throughout time, but always involve a strong agricultural emphasis. This is due in part to historical trends, as well as a climate in the Lower Basin that is highly conducive to winter crop growth. Agricultural use of Colorado River water today hovers around 80% of the river's total supply, whereas municipal and industrial use by cities is closer to 15% of the total. While today's trends are such that irrigated acreage in the basin is declining while municipal demands are increasing, water allotment has not yet shifted to reflect this. Note in **Figure 3**[11], which displays a breakdown of different water uses globally, that the percentage of water dedicated to agriculture in the arid southwest is higher than the global average.

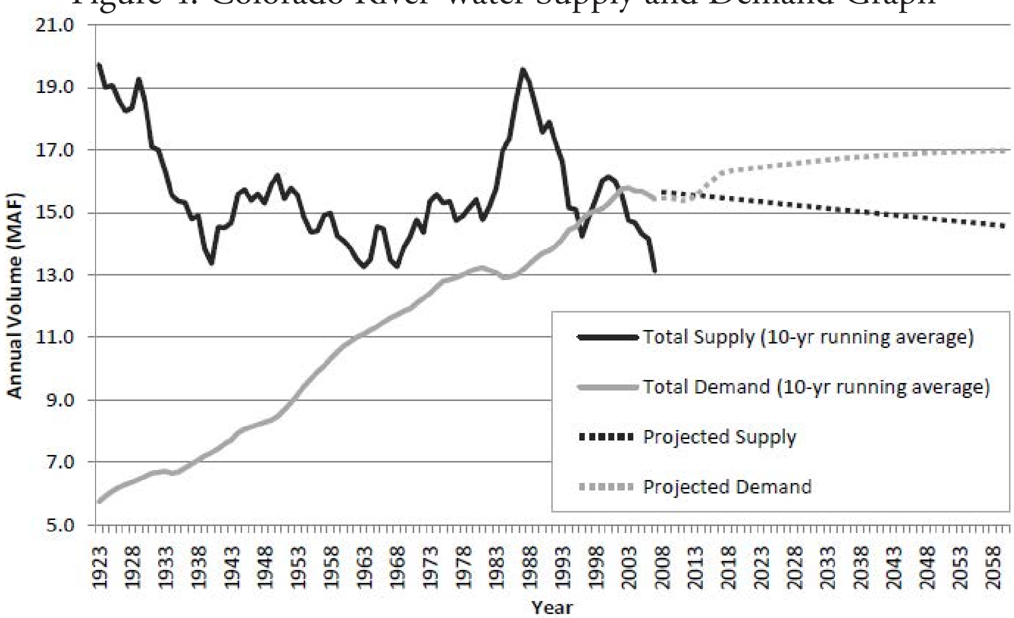
Figure 3: Global Water Use



The major stress in the system today is coming from these expanding municipal demands, created by rapid population growth. The numbers are startlingly simple; the basin and its outside service population are massive compared to the past, and flows are either plateauing or decreasing. With efforts made to conserve water or reduce demand still not enough to have a significant impact, this situation will lead to serious overapportionment and shortages. **Figure 4**, from a recent report by the Colorado River Governance Initiative (CRGI) takes the standard U.S. Bureau of Reclamation supply and demand graph and extends the imbalance projection to the year 2058 with a no-significant-behavior-change scenario.[12] This projection is impossible in actuality for a finite resource such as the Colorado River, and will require adaptation.

Timing is also an issue in the overapportionment of the Colorado River, as increasing numbers of previously marginalized water rights are being recognized. While legally sound, this presents an issue for the already fully-apportioned Colorado River. The delinquency of some Native American reservations in claiming their federally reserved water rights, as well as the delay in recognizing instream flows for national parks and other public lands as a priority, have caused tension as previously senior water rights holders are trumped by these groups. Junior water rights holders experience a further squeeze when these water rights are litigated and claimed, as even with increasing numbers of competing demands there is still only a

Figure 4: Colorado River Water Supply and Demand Graph

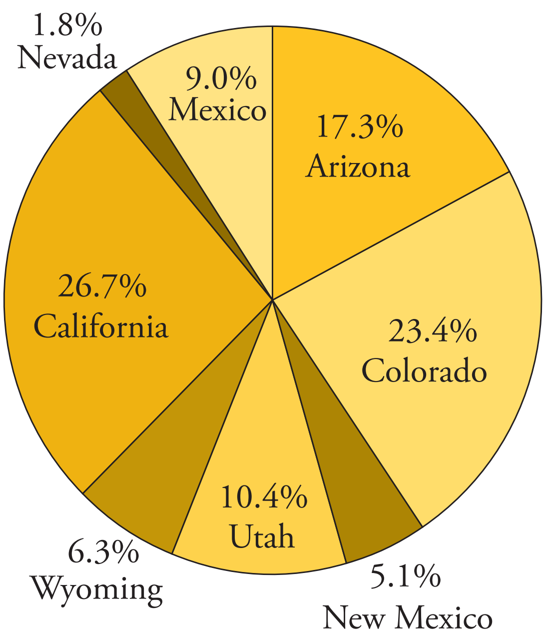


Source: Colorado River Governance Initiative, "Rethinking the Future of the Colorado River," *Draft Interim Report of the Colorado River Governance Initiative,* December, 2010.

finite supply of Colorado River water annually and over multi-year periods.

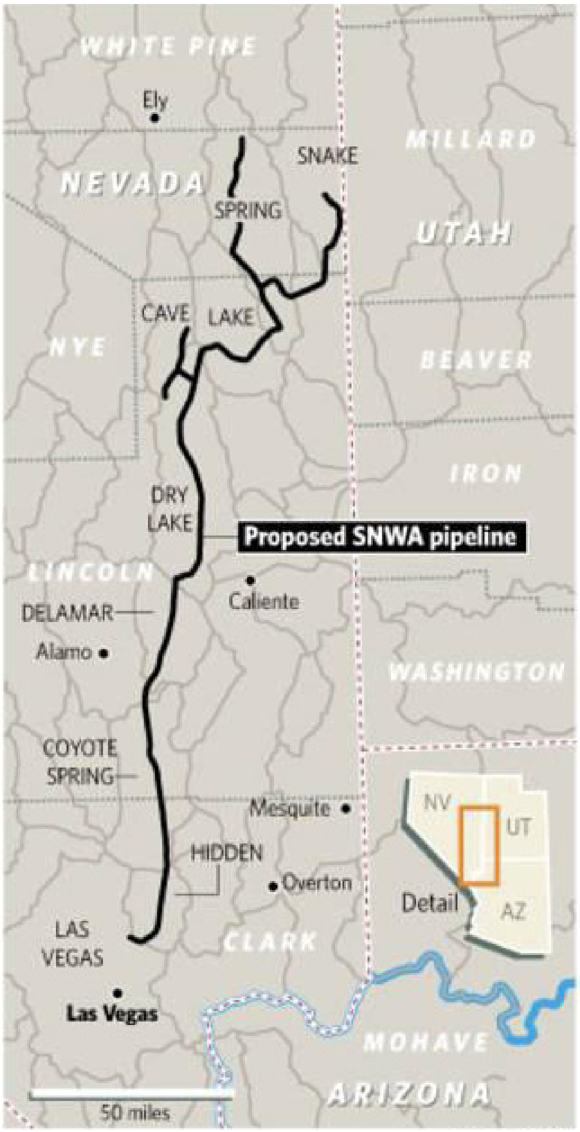
With the passage of the Interim Shortage Guidelines in 2007, the belt around water use is tightening. States, especially the historically larger water users in the Lower Basin, are being more closely held to their allotted water amount, which can be seen in **Figure 5**. One example of this is California, which prior to the shortage requirements was receiving closer to 5.6 maf annually as opposed to their allotted 4.4 maf. This was due in part to their location as one of the last downstream users, allowing them temporarily to take up the extras not consumed by the Upper Basin. It is also feasible because reclamation projects to help the Upper Basin states store and use their shares have been eclipsed by society's changing attitudes towards major dams, as well as severe budget limitations. In spite of this, it has come to the point where Lower Basin demands can only be met if the Upper Basin begins to release amounts beyond the obligations of the Compact.[13] Furthermore, the CRGI reports that demands on the Colorado River system as a whole now likely exceed long-term supplies, even without drought conditions.[14]

Figure 5: Water Apportionment by State



Users of Colorado River water (be they water utilities, project managers, farmers, etc.) had a tendency previously to always seek out new supplies through infrastructure creation, as opposed to accepting finite limits and engaging in conservation. This was due in part to the West's continued stereotype as a remote final frontier, a vision which does not consider the reality of booming metropolises and rapid population growth. One example of a project meant to satisfy growing municipal demand is in Las Vegas, where a $1.5 billion pipeline has been proposed. **Figure 6** provides a visual of the proposed project. The pipeline, which is very controversial among residents of the affected areas, would tap into the groundwater of various basins north of the city.

Figure 6: Las Vegas Pipeline Map



Source: The Las Vegas Sun

Some projects are more ecologically and monetarily feasible than others. One "wild" water supplement suggestion has been to create a pipeline drawing water to the arid West all the way from the Mississippi River Basin, something that most consider damaging and extremely expensive. Limits to growth in the American West are unappealing in a region of the country that is considered a newer economy, still rising to its full potential. Growing cities desire a reliable water supply for secure support, the antithesis of setting limits. As a result, those depending upon water in the Colorado River Basin display path-dependency, desiring to continue unconstrained growth with little or no limits on water. Reality confronts illusion in the current complex situation of existing demand outstripping supply; actions taken now to balance supply and demand will dictate the future withdrawal and instream water uses of the Colorado River.

The Growing Population of the Next Generation

At the advent of the Homestead Acts, population of the remote West began to grow, albeit slowly at first. Being the final frontier made the West a major attraction for farmers, miners, and later, developers. While this region has certainly experienced some serious boom and bust cycles with major transitions (from mining, to railroad, to services), the general trend of positive economic growth has resulted in consistently rapid expansions in population. In fact, perhaps in part due to its previously remote nature, the West has experienced the most intense population growth in recent years of any region in the country.

Between 1950 and 2000, the percentage of the nation's population living in the West[15] increased from just 13.3% to 22.5%, nearly a quarter of the total. The 13 western states (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) accounted for 50% of all U.S. population growth from 1990 to 2000, with 91.5 million (one-third) of the 281 million-person total living in this region.[16] Five of the six fastest-growing states in the U.S. between 2004 and 2005 were located in the West, including three Basin states: Arizona (3.5%), Nevada (3.5%), and Utah (2.0%).[17] **Figure 7** displays the change in population, from 1990 to 2008, of today's 12 largest cities in the basin.

Counter-intuitively for a region whose image is "rough and rural," the southwest U.S. is the most urbanized area of the country.[18] Recent influxes of population into southwestern cities, especially as the baby boomer generation begins to retire and settle in this warm area, have left rural areas in the Rockies region with lower-density populations than previous decades.[19]

Tens of millions of people from outside of the physical basin also acquire some or all of their water from the Colorado River; for example, more than half of the 30 million people receiving water from the basin live in southern California. A recent report by the Pacific Institute found that 70% of the population receiving water from the basin does not actually reside within physical basin boundaries.[20] Trans-basin diversions such as the Colorado River Aqueduct from Lake Havasu to Los Angeles (which pumps 1.2 maf per year) move millions of acre-feet of water out of the basin to municipal users annually, and municipal demands are only increasing as populations grow.

Just as the population served by the Colorado River Basin added 10 million people in only 18 years (1990-2008), so its growth is projected to continue into the future.[21] Nevada alone is expected to grow by one million people in the next 20 years, whereas the numbers for Colorado (an additional two million) and Arizona (an additional three million) are even greater.[22] That's six million additional people in twenty years between only three of the seven basin states, without even considering Mexico, which grew by 156% between 1990 and 2008. These significant additions to Colorado River water users only serve to stress further the already-dwindling river system.

Storage and Diversion: A History of Defying Nature to Optimize the River's Supply over Space and Time

For better or worse, water flowing through the Colorado River no longer reaches the sea at the Gulf of California. This is due to the massive amounts of infrastructure installed on the river, to control its flows for human "beneficial use" as dictated by the 1922 Compact. Beneficial use is defined by the U.S. Bureau of Reclamation (BOR) as "the consumption of water brought about by human endeavors," which includes water for "municipal, industrial, agricultural, power generation, export, recreation, fish and wildlife, etc., along with the associated losses incidental to these uses."[23] Beneficial uses were previously recognized only as those which were directly beneficial to humans, such as agriculture, municipal and industrial use, hydroelectric generation, and export. This also means that even evaporation from reservoirs is considered an

Figure 7: Change in Population of Water Agency and Provider Districts

Water Agency/Provider	1990	2000	2008	Growth, 1990-2008
The Metropolitan Water District (Los Angeles, CA)	14,393,420	16,145,476	17,987,917	25%
Southern Nevada Water Authority	750,621	1,364,248	1,922,069	156%
Tijuana & Rosarito, Mexico	829,233	1,323,214	1,632,508	97%
Phoenix, AZ	997,096	1,339,501	1,566,190	57%
Denver Water	891,000	1,000,000	1,154,000	30%
Tucson, AZ	662,251	835,504	952,670	44%
Mexicali, Mexico	363,149	568,983	890,032	145%
Albuquerque, NM	423,371	497,916	538,586	27%
Mesa, AZ	288,104	410,202	469,989	63%
Coachella Valley	235,722	332,485	462,386	96%
Colorado Springs, CO	303,522	382,693	424,416	40%
Salt Lake City, UT	333,000	372,192	391,515	18%

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 6.

acceptable use because it is associated with a beneficial human use of the same water, saving it as a reliable water source.

Little consideration historically has been given to the idea of leaving water in the river for environmental or recreational purposes. This is more a result of rapid development and previously plentiful supplies than it is an example of hostile neglect. Obvious shortages, changing climatic conditions, and increasing instances of threatened and endangered species have forced a review of what uses constitute "beneficial," if not purely human. While most users understand what qualitatively constitutes beneficial use, the BOR recognizes that "an inability to exactly quantify these uses has led to various differences of opinion."[24]

Furthermore, a beneficial use may be classified as consumptive or non-consumptive based on the nature of water use. If the water is "consumed" in the sense that it cannot be returned to the system in any worthwhile manner, the use is considered consumptive. Examples of this include much of irrigated agriculture (although there are some return flows if the water can be treated) or certain municipal uses such as lawn-watering and air conditioning. Other uses, such as many uses in buildings (sinks, showers, etc.), are considered non-consumptive because they allow water to be returned to a wastewater treatment plant. From there, it can be treated and returned to the river, where it can generally be re-used by downstream water rights holders.[25]

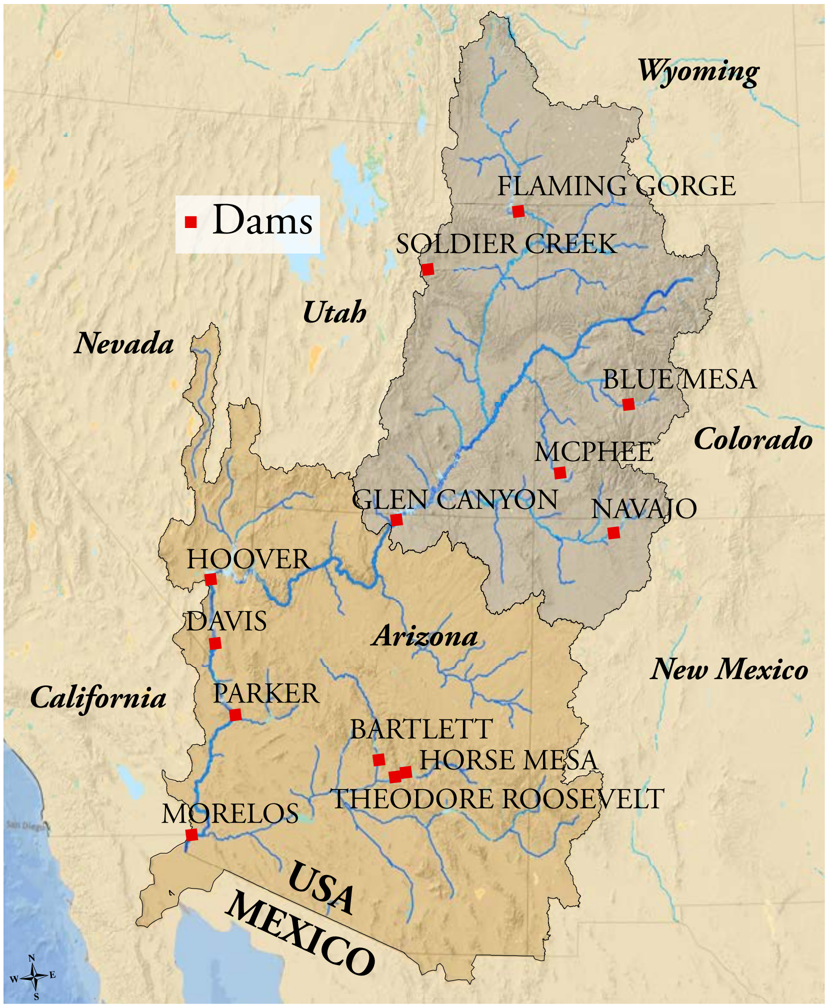
The Colorado River has long been diverted for use by individual farmers, miners, and other small scale uses. In 1902, President Theodore Roosevelt created the BOR by signing the Reclamation Act, authorizing the study of irrigation, needs as well as the construction of dams throughout the U.S. A canal system was already in place in parts of the Colorado River Basin at this time, but it was old and dilapidated. In 1905, high floods broke through one head gate near the Imperial Valley, which flooded the region and recreated the Salton Sea. The 1928 Boulder Canyon Project Act ushered in the age of large-scale infrastructure construction on the Colorado River by authorizing the construction of the Hoover Dam and the All-American Canal. The construction of Parker Dam in 1938 created Lake Havasu and allowed water storage for southern California, and Glen Canyon Dam's completion in 1963 created increased storage for the Upper Basin.[26]

Each dam, reservoir, pipeline and canal on the Colorado River has a different story behind the reasons for its construction, but the underlying theme is increased control of an otherwise hugely variable natural-flow resource. There are over 20 major dams on the Colorado. Considerably more are in the Upper Basin, but the ones located in the Lower Basin are much larger.[27] Many have associated reservoirs as well, which at a most basic level not only protect against damaging floods but also allow for water security by having a reliable water source even in times of drought.[28]

Dams and Reservoirs

The following is a list of the major dams and their associated reservoirs along the Colorado River, which gives background information on their time of completion and main purposes. **Figure 8** is a basin map showing the location of each dam and reservoir on the Colorado River system.

Figure 8: Map of the Colorado River Basin with Major Dams



Source: U.S. Geographic Names Information System

Figure 9 is a table providing the storage and active capacities of each reservoir, allowing for their comparison by size and current capacity. **Figure 10** provides the hydropower output of each major dam, again allowing for a comparison of productivity. This list will be useful when reading further about the issues with massive infrastructure along the river and the possibilities of water sharing between agricultural and urban water users in the following sections.

Hoover Dam:

•Finished 1936

•Located in the Black Canyon between Arizona and Nevada

•First major dam on the Colorado River, as well as the largest

Lake Mead:

•Created by Hoover Dam

•Roughly 28.5 maf capacity: 1.5 maf is reserved for flood control, roughly 2.4 maf for sedimentation control, roughly

Figure 9: Storage and Active Capacity for Major Reservoirs of the Colorado River Basin

Reservoir	Total Storage Capacity (acre-feet)	Active Capacity (acre-feet)	Percent Full on 12/12/2011
Lake Mead	29,755,000	15,853,000	53%
Lake Powell	27,000,000	16,392,535	61%
Flaming Gorge Reservoir	3,788,900	3,428,026	90%
Lake Mohave	1,820,000	No Data	NoData
Navajo Reservoir	1,708,600	1,320,840	77%
Blue Mesa Reservoir	940,800	611,147	65%
Lake Havasu	720,000	No Data	No Data
Fontenelle Reservoir	345,360	231,908	67%

Source: U.S. Bureau of Reclamation

15.8 maf for multiple uses (flood control, power, irrigation, municipal and industrial waters), and just over 10 maf for inactive storage.[29]
•Currently at 46% capacity with 11.95 maf of active storage[30]
•800,000 acre-feet (af) of evaporation annually because 247-square-mile surface area


Sally Hardin, Glen Canyon Dam

Glen Canyon Dam:
•Finished in 1966, part of the 1956 Colorado River Storage Project (CRSP) to develop the Upper Basin
•Located 15 miles upstream of Lee's Ferry in the Upper Basin
•Provides Upper Basin with storage
•Controversial; flooded the colorful Glen Canyon and has since caused numerous ecological issues
•Nearly failed in 1983 due to massive flooding

Lake Powell:
•Created by Glen Canyon Dam
•27 maf capacity
•As of July 2011 was at 18.34 maf (75% capacity)[31]
•Lowest historic level was 33% in 2005
•Threatened by sediment build-up, with an estimated 100 million tons annually (approximately 30,000 dump-truck loads daily)[32]
•Loses 860,000 af annually to evaporation (enough to supply Los Angeles for a year, 6% of the Colorado River's annual flow, and three times Nevada's annual allotment)[33]

Flaming Gorge Dam and Reservoir:
•Located on the Green River, 32 miles downstream of the Utah-Wyoming border in Utah
•Part of the 1956 CRSP
•Reservoir holds 3.8 maf at full capacity
•Reservoir currently at 3.59 maf because of 159% of normal precipitation in 2011[34]

Wayne Aspinall Unit:[35]
•Comprised of three dams and corresponding reservoirs in Colorado
•Part of the 1956 CRSP
•290,000 kilowatt capacity, which is 17% of CRSP system
•Allowed for agriculture in an otherwise fallow system
Blue Mesa Dam and Reservoir
•Furthest upstream of the Aspinall Unit
•Completed in 1966
•Reservoir is the biggest body of water in Colorado with 0.94 maf storage capacity
•Currently at 0.8 maf active capacity
Morrow Point Dam and Reservoir
•Largest and most productive of the three parts with 60% of the unit's total hydropower
•Reservoir is smaller, with a 117,190 af storage capacity and a 113,200 af active capacity at present
Crystal Dam
•Smallest of the three

Figure 10: Table of Dams and Hydropower Capacity

Dam	Location	Installed Hydroelectric Capacity
Hoover	Lower Basin	2,078,800 kW
Glen Canyon	Upper Basin	1,320,000 kW
Davis	Lower Basin	255,000 kW
Flaming Gorge	Upper Basin	151,950 kW
Parker	Lower Basin	120,000 kW
Blue Mesa	Upper Basin	86,400 kW

Source: US Bureau of Reclamation, USBR Projects, accessed December 12, 2011, http://www.usbr.gov/projects/Facility.jsp.

Figure 11: All-American Canal system in the Imperial Valley

Source: The National Atlas of the United States

Parker Dam:
•Located 155 miles downstream of Hoover Dam
•Constructed from 1934-1938
•Often referred to as the world's "deepest dam" because 85% of its structure is located below the riverbed
•Primary purpose was to create increased water storage

Lake Havasu:
•Created by Parker Dam
•Storage capacity is 646,200 af; presently at 584,300 af
•Supplies water for the Colorado River Aqueduct (transports water to Los Angeles, San Bernardino, and San Diego counties) and the Central Arizona Project; incredibly important desert water source[36]

Morelos Dam:[37]
•Located on the border of Arizona and Mexico
•Run by the International Boundary and Waters Commission (IBWC), all operations and maintenance done by Mexico
•Completed in 1950 pursuant to the 1944 treaty requiring 1.5 maf annual flow of the Colorado River into Mexico
•L-shaped, meaning it diverts almost all of the Colorado River and generally stops the natural flow
•No storage component

Infrastructure for Agriculture

The following is a list of Colorado River infrastructure that was constructed mainly to provide for agricultural water needs. All of the major infrastructure for agriculture is located in the Lower Basin.

All-American Canal System:[38]
•Located in the southeastern corner of California, near the border with Mexico
•Authorized by the Boulder Canyon Act of 1928
•Consists of the Imperial Dam and Desilting Works, the All-American Canal (AAC; 80 miles), and the Coachella Canal (CC; 123 miles)
•Water flows through Imperial Dam and Desilting Works, gets desilted, and goes to either the AAC or the CC; **see Figure 11** for a system map
•System irrigates around 600,000 acres of land in Imperial and Coachella Valleys
•Because the reservoir above Imperial Dam quickly filled with sediment (originally 85,000 af storage capacity, now 1,000 af), Senator Wash was built two miles upstream to hold water from sporadic precipitation events

The All-American Canal (AAC):[39]
•Largest irrigation canal in the world
•The canal was leaking lots of water, and after much debate it was relined in 2010; this saves 67,700 af of water annually

Thomas McMurray, Aerial Photograph of Morelos Dam

•The relining required rebuilding 23 miles of the canal
•Water saved will be used to fulfill Native American water rights and to decrease California's current dependence on surplus water
•Disadvantage is that Mexico used to receive water seepage lost from the canal, so their share has been decreased, straining relations further

Drop 2 (Brock) Reservoir:[40]
•Approved in 2007, constructed in Oct. 2010
•8,000 af storage capacity; can save up to 70,000 af annually
•Previously, agricultural water orders were made three days in advance at Parker Dam, then cancelled if there was an unexpected precipitation event, meaning the water was lost to Mexico; now those flows can be stored
•Caused further conflict with Mexico, who benefitted from the excess flows

Infrastructure for Municipalities

The following is a list of infrastructure that was constructed mainly to supply water to various western municipalities that are rapidly growing. Again, the major existing infrastructure for municipalities is located in the Lower Basin; however, there are multiple proposed projects for pipeline construction in the Upper Basin due to population growth and steadily increasing urban demand for water.

Central Arizona Project (CAP):
•Largest and most expensive aqueduct system ever constructed in the U.S., at $4 billion
•Authorized by the 1968 Colorado River Basin Act, intended to irrigate one million acres in Pima, Pinal, and Maricopa counties, but because it took 20 years to complete (1993) water now goes to rapidly developing urban areas (Tucson, Phoenix) as well
•Draws water from Lake Havasu through a 336-mile diversion canal
•All CAP rights are junior to older (senior) rights in California; presently challenging because Interim Shortage Guidelines of 2007 cutback on water use by junior users[41]
•Arizona also invested $28.6 million in California's Drop 2 Reservoir, meaning they will get 100,000 af of California water annually starting in 2016[42]


WikiCommons, Aerial Photograph of the Central Arizona Project

Colorado River Aqueduct (CRA):[43]
•Completed in 1941
•242-mile system that takes water from Lake Havasu to Los Angeles and San Diego
•Consists of two reservoirs, five pumping stations (which move water a total of 1,617 vertical feet), 63 miles of canals, 92 miles of tunnels, and 84 miles of buried conduit and siphons
•Pumps 1.2 maf from the Colorado River annually
•Run and regulated by the Metropolitan Water District of Southern California (MWD); these water rights are junior to the agricultural rights of California, but as a trade-off the MWD gets up to 5 maf of storage in Lake Mead in the future; they have also historically consumed any surplus from Arizona and Nevada, putting California over its 4.4 maf official allotment
•Adds to the complex relationship of water rights between Arizona and California

While agriculture is dwindling as a livelihood, as shown in **Figure 12**, and subsequently as a water-using sector in many parts of the U.S., there are many regions supplied by the Colorado River that are still going strong. Examples include both the Imperial and Wellton-Mohawk Irrigation districts at the southern tip of the Lower Basin bordering Mexico, where around 600,000 acres of land are irrigated with Colorado River water. This continuously presents contention over which new infrastructure developments should be prioritized: those for cities or those for continuing agricultural production. This region of the Lower Basin is an example where agriculture takes priority, but many developing areas in the Upper Basin present the opposite outcome.

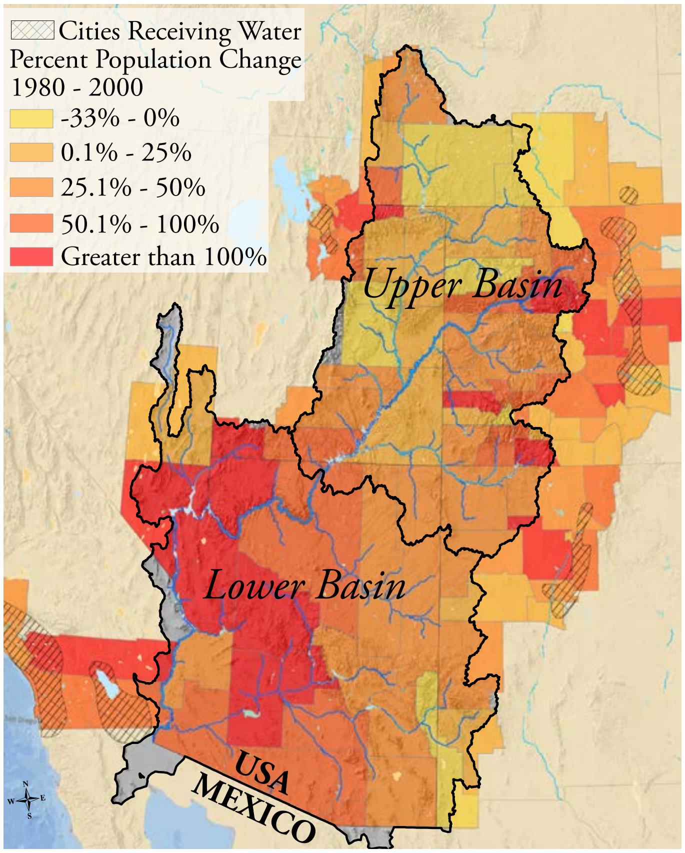
Figure 12: Farming's Changing Role in the Nation's Economy

Year	Percent of Total Labor Force Employed in Agriculture	Agricultural GDP as a share of total GDP
1900	41.0%	No Data
1930	21.5%	7.7%
1945	16.0%	6.8%
1970	4.0%	2.3%
2002	1.9%	0.7%

Source: Compiled by Economic Research Service, USDA. Share of workforce employed in agriculture, for 1900-1970, Historical Statistics of the United States; for 2000, calculated using data from Census of Population; agricultural GDP as part of total GDP, calculated using data from the Bureau of Economic Analysis.

As the West shifts rapidly from a rural to an urbanized region of the country, water infrastructure for municipal purposes is increasingly prioritized on the agendas of water managers. This shift can be seen in the maps in **Figure 13**, charting population density over time in the basin. The question is becoming not only how to sustain these growing populations, but also simultaneously how to allow the dry West's agricultural sector to continue to prosper. Increasing instances of environmental stresses and shortages are causing more and more managers to look towards various water conservation methods as the best alternative for future supplies. However, many proponents of economic growth and development still see continued infrastructure construction as the best option for a secure and reliable water supply. Most of the largest diversions are out-of-basin, moving Colorado River water from within the basin to large municipalities outside. This requires increasing amounts of energy, but generally growing cities are willing to pay.

Figure 13: Population Change by County, 1980-2000



Source: The U.S. Census Bureau

Traditional Beneficial Uses: The Smaller Pieces to the Greater Whole

Many of the stresses on the Colorado River today arise from competing users. All stakeholders believe their consumption purpose to be the most important, but prior appropriation dictates which rights are senior and junior. Agricultural users in the basin hold rights of the highest priority, and nearly 80% of the flows from the Colorado currently

Case Study: The Flaming Gorge Pipeline

Source: Western Resource Advocates, http://www.westernresourceadvocates.org/pipeline/

The Lower Basin has historically demanded more water from the Colorado River than the Upper Basin, in large part due to the incredibly dry climate characterizing the region, but new developments in the Upper Basin prove that water security is desired everywhere. One example is the Flaming Gorge Pipeline, proposed by private developer Aaron Million, as well as a coalition of small water utilities in Colorado and Wyoming. The proposed project would require construction of a 560-mile pipeline east from the Flaming Gorge Reservoir to southeastern Wyoming and south to various locations on the Front Range of Colorado. For comparison, the Central Arizona Project (CAP) is only 336 miles, and CAP is the largest and most expensive aqueduct ever created in the U.S. The Flaming Gorge Pipeline is predicted to cost $9.5 billion to construct, and accrue $217 million each year in operating costs.[44]

If built, the pipeline to the Front Range would supply the municipalities there with 225,000 additional af of water annually, which is the equivalent of a football field covered with a column of water 43 miles high. There is some debate about whether water to supply this amount actually exists on the Green River, as a 2007 study by the Bureau of Reclamation suggested that actual surplus supplies are closer to 165,000 af. Furthermore, in July 2011, the Army Corps of Engineers terminated an environmental impact review of the proposed pipeline, ruling that the purpose of the project fell more closely under the Federal Energy Regulatory Commission's (FERC) line of review due to possible energy generation as part of the project. After this ruling, FERC also ruled the proposal to be "deficient" and have requested greater specificity. Million and the coalition of small utilities continue to push the proposal, however, as they emphasize that the pipeline could potentially supply water to an additional 1.1-1.4 million new residents along the Colorado Front Range,[45] which nears growth estimates for the next 50 years.

All of these existing and proposed transbasin diversions of Colorado River water are two-faced, as they fulfill the necessity of fueling a growing populace while further depleting the limited supplies of the Colorado River.

are used for agricultural purposes. However, farming is beginning to dwindle in the basin as increased urbanization overtakes this historically rural area. Municipal and industrial use of Colorado River water is 15% and growing quickly as populations explode. Most cities have junior water rights, however, due to their later establishment, and therefore agricultural users and municipal users occasionally clash over distributions. Other important beneficial uses of water are for recreation and hydropower production, two activities that are easily forgotten in the resource race between agriculture and municipalities.

Water Use for Agriculture

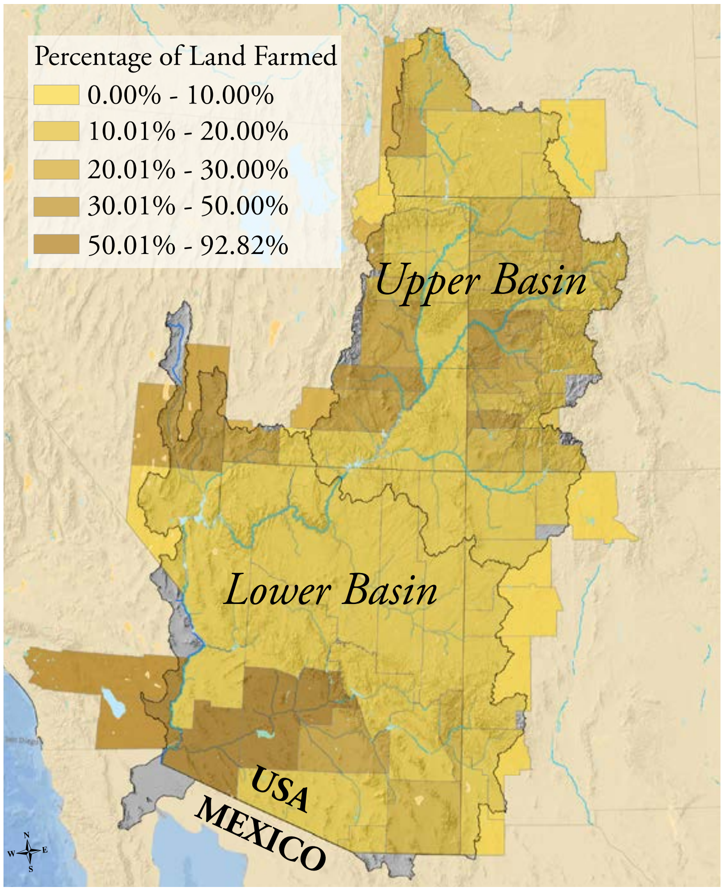
Despite its reputation as perhaps the driest region in the country, large portions of the southwest have a climate generally conducive to year-round farming, as long as water can be provided. According to the Colorado River Water Users Association (CRWUA), the agriculture fed by water from the Colorado River basin supplies 15% of the nation's crops, as well as 13% of the livestock.[46] It is agricultural giants such as Imperial and Coachella Valleys in California and the Wellton-Mohawk District in Arizona that are primarily responsible for this output, but there are also fairly fertile areas in the Upper Basin that host a fair share of irrigated land. **Figure 14** shows the acres of cropland per county as a percentage of that county's total land area.

While the Upper Basin states experience harsh winter climates, Wyoming and Colorado are both boosted by a $1 billion input to their economies from their respective seasonal agriculture. Utah has 340,000 acres that are irrigated by the Colorado River, and New Mexico has 100,000 acres. New Mexico boasts an alfalfa crop that contributes between $35 and $60 million annually to their economy. Nevada is actually the only basin state that uses none of its Colorado River apportionment for agriculture.[47]

Much of U.S. agriculture is feasible because of significant subsidies from the government, which are detailed by the table on agricultural subsidies by county in **Figure 15.** These subsidies are due in part to a continuing belief in the importance of producing our own food as a nation and not relying on imports from other countries. "It's a national resource that we should protect," says Vince Brooke, Assistant Water Manager of the Imperial Irrigation District.[48] For many agriculturalists of the Colorado River Basin, these subsidies come in the form of reduced water and energy prices.

In the Imperial Irrigation District, for example, growers pay nothing for water, but merely pay for the price of its delivery; even then, it is only $20/af.[49] This does not reflect the true cost of water from the Colorado River in the dry Lower Basin, but makes it possible for farmers to grow productive crops without being overly concerned about spending huge amounts on irrigation. A similar situation is true in the

Figure 14: Percentage of Land Farmed per County, 2007



Source: USDA National Agricultural Statistics Service

Figure 15: Top Twenty Basin Counties by Total USDA Subsidies, 1995-2010

County	State	Total USDA Subsidies 1995-2010
Maricopa	Arizona	$485,334,259
Pinal	Arizona	$462,288,174
Yuma	Arizona	$123,530,633
Cochise	Arizona	$99,105,005
La Paz	Arizona	$81,678,473
San Juan	Utah	$43,774,886
Moffat	Colorado	$43,108,035
Montezuma	Colorado	$34,824,040
San Juan	New Mexico	$34,493,923
Dolores	Colorado	$28,781,069
Montrose	Colorado	$22,157,852
Delta	Colorado	$21,775,592
Hidalgo	New Mexico	$21,455,046
Duchesne	Utah	$20,068,643
Uintah	Utah	$17,048,539
Emery	Utah	$13,376,653
Lincoln	Wyoming	$13,222,518
Imperial	California	$10,542,939
Rio Arriba	New Mexico	$9,400,186
Carbon	Wyoming	$9,213,433

Source: Environmental Working Group, 2011 Farm Subsidy Database, accessed December 12, 2011, http://farm.ewg.org/.

Wellton-Mohawk Irrigation District, where each property has a water right of 4 af per year per acre at a low rate. Beyond this, there is a tiered rate system, and water rates have increased for the last four years, but only minimally. Farmers and the overall economy desire an abundant crop, and the irrigation districts are in place to supply water at a low rate to insure this.[50]

The region of Mexico supplied by Colorado River water is also a significant agricultural area. Unlike the U.S., however, the relationship between farmers and the government is less supportive, and Mexican farmers in the Sonoran Valley receive little or no subsidies for their food production. Due to their close proximity to the U.S. border where crops are highly subsidized, Mexican farmers are frequently fighting a difficult battle and losing significant amounts of money through their crops, which cannot compete on a price basis with subsidized U.S. production.[51]

Brendan Boepple, A groundwater pump in the Wellton-Mohawk District

All of this is possible in part because of the seniority of most agricultural rights. Miners, turned farmers after the boom and bust cycle of mining ended in the late nineteenth century, were often the first landowners to establish any water rights in the Colorado River Basin. Wellton-Mohawk Irrigation District, for example, holds the most senior water rights for the Colorado River, meaning when shortages are imposed they are the last water users to feel any change.

Imperial Valley and Wellton-Mohawk combined produce nearly 80% of the nation's winter vegetables, indicating their importance as a production center along the Colorado River. Imperial Valley has 475,000 acres of cropland, most irrigated by flood irrigation, and has an average use of 5 af per acre of crop, annually. The top crops in Imperial in 2009 were alfalfa (28.2%), wheat (21.9%), Bermuda grass (11.1%), Sudangrass (6.6%), and lettuce (6%). For this, Imperial Valley diverts a total of 3.1 maf annually, a significant portion of California's Colorado River allotment (the rest goes to southern California municipalities through the CRA). Evaporation from canals causes a loss of approximately 10% of this water.[52]

Brendan Boepple, The All American Canal in the Imperial Irrigation District

Wellton-Mohawk District (the largest irrigation district in Arizona) is significantly smaller but relatively successful, with only 65,000 irrigated acres of farmland. For this, they divert 450,000 af of Colorado River water annually, but return 120,000 to 140,000 af downstream, flows which actually create the Cienega de Santa Clara wetlands in Mexico (**see case study on page 50**). This means that the annual consumptive use limit of water by the Wellton-Mohawk District is around 278,000 af. The most prevalent crops in Wellton-Mohawk are iceberg lettuce, cotton, wheat, Sudangrass, and some little seed crops. Corn, alfalfa, and wheat all require flood irrigation, which is generally less efficient than drip irrigation. Twelve-thousand af are reserved for municipal and industrial uses in the district annually, but because of having a rural population, rarely is the 12,000 af ever fully used.[53]

Because of extreme uncertainty over prices in agriculture, most farmers in these regions of the Colorado River Basin attempt to diversify their crop yield. One example of this is the fact that cotton is selling for some of the highest prices it has in decades. It also helps that farmers are able to grow two crops each year in some fields, due to the warm climate.[54]

The largest economic revenue, however, comes from the livestock in Imperial and Wellton-Mohawk Valleys. The latter has the largest cattle feeding yard west of the Mississippi River at 150,000 head, but the lot actually consumes more power than it does water.[55] Livestock is the biggest agricultural commodity revenue-wise in Imperial as well, where it generated an income of $343,201,000 in 2009.

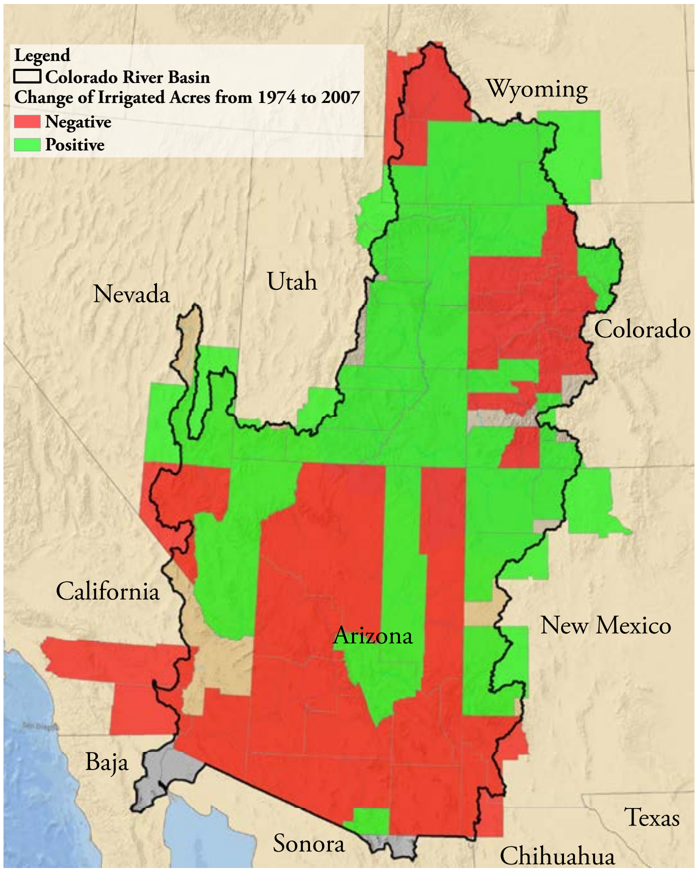
Despite large subsidies, the revenue generated by agriculture in various regions of the basin is still fairly significant. As the largest agricultural region in the basin, Imperial's commodity total in 2009 was $1.45 billion, down from $1.68 billion in 2008. For comparison, the entire state of Arizona generated $1.8 billion in agricultural revenue in 2007, including the contributions of the Wellton-Mohawk District. Because farms in the Upper Basin are generally smaller or more specialized (an example being the Western Slope of Colorado), revenue is not quite on the same scale, although Colorado and Wyoming regularly bring in close to $1 billion annually.[56]

Changes are occurring throughout the basin, however, as the population becomes increasingly urbanized. Demands for water transfers from agriculture to urban areas are growing steadily as pressures are put on water managers to supply increasing water to municipalities. This has caused some tension between agricultural communities and cities in the basin. "If they're short water, the first thing they do is run to the ag communities to get it," said Vince Brooke.[57] Imperial Valley has actually started a fallowing program, however, in which farmers are compensated for leaving their fields bare and transferring water over to municipal users.[58] This is true of many agricultural regions throughout the basin, where programs from basic fallowing all the way to the "buy and dry" technique are being implemented to better balance out water supply and demand. **Figure 16** shows the change in irrigated acreage throughout the basin since 1974. While some areas have experienced an increase in irrigated acreage, overall irrigated acreage in the basin decreased by 13.7%.

In Imperial Valley, over $40.1 million has been put towards advancing a successful fallowing program since December 2003. Over 1,100 fields have been contracted out for fallowing purposes, and in total over 111,000 acres have been left fallow. This amounts to approximately 700,000 af of water 'conserved,' or delegated for other uses throughout the basin.[59]

These programs are especially pressing in regions of the Upper Basin where agricultural areas are not quite as large or well-established as those in the Lower Basin. This is also arguably where the pressing demands of urbanization are being felt most as the population is jumping from rural to urban at an unprecedented rate. Because of the historic nature of agriculture in the West, however, there is much opposition to these changes. Agriculture is an ingrained part of much of the cultural identity throughout the Colorado River Basin. Along with mining, it was one of the key livelihoods of nineteenth-century settlers, and even as times change people are reluctant to relinquish this past livelihood, which is still moderately successful.

Figure 16: Percentage Change of Irrigated Acres from 1974 to 2007



Source: USDA National Agricultural Statistics Service

Water use and distribution have always been politically charged topics, and in times of shortage, the tension only heightens. It is hard during shortages to recognize and weigh the importance of various water uses on the Colorado River. Population centers claim to be of primary importance, serving the needs of the people. Yet, as Kenny Baughman of the Wellton-Mohawk Irrigation District said, "The people… thought that milk and bread came from the grocery store. They have no idea it comes from farms."[60] While agriculture can often appear as hoarder of Colorado River waters, it is equally necessary to recognize its importance.

Municipal and Industrial Water Use

The numbers are crystal clear when it comes to Colorado River supply and demand. The population is increasing, which leads naturally to increasing demand. The Pacific Institute recently published a report detailing municipal water use inside and outside the Colorado River Basin, which found that although per capita use of water is actually declining in the basin, total overall demand continues to increase.[61] This is

Figure 17: Change in Water Use as Compared to Change in Population, 1990-2008

State	Gallons Per Capita per Day (GPCD) Change	GPCD Percent Change	Population Increase
Arizona	-53	-23%	2,659,637
California	-51	-21%	6,548,506
Colorado	-47	-22%	1,548,817
Nevada	-107	-31%	1,343,930
New Mexico	-60	-27%	449,791
Utah	-84	-28%	928,966
Wyoming	20	10%	70,361

Source: United States Census Bureau; Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 7.

due to a population growth rate that outstrips the rate of decrease in water use. **Figure 17** details the decline in gallons per capita per day (GPCD) for each state in the basin. These numbers can then be compared to **Figure 4** earlier in this section. It is evident that the GPCD percentage declines do not cover the massive population growth rates.

Municipal uses vary extensively from city to city, depending on people's needs, the climate, or water availability. The average human requires two quarts of water each day for basic survival. However, the U.S. average for a single family home is 80 gallons per person per day in winter, and 120 gallons in summer.[62] This is quite high compared to drought-stricken areas such as the Murray-Darling Basin in Australia, where an extreme lack of water has forced water use in cities such as Brisbane all the way down to 38 GPCD.[63] Water use in the Colorado River Basin, however, is even higher than the national average, due in part to a drier climate, as well as a higher consumptive pattern.[64]

Apart from industry, households are the main consumers of water in municipalities, especially in suburban regions with large lawns and properties. In cities such as Las Vegas and Denver, where the climate is not naturally conducive to luscious lawns, upwards of 50% of municipal water is often used on maintaining non-native grasses.[65] This is a consumptive use, as the water cannot be easily reclaimed for reuse downstream. Many efforts are being made, especially in Las Vegas, to replace turf with more water-efficient materials such as rocks and desert plants (Xeriscaping), but many people are hesitant to yield the aesthetic comfort of green lawns.

Using Las Vegas as an example of municipal water use, we see that about 40% of water goes to buildings (mostly non-consumptive) while 60% is used outside (consumptive). For Las Vegas, there is the added factor of both resorts and tourists. Contrary to popular belief, however, resorts are not huge water users; they only consume about 3% of Nevada's Colorado River apportionment, but provide 70% of Las Vegas's economic benefits. Furthermore, upwards of 80% of Las Vegas's permanent residents live in planned communities, which are culprits of large lawns and general water inefficiency (appliances). One of the largest consumptive uses of water in Las Vegas today (as many lawns are phased out in favor of Xeriscaping) is actually air conditioning, due largely to the warm, dry climate.[66]

The Pacific Institute study reports that even with a general decline in per capita municipal demand (people are using less water now than they did in 1990), agencies delivering water from the Colorado River now deliver approximately 6.7 maf annually, as opposed to the 6.1 maf that was the norm in 1990 due to an overall growth of urban population.[67] The following section discusses conservation and efficiency measures that are being pushed in order to decrease municipal water demand further. It is important to remember that at present, the driving issue is not vast overconsumption of water by municipalities, but rather the ballooning population of cities dependent on water from the Colorado River.

Other Uses

There are many other uses, apart from just agriculture and municipal/industrial water use, which are deemed beneficial in the Colorado River Basin. However, these uses make up only a small fraction of total demand in comparison to the two giants. There is increasing attention being paid to the careful balance that must exist between users in order for there to be enough water to go around, as well as rising emphasis being put on instream flows and the idea of leaving water in the river for environmental purposes. It is a challenge, however, to shift apportionments and prioritization of uses in modern times when allocations and water use structures were molded by the Compact in 1922 when society did not recognize the eventual value of dedicated instream flows.

Hydroelectric power generation is another fairly significant user of Colorado River water, and is an added benefit that comes from infrastructure creation. While dams do have harmful environmental impacts, hydropower is relatively environmentally-friendly in that it does not require consumptive use of water and does not discharge carbon dioxide into the atmosphere.

Recreation is another beneficial use, as it generates fairly significant revenue for the western states in which it occurs (see page 76 for the Recreation section in this report). These activities need not only be river-based, but can also include anything that relies on water from the Colorado River (i.e., skiing). However, because recreation generally relies on water that stays in the river, there is no prioritization or given allotment; it is merely an enjoyable side effect of a healthy river system. Many are concerned about what the future will bring for river recreation, with near over-apportionment at present and the looming risk of climate change which threatens to further dry up river supplies.

The Next Generation of Colorado River Water Users: Is it a Zero Sum Game?

At some point, the questions of competing uses, supply and demand imbalances, and growing transbasin diversions boil down to a single question: Is there enough water to go around? Can we find a way to equitably meet the demands (on a reasonable scale) of all users, while maintaining a healthy river system? Or will differing uses, overapportionment, and continued shortages out-compete one another, making it so that use by one stakeholder cancels out that of another in what is termed a zero sum situation?

Understanding the Basin's Natural and Geographic Limits and Possibilities

With 45% of the Colorado River's waters leaving the basin to supply 70% of the population partially or fully reliant on the Colorado River,[68] transbasin diversions are a point of contention in water use. On the one hand, the cities are outside the basin; Los Angeles, San Diego, Denver, Albuquerque, Salt Lake City, and Colorado Springs, among others, as can be seen in **Figure 18**. On the other hand, increasing amounts of water leaving the basin to support these growing external population centers presently only mean less water for those users on its interior.

Out-of-basin municipalities are also pushing for increased reliability of water sources, meaning the creation of more storage reservoirs. This is due in part to experience with shortages from the recent prolonged drought, as well as the desire to successfully support continued population growth in urban areas. Presently, 25% of Colorado River storage capacity directly supports municipalities, and this is only growing, especially as cities are able to acquire agricultural water

Figure 18: Map of Transbasin Diversions

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. v., and Ray Ahlbrandt, U.S. Bureau of Reclamation.

rights that accompany their storage. However, reservoirs are both costly and inefficient, as they have a high loss of water due to evaporation and their costs must be paid for up front. In their recent report entitled "Filling the Gap," Western Resource Advocates expands on the disadvantages of reservoirs, and pushes instead for decreasing the demand side of the equation through improved conservation measures.[69]

Also associated with the downsides of reservoirs are the pipelines that are needed to pump water out of the basin. These are costly to construct and are hugely energy-inefficient.[70] According to the Filling the Gap report, it is estimated that six pipelines that are currently being considered would each cost somewhere between $8 billion and $10 billion in just capital costs, not to mention operation and maintenance costs.[71]

One alternative to massive reservoir and pipeline construction is the creation of small, efficient reservoirs that are designed to take advantage of existing supplies and peak-season runoff, called "smart-storage."[72] These projects would work with the river and its natural flow variability, storing naturally-occurring downstream flows for later use. Their smaller size makes them less intrusive of the existing ecosystem, as well as less susceptible to major evaporation loss.[73]

Some cities are desperate for water, however, and will do anything to increase supplies through infrastructure. Las Vegas is a perfect example, in part because it is one of the leading cities in terms of conservation and low demand. Despite these conservation achievements, their reality as a metropolis in a desert requires water managers such as Southern Nevada Water Authority (SNWA) head Patricia Mulroy to look into tapping the groundwater systems of other basins, including the Great Basin. Opposition to the proposed Las Vegas pipeline is fierce in the Great Basin, however, in part due to the pervasive notion that it would drastically alter the ranching lifestyle in the region by creating a zero sum environment; water taken by Las Vegas would no longer be available for Great Basin ranchers.[74]

The *Filling the Gap* report addresses just that question, of zero sum tradeoffs. By reviewing the water situation on Colorado's Front Range, they reveal four strategies—acceptable planned projects, conservation, reuse, and ag/urban cooperation—that will work together to decrease demand while simultaneously creating additional water supply.[75] While such strategies would require both sacrifices and cooperation, shortages are becoming enough of a reality that the benefits of comprise may soon outweigh any perceived disadvantages.

Weighing the Agricultural Tradition Against the Growing Demographic Pressure: Potential Solutions for Future Water Sharing

Water distribution is the newest battleground for users of the Colorado River. At present, a standoff is developing between agricultural water users, who have regional history backing them, and municipal users, who are quickly growing in numbers. Agriculture holds the senior water rights, is often actually located within the basin, and has the title of largest user of Colorado River waters by a long shot—nearly 80%.

There is also a deep history of agriculture present in the region, still very much felt by the agricultural community, and so while they may be small in numbers, they are strong in organizing against any movements to take away their water. Municipalities generally hold junior water rights, and have the disadvantage of often being located outside the basin—but this is where the people are, with an increasingly loud voice demanding water.

The topic is wildly charged, with each side on the defensive about who gets what water at what priority. If this present path is followed, then the Colorado River is headed for self-destruction; it is not feasibly sustainable. However, many experts believe that this relationship need not be zero sum. In fact, this interface of users provides the perfect opportunity for a give-and-take relationship that has the potential to restore a semblance of balance to the Colorado River system.

Figure 19: Change in Gallons Per Capita Per Day (GPCD), 1990 to 2008

State	GPCD in 1990	GPCD in 2008	GPCD Change	Percent Change
Arizona	234	181	-53	-23%
California	246	195	-51	-21%
Colorado	214	167	-47	-22%
Nevada	348	242	-107	-31%
New Mexico	223	163	-60	-27%
Utah	298	214	-84	-28%
Wyoming	197	217	20	10%

Source: Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, p. 7.

One proposed solution is decreasing the demand side of the equation, which would mostly require efforts on the part of municipal water users. This would include heightened water conservation and reuse measures. Experts believe that reuse strategies are more promising, as conservation in the last decade has been startling effective and yet the continually growing population essentially negates this progress. There have been substantial per capita declines in water use, meaning that municipal deliveries would be nearly 2 maf lower than in 1990 if demand had remained constant[76] (**see Figure 19**). However, because of population increases, these demands were instead increased, hence the turn towards reuse as a more reliable strategy for water consumption reduction.

Reuse generally encompasses two different strategies. First, water can be physically reused by municipalities after treatment at a wastewater treatment plant, or after storage (direct reuse). Second, water can be returned to the river in the form of return flows for use by downstream users (indirect reuse). In this second situation, the upstream user is compensated for their water return.[77]

Part of what direct reuse would entail is municipal infrastructure that is friendlier towards grey-water usage, for example in Colorado Springs where green lawns are sometimes watered with non-potable waters in order to cut down on overall consumption. There need not be a massive overhaul of all plumbing systems in municipalities, merely incentives in place to entice water customers to reuse, as well as methods that make reuse an easier practice. Giving big water consumers, especially industrial users, incentive to reuse waters in their various processes would likely have the most noticeable impact. Western Resource Advocate's "Filling the Gap" report indicated that an additional 199,000 af of water would be made available annually if Colorado Front Range water users were to engage in reuse practices.[78]

The main disadvantages to both conservation and reuse are their voluntary nature. There are some regulations in place in many cities fed by Colorado River water, such as sanctions on lawn-watering during drier, hotter months, but nothing that is stringent enough. It would be possible for water providers to introduce a tiered water rate structure, meaning that water would become significantly more expensive the more a user consumed; however, at present, this is less economically desirable for all involved parties. As Doug Bennett, Conservation Manager for the Southern Nevada Water Authority, said in reference to water conservation, "Conservation loves a crisis."

The second approach to balancing the supply and demand equation of the Colorado River involves increased cooperation between agricultural and municipal water users. The simplest way of viewing the issue and solution is that agricultural users have a significant portion of the water rights, and therefore a significant portion of the water; municipal users have far fewer water rights, and therefore far less water. However, because irrigated acreage in many parts of the basin is decreasing (excluding the southern-most agricultural producers like Imperial Valley and Wellton-Mohawk), the need by agricultural users for that water is arguably decreasing as well. For example, there has been a decrease in irrigated acreage in Colorado from a high of 1.02 million acres in 1976 to only 840,000 acres in 2005.[79]

One way to use this imbalance of water rights and needs to provide increased water to municipalities is through a more traditional system termed "buy and dry." This is when municipal water users, who generally have a fairly high willingness to pay for water, buy up certain acres of agricultural land that are not productive enough to make them worthwhile to the farmer (or because the offer is more agreeable than producing crops would be). This purchase transfers the senior agricultural water right to the municipal user along with the land. However, it also permanently puts the land out of commission for agricultural purposes, which is often very unappealing to farmers who depend on the land for their continued livelihood.[80]

Instead of this socioeconomically undesirable method, more and more water managers are looking towards a combination of rotational fallowing and water banking to ease the process of transferring water from agricultural to municipal water users. Markets are an ideal tool to allocate a scarce resource, and therefore the creation of organized, regulated water banks composed of various willing agricultural water rights holders has the promise to be both more efficient and more socially acceptable.[81]

Having a rotational fallowing arrangement means that farmers do not have to permanently sell their fields, but instead can leave certain acres fallow and temporarily transfer that water right to a bank. This does not physically mean the transfer of water, but rather that the water that would normally be used is instead left in the river, available for use by the purchaser of that particular water right. This is economically favorable to agriculturalists because it allows for compensation of revenue lost by not growing and selling crops for a season. The "water bank" itself is merely a regulator of transactions between agriculturalists and municipal users, making sure that the process runs smoothly and that there is appropriate compensation.[82]

This strategy has already been successfully implemented by the Super Ditch Company in the Arkansas River Valley. Here, several Arkansas River ditch companies pooled their water rights under a centralized banking system, from which municipalities can then lease them. The key factor here is that many ditch shareholders expressed interest and willingness to enter into this centralized collective, because without that, water banks cannot exist or succeed.[83]

There are a few issues with water banking that have already been identified. First, it requires extensive cooperation between agricultural communities and municipal water users, something that is not always appealing to the agricultural community due to past grievances (so frequently being accused of being water hogs, wanting to uphold a culture of agriculture, etc.).[84] There are also problems with instream flow rights being disrupted because of water being taken out of a different area of the river than before. Finally, transaction costs to quantify and legally transfer water rights are quite high, which makes the whole endeavor less profitable for the agriculturalist and simultaneously more expensive for the municipal buyer.[85] Despite these flaws, however, water banking using rotational fallowing is arguably the most economically, socially, and environmentally palatable strategy yet implemented for addressing the crisis of supply and demand along the Colorado River.

Conclusion: Is the Colorado River Basin Faced with a Zero Sum Struggle?

Decades of immense human ingenuity and vast sums of money have been invested in "taming" the Colorado River. This is often seen as one of the human wonders of the world: carving out immense reservoirs backed up behind gigantic dams, while diversion structures carry water hundreds of miles from the river itself to fertile agricultural regions and urban areas even beyond the hydrologic boundaries of the basin. A steady supply of water over the decades, varying by the year according to drought conditions, is now rapidly being disrupted by growing demand for water to be put to "beneficial" uses. Colliding with the traditional definitions of "beneficial uses," new demands arise for maintaining instream flows to protect the fragile riparian areas and vast public lands of the region.

Many believe that the height of human engineering in the basin is nearing an end, with a few remaining proposals for massive diversion increasingly being challenged by environmental concerns. The result: a situation that increasingly pits existing users against one another, as urban areas seek to obtain water dedicated to agriculture, and out-of-basin demands seek any remaining surplus or unused allotments to individual states.

We have traced the thread of human development of the Colorado River Basin in this section, with the purpose of seeking answers to what many argue is now a zero sum game. Additional water obtained by urban areas must now come from a decline in water use by agriculture (potentially signaling a decline in agricultural production itself). Any further water diversions, even pursuing remaining surplus allotments to individual states, must come at the expense of diminished instream flows, thus harming further rivers and their associated flora and fauna.

Should today's youth look at this collision of steady and perhaps dwindling water supplies, as climate changes occur, against rising human demands as the ultimate threat to the basin as we know it? Or are we witnessing in the vibrant experiments discussed above innovative opportunities for new techniques of water sharing and conservation? The tentative answer we reach as Colorado College State of the Rockies Project student researchers is that the future sustainability of the Colorado River Basin remains to be determined. Encouraging signs of conservation and water sharing techniques give hope that our children will inherit a vibrant Colorado River. Water use in the Colorado River Basin need not be a zero sum game. On its current trajectory, it could certainly be classified as such. However, we are encouraged by promising alternatives for water conservation, reuse, and sharing of this scarce resource that together have the power to alter this path of destruction.

[1] Our Documents Initiative, *Homestead Act* (1862), accessed December 7, 2011, http://www.ourdocuments.gov/doc.php?doc=31.
[2] The Springs Preserve. Visit by author, Las Vegas, Nevada. July 17, 2011.
[3] Bureau of Reclamation, *History*, accessed August 1, 2011, http://www.usbr.gov/main/about/.
[4] Peter McBride and Jonathan Waterman, *The Colorado River: Flowing Through Conflict* (Boulder: Westcliffe Publishers, 2010), 96.
[5] Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," Report to the Western Water Policy Review Advisory Commission, 1997, 6.
[6] U.S. Geological Survey, *Climatic Fluctuations, Drought and Flow in the Colorado River Basin*, accessed July 9, 2011, http://pubs.usgs.gov/fs/2004/3062/.
[7] Sue McClurg, "How is the Colorado River Shortage Agreement Working?" In *River Report*, edited by Rita Schmidt Sudman, Sacramento: Colorado River Project, Fall 2008, 7.
[8] Felicity Barringer, "Lake Mead Hits Record Low Level," *New York Times*, October 18, 2010, Green blog.
[9] America's Wetland Foundation, *The Mississippi River Delta*, accessed July 2, 2011, http://www.americaswetland.com/custompage.cfm?pageid=257.
[10] Bob Ribokas, *Grand Canyon Explorer: The Colorado River*, accessed July 2, 2011, http://www.bobspixels.com/kaibab.org/misc/gc_coriv.htm.
[11] Glen Canyon Dam Visitor Center, visit by author, Page, Arizona, July 16, 2011.
[12] Colorado River Governance Initiative, "Rethinking the Future of the Colorado River," December 2010, 9.
[13] Ibid., 8.
[14] Ibid.
[15] United States Bureau of the Census. *Census Regions and Divisions of the United States*, accessed December 5, 2011. www.census.gov/geo/www/us_regdiv.pdf.
[16] Western Governors Association, "Water Needs and Strategies for a Sustainable Future," June 2006, 4.
[17] Western Resource Advocates, "Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest," December 2003, 9.
[18] Ibid., 22.
[19] Mark Lellouch, Karen Hyun, and Sylvia Tognetti, "Ecosystem Changes and Water Policy Choices: Four Scenarios for the Lower Colorado River Basin to 2050," Sonoran Institute, September 2007, vi.

[20]Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," Pacific Institute, June 2011, iii.
[21]Ibid.
[22]Western Resource Advocates, "Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest," 95.
[23]U.S. Bureau of Reclamation, *Law of the River*, accessed July 30, 2011, http://www.usbr.gov/lc/region/pao/lawofrvr.html.
[24]Ibid.
[25]Doug Bennett, interview by author, Las Vegas, Nevada, July 18, 2011.
[26]Peter McBride and Jonathan Waterman, *The Colorado River: Flowing Through Conflict*, 156.
[27]Dale Pontius and SWCA, Inc. Environmental Consultants, "Colorado River Basin Study: Final Report," 8.
[28]Doug Kenney with Andrea Ray, Ben Harding, Roger Pulwarty, and Brad Udall, "Rethinking Vulnerability on the Colorado River," *Journal of Contemporary Water Research & Education*, no. 144 (2010): 7.
[29]US Bureau of Reclamation, *Hoover Dam*, accessed December 2, 2011, http://www.usbr.gov/projects/Facility.jsp?fac_Name=Hoover+Dam&groupName=Overview.
[30]US Bureau of Reclamation, *Lake Mead End of Day Elevation*, accessed December 8, 2011, http://www.usbr.gov/lc/region/g4000/hoover.pdf.
[31]US Bureau of Reclamation, *Upper Colorado Region: Water Resources Group*, accessed December 8, 2011, http://www.usbr.gov/uc/water/rsvrs/ops/crsp_40_gc.html.
[32]Glen Canyon Institute, *All Dams are Temporary: Sedimentation*, accessed July 8, 2011, http://www.glencanyon.org/glen_canyon/sediment.
[33]Glen Canyon Institute, *Lake Powell Reservoir: A Failed Solution*, accessed July 8, 2011, http://www.glencanyon.org/glen_canyon/failed.
[34]US Bureau of Reclamation, *Upper Colorado Region: Water Resources Group*, accessed December 8, 2011, http://www.usbr.gov/uc/water/rsvrs/ops/crsp_40_gc.html.
[35]US Bureau of Reclamation, *Upper Colorado Region: Colorado River Storage Project*, accessed August 5, 2011, http://www.usbr.gov/uc/rm/crsp/aspinall/aspFacts.html.
[36]US Bureau of Reclamation, *Parker Dam*, accessed November 21, 2011, http://www.usbr.gov/projects/Facility.jsp?fac_Name=Parker+Dam&groupName=Overview.
[37]Osvel Hinojosa-Huerta, interview by author, Los Algodones, Baja California, Mexico, July 20, 2011.
[38]US Bureau of Reclamation, *Boulder Canyon Act—All-American Canal System*, accessed December 1, 2011, http://www.usbr.gov/projects/Project.jsp?proj_Name=Boulder+Canyon+Project++-+All-American+Canal+System.
[39]Osvel Hinojosa-Huerta, interview by author, Los Algodones, Baja California, Mexico, July 20, 2011.
[40]US Bureau of Reclamation, *Drop 2 Storage Reservoir Project*, accessed December 1, 2011, http://www.usbr.gov/lc/region/programs/drop2reservoir.html.
[41]Central Arizona Project, *Law of the River*, accessed July 8, 2011, http://www.cap-az.com/AboutUs/LawOfTheRiver.aspx.
[42]Central Arizona Project, *CAP Supports Efforts to Relieve Water Shortage*, accessed July 8, 2011, http://www.cap-az.com/AboutUs/LawOfTheRiver.aspx.
[43]David Zetland, "Colorado River Aqueduct," August 2009, 10-15.
[44]Western Resource Advocates, *Flaming Gorge Pipeline*, accessed December 9, 2011, http://www.westernresourceadvocates.org/pipeline/.
[45]Ibid.
[46]Colorado River Water Users Association, *Agriculture*, accessed June 21, 2011, http://www.crwua.org/ColoradoRiver/RiverUses/Agriculture.aspx.
[47]Ibid.
[48]Vince Brooke, interview by author, Imperial, California, July 19, 2011.
[49]Ibid.
[50]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[51]Osvel Hinojosa-Huerta, interview by author, Los Algodones, Baja California, Mexico, July 20, 2011.
[52]Vince Brooke, interview by author, Imperial, California, July 19, 2011.
[53]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[54]Vince Brooke, interview by author, Imperial, California, July 19, 2011.
[55]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[56]Colorado River Water Users Association, *Agriculture*, accessed June 21, 2011, http://www.crwua.org/ColoradoRiver/RiverUses/Agriculture.aspx.
[57]Vince Brooke, interview by author, Imperial, California, July 19, 2011.
[58]Ibid.
[59]Ibid.
[60]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[61]Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," iii.
[62]Glen Canyon Dam Visitor Center, visit by author, Page, Arizona, July 16, 2011.
[63]Robert Wiggington, interview by author, Boulder, Colorado, June 27, 2011.
[64]Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," iii.
[65]Doug Bennett, interview by author, Las Vegas, Nevada, July 18, 2011.
[66]Ibid.
[67]Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," iii.
[68]Ibid.
[69]Western Resource Advocates, "Smart Water: A Comparative Study of Urban Water Use Efficiency Across the Southwest," 11.
[70]Drew Beckwith, phone interview by author, August 2, 2011.
[71]Western Resource Advocates, "Filling the Gap: Commonsense Solutions for Meeting Front Range Water Needs," February 2011, 27.
[72]Ibid., 11.
[73]Ibid.
[74]Great Basin Water Network, *Don't Drain the Basin*, accessed July 10, 2011, http://www.greatbasinwater.net/.
[75]Western Resource Advocates, "Filling the Gap: Commonsense Solutions for Meeting Front Range Water Needs," xiii.
[76]Michael J. Cohen, "Municipal Deliveries of Colorado River Basin Water," 3.
[77]Western Resource Advocates, "Filling the Gap: Commonsense Solutions for Meeting Front Range Water Needs," 17.
[78]Ibid., xiii.
[79]Ibid., 35.
[80]Colorado Corn, *CWCB Alternatives to Buy and Dry*, accessed August 2, 2011, http://www.coloradocorn.com/about/committee-structure/research-action-team/cwcb-alternatives-buy-dry
[81]Tom Iseman, "Banking on Colorado Water," *PERC reports*, no. 1(2010): 15.
[82]Ibid., 17.
[83]Western Resource Advocates, "Filling the Gap: Commonsense Solutions for Meeting Front Range Water Needs," 36.
[84]Ibid.
[85]Tom Iseman, "Banking on Colorado Water," *PERC reports*, no. 1(2010): 16.

Case Study: The Wellton-Mohawk Irrigation District and the Cienega de Santa Clara

Many environmental problems of serious nature have arisen on the Colorado River as more and more infrastructure is added to dam and divert the river's contents. Rarely has anything ecologically beneficial come from such projects. Yet the Cienega de Santa Clara, a 40,000-acre-wetland near where the Colorado River used to meet the Gulf of Mexico, defies this generalization.

The Cienega is created by the brackish, overly saline drain waters coming from the Wellton-Mohawk Irrigation and Drainage District (WMIDD). The WMIDD, located in southwestern Arizona by the border with Mexico, is largely composed of 65,000 acres of irrigated cropland and is a highly productive agricultural region. The drain waters used to be a part of Mexico's annual Colorado River allotment (1.5 million acre-feet/year) designated by the 1944 Treaty with Mexico, until they were ruled to be too saline for beneficial use.[1]

The Colorado River has not reached the sea since 1998,[2] but the delta region was parched long before this. The wetlands that used to make up the delta region were compromised and eventually destroyed by a lack of water flowing to that region, due largely to urban development, construction of dams, and agricultural water use in the United States region of the Colorado River Basin. However, the flows of brackish water in what is termed the Mode Canal, which stretches from the WMIDD down into Mexico just east of the Colorado River's original path, have created a vibrant ecosystem in this previously desolate region.[3] The delta itself is still barren, but the Cienega de Santa Clara, just east of it, hosts a vibrant selection of healthy flora and fauna.

Ecology

The Cienega de Santa Clara is home to thousands of both migratory and resident birds. Located in a key region of migration corridors (including the Pacific Flyway), the wetlands at one point or another serves upwards of 75% of North American birds. It is the habitat of several endangered species, including 70% of the total Yuma Clapper Rail population in existence, and boasts a very healthy array of brackish riparian vegetation.[4]

The Biosphere Reserve of the Upper Gulf of California and the Colorado River Delta was extended to include the Cienega as a protected area, an important step in its conservation. Further, the Cienega was included in the Ramsar Convention on Wetlands of International Importance, meaning that the whole delta region's critical ecological role has been recognized and will subsequently be protected. Finally, Minute 306 was created for further protection; it jointly commits the United States and Mexico to continued study of the delta ecosystem in order to define water needs and identify ways to secure this water.[5] This includes finding alternate water supplies if the Yuma Desalting Plant ever comes into operation, desalinating the brackish flow from the Mode Canal and no longer sending this water down to the Cienega.

The Salinity Control Act of 1974

The highly saline drain water from WMIDD was historically included in Mexico's 1.5 maf total allotment from the United States. However, the Salinity Control Act of 1974 declared this water to be too brackish for human consumption and subsequent beneficial use. The Bureau of Reclamation was therefore responsible for finding other water to replace this, so that the full allotment was still met.[6] Arizona continues to get return credit for the Mode Canal flows, however, even with the Salinity Control Act in place.[7]

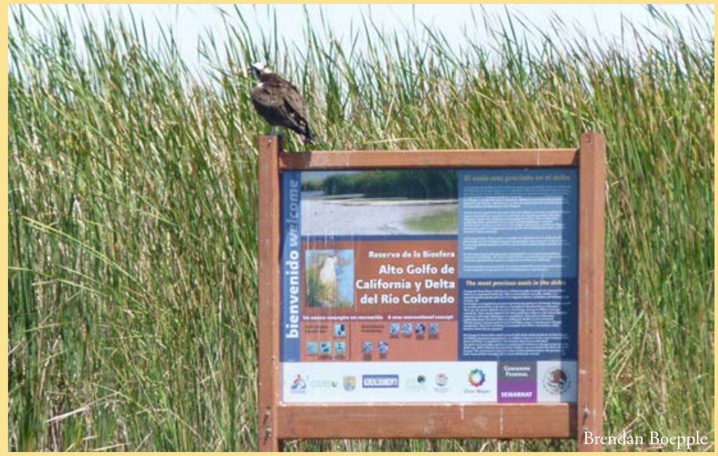
At first, the Bureau of Reclamation used surplus water from the lining of the Coachella and All-American Canals (previously lost to leakage) to fulfill Mexico's allotment. However, California's water rights were lowered and therefore the water was no longer surplus, and was instead needed to fulfill California's own allotments.[8]

Yuma Desalting Plant

The Yuma Desalting Plant (YDP) seemed to be the easiest solution to the problem. This large reverse-osmosis center in Yuma, Arizona, was intended to treat the saline return flows of the WMIDD, making them usable as part of Mexico's Colorado River allotment. Since its construction in 1992, however, it has only been used twice, both trial runs (one at one-third capacity and the other at two-thirds) to see what various effects the plant would have on water conditions.[9]

When it was built, the energy-intensive YDP cost $258 million. It has sat largely idle since that point, and it costs an average of $2.2 million each year to maintain. If in operation, this cost would be raised to between $33 and $42 million each year. This is in order to produce 68,000 acre-feet (af) annually, which is still 40,000 af short of the 108,000 af currently supplied to Mexico by the Yuma Area Bureau of Reclamation office. When one does the math, this comes out to anywhere between $305

Brendan Boepple



Brendan Boepple

and $480 per acre-foot for treated water,[10] compared to some agricultural water in the WMIDD, which (due to subsidies) can cost farmers as little as $4/af.[11] Therefore, the YDP is arguably not cost-effective at present.

Environmentally speaking, the YDP would also be damaging. The Cienega wetland has proven to be fairly resilient in the wake of the trial runs, as lost acreage returned quickly with renewed water supply.[12] In 1993, however, flooding and repairs in the WMIDD led to a temporary cut-off of flows, causing a 60% habitat loss. Running the YDP continuously without finding a replacement water source to the Cienega would result in the Cienega's eventual disappearance.[13] It would cause a 70% decrease in the amount of water delivered to the Cienega, and a three-fold increase in salinity levels, throwing the ecosystem entirely out of balance due to water-starved and salt-choked marshlands.[14]

The YDP is not without its advantages. The overarching reason for its construction was to help decrease the risk of long-term water shortages in the Colorado River's Lower Basin. The idea behind this is that agricultural return flows that are treated and sent to Mexico will leave more water in Lake Mead for use in the United States.[15]

Presently, the YDP is not in operation, and the Cienega is thriving. In order to fulfill its allotments to Mexico, the Bureau of Reclamation is engaging in a form of water transfer in which they lease water from willing sellers.[16] The ultimate goal is to create an actual market for water leasing, but if this does not happen the Cienega will once again be under threat.

[1]Jennifer Pitt, "Yuma Desalinization Plant and the Cienega de Santa Clara," Report to the Sonoran Joint Venture, www.sonoranjv.org/news/action_items/YDP_whitepaper.pdf.
[2]Peter McBride and Jonathan Waterman, *The Colorado River: Flowing Through Conflict* (Boulder: Westcliffe Publishers, 2010), 45.
[3]Osvel Hinojosa-Huerta, interview by author, Los Algodones, Baja California, Mexico, July 20, 2011.
[4]Jennifer Pitt, "Yuma Desalinization Plant and the Cienega de Santa Clara."
[5]Ibid.
[6]Ibid.
[7]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[8]Jennifer Pitt, "Yuma Desalinization Plant and the Cienega de Santa Clara."
[9]Osvel Hinojosa-Huerta, "Unheard Voices of the Colorado River" (presented at the State of the Rockies Event, Colorado Springs, Colorado, January 30, 2012).
[10]Bureau of Reclamation, *Yuma Desalting Plant*, accessed February 5, 2012, http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp.html.
[11]Kenny Baughman, interview by author, Wellton, Arizona, July 21, 2011.
[12]Osvel Hinojosa-Huerta, "Unheard Voices of the Colorado River."
[13]Ibid.
[14]Jennifer Pitt, "Yuma Desalinization Plant and the Cienega de Santa Clara."
[15]Bureau of Reclamation, *Yuma Desalting Plant*, accessed February 5, 2012, http://www.usbr.gov/lc/yuma/facilities/ydp/yao_ydp.html.
[16]Jennifer Pitt, "Yuma Desalinization Plant and the Cienega de Santa Clara."

Laws of the Colorado River Basin: Obsolete or Flexible for a Sustainable Future?

By Warren King

Key Findings:

-The Colorado River Compact has never been amended in its 89 years of existence.
-The current water adjudication process has hindered the ability of many Native American reservations to quantify their reserved rights within the basin.
-The lining of the All-American Canal and creation of the Yuma Desalting Plant pose potential threats to the Mexicali Valley and the Cienega de Santa Clara in Mexico.
-The Colorado River Compact's original wording places a delivery obligation on the Upper Basin which could potentially reduce Upper Basin water supplies in a time of shortage while Lower Basin supplies remain the same.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Author:
Warren King (Colorado College class of '12) is a 2011-12 Student Researcher for the State of the Rockies Project.

Will Stauffer-Norris

"The question that is posed is whether that law, that series of laws, those pieces (the Law of the River), can continue to be effective at leading us into the next hundred years?...I think the challenge before us is substantial. We have reached a point in our uses of the water of the basin where the Bureau of Reclamation has now acknowledged that we are fully consuming every drop of water that the basin produces. We have already reached that point, and the question is: How do we move ahead with obvious continuing demands and needs and interests of all of the seven states, the Republic of Mexico, the many Indian tribes that have reservations within this area, and all of the diverse interests we have in the water and the river?"

-Lawrence J. MacDonnell, Professor of Law and Colorado River Legal Scholar, speaking at the Colorado College, October 5th, 2011 as part of the State of the Rockies Project Speakers Series

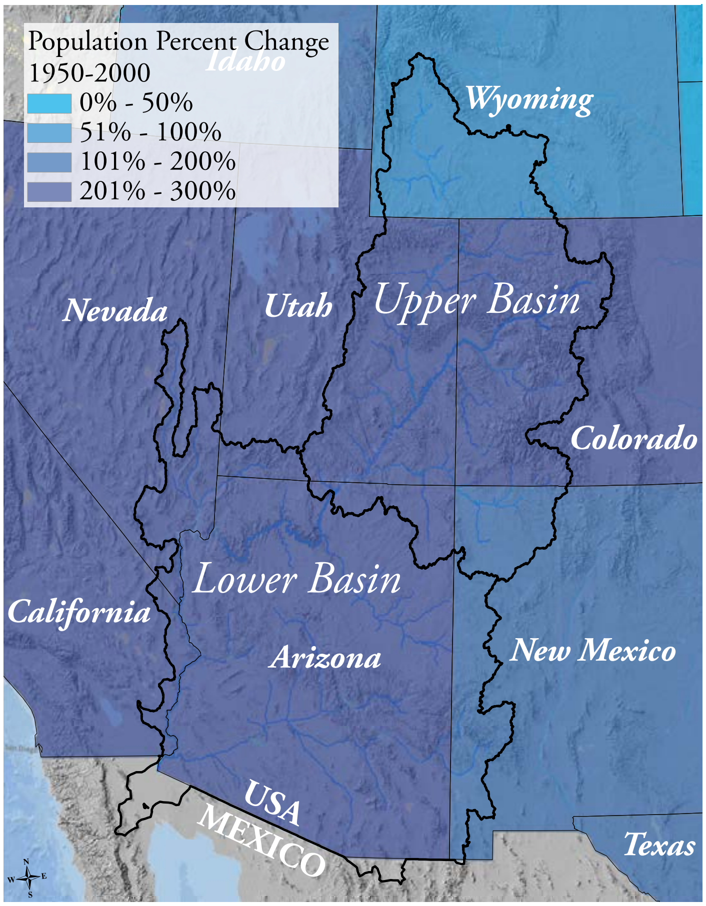
Introduction

In May of 1869 a young soldier, geologist, and explorer by the name of John Wesley Powell, along with a crew of ten others, set off down the Green River in Wyoming, in an effort to explore the Colorado River and contribute his findings to enhance American science.[1] The Colorado River Exploring Expedition may have been the byproduct of American expansionist idealism, but Powell differed from many of his time in his thoughts of the West. While the majority of Americans saw a land of plentiful opportunity and limitless expansion, Powell was one of the first to remark on its essential aridity and limited supply of natural resources. He challenged the popular belief that the growth of the American empire faced no environmental constraints.[2] Despite the efforts of those like Powell, development of the West boomed throughout the twentieth century. Few looked to oppose this notion of progress, and almost none acknowledged water availability as a limiting resource in future growth.

Of the seven states that make up the Colorado River Basin (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) at the time of Powell's expedition, only two- Nevada and California- had attained statehood, and the combined population of all seven basin states and territories was roughly 650,000.[3] Today, the combined population of the same seven states according to the 2010 census is 56,762,410,[4] with the majority of the growth occurring in the last 20 years. **Figure 1** provides a graphical representation of the growth trends witnessed in this region. In fact, Arizona's population jumped from 3.7 million in 1990 to over 5.1 million in 2000, a 40 percent increase, and Colorado's population rose by 30 percent, from 3.3 million to about 4.3 million in the same time period.[5] These trends in population growth are not predicted to slow any time soon: three of the six fastest growing states in the nation (Arizona, Nevada, and Utah) are located within the basin, with states like Arizona, Colorado, and Nevada estimated to become home to an additional seven million people over the next 30 years.[6] While population growth poses a significant challenge to the world in general, the Colorado River Basin, home to some of the driest states in the nation, faces a serious threat. An already over-allocated Colorado River (allocations currently exceed average flows by 15-20%) supplies water to nearly 30 million people, and despite human ingenuity, no amount of additional storage alone will be able to accommodate the expected growth in water demands associated with the estimated population growth.[7]

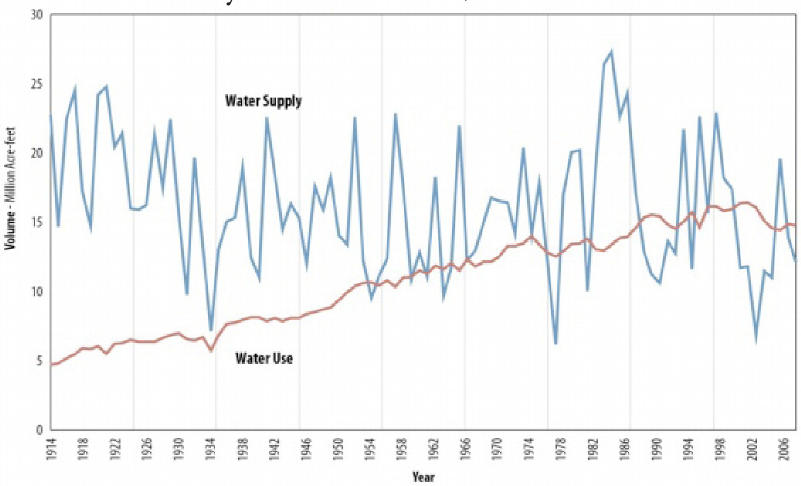
The trends in population growth witnessed in the basin region have been accompanied by an equally startling reduction in annual flow rates in the Colorado River. The annual flow rate as measured at Lee's Ferry, Arizona, over the past century is around 15 million acre-feet (maf).[8] The annual natural flow, as well as historic supply and demand, can be

Figure 1: Percent Change in Total Population by State, 1950-2000



Source: U.S. Census Bureau, *Demographic Trends in the 20th Century* seen in **Figure 2.** From 1934 to 1984, the ten-year running average has almost always been below the annual average of 15 maf as seen in **Figure 3**.[9] Of even greater concern is the drought that began a decade ago in 2002. From 2002 to 2005, the average annual flow was a mere 9.6 maf, the most severe multi-year drought on record.[10] Similar to the trend in population growth, those of precipitation and flow rate show no signs of reversing. According to the Bureau of Reclamation (BOR), mean annual runoff in the basin is projected to decrease by 8.5% by 2050.[11] Additionally, a projected mean annual temperature increase and 7.2-9.6°F by 2099 may result in peak snowmelt runoff 15-35 days earlier than average, which could translate into a drop in water supply for meeting irrigation demands.[12]

Figure 2: Natural Flow of the Colorado River at Lees Ferry and Water Use, 1914-2006



Source: U.S. Bureau of Reclamation

Currently this body of water is governed under what had been termed "The Law of the River," a series of legislative acts and court opinions that have shaped the way Colorado River water has been allocated, used, and conserved for the last century. It may be preferable, however, in light of the integrated ecosystems management school of thought and the realization that the way land is managed has a direct effect on water quality and quantity, to call this legislative-administrative compilation the "Law of the Colorado River Basin." Years of conflict and compromise have left us with the water allocations we see today; however, issues still persist. In the face of regional climate change and predicted flow reductions, Upper Basin states fear they face a delivery obligation to the Lower Basin, forcing them to take the brunt of the impact. Minority interests of Colorado River water, such as those represented by Native American reservations in the U.S. and those of the United Mexican States, have historically been ignored in practice, allowing years of legislation to be shaped without their active participation. In addition, the push for environmental protection in the basin has led many to argue for mandatory instream flows to protect vital riparian corridors. And all Colorado River water users and stakeholders face the challenge of working within the constraints of a set of laws that may not allow the flexibility needed to remedy all of these concerns. Perhaps one must ask, "Does the Law of the Colorado River Basin need to be amended?"

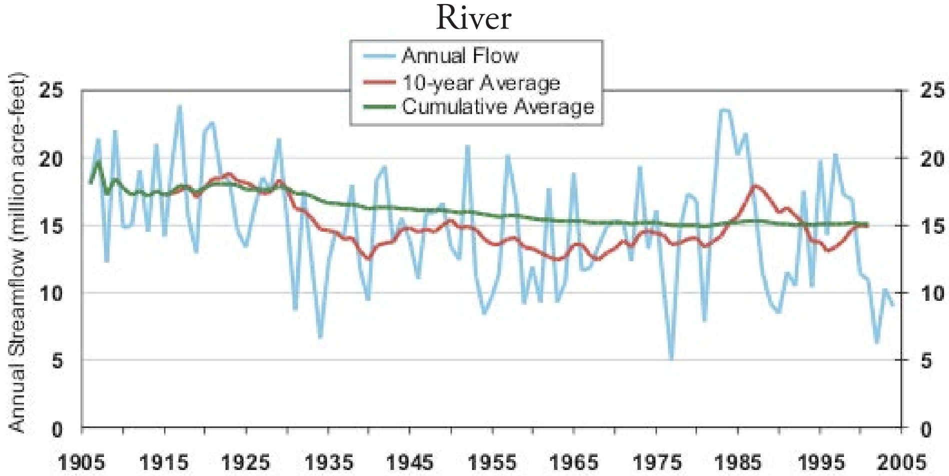
This question is complex even for experts, and nearly impossible to contemplate without at least a basic understanding of what constitutes the "Law of the River," and how it has evolved over nine plus decades. This year's *Report Card*, focusing entirely on the Colorado River Basin and its future sustainability, requires that we step back and consider the human constructs of laws and administrative arrangements (which largely underpin the physical infrastructure of dams, pipelines and reservoirs), that govern uses of water and thus conditions of land, people and environment in the basin. Too often society looks for easy answers to complex issues, resulting in more problems for the future. It is a challenge to understand enough about the Colorado River Basin in all of its multifaceted dimensions so that today's youth can be informed and active participants in the dialog about a sustainable future. The Rockies Project believes today's youth are up to the challenge. Thus, we put forth this *Report Card* to enhance the learning process.

Nine Decades of Law in Historical Perspective

Prior Appropriation: Conceptual Foundation for Water Scarcity

Historically water rights in the western United States have been governed under the doctrine of prior appropriation. The mantra of those who abide by this law is "first in time, first in right," meaning the first person to put a given quantity of water to "beneficial use" has a right to that water. Unlike

Figure 3: 10-Year Running Average Historic Flow of the Colorado River



Source: Western Water Assessment, *Colorado River Streamflow: A Paleo Perspective, The Lees Ferry Gaged Flow Record*, accessed March 27, 2012, http://wwa.colorado.edu/treeflow/lees/gage.html.

the riparian doctrine upheld in the East, title or ownership to property abutting a water source does not imply rights to that water. Prior appropriation as a legitimate law began its development with the passage of the Homestead Act in 1862. The Homestead Act, in an attempt to encourage the settlement of the West, allowed for the acquisition of "one quarter section or less of unappropriated public lands…at one dollar and twenty-five cents, or less, per acre"[13] by any individual who had never taken up arms against the United States, pending the filing of an application. If after five years the land was improved upon and used for the actual purpose of settlement and cultivation, it was to remain as property of the said individual. The passage of the Act was followed by increased development; however, the majority of those lands claimed were bordering waterways. The expenses associated with actually developing a farm, as well as the ambiguous language of the Act, proved to be a deterrent for most of the nation's population and an attractive opportunity for the likes of speculators, miners, and cattlemen. As a result much of the land claimed remained unoccupied or in the hands of those not intent on truly settling the region.

By the late 1800s, it became evident that the riparian doctrine that worked so well in the East was simply not suitable for the arid conditions of the West. In order to encourage expansion beyond riparian zones, a new sort of law developed, called prior appropriation. Those living in a particular region more often than not determine the laws that govern that area. This was the case in the development of water law in the West. Miners constituted a majority of the initial population to reach the West and as a result formed small "towns," or mining camps.

Early mining techniques were a water-intensive endeavor and in a water deficient area necessitated the creation of some code, which would dictate how water was allocated. The first case to address this issue was *Irwin v. Phillips* in California in 1855. This case looked to answer the question, "Can an individual divert water for mining even though that diversion causes inadequate water supplies for those users downstream?"[14] Several principles emerged from the opinion in this case: one being that the person who first applied water to a beneficial use would be entitled to use that amount of water in the future and would have priority over subsequent users; and another being that the court acknowledged this system had been created and agreed upon and was a legitimate measure for water allocation. It also established the idea of beneficial use and claimed riparian law irrelevant.[15]

As University of Wyoming professor of Law and Colorado River scholar, Larry MacDonnell, so eloquently describes the prior appropriation doctrine, "It staked out a definable interest in a limited common resource, measured by the actual capture and control of some portion of water…[and removed] it from the commons."[16] This easy to regulate, widely understandable system of water allocation allowed for the improvement of lands away from aquatic ecosystems and spurred the development of irrigation systems with which to accomplish this task. The prior appropriation doctrine over decades has been transformed into the preeminent water doctrine of the western United States today. It maintains that "proper and legal" water use requires that the water be diverted from a specific source, at a certain flow rate, to be used at a particular location, and must be put to beneficial use for a specific purpose, with any return flow usable by others.[17] The other key feature that has already been remarked upon, but is of sufficient importance to note, is that senior rights will always have priority over junior rights. A person's right is senior only if that water was verifiably put to beneficial use prior to another user's beneficial use of water. Many other court proceedings helped to clarify and reemphasize the doctrine of prior appropriation in the West and resulted in today's form of western water law.

Legal Focus on the Colorado River

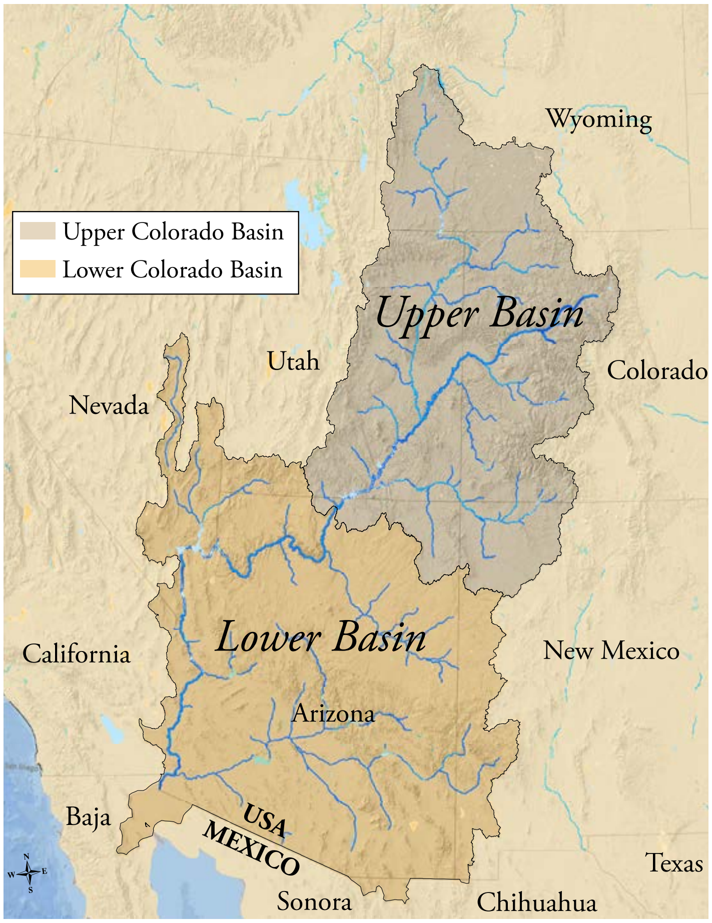
While prior appropriation has come to dominate water law in the West, the Colorado River itself is governed by a compilation of legislative acts and court opinions jointly titled "The Law of the River," or as I prefer to call it "The Laws of the Colorado River Basin." Beginning in 1902 and continuing to the present, over 30 opinions and laws have come to affect the way the waters of the Colorado River are managed, leading many to call it one of the most regulated rivers in the world.

Diversion and Apportionment

With such an immense and diverse set of laws governing this river system, it is helpful to separate and group together those rulings that attempt to deal with similar issues. The first set of directives affecting the waters of the Colorado River look almost exclusively at the erection of diversion structures and issues of apportionment. The first of these came into effect in 1902 when Congress passed the Newlands, or Reclamation Act. Under this act "…all monies received from the sale and disposal of public lands in [the West]…[would be] set aside, and appropriated as a special fund in the Treasury to be known as the 'reclamation fund.'" These funds were to be used in the examination and survey for the construction of irrigation works for "…the development of waters for the reclamation of arid and semi-arid lands in the said States and territories."[18] This act funded some of the first irrigation projects for the arid lands of 20 states in the American West, including the Yuma Reclamation Project, the first diversion structure and reclamation project on the Colorado River. In 1920, this initial push for development was renewed with the passage of the Kincaid Act (41 Stat. 600). The Kincaid Act directed the Secretary of the Interior to make a full and comprehensive study and to report on the possible diversion and uses of the waters of the Colorado River,[19] thus paving the way for what was to come: massive human constructs of water impoundment, diversion, and use.

The enthusiasm for putting this water to work continued into the 1920s, when in the course of only ten years, the foundation on which the Law of the River operates was developed. The year 1922 proved to be a landmark year with the adoption of the Colorado River Compact, as well as the rendering of the final opinion of the Supreme Court in the case of *Wyoming v. Colorado* (259 U.S. 419). *Wyoming v. Colorado*, while affecting the way the basin was managed, extended beyond this limited region by upholding the doctrine of prior appropriation regardless of state lines.[20] This decision issued on June 5, 1922, along with the fear that California would gain senior rights to an inequitable share of the basin's waters restricting Upper Basin use in the future, prompted the basin states to begin negotiations for, and finalize the Colorado River Compact on November 24 of that same year. The Colorado River Compact is regularly recognized as the cornerstone of the Law of the River. The Compact negotiations were riddled with dispute and in the end were saved only by the brokering of then Secretary of Commerce Herbert Hoover. Arizona held out as a signatory until 1944.

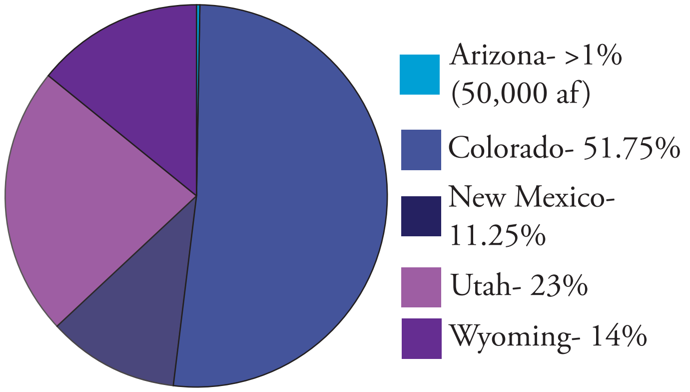
Figure 4: Colorado River Basin Map divided into Upper and Lower Basin



Although the Compact did not satisfy all of the original intents, it did "…provide for the equitable division and apportionment of the use of the waters of the Colorado River System."[21] Using estimated average annual flows, it apportions a total of 15 maf among the seven basin states, granting the Upper and Lower Basins the "exclusive beneficial consumptive use of 7.5 maf per annum," and with the Lower Basin given rights to an additional 1 maf per annum.[22] The Compact also states that the Upper Division is not to cause the flow of the river at Lee's Ferry, Arizona- the arbitrary dividing line between Upper and Lower Basin as established by the compact as depicted in **Figure 4** -to be depleted below an aggregate of 75 maf over any ten-year period.[23] Although the Colorado River flowed through the United Mexican States into the Gulf of California, no Mexican representative was invited to take part in the Compact negotiations, nor was any water apportioned to Mexico. It was stated, however, that if the U.S. was to allow Mexico any rights to these waters, that water would be supplied first from any surpluses and if that proved insufficient, the deficiency would be shared by both Upper and Lower Basins.[24] The Colorado River Compact has never been amended in 89 years.

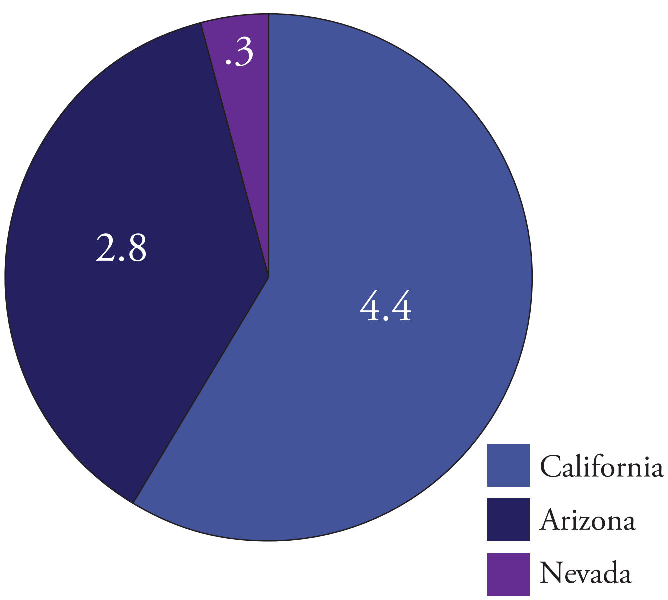
The Boulder Canyon Project Act, passed in 1928, authorized the construction of Boulder (Hoover) Dam and allowed the Lower Basin states of Arizona, California, and Nevada to use the stored water under contract with the United States.[25] It apportioned 300,000 af to the state of Nevada, 2.8 maf to the state of Arizona, and limited California to 4.4 maf per year, with Arizona and California allowed half of any surplus waters.[26] Arizona was also given exclusive rights to the Gila River.[27] Despite continued efforts by the states, such as the 1929 California Limitation Act (where California agreed to meet the obligations placed on it under the Boulder Canyon Project Act) and the 1931 California Seven-Party Agreement (where California listed the relative priorities of rights among the major water users in that state) the division of Lower Basin water shares was disputed until 1963 when it was finally settled in *Arizona v. California* (373 U.S. 546). Twenty years later, the Upper Basin states looked to do the same in terms of quantifying individual allocations for states; and did so with far more success, under the Upper Colorado River Basin Compact of 1948. This compact divided the 7.5 maf designated to the Upper Basin granting Colorado 51.75%, New Mexico 11.25%, Utah 23%, Wyoming 14% and Arizona 50,000 af per year.[28] The compact also reemphasizes the Upper Basin's delivery obligation in Article IV by providing principles that will guide the curtailment of water use by the Upper Basin so as not to deplete the flow at Lee's Ferry below that which is required under section III of the Colorado River Compact.[29] The Upper Basin Compact is an example of a well-thought-out system of allocations. **Figure 5** highlights the exact apportionments granted to each Upper Basin state under the Upper Colorado River Basin Compact.

Figure 5: Upper Colorado River Basin Apportionments



By 1963, most allocation issues had been resolved among the seven basin states. The Supreme Court Case, *Arizona v. California* (373 U.S. 546), put the last of those issues to rest. This case revolved almost exclusively around interpreting the Boulder Canyon Project Act of 1928. The Supreme Court's opinion, delivered by Justice Black, made more than a few determinations. First it was confirmed that Congress had allocated Colorado River water in the Boulder Canyon Project Act, giving 4.4 maf to California, 2.8 maf to Arizona, and 0.3 maf to Nevada, with any surplus being divided equally between California and Arizona.[30] **Figure 6** presents the finalized apportionments granted to each Lower Basin state. The Court, in response to Arizona's continued claim that it had a private right to the waters of the Gila River, also determined states have the exclusive rights to those tributaries originating within their boundaries, but designated the Secretary of the Interior as "water master" for the lower main stem, with the power to allocate water in times of shortage.[31] Furthermore, the Court decision built upon the progress made in *Winters v. United States* (207 U.S. 564), stating that Indian reservations along the Colorado River have rights to use approximately 1.0 maf from the river, the uses to be counted against the shares allocated to the states in which the reservations are located.

Figure 6: Lower Colorado River Basin Apportionments (maf)



While the preceding discussion of laws and court decisions highlights the early diversion and apportionment laws put into place, it is important to note that there are other stakeholders up to the 1940s who had little or no say in the struggle for water rights. Aside from the brief mention of Mexico in both the 1922 Colorado River Compact and the 1928 Boulder Canyon Project Act, there was only one serious attempt to include Mexico's interests in the discussion of allocation, and it did not occur until 1944. In November of that year, the Mexican Water Treaty (59 Stat. 1219) was signed in Washington, D.C. This treaty was created in an effort to reserve for Mexico the proper quantities of water they were entitled to from both the Colorado and Rio Grande Rivers. The section of the treaty regarding the waters of the Colorado is all that interests us here. The accord guarantees Mexico 1.5 maf per year and in times of surplus no more than 1.7 maf.[32] This statement is qualified later on in Article 10 subparagraph (b), stating that "In the event of extraordinary drought… the water allotted to Mexico… will be reduced in the same proportion as consumptive use in the United States."[33] Moreover, the treaty makes no mention of water quality, remarking on neither sediment nor salinity issues.

With so many competing and growing interests and a variable water supply, it became evident that more water was necessary. While augmenting supply by constructing large trans-basin diversions has never been out of the question, those entrusted with the task of increasing available water had a more reasonable solution- dams.

Storage: Troughs for the Thirsty

Until 1956, the Upper Basin had failed to obtain any funding for the installation of any form of water storage along the Colorado. In fact, the only major dam on the river up to that point was the Hoover Dam, the construction of which was completed in 1936. Twenty years later the Colorado River Storage Project Act (70 Stat. 105) (CRSP) was enacted, authorizing the construction of Glen Canyon, Flaming Gorge, Navajo and Curecanti dams "In order to initiate the comprehensive development of the water resources of the Upper Colorado River Basin…" and "…[make] it possible for the states of the Upper Basin to utilize…the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact…."[34] The new units allowed for river regulation, power production, and irrigation in the Upper Basin. Glen Canyon Dam, in particular, was installed as an insurance measure to make sure the Upper Basin could meet their delivery obligation to the Lower Basin. This act marked the beginning of a search for additional water.

The 1962 Filling Criteria for Lakes Powell and Mead followed the passage of the CRSP and was responsible for dictating how Hoover and Glen Canyon Dams were to operate during the filling period, or until Lake Powell reached elevation 3700 and Lake Mead's storage was simultaneously at or above elevation 1146.[35] It also prohibited the diminution of Lake Powell below elevation 3490 and Lake Mead below elevation 1123. (These elevation limits were to be surpassed in years to come.)[36] The coordinated and integrated operation of Lakes Powell and Mead pointed towards an early move in the direction of holistic management. These filling criteria were latter expanded upon in 1970 with the creation of the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, which provided for the coordinated operation of reservoirs in the Upper and Lower Basins and set conditions for water releases from Lakes Powell and Mead in normal, surplus, and shortage years.[37]

The 1968 Colorado River Basin Project Act built upon the CRSP and Filling Criteria in the effort to meet the future water needs of the basin. The object of the act was to "…provide a program for the further comprehensive development of the water resources of the Colorado River Basin and for use in the Upper as well as in the Lower Colorado River

Basin."[38] To accomplish this task, the Act authorized the construction of the Central Arizona Project (CAP), an initiative pursued by Arizona to transport water from the Colorado River to southern Arizona, including the major metropolitan areas of Phoenix and Tucson. It is currently the largest single source of "renewable" water supplies in the state, transporting close to 1.5 maf a year into Arizona.[39] Approval for the project was granted only after assurance that in a time of shortage California would maintain priority over the CAP. The Basin Project Act led to the creation of the Criteria for Long-Range Operation of Colorado River Reservoirs in 1970. Also worth noting is Congress's declaration that "…the satisfaction of the requirements of the Mexican Water Treaty from the Colorado River constitute a national obligation…."[40] This is one of the first times the United States as a country recognized its water delivery commitment to Mexico. The Basin Project Act was one of the last pieces of legislation to authorize a major water development initiative.

Water Quality Counts

With the push for increased development of the waters subsiding, new issues rose into the limelight, and in 1965 water quality became an international issue. The International Boundary and Water Commission (IBWC) Minute No. 218 was signed in March of that year. Its purpose was to consider measures to reach a permanent and effective solution to the salinity problem in Mexico. This minute recommended the United States construct a bypass channel from the Wellton-Mohawk Irrigation District into Mexico to deposit irrigation runoff- the source of the excessive salinity- below Morelos Dam.[41] In this manner those flows, which where contributing most directly to the increased Colorado River salinity levels, were excluded from the delivery to Mexico. In 1972, Minute 218 was replaced by Minute 241, which now required those waters excluded from Mexico's delivery to be replaced by substituting in an equal quantity of other waters.[42]

A more permanent solution to the Lower Colorado River salinity issue was reached one year later in 1973 with the creation of Minute 242. With the addition of this Minute,[43] the United States is required to adopt measures to assure that Mexico receives water with an average salinity of no more than 115 parts per million (ppm) ± 30 ppm over the average annual salinity at Imperial Dam.[44] This stipulation, however, applies only to those 1.36 maf of water delivered through Morelos Dam and not to the additional 140,000 af delivered via the southern boundary delivery at San Luis. Such an explicit directive regarding water quality had to this point been unheard of.

Pursuant to Minute 242, the Colorado River Basin Salinity Control Act was passed in 1974, authorizing a number of desalination and salinity control projects including the construction of a major desalination plant in Yuma, Arizona.[45] Unlike many of the previous IBWC Minutes the Salinity Control Act looks to improve "…the quality of water available in the Colorado River for use in the United States…" as well as in Mexico.[46] Salinity and water quality, in general, were being seen as, if not priorities, then at least issues that needed remedying.

What About the Environment?

The modern environmental movement began in the U.S. in the mid-1960s, and the rise of environmental concern for the Colorado River followed in the 1980s. With basic apportionment and storage issues out of the way, and more interest groups intent on having their voices heard, environmental concerns took on a more prominent role in the legislative history of the basin. The commencement of the Glen Canyon Environmental Studies (GCES) in 1982 marked this transition. Glen Canyon Dam had been constructed prior to the passage of the National Environmental Policy Act of 1969, and therefore did not have a formal environmental impact statement (EIS) prepared during the proposal period.[47] As a result, there was little or no monitoring being done on the environmental impacts the dam was having on downstream riparian zones such as those in Glen, Marble, and the Grand Canyons.[48] The study program reported in its findings that the operation of Glen Canyon Dam was and would continue to affect downstream environments.[49] In response to such findings, subsequent monitoring and scientific programs were developed in an attempt to mitigate these damages.

The GCES program was followed in 1983 by the La Paz Agreement. This agreement between the United States and Mexico marked a new step in international relations as the two countries recognized "the importance of healthful environment to the long-term economic and social well-being of present and future generations of each country…"[50] and agreed to cooperate to protect the environment in the border area. The agreement would "establish the basis for cooperation between the Parties for the protection, improvement and conservation of the environment and the problems which affect it."[51] It also addressed pollution control and prevention. Although it only targeted the limitrophe region,[52] it represented a significant step in terms of environmental protection along the Colorado River.

Similar to the La Paz Agreement, the Grand Canyon Protection Act of 1992 looked to resolve environmental issues in the basin by targeting a specific area for protection. It requires the Secretary of the Interior to operate Glen Canyon Dam "in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established…."[53] It goes on to define a new set of operating criteria for Glen Canyon Dam and calls for the completion of a Glen Canyon EIS.[54] The Grand Canyon Protection Act and the resulting 1995 EIS served as the guiding documents for the Glen Canyon Adaptive Management Program implemented in 1996, which required modification to Glen Canyon operations and established a participatory stakeholder group and ecological monitoring program.[55]

These few programs and acts provide only a specific supplementary role to the larger pieces of legislation, such as NEPA, the Clean Air Act, and the Endangered Species Act that play a much larger role in the protection of the river environment. The importance of these larger acts will be discussed in increased detail later in this section.

Surplus, Drought, and Mexico - Modern Challenges

The first decade of the twenty-first century has presented the Colorado River Basin with its fair share of trials and tribulations, leaving only one thing certain, uncertainty. In 2003, the Interim Surplus Guidelines for the basin were adopted. They recognized the increased demand for surplus water in the Lower Basin and the need for more specific criteria to assist the Secretary in making the annual surplus determinations. The guidelines are used annually to distinguish between normal, shortage, and surplus conditions.[56] The surplus conditions are broken down into four subsections, each dictating what actions are to be taken given various levels of surplus. Under all conditions the surplus waters are available for use by Arizona, California, and Nevada.[57]

In 1999, coinciding with the development of the Surplus Guidelines, began one of the worst droughts in recent basin history. Water years 2000-2005 represent the driest five-year period in over 100 years of record keeping, with the 2002 inflow into Lake Powell being the lowest ever recorded since it began filling in 1963.[58] Such an unprecedented reduction in flows prompted the creation of the Interim Shortage Guidelines in 2007. The Shortage Guidelines, based on the preferred alternative reviewed in the Final EIS for the Guidelines, provide for the adoption of specific interim guidelines for Lower Basin shortages and coordinated operations of Lakes Powell and Mead. Normal, shortage, and surplus conditions for Lake Mead are described in more detail in **Figure 7**. The coordinated operations of Lakes Powell and Mead are illustrated in **Figure 8**. This figure shows the elevation in feet of water and the corresponding live storage in maf of Lake Mead and the associated delivery that will take place given those specific conditions. It also illustrates the elevation and live storage of Lake Powell along with the release amounts that correspond with those specific levels or tiers. The levels of Lakes Mead and Powell are matched in this table and represent not only the conditions in Lake Powell that call for specific releases, but also the levels in Lake Mead that also necessitate a certain release from Lake Powell. It is in this way that the two reservoirs are operated in concert. The Shortage Guidelines also encourage the development of Intentionally Created Surplus (ICS), as a form of augmentation and conservation. "ICS" water is defined as water that has been conserved through extraordinary conservation measures, such as land fallowing.[59] It is anticipated that such development could yield 2.1-4.2 maf of additional ICS water.[60] The combined actions of coordinated dam operations and ICS creation should allow the basin to better deal with periods of drought like the present one.

Figure 7: Normal, Shortage, and Surplus levels for Lakes Powell and Mead based on Shortage Guidelines

Condition	**Lake Mead Water Elevation**
Surplus	<1,145 feet
Normal	1,075-1,145 feet
Shortage	>1,075 feet

Source: U.S. Bureau of Reclamation

Figure 8: Coordinated operations of Lakes Powell and Mead according to the 2007 Interim Guidelines

Lake Powell

Elevation (feet)	Operation According to the 2007 Interim Guidelines	Live Storage (maf)[1]
3,700	**Equalization Tier** Equalize, avoid spills or release 8.23 maf	**24.3**
3,636- 3,666 (2008-2026)	**Upper Elevation Balancing Tier[3]** Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	**15.5 - 19.3** (2008 - 2026)
3,575	**Mid-Elevation Release Tier** Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf	**9.5**
3,525	**Lower Elevation Balancing Tier** Balance contents with a min/max release of 7.0 and 9.5 maf	**5.9**
3,490		**4.0**
3,370		**0**

Lake Mead

Elevation (feet)	Operation According to the 2007 Interim Guidelines	Live Storage (maf)[1]
1,220	**Flood Control Surplus or Quantified Surplus Condition** Deliver > 7.5 maf	**25.9**
1,200 (approx.)[2]	**Domestic Surplus or ICS Surplus Condition** Deliver > 7.5 maf	**22.9** (approx)[2]
1,145	**Normal or ICS Surplus Condition** Deliver ≥ 7.5 maf	**15.9**
1,105		**11.9**
1,075	**Shortage Condition** Deliver 7.167[4] maf	**9.4**
1,050	**Shortage Condition** Deliver 7.083[5] maf	**7.5**
1,025	**Shortage Condition** Deliver 7.0[6] maf Further measures may be undertaken[7]	**5.8**
1,000		**4.3**
895		**0**

Diagram not to scale

[1]Acronym for million acre-feet

[2]This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

[3]Subject to April adjustments which may result in a release according to the Equalization Tier.

[4]Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada

[5]Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada

[6]Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada

[7]Whenever Lake Mead is below elevation 1,025 feet, the Secretary shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consent with applicable Federal Law.

Source: Bureau of Reclamation

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

In light of current conditions, and recognizing the possible affects of climate change, the SECURE Water Act was enacted in 2009. The SECURE Water Act provides authority for federal water and science agencies to work with state and local water managers to plan for climate change and other threats to water supplies. In 2010, Secretarial Order 3297 expanded upon the SECURE Water Act, establishing the WaterSMART program, as well as the basin study program. Together these programs look to pursue a sustainable water supply for the nation by establishing a framework to provide federal leadership and assistance on efficient use of water, sustainable use of natural resources, and the coordination of various conservation activities.[61] The SECURE Water Act and WaterSMART program are unique in that they focus on sustainability in an attempt to secure water for future generations. They are two of the latest sustainability initiatives being pursued not only in the Colorado River Basin but also nationwide.

In the last ten years the basin has been subject to legislation regarding surplus, shortage, and conservation for the future. Most recently, however, the subject at hand is once again Mexico. In 2010, the IBWC Minutes 316, 317, and 318 were passed. Minute 316 addressed the issue of the possible effects of the pilot run of the Yuma Desalination Plant on the Cienega de Santa Clara.[62] Minute 317 set up a conceptual framework for a bi-national council to assist in cooperative actions between the United States and Mexico.[63] Minute 318 attempted to mitigate the effects of the April 2010 earthquake in the Mexicali Valley by allowing Mexico to curtail its water supplies from the United States by storing unused water north of the Morelos Dam in U.S. facilities.[64] These international minutes represent growth in U.S.-Mexico relations and illustrate first-hand the cooperative potential that lies beneath the desire for more water.

The above discussion is but an overview of the multitude of laws, regulations, and court opinions that govern the Colorado River Basin. This compilation known as the "Law of the River" has come to dictate how the Colorado River operates and is managed. More so than precipitation patterns and seasonal snowmelt, human laws and resulting actions largely define conditions upon which the basin's survival depends.

The Elephant in the Room: Larger Scale Federal Legislation

The Law of the River has its foundations in a relatively uncontested set of laws, treaties and court decisions, each dealing specifically with the river in terms of allocation, quantity, or quality. It is appropriate to look beyond these established laws that are relatively narrow in scope, and identify those larger federal acts that also have a major impact on how this basin is managed. It seems almost obvious that a complete picture of the "Law of the River" cannot be painted without such information.

Some of the pieces of legislation included in the following section do not currently play a significant role in the management of the Colorado River. They have been included however because they represent potential avenues through which current policies could be forced to change and could affect the way the river is administered in the future.

The Wilderness Act is one of those acts that currently has little influence on management decisions in the Colorado River Basin, but could at some point in the future. Passed in 1964, the Wilderness Act set aside given tracts of land "to assure that an increasing population, accompanied by expanding settlement and growing mechanization, does not occupy and modify all areas within the United States and its possessions, leaving no lands designated for preservation and protection…."[65] It allowed Congress to set aside designated lands to remain unimpaired for future use in their primeval state. Section 4(b) of the act states that each agency administering a wilderness area is responsible for administering that area for such other purposes for which it may have been established. Following the Winter's Doctrine, which established federally reserved water rights for Native American tribes, and the McCarran Amendment, which requires the U.S. to participate in state, general adjudication proceedings to establish federal water rights, one could argue that minimum instream flows are necessary to uphold Section 4(b) of the Wilderness Act. Therefore, a wilderness area could have federally reserved water rights to secure instream flows. In order to affect the Colorado River, however, sections of the river would have to be declared wilderness areas. It is evident that this is a stretch in terms of influencing decisions made regarding the basin; however, it is a route with at least a touch of promise.

The Wild and Scenic Rivers Act of 1968 could be applied in a similar fashion to enhance the protection of the Colorado River. The Wild and Scenic Rivers Act aims to protect for current and future generations select rivers with "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, and other similar values" in free flowing condition.[66] For a river to qualify, the Act stipulates the river be free flowing without any diversion impoundment or other modification structures, possess one of the outstanding values, and be in the public's interest to protect.[67] Currently only three tributaries to the Colorado are designated as wild and scenic rivers under the act; Fossil Creek and the Verde River in Arizona and the tributaries of the Virgin River in southwestern Utah.[68] Unfortunately, none of these tributaries has a significant impact on the Colorado River and therefore their protection under the Act does little to improve its quality. However, there is promise in the legislation itself. If more influential tributaries were to be classified as wild and scenic rivers, that extended protection could force water quality standards to be altered throughout the basin. However, the Colorado River and its tributaries are some of the most highly regulated waterways in the world. It would be hard for any major tributary in the basin to meet the strict qualification standards imposed by the act.

The National Environmental Policy Act (NEPA), signed into law by President Nixon in 1970, directed the federal government to "use all practicable means and measures… to create and maintain conditions under which man and nature can exist in productive harmony."[69] Looking past this lofty and rather ambitious goal, NEPA became a successful piece of legislation through its requirement that all federal agencies prepare an environmental impact statement (EIS) on any major federal actions significantly affecting the quality of the environment.[70] In the case of the Colorado River, for example, NEPA would require an EIS to be prepared prior to the construction of a dam or other diversion structure. All of the major dams and diversion structures built on the Colorado were approved and completed prior to the passage of this legislation. This does not mean, however, that it has become irrelevant in respect to the river. NEPA continues to influence what is and is not approved along and around the Colorado River. The operation of the Yuma Desalination Plant provides a first-hand look at NEPA at work today. A pilot run was completed from 2010-2011, pending the findings of an environmental assessment (EA) that resulted in IBWC Minute 316 in which the United States, Mexico, and NGOs provided the water necessary to sustain flows to the Cienega de Santa Clara. The plant is not currently in operation; however, if it were to be put back on line another EA or EIS would be required under NEPA to evaluate the effects on the environment.

Another act of significance to the Colorado River Basin is the Federal Water Pollution Control Act, or Clean Water Act (CWA). Enacted in 1972, the CWA bans the unpermitted discharge of pollutants into surface water without a permit. The CWA established the National Pollutant Discharge Elimination System (NPDES), a national permit program, and requires dischargers to apply technology-based controls.[71] The CWA is the predominant piece of legislation regarding water quality of the waters of the United States. It has protected the quality of the Colorado River since its entrance into law. The CWA regulates point source pollution extremely well, but is at a loss when it comes to non-point source pollution. Thus, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act (i.e., agricultural runoff) is not required to have a permit.[72] A 1987 amendment to the act addresses the need for greater leadership in addressing non-point source pollution; however, as of today non-point sources continue to impair the waters of the Colorado.

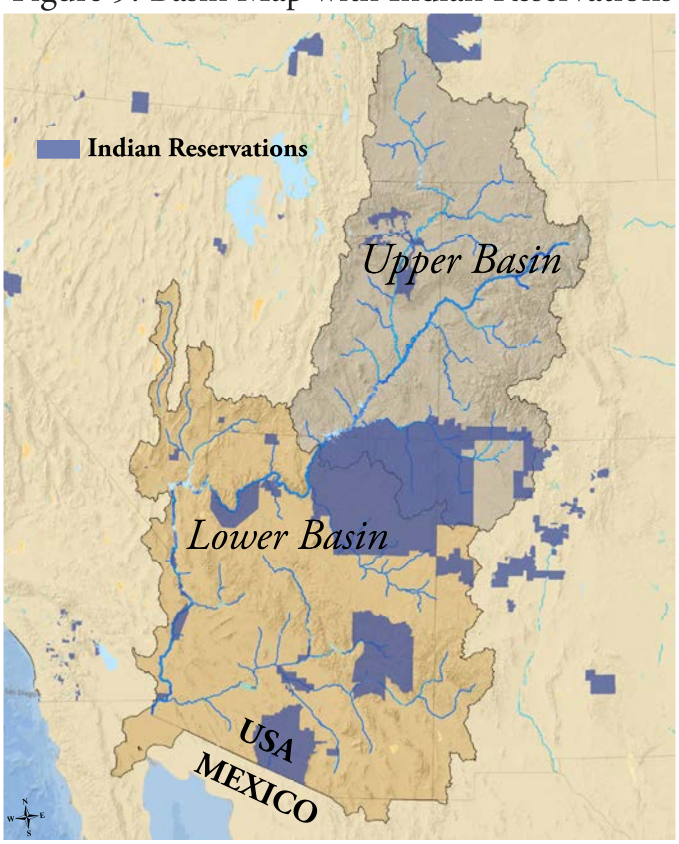
The Endangered Species Act (ESA), passed in 1973, possesses the power to become one of the most formidable acts in terms of environmental protection not only in the basin but also across the country.[73] The ESA defines species in two categories, those that are "threatened" and those that are "endangered." Those species listed are then published in the Federal Register and reviewed every five years. The qualification of the species dictates how much and what kind of protection they are to receive. Under the ESA § 9, all entities are prohibited from "taking" any endangered species, which includes significantly modifying a species habitat; and under § 7, all federal agencies are required to insure that their actions are "not likely to jeopardize the continued existence of any endangered species or threatened species."[74] Though the ESA contains many more stipulations, these mandates are

Brendan Boepple

most applicable to the Colorado River. The river itself is currently home to four endangered fish species; the bonytail chub, razorback sucker, humpback chub, and Colorado River squawfish, with hundreds of other threatened or endangered species calling the basin home.[75] As a result, the ESA has the ability to greatly limit actions taken by federal agencies along the river.[76] Although it has not been done yet, a favorable interpretation of §9 of the ESA by the court could in the future require mandatory instream flows to ensure that the habitats of these fish are not impaired to the point where it could qualify as "taking."

While high salinity and sediment counts present the greatest environmental problems on the river, the leaching of heavy metals and other toxins from abandoned mining facilities poses a threat to the quality of the water as well. The Colorado River Basin has always been an area of active mining with rich reserves of coal, natural gas, and uranium. The byproducts of these activities include highly toxic contaminants that, if improperly disposed of, can leach into water systems damaging the quality of the water itself and harming those who rely on it. Many of these sites along the river have been abandoned over the years, leaving piles of tailings exposed to the elements. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund, was passed in 1980 as a way to deal with contaminated sites even if no liable party could be found. CERCLA established a strict liability system for releases of hazardous substances and developed a "superfund" program (now defunct), to assist with remediation costs.[77]

Figure 9: Basin Map with Indian Reservations



Source: U.S. National Land Atlas Federal and Indian Lands Areas

Through CERCLA many of the once contaminated locations have been restored. In fact, only one major uranium site remains along the river in Moab, Utah, and remediation efforts are currently underway.[78] In many ways CERCLA is reactive. It attempts to assign liability to a responsible party and where none can be found allows the EPA to use the resources at hand to assist in the clean-up. In such cases the land has already been impaired. However, it can also be proactive. Stringent liability standards and the harsh criminal penalties that accompany them work as a deterrent for future generation of hazardous waste or illegal dumping. Both in its retroactive and preventative form, CERCLA has worked well to protect not only the Colorado River but also lands throughout the United States.

The "Law of the River," in the traditional sense and as seen by many, includes the Colorado River Compact, the Boulder Canyon Project Act, the California Seven-Party Agreement, the Mexican Water Treaty, the Upper Colorado River Basin Compact, the Colorado River Storage Project Act, the opinion in *Arizona v. California*, the Colorado River Basin Project Act, the Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, IBWC Minute 242, and the Salinity Control Act.[79] However, by including only these aforementioned acts and opinions, you are limiting your view of the law, and leaving out some of the guiding principles.

Challenges to a Sustainable Basin: Major Issues

Despite this extensive set of laws, opinions, minutes, and provisions, inequities and disputes remain an ever-present feature of the Colorado River Basin. The twenty-first century presents some real and imminent threats to the basin. The waters of the Colorado are already over-apportioned and current water shortages will be compounded by predictions of decreased regional precipitation, as well as soaring population growth trends. Currently there are no flows reserved for the environment; Native American reservations are struggling to secure the water they need; Mexico faces issues of water quality and quantity; the Upper Basin continues to struggle over the question of whether they have a delivery obligation, or whether there is an over-arching obligation not to deplete. All of this hinges on one big question: Is the "Law of the River Basin" flexible enough to deal with these new challenges?

Native American Water Rights Issues

There are 34 Native American reservations situated within the Colorado River Basin including the Navajo Nation, the largest in the United States. **Figure 9** depicts all major Native American reservations within the Colorado River Basin. The establishment of these reservations predates by decades formal decisions on "dividing the waters" and their inhabitants have been struggling to attain the amount of water they need. The lack of useable water has lead to harsh living conditions in many regions. In fact, the highest rates of waterborne illness in the United States are found among Native tribes.[80] Many tribes have, and continue to fight for, increased apportionments; however, the root of this problem may lie in the Law of the River itself.


John Nestler

Efforts to Include Native Americans: Legislative History

While the "Law of the River" governs the waters of the Colorado in a broad sense, there is a subsection of law that has developed to dictate how these waters will be apportioned to Native American reservations, beginning with the individual reservation treaties signed by tribes throughout the United States. While the treaties differ, they all accomplish a similar task. They transfer rights or lands from Native American tribes to the U.S. and reserve other lands for the tribes. These treaties implicitly look to make farming communities out of the tribes. No treaty explicitly reserves water for these purposes; however, the reserved rights doctrine assumes reservations and public lands that have been set aside should have adequate water to fulfill the purpose for which that land was reserved.[81] While most water rights in the West are based on priority, determined by when water was first put to beneficial use, reserved rights have priority dating back to when those reservations were first established.[82] This was not legally recognized until *Winters v. United States* in 1908.

The General Allotment, or Dawes Act of 1887, was created in an attempt to parcel reservation lands into individual holdings, with the objective of instilling a sense of property ownership in the Native American community. It was seen as a step towards "civilizing" those once thought of as uncivilized. Under the Dawes Act, each head of a family was granted one-quarter section (160 acres), and each single person or orphan over eighteen was given one-eighth section.[83] The idea was that with such expansive lands families would take up farming and grazing practices while simultaneously giving up a nomadic way of life that required large ecosystems. If making reservations into agricultural societies was the intention of the act, would it not seem reasonable to assume that water rights be designated along with the lands? What good does 160 acres do if the "owner" cannot irrigate it? The Supreme Court, in *Winters v. United States*, answered these questions, affirming that it was indeed the intent of Congress to convert the Native Americans into an agrarian people, and therefore that water was reserved. While this stipulation allows for water to be allocated in the future, it does not address the problem up front and because of that secures no actual water rights for reservations. The Merriam Report, completed in 1928, assessed the economic and social impacts of the Dawes Act and revealed the disastrous outcome of the allotment policy on Indians. As a result the Indian Reorganization Act of 1934 repealed the Dawes Act in an attempt to reduce state influence over Indian resources and eliminate the sale of reservation lands to non-Indians.[84]

In 1905, the opinion delivered by the Supreme Court in the case of *United States v. Winans* was a step in the right direction in terms of securing water rights for Indian reservations. In this case, Lineas and Audubon Winans owned a fishing operation on the Columbia River that utilized fish wheels.[85] The Yakima tribe contested that this operation was depleting their fish supply that had been granted to them in a treaty signed in 1855. The Winans claimed that when Washington became a state, it regained power over all property regardless of existing treaties.[86] This included those treaties previously made with Native Americans. As a result, the Winans were denying the Yakima their "right of taking fish at all usual and accustomed places in common with the citizens of the territory," as well as their right to access the fishing grounds.[87] The Supreme Court ruled that a state entering the union does not rescind previous treaty rights granted to Native Americans and that an individual may not prohibit Native Americans access to those places. Although this case does not explicitly deal with water rights for reservations in the Colorado River Basin, it was an important step in confirming that reservation treaties would be upheld and that the rights granted to tribes under them would be sustained.

The Supreme Court case, *Winters v. United States*, decided in 1908 did address the water issue. The opinion, given by Justice McKenna states, "It was the policy of the

Government, it was the desire of the Indians to change those habits to become a pastoral and civilized people"; "The lands were arid and, without irrigation, were practically valueless"; without the cession of waters the lands would be "… valueless, and civilized communities could not be established thereon."[88] Put simply, it was determined that Congress had set aside land for Indians, giving them less land so they would become agrarian and civilized. To take away water rights would be to take away this potential. It could not have been Congress's intent to leave the tribes destitute and therefore Native American reservations have implied federally-reserved water rights. It was this opinion that entitled reservations to claim an allotment of water.

At the very foundation of the Law of the River lies the Colorado River Compact of 1922. Despite the opinion of the Supreme Court in the Winters case, no tribal representatives were present or even invited to the negotiations of the Compact. The lack of a minority tribal voice is evident from the limited mention of Native American water rights. In fact, Article VII is the only place in the Compact where Indian rights are mentioned. Article VII states, "Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian tribes."[89] In the entire Compact one sentence is given to this issue. In retrospect it appears that the authors of the Compact were either unconcerned or simply ignorant. It is a telling sign that the heart of the Law of the River fails to address the issue of Native American water rights, and is one of the major reasons why this issue persists today.

It was not until 1952 that this issue was again brought up. The McCarran Amendment was a statute passed by Congress that requires the U.S. to participate in state, general adjudication processes to establish federal water rights. Although Indian reservations are domestic sovereigns, they exist in a fiduciary relationship with the United States government.[90] In other words, they rely on the federal government for protection of their legal rights. Therefore, although reservations have implied water rights under the reserved rights doctrine, those rights still have to be quantified in state courts. The United States, under the McCarran Amendment, waives its sovereign immunity and takes part in the state adjudication process on behalf of the reservations to quantify those rights. The water that will be transferred to the reservations is a portion of that which has been allocated to the state under the Compact, making reserved water right adjudications highly controversial.

Only in 1963 was a process established for determining what quantities were necessary for reservations. This precedent came out of the opinion given by Justice Black in the Supreme Court case *Arizona v. California*. This case determined that the amount of practicably irrigable acreage (PIA) would set the standard for what was a sufficient amount of water. PIA is defined as that water necessary to fulfill all future, as well as present, needs of the Indian reservations, including enough water to irrigate all lands that are practicably irrigable.[91] The court ruling also resulted in the reservation of nearly 1.0 maf of Colorado River water for the Chemehuevi, Cocopah, Yuma, Colorado River, and Fort Mohave Indian reservations on the lower mainstem of the Colorado.[92] The principles established in *Arizona v. California* represent the most recent major precedents set in regard to Native American water rights.

Will Stauffer-Norris, The headwaters of the Green River in Wyoming's Wind River Range

Current Path to Obtaining Water

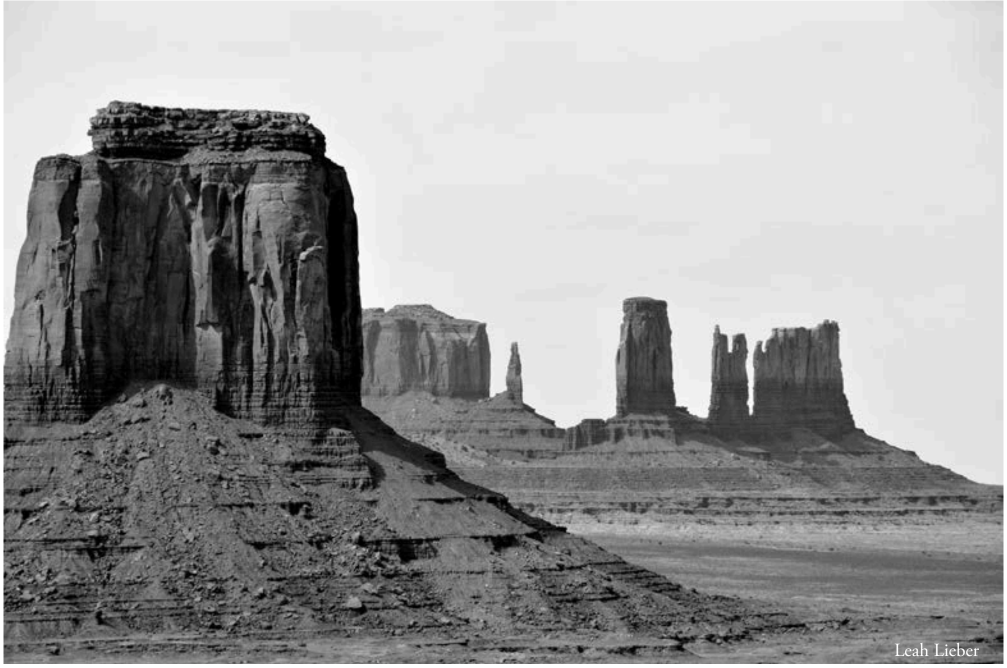
Through this convoluted legal framework, reservations can supposedly acquire the reserved water rights to which they are entitled. Currently, water right disputes between reservations and states become quantified in one of two ways. The most common approach is through adjudication. This process can be initiated through a suit by the United States against all other water users from a source, or once governmental immunity is waived can be initiated by the United States, submitting itself to the suit by joining voluntarily. The second option is available due to the passage of the McCarran Amendment. Quantification through adjudication frequently utilizes the practicably irrigable acreage standard set in *Arizona v. California*. Seeking quantification in this way poses some serious problems for Native American reservations that wish to gain their water rights. First and foremost it is a painstakingly long process. It requires every water rights holder to go to court to defend his or her right. Each user must prove when he/she first put water to "beneficial use" in order to establish his/her position in the water use order. This means that if a reservation in Arizona wants to quantify their rights on the Colorado River, it would require all users in Arizona of the Colorado to enter into this process. The Navajo Nation, for example, has Upper as well as Lower Basin rights, and rights in Arizona, New Mexico and Utah. Hypothetically, in order to receive their full entitlement, all users from both states and those from the Upper and Lower Basin portions of Arizona would have to appear in court. With so many stakeholders involved, the proceedings would last decades. The adjudication process is slowed down further by various interest groups' desire to slow the process. Because reservations have federally-reserved rights established at the time of the reservation agreement, their water rights trump almost all other rights in the state. Therefore, it is in no one's interest, aside from the reservation's, to quantify the reserved rights.

Due to the arduous nature of the adjudication process, many tribes look to avoid it by instead settling their rights in formal agreements with the state. Congress still must approve such agreements; however, such an approach to adjudication can drastically reduce the time, energy, and costs associated with quantification. Such agreements tend to have a much higher rate of success. According to David Getches, from 1982 to 1997, negotiated settlements had been reached with some 20 tribes in 10 states.[93] States more readily agree to such settlements because they often result in a reduction of the quantity of water the tribe initially claimed. Tribes benefit from these arrangements as states often provide funding to assist in the development of those waters. In this way tribes not only receive some assured water- though not the full entitlement- but also receive assistance with the construction of the diversion and transport structures necessary to bring the water onto the reservation.

Issues

While quantification through both adjudication and settlement provide valid avenues for Native Americans to secure their water rights, we still see many reservations with well below adequate water supplies. It is possible to point out four principal barriers to actually recognizing these reserved rights; they include poverty, jurisdictional issues, other parties' attempts to slow the process down, and a general lack of law pertaining to the subject.[94]

The truth of the matter is that Native American reservations, especially those in the Colorado River Basin, have insufficient funds to properly represent their interests in court and erect the infrastructure necessary to utilize their entitlements. The median earnings in 1999 for all American Indian males (who worked full time, year round) was just under $29,000, while the median earnings for all males nationwide was over $37,000 for the same year.[95] The median earnings for males of the Navajo Reservation, the largest tribe in the Colorado River Basin, fall below both of these averages at $26,000 a year. Perhaps more telling than median earnings is the poverty rate. In 1999, only 12.4 percent of the total U.S. population was living in poverty compared to 25.7 percent of all American Indians and Alaskan Natives, and 37 percent of all Navajo tribal members. Such extensive poverty represents a serious obstacle in the effort to secure water rights. The adjudication processes not only take a large amount of time but also consume an equally large amount of money in the form of legal expenses. While the U.S. pays for the majority of the legal expenses, reservations will often hire private attorneys as well in order to assure that their interests are properly represented. Even if the quantification settlements are resolved, reservations often lack the funds to construct the infrastructure necessary to transport the water to a location where it can be put to use. As Bidtah Becker, attorney for the Water Rights



Leah Lieber

Unit of the Navajo Nation Department of Justice, stated, “If we weren’t poor we wouldn’t be having these issues.”[96] She makes a very good point. If more was done in the way of financial assistance for the creation of infrastructure and the hiring of personal attorneys, quantification settlements could be pursued, allowing tribes their full reserved rights and the ability to develop their newly apportioned water.

The lack of wealth is not the only hindrance, however; jurisdictional issues often slow and complicate the process to an even greater extent. Some tribal reservations cross state boundaries and exist in more than one state at a time. This complicates the water adjudication process as it expands the number of parties involved. Nowhere is this issue more visible than in the Navajo Nation. The Navajo Nation Reservation has land in Arizona, New Mexico, and Utah. Because of this, the reservation’s water rights, when quantified, must be made up of portions of each state’s water allocation. **Figure 10** illustrates the multiple jurisdictions crossed into by the Navajo Nation. To complicate matters further the reservation also has claims to both Upper and Lower Basin waters. With so many competing interests it is easy to see why the Navajo Nation has not yet settled all of their water rights disputes. These types of jurisdictional problems could easily have been avoided had tribal representatives been given the opportunity to take part in compact proceedings when the water was first being allocated. Issues like this will persist if minority interests are not better represented in negotiations over water issues in the Colorado River Basin.

Figure 10: Navajo Nation with State, Basin, and other Indian Reservation Boundaries

Source: U.S. National Land Atlas Federal and Indian Lands Areas

While the adjudication process itself is lengthy, other parties often attempt to slow the process down further. As mentioned before, quantification proceedings require that all individuals with a stake in the river prove their rights in court. Often those with the most junior rights are the ones who suffer from Native American claims. Junior rights holders are subject to the possibility of losing part or all of their water rights. This, in turn, provides them with an incentive to draw out the process. Such a strategy can lead to an out-of-court settlement as opposed to a fulfillment of all claimed water rights, therefore reducing the amount of water being granted to tribes. Although the federal government is legally entrusted with the duty of protecting Native American rights, some claim that government lawyers themselves are not aggressive enough in the courtroom.

Although a lack of wealth, jurisdictional issues, and the interests of other parties all encumber the process, the overarching issue is the general lack of law on the subject. Since the passage of the Dawes Act in 1887, only three major court cases and three major pieces of legislation have affected the way we deal with Native American water rights issues. As Bidtah Becker explains, “There is so little law that most of the time is spent litigating legal questions. This makes it hard to get to the factual issues.”[97] Bidtah makes a good point with this statement. If you look at any one of the major court cases referred to, whether it be *United States v. Winans*, *Winters v. United States*, or *Arizona v. California*, the majority of the opinions given are dedicated to answering legal questions like, “Does a state entering the union negate previous treaty agreements?”; “What was Congress’s intent in establishing reservations?” and “How do you quantify reserved rights for reservations?”[98] Aside from *Arizona v. California*, none of these cases allocated any water to reservations. While these cases undoubtedly contributed to progress in the field of Indian water rights, there are still more questions to be answered before the Native Americans can swiftly obtain those rights belonging to them.

Mexican Water Rights Issues

The United States and Mexico share a 1,800-mile border and two major river systems, one of them being the Colorado.[99] For the last 112 miles of its journey the river passes through Mexico on its way to the Sea of Cortez. Through the creation of infrastructure, such as Morelos Dam and an intricate series of canals, the water is diverted to serve the needs of thousands of people, including the growing metropolitan area of Tijuana. **Figure 11** highlights the major pieces of infrastructure erected in Mexico. Despite a yearly allocation of 1.5 maf, Mexico faces problems similar to those currently being experienced by both the Upper and Lower Basin states where U.S. population growth rates are booming, agricultural production is on the rise, and precipitation events are predicted to decrease. All of this translates into one prominent issue- there’s just not enough water.

Figure 11: Major Mexican Colorado River Infrastructure

Source: Microsoft Bing Maps

Legislative History

Getting Water

Mexican interests, like those of Native American tribes, have been largely ignored for the better part of the last century in regards to water allocations of the Colorado River. In fact, the Colorado River Compact, the cornerstone of the "Law of the River," mentions Mexico only in passing in article 3(c), which states:

> "If, as a matter of international comity, the United States of America shall hereafter recognize in the United States of Mexico any right to the use of any waters of the Colorado River System, such waters shall be supplied first from the waters which are surplus over and above the aggregate of the quantities specified in paragraphs (a) and (b); and if such surplus shall prove insufficient for this purpose, then, the burden of such deficiency shall be equally borne by the Upper Basin and the Lower Basin, and whenever necessary the States of the Upper Division shall deliver at Lee Ferry water to supply one-half of the deficiency so recognized in addition to that provided in paragraph (d)."[100]

The phrasing "If America shall recognize in the United States of Mexico any right to the use of water…" is the most telling sign in this article. Not only does the Compact not allocate any water to Mexico, but it also does not even admit that Mexico has a right to any Colorado River water. Furthermore, if in the future the United States does recognize Mexico's right, they are to receive only surplus waters from the river. Though the Upper and Lower Basins are intended to make up any "deficiency," it is difficult to foresee a situation in which those additional waters would be delivered. Again, as was the case with Native American representatives, the exclusion of Mexico from Compact proceedings has only made resolutions down the road more difficult.

It was not until 1944 that Mexico was formally recognized by the United States as having rights to any portion of water whatsoever. The signing of the Mexican Water Treaty that year was a monumental step in U.S.-Mexico relations, and in securing water for Mexico. The Treaty granted Mexico rights to water from both the Colorado and Rio Grande Rivers. It also sets the framework for implementing these measures, establishes the International Boundary and Water Commission (IBWC), and sets priorities for water allocation in the face of drought.[101] Section III, article 10(a) guarantees for Mexico an annual quantity of 1.5 maf.[102] Mexico is also entitled to any surplus waters, the total quantity of which, in addition to the guaranteed 1.5 maf, is not to exceed 1.7 maf annually.[103] Despite the guaranteed allocation to Mexico, the treaty itself is flawed in several ways. First, it gives little thought to future planning of water resources. The ideas of sustainability and an obligation to future generations were not of great concern, nor did they even exist, to the drafters of the treaty.[104] Of even greater concern is the glaring absence of any quality provisions. Not once in the treaty are there any guidelines to ensure the water that arrives in Mexico is of usable quality.[105] The treaty does possess a positive attribute in that it was left relatively general, granting future interpreters greater flexibility and discretion.[106]

Quality Control

Beginning in the 1960s irrigation projects in the United States began to drastically increase salinity levels in the Colorado, impairing the water that made its way to Mexico. At one point salinity levels were so high they began to kill a portion of the Mexican crops.[107] In response to this problem the IBWC passed Minute 218 in 1965. Minute 218 "…to consider measures 'to reach a permanent and effective solution' of the problem of salinity of the waters of the Colorado River which reach Mexico."[108] Highly saline drainage water from the Wellton-Mohawk agricultural district in Arizona was being introduced into the Colorado River just miles before reaching Mexico. As a result the Minute recommended the U.S. construct an extension to the current drainage canal that would allow these waters to be discharged below Morelos Dam.[109] Minute 241 replaced Minute 218 in 1972 when Mexico contested that they were not seeing the improvement in water quality they had expected. Minute 241 directed the United States to discharge Wellton-Mohawk water below Morelos Dam at the rate of 118,000 af per year and replace the diverted waters with those of an equal quantity and lower salinity.[110]

IBWC Minute 242 was the first addendum to the Mexican Water Treaty that really generated the results both parties were looking for. Minute 242 requires the United States to adopt measures to assure that the water that arrives at Morelos Dam has an average salinity of no more than 115 ppm ± 30ppm over the average annual salinity at Imperial Dam.[111] This stipulation, however, applies only to those 1.36

maf of water delivered through Morelos Dam and not to the additional 140,000 af delivered via the southern boundary delivery at San Luis. To assist in meeting these obligations, Minute 242 recommended the extension of the Wellton-Mohawk bypass drain, and the construction of an additional bypass drain that would feed into the Santa Clara Slough.[112]

In 1974, pursuant to Minute 242, the Colorado River Basin Salinity Control Act was passed. Referred to above in the "Law of the River," the Salinity Control Act authorized the construction of the Yuma Desalination Plant in Arizona in order to treat the bulk of the Wellton-Mohawk wastewater. It also called for the lining of the Coachella Canal in California and the construction of a well field along the southern border of the United States.[113] While the act established measures to reduce salinity in the river in many ways, it was more of an attempt by the U.S. to reclaim "wasted" water. The Yuma Desalination Plant would allow for Wellton-Mohawk water to be put to beneficial use in the United States rather than being discharged into the slough in Mexico; the lining of the canal would eliminate seepage to Mexico; and the construction of a well field would allow the U.S. to extract whatever water aquifers on the U.S.-Mexico border may contain. In actuality, the authorization of many of these projects would come to inspire problems in the future.

Environmental Protection

Another critical feature absent from both the Colorado River Compact and Mexican Water Treaty is the protection and preservation of the environment in Mexico. Article 3 of the Treaty lists the priority of beneficial uses citing (1) domestic and municipal uses, (2) agriculture and stock-raising, (3) electric power, (4) other industrial uses, (5) navigation, (6) fishing and hunting, and (7) any other beneficial uses which may be determined by the Commission.[114] Nowhere are ecological questions referenced. In an attempt to remedy this issue, the La Paz Agreement was adopted in 1983 to "...establish the basis for cooperation between the Parties for the protection, improvement and conservation of the environment and the problems which affect it, as well as to agree on necessary measures to prevent and control pollution in the border area."

The issue of ecosystem preservation was not formally considered again until 2000 and the creation of Minute 306. Minute 306 was a conceptual framework for cooperation between the United States and Mexico to engage in joint studies that include possible approaches to ensure water for ecological purposes. It prompted the development of current environmental protection and restoration programs such as the Multi-Species Conservation Plan for the Lower Colorado River (MSCP) that attempts to mitigate losses of endangered species that results from poor river management and consumptive uses on the Lower Colorado.[115] Efforts by NGOs, as well as other interested parties, have assisted in environmental protection of the region as well. In 2001, the Cocopah Tribe, whose reservation encompasses portions of the limitroph region, provoked talks of creating an international protection area.[116] NGOs along with Arizona Fish and Wildlife began efforts to further this concept. The environmental group, Pro Natura, has been doing its part in Mexico as well. To date, they have secured 5,000 af per year to maintain environmental instream flows and hope to purchase rights for an additional 45,000 af per year.[117] Despite the nonexistence of environmental protection measures in either the Colorado River Compact or the Mexican Water Treaty, efforts have been made to ensure the continued proliferation of the riparian ecosystems.

Recent Legislation

In just the past two years an additional three Minutes have been agreed upon illustrating an increase in cooperative efforts. Minute 316, passed in 2010, authorized the pilot run of the Yuma Desalination Plant constructed subsequent to the Salinity Control Act. It looks predominantly at the effects the operation of the plant may have on the Cienega de Santa Clara. The water that created the wetland in 1976 and sustains the wetland today is the wastewater transported from the Wellton-Mohawk District. If the plant is in operation, a portion of that water will be reclaimed and returned to the Colorado River for consumptive use. As a result the wetland is subject to reduced in-flows. To mitigate any harm to the wetland, the United States, Mexico, and various NGOs each arranged to supply 1/3 of the water that would be removed due to YDP operations.[118] Minute 316 provides an example of international collaboration and demonstrates the push for environmental protection.

The year 2010 brought with it the creation of two more IBWC Minutes, 317 and 318. Minute 317, simply put, established a framework for a binational council.[119] Minute 318, like 316, showed again increased international cooperation. In April 2010, a massive earthquake struck in Mexico, destroying miles of irrigation infrastructure in the Mexicali Valley. As a result Mexico was unable to utilize its apportionment of Colorado River water. Minute 318 attempted to mitigate the effects of the earthquake on Mexico by allowing the deferment up to 260,000 af of its annual allotment of water while repairs are made to the irrigation system.[120] Through the year 2013, the United States has allowed Mexico to store their unused water in American facilities. Steps like those taken in the 2010 IBWC minutes show hope for future U.S.-Mexico relations pertaining to the Colorado River.

Issues

The recent successes in U.S.-Mexico cooperation are impressive; however, they do not mean there are not serious problems still in need of attention. The Yuma Desalination Plant, the All-American Canal Lining Project, and the implementation of Drop 2 Reservoir all pose serious challenges for the Mexican side. Though all separate projects, each has the ability to greatly reduce the quantity of water reaching Mexico. It is important to have an understanding of these current matters in order to identify what in the current legislation must be amended to remedy them.

The Lining of the All-American Canal

Stretching 80 miles from the Imperial Dam near Yuma, Arizona, this canal provides Colorado River water to an agricultural mecca and sizable population of residents in southern California. The All-American Canal provides a classic illustration of the historically poor relationship between the United States and Mexico in issues pertaining to the Colorado River. The construction of the canal was authorized under the Boulder Canyon Project Act of 1928 and completed in 1942.[121] For the majority of its existence the canal existed unlined. Due to the porous nature of the channel some 67,600 af of water being conveyed to California would seep out, making its way down to Mexico and replenishing subsurface aquifers along the way.[122] This water is not counted as a part of the delivery required of the United States to Mexico and provides an essential source of water for numerous farmers in the Mexicali Valley. Since the construction of the canal, Mexico has installed numerous pumping units to retrieve approximately 18,000 af per year.[123] In 1988, the USBR sought approval for a plan to line the canal in an effort to eliminate the water that was being "lost" to Mexico. In 1994, the final environmental impact statement was completed; later that year a Record of Decision was signed, allowing for the lining of a 23-mile segment.[124] Construction began in 2007 and was completed in early 2010.

The proposition and subsequent EIS quickly sparked international debate. The lining of the canal would eliminate the majority of the seepage that had made its way to Mexico, resulting in economic loss to farmers and rampant environmental degradation of the Mexicali Valley. One of the major issues brought up was the applicability of U.S. environmental statutes such as NEPA, the Endangered Species Act, and the Migratory Bird Treaty Act to trans-boundary situations. These issues were addressed again in 1999 when the USBR conducted a reexamination of the EIS and in 2005 when a biological analysis was completed. The conclusion of both reports was that no consultation with the USFWS was required for the trans-boundary effects on Mexico. In 2006, a Supplemental Information Report was issued, stating no substantial changes or new information existed and therefore no supplemental EIS was required.

The Consejo de Desarrollo Economico de Mexicali, A.C. v. U.S. case in 2007 was prompted by a group of parties filing for injunctive relief.[125] They argued that the project was an unconstitutional deprivation of property, a usurpation of water right, a breach of affirmative duty owed by the Secretary to implement the project in such a manner consistent with reasonable utilization of water in the Mexicali Valley, and that the project violated NEPA, the Endangered Species Act, the Migratory Bird Treaty, and the Settlement Act, among many other things.[126] Systematically the court dismissed these complaints. The court ruled that the Tax Relief and Health Care Act of 2006 rendered the claims made by the appellant moot. Under the Tax Relief Act, the lining project was granted permission to proceed "notwithstanding any other provision of law."[127] This essentially preempted the court from making any ruling regarding the necessity of an additional EIS.

The environmental consequences of this decision are fairly self-explanatory and the economic impact it will have on Mexicali Valley farmers may be substantial. What is less obvious, however, is the precedent that this decision may have made. In this instance, Congress opted to ignore trans-boundary environmental issues and instead chose to proceed with development at all costs. The resulting issue is that this example has set the precedent that access to Colorado River water will supersede environmental protection in the future-not only in Mexico but in the U.S. as well.[128] The negotiations that took place regarding the lining project were ultimately

Brendan Boepple

one-sided. The issues raised by Mexico were quickly dismissed. Osvel Hinojosa-Huerta, Director of the Water and Wetlands Conservation division of the Mexican NGO ProNatura, summed up the events as "an example of how negotiations can fail" and an illustration of fighting instead of collaboration.[129] Although viewed as a success by some in the U.S. (it won the 2010 APWA Project of the Year Award), it is in just as many ways an example of a failure; a failure of environmental protection and more importantly a failure of international negotiation. Despite the resulting environmental degradation and a dangerous precedent, the lining of the All-American Canal must be viewed as a learning process. The lessons learned here could and must be applied to the decisions to operate the Yuma Desalination Plant and any other action on the Colorado River threatening the trans-boundary environment.

Yuma Desalting Plant

The Cienega de Santa Clara is a 40-hectare slough in Mexico, home to eight wetland varieties, 250 bird species including the endangered Yuma clapper rail, and one of the last remaining stopping grounds for North American migratory birds.[130] It was "artificially" create in 1972 following the passage of IBWC Minutes 241 and 242. Minutes 241 and 242 attempted to remedy the salinity crisis in Mexico by requiring the United States to discharge Wellton-Mohawk irrigation water below Morelos Dam, keeping it out of the Colorado River, and separate from the 1.5 maf requirement. As a result the water was diverted and dumped below the dam, creating the thriving wetland present today. Although unintentionally created, the Cienega has helped to restore life to the now desolate delta region.

However, this area of biological proliferation is in danger once again. In 1974, the Colorado River Basin Salinity Control Act was passed, authorizing the construction of a desalination plant in Yuma, Arizona. The plant now fully constructed and with two pilot runs completed utilizes the diverted agricultural runoff from the Wellton-Mohawk Irrigation District in its desalination process. The treated water is then returned to the Colorado River to be counted towards the delivery requirement to Mexico. The resulting brine is left to flow into the Cienega. Two major problems arise here. First, the Cienega will see reduced inflows. This is likely to reduce the size of the slough and adversely affect the ecosystem. Second, the water that does make its way to the Cienega will have such high concentrations of salinity that it may be of little use or, in fact, harmful to the environment. In essence, it appears that full utilization of the Yuma plant's capacity would result in the destruction of the Cienega.

It is important to note, however, that in 2010, prior to the 18-month pilot run of the plant, the IBWC passed Minute 316 that asserted no harm would come to wetlands in Mexico as a result of the plant's operations. This was assured through the joint commitment of the United States, Mexico, and various NGOs each of whom agreed to make up 1/3 of the water the Cienega lost during the pilot run. In this way the parties cooperated to ensure the Cienega would remain unimpaired.

The real issues arise when one looks towards the future. If the YDP was to become fully operational, would such an agreement be made between parties? Replacing water taken from the Cienega would essentially go against the intent of the plant, which was to reduce the amount of water lost to Mexico. It is difficult to imagine a scenario in which such an agreement would be made in the future.

The concerns raised above focus predominantly on the environmental impacts of operating the Yuma Desalination Plant, but there are efficiency concerns as well. For example, is the amount of energy required to run the plant worth the small amount of water treated? According to Ken Bowman of the Wellton-Mohawk Irrigation District, the plant is "…a complete waste of money."[131] During the 2010-2011 pilot run, only 30,000 additional af were recovered.[132] Additionally, due to the salinity requirements put in place after the passage of IBWC Minute 242, the United States attempts to deliver water with the highest salinity mandated by the Minute. As a result, much of the purified water has brine added back to it prior to its entrance into the Colorado River. Jennifer McCloskey of the USBR Yuma office actually stated, "It is our job to put salt back."[133] The process is full of inefficiencies and may be the reason the plant has not yet been put to full use.

The Yuma Desalination Plant is a prime example of the issues Mexico may have to face in the coming years. Changes in regional precipitation patterns along with the over-allocation of current supplies means that full utilization of the Yuma plant may become a reality in the coming years. However, given the inefficiencies associated with the process, as well as the potential environmental impacts that may result from the plant's operations, it is now more than ever necessary to address these issues and find alternative solutions. The Yuma Desalination Plant is not the answer to the looming water crisis. If anything, it will only compound the existing problems facing those reliant upon the Colorado River Basin.

Drop Two Storage Reservoir

Drop Two Storage Reservoir is the newest creation in a series of reservoirs being built by the USBR in an attempt to reclaim non-storable flows. Non-storable flows consist of that water, which has been ordered downstream from Parker Dam but cannot be delivered. A delivery may be cancelled for various reasons, including a precipitation event that makes the order unnecessary. Due to a lack of sufficient storage capacity, this water is typically unable to be put to beneficial use and as a result makes its way to Mexico.[134] In 2006, Public Law 109-432 (the same statute that authorized the All-American Canal Lining Project) directed Reclamation to design, construct, and operate a water storage facility to eliminate this loss.[135] With construction completed, Drop 2 now allows for the capture of close to 72,000 af per year of non-storable flows.[136] Under the new system this water will be collected and re-released later to meet delivery obligations to Mexico. The issue posed here is similar in nature to that discussed in the All-American Canal Lining case. From an environmental perspective the reduction in excess flows making their way to Mexico could potentially threaten the limitroph and delta regions even more

and from an economic and social perspective this will contribute in a loss of available water for farmers and municipalities who until recently received this water separate from the Treaty obligation. It is hoped that lessons learned in the All-American Canal fiasco will be applied here in order to limit the impact on the environment and reduce the strain in relations between Mexico and the United States.

The Law of the River: Rigid Relic or Flexible Foundation for the Future?

The twenty-first century poses a plethora of problems, none of which could have been envisioned by the drafters of the Colorado River Compact in 1922. The idea of global climate change was nearly sixty years away from being conceived; the combined population of the western states and territories was only 650,000; the United States as a nation had just begun to tap into its vast natural capital, and environmental consequences were largely ignored; Mexican and Native American interests were largely ignored; and no one believed the mighty Colorado would ever be stretched to the point of over-allocation. Nonetheless, in 2011 climate change has become a very real phenomena and regional climate models project changing precipitation patterns in the basin area. The population of the seven basin states has soared to over 56 million as of 2010, stressing the water resources of an arid land. Legislation such as NEPA, the Endangered Species Act, and the Clean Water Act have been passed, representing the change in social opinion towards a greater degree of environmental consciousness. Mexican and Native American interests have since started to be addressed. And allocations of water now exceed the average flow of the Colorado River by 15-20%.

Of course, no one in 1922 could have predicted such drastic and varying changes in the basin. It is a waste of time to critique the prophetic abilities of the drafters of the Compact. Instead the issue at hand is to analyze the complex legislation that has evolved since the passage of the Compact and determine whether this set of laws has the inherent flexibility necessary to deal with the problems facing the Colorado River Basin and its water users today.

A Rigid Relic?

The most obvious examples of rigidity in the "Law of the River" are highlighted in the ongoing Mexican and Native American water rights issues, in shortage scenarios resulting from changes in regional precipitation patterns, and the environmental degradation caused by the absence of secured instream flows.

The situation with Mexico has presented several issues each of which underscore the Law of the River's rigidity. Most relevant to this discussion are the All-American Canal Lining Project, the construction of Drop 2 Reservoir and the operation of the Yuma Desalination Plant. In each of these instances it is obvious that Mexican interests were largely ignored during the initial planning process. This represents a failing of the Law of the River in facilitating the international discussion required to handle trans-boundary issues. The IBWC was created in an effort to manage such negotiations; however, in light of recent events it has failed to operate effectively. Instead of opening discussion on the lining project the case was brought to court, and it could be argued, resulted in an unfair resolution. In the cases of Drop 2 and the YDP, it remains to be seen whether the Law of the River and IBWC will be able to responsibly and equitably resolve any resulting problems.

Concerns dealing with Native American water rights are an even more striking example of the failings of the Law of the River. Nearly all reservations within the Colorado River Basin lack the water necessary to support their populations. The original 1922 Compact mentioned tribal water rights only in passing in Article VII, stating, "Nothing in this compact shall be construed as affecting the obligations of the United States of America to Indian tribes."[137] Despite this vague promise no tribes were brought to the table for discussion and all of the waters of the Colorado River system were subsequently fully apportioned, explicitly reserving none for reservations. While succeeding court cases such as *Winters v. United States* and *Arizona v. California* established reserved water rights, as well as a process through which reservations could quantify these rights, the Law of the River itself has done little to assure these interests are fulfilled. The adjudication and quantification process is long and expensive, often exceeding the funds available to the reservations. Even if a tribe is eventually able to quantify their rights, they frequently lack the infrastructure necessary to transport the water to where it is needed. There has been little done to remedy these persisting issues. It seems as though the Law of the River lacks the flexibility necessary to implement such necessary measures.

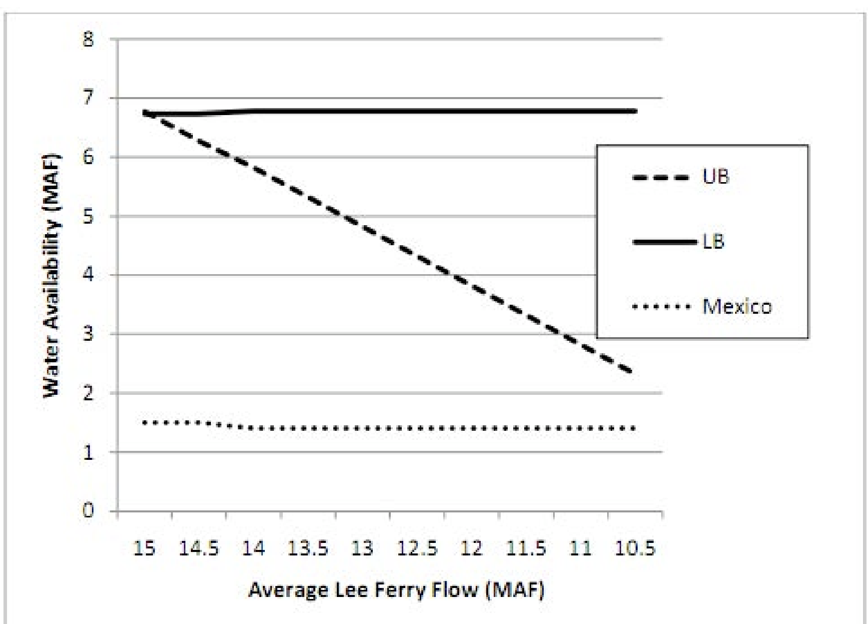
One of the most obvious examples of the Law of the River's inability to deal with today's problems is seen in the environmental damage that has resulted from the over-allocation of the Colorado River and the lack of secured water rights for instream flows. The Colorado River itself is home to four different endangered fish species, including the hump-back cub, Colorado pikeminnow, bonytail, and the razorback sucker. While the introduction of invasive species and habitat loss have contributed to this decline, one remedy to biodiversity loss is more water.[138] Nowhere is the environmental degradation of the basin more evident than in the delta region. The scene depicted by John Wesley Powell upon his arrival in the Delta is no more. The Colorado has not flowed all the way to the sea since the mid-1990s and the riparian environment has suffered as a result. Much of this can be attributed to the Law of the River's lack of environmentally conscious legislation. The Compact itself never addresses the environment. At the time it was written there was no precedent for reserving water rights for instream flows. The recent shift in public values towards a more ecologically conscious mind-set is not reflected in any of the original legislation. On top of this the programs that have been instituted to address the environmental issues are not working well.[139] Many are too specific and address only certain ESA goals rather than focusing on an ecosystem wide approach.[140] As a result a particular species may see a recovery; however, the riparian ecosystem as a whole may continue to suffer. The effects of projects such as the All-American Canal Lining and the Yuma Desalination Plant show first-hand the inflexibility of the Law of the River. Even today when environmental priorities have become important, projects such as these have been given approval despite the environmental impacts. That the Mexicali Valley was allowed to dry up as a result of the lining of the canal shows that working within the framework of the Law of the River, development will take precedent over the environment.

Perhaps the strongest argument made against the continued usefulness of Law of the River, however, lies in the wording of Article III paragraph (d) of the 1922 Compact. Here the Compact states, "The states of the Upper Division will not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75,000,000 acre-feet for any period of ten consecutive years…."[141] It is this sentence that has sparked an intense debate over whether the Compact contains a collective obligation not to deplete or whether the real burden

Will Stauffer-Norris, Flaming Gorge Dam

falls upon the Upper Basin, which is faced with a delivery obligation to the Lower Basin. Given regional climate change projections that predict reduced precipitation, the Upper Basin states fear that a strict interpretation of the Compact may require them to deliver the required 75 maf to the Lower Basin over any ten-year period regardless of available water. Lake Powell was constructed in an effort to hedge against this; however, with Lake Powell's levels plummeting from roughly 22 maf in 1998 to 14 maf in 2010, and quickly filling with sediment (nearly 100 million tons annually) thus reducing storage capacity, there is no way of knowing if Lake Powell can be relied on to meet this obligation in the future.[142] Therefore, if precipitation patterns change, the Upper Basin will be forced to reduce its consumption in order to meet this delivery requirement. As overall water levels drop, so will water available for use by the Upper Basin. Water available to the Lower Basin, however, will remain consistent. **Figure 12** presents a generalized graph of the possible resulting scenario where the Upper Basin is forced to make annual deliveries thus giving up a high percentage of its 7.5 maf, while the Lower Basin and Mexico retain their initial allotments. High water years, such as the one in the spring of 2011, make those in charge too quickly forget about this very important issue. Everyone is willing to cooperate and in the abstract publicly state his or her commitment to collaboration. The trouble will arise in the coming years as water levels begin to drop substantially. Under such a scenario, people will again most likely act in their own self-interest, and in the case of the Lower Basin states that most undoubtedly means returning to a strict interpretation of the Compact in an effort to secure as much water as possible. The resulting inequality points out the incompatibility of the Law of the River with one of today's most important issues.

Figure 12: Upper Basin Delivery Obligation



Source: Colorado River Governance Initiative, "Rethinking the Future of the Colorado River," *Draft Interim Report of the Colorado River Governance Initiative,* December, 2010.

A Flexible Framework?

Just as the Law of the River has proven itself a rigid relic of the past, so has it shown instances of flexibility. There are multiple examples where working within this framework has led to beneficial results. Those most important to highlight include the IBWC Minute process, the 2007 shortage guidelines, and the Arizona-Nevada water sharing agreement. Many of the successes of the Law of the River stem from the 1922 Compact's relatively vague language; because it does not impose many stringent requirements it is open for interpretation and therefore allows for subsequent legislation and programs to be passed to remedy any issues that may develop over time.

The IBWC began as the International Boundary Commission (IBC) in 1889 as a way to facilitate talk between Mexico and the United States, and was later renamed the International Boundary and Water Commission (IBWC) following the Treaty with Mexico in 1944. It has since become the most important venue in resolving international disputes over the Colorado River. While created prior to the passage of the Colorado River Compact, the IBWC plays an essential role in amending the Law of the River. Much of this success is derived from the minute process. Unlike passing legislation in the United States, where Congress must ratify the bill, the IBWC has the authority to create minutes. Through this process the IBWC is able to quickly address concerns arising between the United States and Mexico. IBWC Minute 242, for example, lead to the adoption of measures to reduce the average salinity in the waters reaching Mexico by the United States, thus beginning the process of remedying the salinity crisis in Mexico. More recently Minute 318 was created to mitigate the effects of the 2010 earthquake on Mexico by allowing for the storage of Colorado River water to Mexico in the United States. In both cases the flexibility of the Law of the River allowed for the use of the Minute process which itself has become one of the more adaptive tools used in governing the Colorado River.

The creation of the 2007 Interim Shortage Guidelines is another example of this flexibility. Faced with the prospect of changing precipitation patterns, and in the midst of one of the worst droughts on record in the basin, the basin states were able to come together to create a set of specific interim guidelines for Lower Basin shortages and coordinated operations guidelines for management of Lake Powell and Lake Mead. The Shortage Guidelines also encourage the development of Intentionally Created Surplus (ICS), as a form of augmentation and conservation. These two programs should allow the basin to better deal with periods of drought. The '07 guidelines are exemplary of how legislation can be passed within the existing framework to tackle new issues.

Most hopeful of all, however, has been the Arizona-Nevada water sharing and storage agreement. It is one of the best examples of interstate water banking in existence today. Under this agreement the Arizona Water Banking Authority agreed to recharge and store unused Colorado River water in its groundwater aquifer for Nevada.[143] This way Nevada would have the water resources it needs to continue to grow while at the same time ensuring Arizona's unused water did not make its way to California where the region would become dependent upon it.[144] Such an agreement illustrates the flexibility inherent in the Law of the River and the Colorado River Compact.

Concluding Remarks

While the issues that remain, such as the unexpected future of the Cienega de Santa Clara, declining native fish populations, and under-served Indian reservations all highlight the rigidity of the Law of the River, one can just as easily look at the minutes created by the IBWC, the water sharing programs established in Arizona and Nevada, and the 2007 Shortage Guidelines as examples proving that disputes and issues can be resolved using the existing framework of the Law of the River and the Compact. What may be most important to acknowledge is what Southern Nevada Water Authority President Patricia Mulroy stated: "The Compact inextricably binds them [the basin states] together in a framework that is as rigid or as flexible as the parties as a whole desire."[145] That is to say, it may not be necessary to choose between stringently adhering to the Law of the River and creating a new Compact. What is most important is the political will of those involved to cooperate. However, given the issues that have arisen, and those that are destined to come, might it not be time to formalize this spirit of cooperation that Patricia Mulroy so vehemently defends? What is needed at this point is an amendment or an addition to the Law of the River, which will take into account the enduring issues and formalize a process for discussion and action on those existing and forthcoming issues.

[1]Donald Worster, "A River Running West: Reflections on John Wesley Powell," Journal of Cultural Geography 26, no. 2 (2009): 113-126.
[2]Ibid.
[3]University of Virginia Library, *Historical Census Browser*, accessed August 1, 2011, http://mapserver.lib.virginia.edu/php/start.php?year=V1870. (Census data unavailable for territories Arizona, New Mexico, Utah, Wyoming.)
[4]United States Bureau of the Census, 2010 Decennial Census, Census 2010 Summary File 1 (SF 1) 100-Percent Data.
[5]National Research Council of the National Academies, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability* (Washington, D.C.: The National Academies Press, 2007).
[6]Western Governors' Association , "Water Needs and Strategies for a Sustainable Future," (Denver, 2006).
[7]Doug Bennett. Interviewed by author, Las Vegas, Nevada. July 18, 2011.
[8]Western Water Assessment, *Colorado River Streamflow, a Paleo Perspective: The Lees Ferry Gaged Flow Record*, accessed August 6, 2011. http://wwa.colorado.edu/treeflow/lees/gage.html.
[9]Ibid.
[10]Ibid.
[11]US Bureau of Reclamation, Basin Report: Colorado River, accessed November 8, 2011. http://www.usbr.gov/climate/SECURE/factsheets/colorado.html.
[12]Ibid.; Western Water Assessment, *Colorado River Basin Climate: Paleo, Present, Future*, accessed November 8, 2011. http://wwa.colorado.edu/colorado_river/docs/Colorado_River_Basin_Climate.pdf.
[13]*The Homestead Act of 1862*, Public Law 37-64, U.S. Statutes at Large 12 (1862).
[14]*Irwin v. Phillips*, et al. 5 Cal. 140 (1855).
[15]Ibid.
[16]Lawrence J. MacDonnell, "Out-of-Priority Water Use: Adding Flexibility to the Water Appropriation System," *Nebraska Law Review* 83, no.485 (2004).
[17]Ibid.
[18]*National Reclamation Act of 1902*, Public Law 57-161, U.S. Statutes at Large 32 (1902).
[19]*Kincaid Act of 1920*, 41 Stat. 600 (1920).
[20]*Wyoming v. Colorado*, 259 U.S. 419 (1922).
[21]*The Colorado River Compact of 1922* art. I (1922).
[22]*The Colorado River Compact of 1922* art. III, §(a) (1922).
[23]*The Colorado River Compact of 1922* art. III, §(d) (1922).
[24]*The Colorado River Compact of 1922* art. III, §(c) (1922).
[25]*Boulder Canyon Project Act*, Public Law 70-642, U.S. Statutes at Large 32 (1928).
[26]Ibid.
[27]Ibid.
[28]*Upper Colorado River Basin Compact*, Public Law 81-37, U.S. Statutes at Large 63 (1948).
[29]Ibid.
[30]*Arizona v. California*, 373 U.S. 546 (1963).
[31]Ibid.
[32]*The Mexican Water Treaty*, 59 Stat. 1219 (1944).
[33]Ibid.
[34]*The Colorado River Storage Project Act*, Public Law 485, U.S. Statutes at Large 70 (1956).
[35]*General Principles to Govern, and Operating Criteria for, Glen Canyon Reservoir (Lake Powell) and Lake Mead During the Lake Powell Filling Period*, 27 F.R. 6851 (1962).
[36]Ibid.
[37]*Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs*, 70 F.R. 7138 (1970).
[38]*Colorado River Basin Project Act,* Public Law 90-537, Statutes at Large 45 (1968).
[39]Central Arizona Project, FAQ, accessed August 10, 2011, http://www.cap-az.com/AboutUs/FAQ.aspx.
[40]*Colorado River Basin Project Act*, Public Law 90-537, Statutes at Large 45 (1968).
[41]International Boundary and Water Commission. "Minute No. 218: Recommendations on the Colorado River Salinity Problem," March 22, 1965.
[42]International Boundary and Water Commission. "Minute No. 241: Recommendations to Improve Immediately the Quality of Colorado River Waters Going to Mexico," July 14, 1972.
[43]A "minute" in this context is a written agreement between the United States and Mexico.
[44]International Boundary and Water Commission. "Minute No. 242: Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River," August 30, 1973.
[45]*Colorado River Basin Salinity Control Act*, Public Law 93-320, Statutes at Large 109 (1974).
[46]Ibid.
[47]National Research Council of the National Academies, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*.
[48]United States Geological Survey, *Glen Canyon Environmental Studies: Multidisciplinary Studies of the Effects of Glen Canyon Dam*, accessed August 1, 2011. http://walrus.wr.usgs.gov/grandcan/gces.html.
[49]National Research Council of the National Academies, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability.*
[50]"La Paz Agreement," August 14, 1983, *Treaties and Other International Acts Series*, no. 10827.
[51]Ibid.
[52]The "Limitroph" region is the segment of the Lower Colorado River that serves as the international boundary between the U.S. and Mexico.
[53]*Grand Canyon Protection Act of 1992*, Public Law 102-575, U.S. Statutes at Large 106 (1992).
[54]The EIS was completed in 1995.
[55]National Research Council of the National Academies, *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability.*
[56]"Colorado River Interim Surplus Guidelines." Federal Register 66:17 (January 25, 2001) 7772-7782.
[57]Ibid.
[58]United States Bureau of Reclamation, *Drought in the Upper Colorado River Basin*, accessed August 3, 2011. http://www.usbr.gov/uc/feature/drought.html.
[59]United States Bureau of Reclamation, *Demonstration Programs*, accessed August 3, 2011. http://www.usbr.gov/lc/region/programs/demo.html.
[60]US Bureau of Reclamation. 2007. *Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations for Lake Powell and Lake Mead.* http://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf.
[61]Secretarial Order 3297. *Department of Interior WaterSMART Program- Sustain and Manage America's Resources for Tomorrow*, February 22, 2010.
[62]International Boundary and Water Commission. "Minute No. 316: Utilization of the Wellton-Mohawk Bypass Drain and Necessary Infrastructure in the United States for the Conveyance of Water by Mexico and Non-Governmental Organizations of Both Countries to the Santa Clara Wetland During the Yuma Desalting Plant Pilot Run," April 16, 2010.
[63]International Boundary and Water Commission. "Minute No 317: Conceptual Framework for U.S.-Mexico Discussions on Colorado River Cooperative Actions," June 17, 2010.
[64]International Boundary and Water Commission. "Minute No 318: Adjustment of Delivery Schedules for Water Allotted to Mexico for the Years 2010 Through 2013 as a Result of Infrastructure Damage in Irrigation District 014, Rio Colorado, Caused by the April 2010 Earthquake in the Mexicali Valley, Baja California," December 17, 2010.
[65]*Wilderness Act*, Public Law 88-577, *U.S. Statutes at Large* 78 (1964).
[66]Sarah Turner. "Wild and Scenic Rivers: The Importance of Federal River Protection in the Rockies." In the *2009 Colorado College State of the Rockies Report Card*, edited by Walter E. Hecox, Matthew K. Reuer, and Elizabeth L. Kolbe, Colorado Springs: Colorado College, 2009. 65.
[67]Ibid.
[68]US Fish and Wildlife Service, *Designated Wild and Scenic Rivers*, accessed December 14, 2011. http://rivers.gov/wildriverslist.html.

[69]Robert V. Percival et al., *Environmental Regulation: Law, Science, and Policy* (New York: Aspen Publishers, 2009) 858-859.
[70]Ibid.
[71]Ibid.
[72]United States Environmental Protection Agency, *What is Nonpoint Source Pollution?*, accessed July 8, 2011. http://water.epa.gov/polwaste/nps/whatis.cfm.
[73]Granted the federal government stops making exceptions.
[74]Percival, et al., *Environmental Regulation: Law, Science, and Policy*. 940-941.
[75]Upper Colorado River Endangered Fish Recovery Program, *About the Endangered Fish*, accessed August 10, 2011. http://www.coloradoriverrecovery.org/general-information/about-fish.html.
[76]More on T&E species can be found further on in the *Report Card*.
[77]Percival, et al., *Environmental Regulation: Law, Science, and Policy*. 393-396.
[78]Paul Henderson. Interview by author, Moab, Utah. July 14, 2011.
[79]US Bureau of Reclamation, *The Law of the River,* accessed June 18, 2011. http://www.usbr.gov/lc/region/g1000/lawofrvr.html.
[80]Bidtah Becker. Interview by author, Fort Defiance, Arizona. July 23, 2011.
[81]David H. Getches, *Water Law in a Nutshell* (St. Paul: West Publishing Co., 1997).
[82]Ibid.
[83]*General Allotment Act*, 24 Stat. 388, (1887).
[84]*Indian Reorganization Act*, Public Law 280, U.S. Statutes at Large 48 (1934).
[85]A fish wheel allows salmon and other fish to be caught by the ton, thus drastically reducing numbers in the river.
[86]*United States v. Winans*, 198 U.S. 371 (1905).
[87]Yakima Treaty of 1855, art. 3, ¶ 2, 12 Stat. 951.
[88]*Winters v. United States*, 207 U.S. 564 (1908).
[89]*The Colorado River Compact of 1922* art. VII.
[90]Getches, *Water Law in a Nutshell*.
[91]*Arizona v. California* 373 U.S. 546 (1963).
[92]Colorado River Water Users Association, *Ten Tribes Partnership*, accessed June 20, 2011. http://www.crwua.org/TenTribes.aspx.
[93]Getches, *Water Law in a Nutshell*.
[94]Bidtah Becker. Interview by author, Fort Defiance, Arizona. July 23, 2011.
[95]United States Bureau of the Census. Census 2000 Special Reports. *We the People: American Indians and Alaskan Natives in the United States*. By Stella U. Ogunwole.2006. accessed December 14, 2011. http://www.census.gov/prod/2006pubs/censr-28.pdf.
[96]Bidtah Becker. Interview by author, Fort Defiance, Arizona. July 23, 2011.
[97]Ibid.
[98]*United States v. Winans*, 198 U.S. 371 (1905); *Winters v. United States*, 207 U.S. 564 (1908); *Arizona v. California* 373 U.S. 546 (1963).
[99]David H. Getches, "Water Management in the United States and the Fate of the Colorado River Delta in Mexico," *United States-Mexico Law Journal* 11, (2003): 107-113.
[100]*The Colorado River Compact of 1922* art. III § (c).
[101]Stephen P. Mumme, "Revising the 1944 Water Treaty: Reflections on the Rio Grande Drought Crisis and Other Matters," *Journal of the Southwest* 45, no. 4 (2003): 649-670.
[102]*The Mexican Water Treaty*, 59 Stat. 1219 (1944).
[103]Ibid.
[104]Mumme, "Revising the 1944 Water Treaty: Reflections on the Rio Grande Drought Crisis and Other Matters."
[105](Gleick 1988).
[106]Ibid.
[107]Getches, "Water Management in the United States and the Fate of the Colorado River Delta in Mexico."
[108]International Boundary and Water Commission. "Minute No. 218: Recommendations on the Colorado River Salinity Problem," March 22, 1965.
[109]Ibid.
[110]International Boundary and Water Commission. "Minute No. 241: Recommendations to Improve Immediately the Quality of Colorado River Waters Going to Mexico," July 14, 1972.
[111]International Boundary and Water Commission. "Minute No. 242: Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River," August 30, 1973.
[112]Ibid.
[113]*Colorado River Basin Salinity Control Act*, Public Law 93-320, Statutes at Large 109 (1974).
[114]*The Mexican Water Treaty*, 59 Stat. 1219 (1944).
[115]Jennifer Pitt, "Dredging for Diplomacy? Colorado River Management at the United States-Mexico Border," *Pacific McGeorge Global Business & Development Law Journal* 19, (2006): 47-59.
[116]Ibid.
[117]Osvel Hinojosa-Huerta. Interview by author, Sonora, Mexico. July 20, 2011.
[118]International Boundary and Water Commission. "Minute No. 316: Utilization of the Wellton-Mohawk Bypass Drain and Necessary Infrastructure in the United States for the Conveyance of Water by Mexico and Non-Governmental Organizations of Both Countries to the Santa Clara Wetland During the Yuma Desalting Plant Pilot Run," April 16, 2010.
[119]International Boundary and Water Commission. "Minute No 317: Conceptual Framework for U.S.-Mexico Discussions on Colorado River Cooperative Actions," June 17, 2010.
[120]International Boundary and Water Commission. "Minute No 318: Adjustment of Delivery Schedules for Water Allotted to Mexico for the Years 2010 Through 2013 as a Result of Infrastructure Damage in Irrigation District 014, Rio Colorado, Caused by the April 2010 Earthquake in the Mexicali Valley, Baja California," December 17, 2010.
[121]*Boulder Canyon Project Act*, Public Law 70-642, U.S. Statutes at Large 32 (1928).
[122]Erin K. Bradley, "California Draining: Lining the American Canal," *Great Plains Natural Resources Journal* 12, (2007): 36-57.
[123]Osvel Hinojosa-Huerta. Interview by author, Sonora, Mexico. July 20, 2011.
[124]US Bureau of Reclamation. 2006. *All-American Canal Lining Project: Supplemental Information Report*. http://www.usbr.gov/lc/region/programs/AAC/SIR_1-12-06.pdf.
[125]Bradely, "California Draining: Lining the American Canal."
[126]Ibid.
[127]Ibid.
[128]Ibid.
[129]Osvel Hinojosa-Huerta. Interview by author, Sonora, Mexico. July 20, 2011.
[130]Osvel Hinojosa-Huerta. Interview by author, Sonora, Mexico. July 20, 2011.; Jeffrey P. Cohn, "Meting Out Water in Arizona," *BioScience* 60, no. 9 (2010): 772.
[131]Ken Bowman. Interview by author, July 21, 2011.
[132]Jennifer McCloskey. Interview by author, July 21, 2011.
[133]Ibid.
[134]U.S. Bureau of Reclamation, *Drop 2 Storage Reservoir Project,* accessed November 8, 2011. http://www.usbr.gov/lc/region/programs/drop2reservoir.html.
[135]Ibid.
[136]Bradely, "California Draining: Lining the American Canal."
[137]*The Colorado River Compact of 1922* art. VII.
[138]Robert W. Adler, "Revisiting the Colorado River Compact: Time for a Change?," *Journal of Land, Resources, & Environmental Law* 28, (2008): 19-47.
[139]Ibid.
[140]Ibid.
[141]*The Colorado River Compact of 1922* art.III § (d).
[142]U.S. Bureau of Reclamation, *Upper Colorado River Reservoir Operations*, accessed December 14, 2011. http://www.usbr.gov/uc/crsp/charts/displaysites.jsp?40days=n ; Glen Canyon Institute, *Why Glen Canyon?*, accessed December 14, 2011. http://www.glencanyon.org/glen_canyon/why-glen-canyon.
[143]Patricia Mulroy, "Beyond the Divisions: A Compact that Unites," *Journal of Land, Resources & Environmental Law* 28, (2008): 105-117.
[144]Ibid.
[145]Ibid.


Leah Lieber

Recreation in the Colorado River Basin: Is America's Playground Under Threat?

By Benjamen N. Taber

Key Findings:

-Recreation and Tourism accounted for 8.1% of 2010 private earnings in Basin States, compared to 5.2% nationally.
-"Soft-use" recreation is replacing "hard-use" extractive industries.
-Management needs for the environment and recreation are often the same.
-Ski areas will need to adapt to climate change through technological innovation and change in business practices.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Author:
Ben Taber (Colorado College class of '12) is a 2011-12 Student Researcher for the State of the Rockies Project.

Will Stauffer-Norris

"The river is also a great economic engine because of all the tourism that revolves around the river, particularly in fishing. But much of the fishing is for non-native species like the rainbow trout, when in fact these introduced species are taking away from the native species and preying upon the native species."

-Jonathan Waterman, Author and Colorado River Explorer
speaking at the Colorado College, September 12th, 2011 as
part of the State of the Rockies Project Speakers Series

Introduction

The development of recreation in the Colorado River Basin has brought about a transition from the extraction-based economy of mining and forestry to the potentially more sustainable recreation-based economy. In 2008, recreation and tourism generated $23 billion in income and supported 1.2 million jobs in six basin states—not including California—and $37 billion in income and 1.7 million jobs in California alone.[1] However, the economic impact of tourism and recreation in California's portion of the Colorado River Basin is minimal.

The *2011 State of the Rockies Report Card* focused primarily upon the economic impacts of recreation in a section: "Nature Based Recreation in the Rockies: The New Value of the Region's Resources." While that report noted the importance of recreation to the Rocky Mountain West, and by extension the Colorado River Basin, the aim of this report is not to simply update the *2011 Report Card,* but rather to analyze the stresses on and evaluate the future of recreation in a specific and vulnerable part of the region: the Colorado River Basin.

For the purpose of this report on the basin, outdoor recreation activities are those in which participants have direct interactions with the environment and natural resources. For nature-based recreation, we follow the definition of the Outdoor Industry Foundation and include the following activities: backpacking, biking, camping, climbing, fishing, hiking, hunting, skiing (including nordic, alpine and telemark), trail running, and wildlife-viewing. In some sections motorized off-highway vehicle (OHV) and motorized boating use will be considered as well, but such considerations will be explicitly noted. When we look at the economic impact of various industries, however, the use of the broader "Tourism and Recreation" sector will be employed.

According to Dan Grossman, the Rocky Mountain Director of the Environmental Defense Fund, "Active outdoor recreation in the Colorado River Basin contributes more than $75 billion annually to the region's economy and supports more than 780,000 jobs."[2] Since much of this recreation is dependent upon the environmental health of the region, Grossman and others argue that this is a major reason for needing to protect the health of the Colorado River system—and the "economies it supports."

Recreation is generally a non-consumptive use of the waters and lands of the Colorado River Basin. Fishing, boating, and skiing use water "in passing," allowing the water to be used by agricultural, municipal, industrial, and environmental uses and "in passing" support recreation. Because recreation is almost exclusively a non-consumptive use of water, however—with the notable exception of much of the ski industry—recreation has not historically owned water rights. Instead, water used for recreational purposes is subject to the whims of the holders of the "beneficial" water rights. As Emily Brophy of Living Rivers asked, "Is this a pipeline system for water, or is this a source of recreation income?"[3]

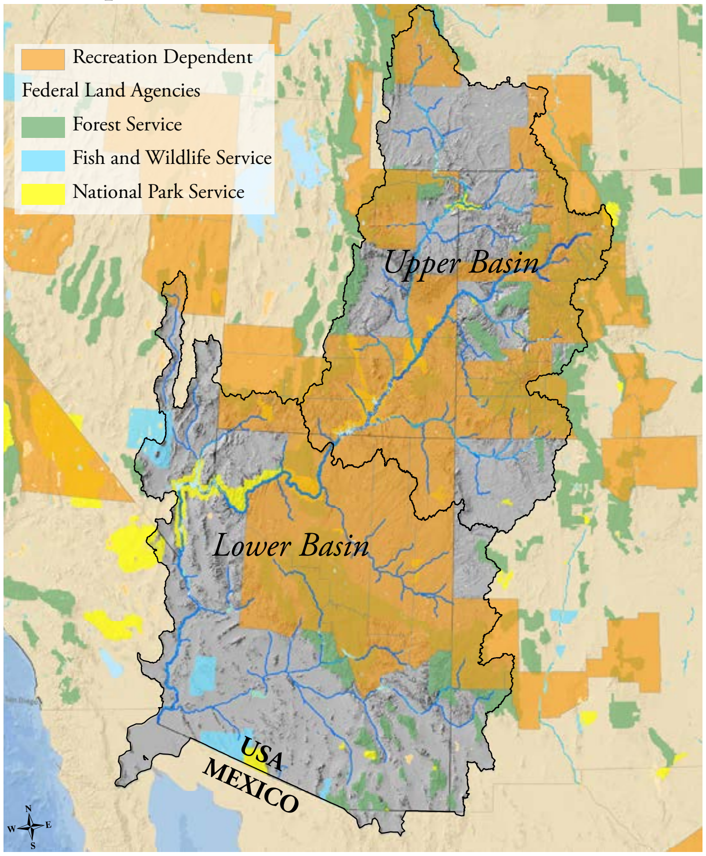
The Colorado River Basin is a massive playground of the United States and a world-renowned natural heritage—an area where millions flock annually to enjoy the myriad sources of nature-based entertainment. The tourism income generated provides major support to the local economies throughout the basin. But with increasing stresses on the water supply from climate change and confrontations between different water users, is America's and the world's playground under threat?

Economic Analysis of Recreation in the Basin

Prior to the recent economic downturn, tourism had been growing worldwide. Post 2008, however, international tourist arrivals world-wide dropped by 4.2% to 880 million in 2009, while international tourist arrivals to the United States decreased by 5.3% to 54.9 million.[4] International tourist arrivals in 2010, however, showed a marked recovery, increasing by 6.6% to set a new record of 940 million, and preliminary data for 2011 shows a further increase of around 4.5%.[5] The Colorado River Basin—home to majestic mountains, desert metropolises, iconic rivers, deep canyons, and sunshine—draws millions of these visitors annually. The economic impact of international, as well as domestic tourism, does and will continue to provide much to the economic benefits to the region: in 2010, recreation and tourism were responsible for 8.1% of private earnings in the basin states, compared to 5.2% nationally.

Many counties within the Colorado River Basin are dependent upon recreation. **Figure 1** highlights rural counties dependent upon recreation, as defined by the United States Department of Agriculture Economic Research Service (USDA ERS).[6] Note that the USDA ERS does not include metropolitan counties—such as Clark County, Nevada—as recreation-dependent. These rural counties have a higher percentage of seasonal housing and hotel/motel visits, and attract visitors, retirees, second-home owners, and new businesses than their non-recreation dependent counterparts.[7] There is some correlation between the presence of public lands and recreation dependence, as recreation centers like Moab, Utah, and Summit County, Colorado, are surrounded by federally-owned lands. Recreation dependent counties also have a

Figure 1: Colorado River Basin Recreation Dependent Counties with Federal Lands



Source: USDA Economic Research Service

natural amenity index of 5.3, higher than the Rockies average of 4.8,[8] demonstrating that environmental quality is an important feature for recreation and tourism.

Tourist and recreation-related spending is dispersed among many sectors of the economy, and no single definition of "tourism" exists. As such, for our economic analysis we define "recreation and tourism" as the sum of categories 71 and 72 in the North American Industry Classification System (NAICS)[9]: "arts, entertainment, and recreation" and "accommodation and food services," respectively. **Figures 2 and 3** employ this definition of tourism and recreation.

Figure 2 illustrates how the recreation and tourism industry compares to other selected industries. For the basin states of Arizona, Colorado, Nevada, New Mexico, Utah, and Wyoming, recreation and tourism at 8.1% represents a larger percentage of total private earnings than the national average. (California is excluded both due to its overwhelming size and economy, as well as the fact that only a small portion of California lies within the Colorado River Basin.) **Figure 4** shows that Nevada is notably reliant upon recreation and tourism, with 22.1% of total private earnings coming from said industry versus 5.2% for the U.S.—a figure boosted by the impact of gambling in Clark and Washoe counties. Some 44% of Nevada's total revenue in the arts, entertainment, and recreation industry is derived from gambling.[10] Of the basin states, only Utah has private earnings below the national average in recreation and tourism. What stands out is the robust size of recreation and tourism, verging on ten times the size of extractive industries and contrary to long-standing expectations, even myths, that mining, forestry, and related activities are a major sector in the economies of the American West.

Manufacturing at 8.6% of private earnings is less in the basin states than the national average of 13.3%, but extractive industry earnings at 2.9% —including mining, forestry, fishing, and related activities—is higher than the national average. Wyoming is the notable standout here. With large coal, oil, and gas reserves and a small population, 19.4% of private earnings in 2010 came from extractive industries. While construction in the basin at 8.0% remains higher than the national average of 6.6%, there has been a drop in the

Figure 2: Percent of Total Private Earnings in Selected Industries, 2010

Percent of Total Private Earnings in Selected Industries, 2010	Recreation and Tourism	Extractive Industries	Manufacturing	Construction	Information	Finance, Insurance and Real Estate	Professional, Scientific and Technical services
United States	5.2%	1.5%	12.3%	6.6%	4.1%	10.9%	12.2%
Basin States	8.1%	2.9%	8.6%	8.0%	4.1%	9.8%	11.7%
Arizona	6.2%	1.1%	10.4%	7.0%	2.3%	10.7%	10.0%
California	5.9%	1.1%	12.7%	6.0%	6.6%	9.6%	14.9%
Colorado	5.9%	2.9%	7.4%	7.4%	7.8%	10.5%	14.9%
Idaho	5.0%	2.1%	13.3%	8.8%	2.0%	7.1%	11.7%
Montana	7.0%	4.8%	5.9%	9.9%	2.3%	8.2%	8.4%
Nevada	22.1%	2.3%	4.5%	8.8%	1.7%	8.7%	8.6%
New Mexico	6.2%	5.6%	6.6%	8.8%	2.4%	6.8%	15.4%
Utah	4.6%	1.8%	13.3%	8.6%	3.4%	9.9%	10.4%
Wyoming	6.9%	19.4%	5.3%	13.2%	1.5%	6.8%	6.1%

Note: "Basin States" includes AZ, CO, NV, NM, UT, and WY (not CA) and "Extractive Industries" includes Mining, Forestry and related activities.

Source: Regional Economic Information System, Bureau of Economic Analysis, US Department of Commerce.

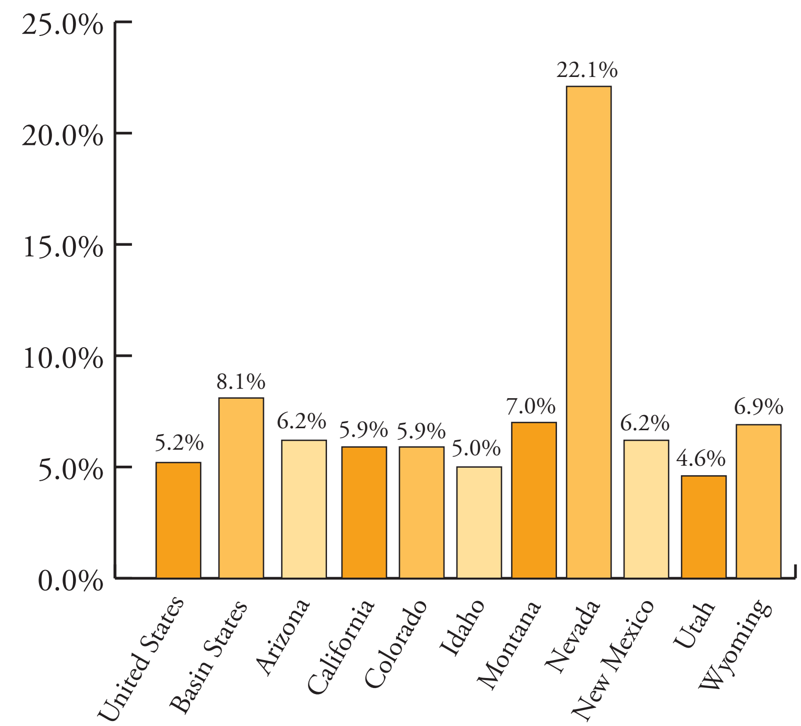
Figure 3: Percent of Total Employment in Selected Industries, 2010

Percent of Total Private Earnings in Selected Industries, 2010	Recreation and Tourism	Extractive Industries	Manufacturing	Construction	Information	Finance, Insurance and Real Estate	Professional, Scientific and Technical services
United States	9.1%	1.2%	7.0%	5.1%	1.9%	9.8%	6.7%
Basin States	11.4%	1.7%	4.7%	5.6%	1.9%	11.7%	7.0%
Arizona	9.5%	1.0%	5.0%	5.1%	1.5%	12.3%	6.4%
California	9.7%	1.3%	6.8%	4.4%	2.6%	10.3%	8.6%
Colorado	10.2%	1.8%	4.5%	6.0%	2.6%	12.0%	8.7%
Idaho	8.2%	1.8%	6.7%	6.3%	1.5%	9.3%	3.8%
Montana	10.9%	2.8%	3.3%	6.7%	1.4%	8.9%	5.3%
Nevada	22.7%	1.2%	2.8%	5.1%	1.2%	12.5%	5.4%
New Mexico	9.9%	2.9%	3.4%	5.9%	1.6%	7.2%	7.4%
Utah	8.3%	1.1%	7.3%	5.7%	2.1%	12.9%	6.5%
Wyoming	10.1%	8.6%	2.8%	8.1%	1.2%	8.9%	4.3%

Note: “Basin States” includes AZ, CO, NV, NM, UT, and WY (not CA) and “Extractive Industries” includes Mining, Forestry and related activities.
Source: Regional Economic Information System, Bureau of Economic Analysis, US Department of Commerce.

percentage of private earnings in construction in every state since 2008.[11] The greatest of these reductions occurred in Nevada, which saw a reduction of six percentage points to below 9%. **Figure 2** shows that while there is variability within the basin states with regards to the Information, Finance, Insurance and Real Estate and Professional, Scientific and Technical Services Industries, the region is on par or slightly below the national average as a whole.

Figure 4: Percent of Total Private earnings from Recreation and Tourism, 2010

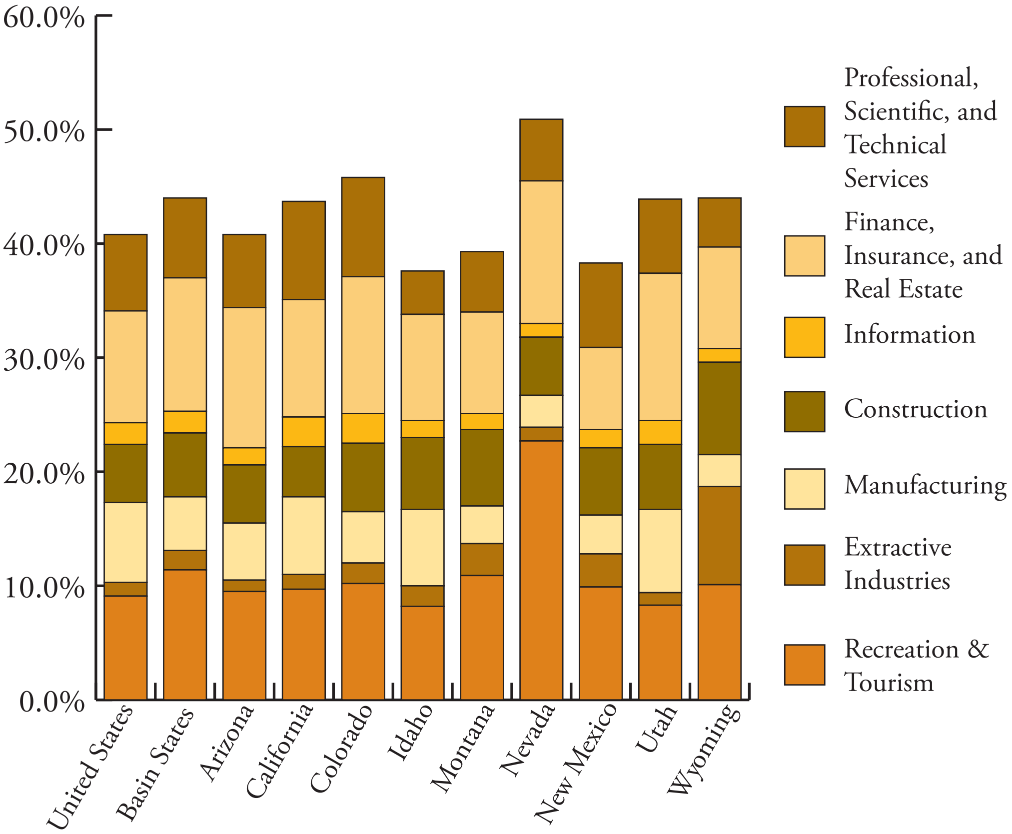


Note: "Basin States" includes AZ, CO, NV, NM, UT, and WY (not CA) and "Extractive Industries" includes Mining, Forestry and related activities.
Source: Regional Economic Information System, Bureau of Economic Analysis, US Department of Commerce.

The Painted Wall in Black Canyon of the Gunnison National Park

The 2010 employment figures in **Figure 3** echo those of the private earnings shares in **Figure 2**. **Figure 5** shows that in each of the basin states, as well as for the entire Colorado River Basin,—with the exception of Wyoming—employment in recreation and tourism is many times the size of employment in the extractive industries. While the percentage of private earnings in Finance, Insurance and Real Estate (including rentals and leasing) were over one percentage point higher nationally than in basin states, total employment in that sector is nearly two percentage points higher in basin states than the national average. This may be attributed to the transient nature of the tourism and recreation industry, the agricultural sector, and the preponderance of retirees and second-homes. This difference has likely been exacerbated by the economic downturn, as 2008 data shows a similar but smaller difference between the region and the national average.[12]

Figure 5: Percent of Total Employment for Selected Industries



Note: "Basin States" includes AZ, CO, NV, NM, UT, and WY (not CA) and "Extractive Industries" includes Mining, Forestry and related activities.
Source: Regional Economic Information System, Bureau of Economic Analysis, US Department of Commerce.

Another approach to demonstrating the vibrancy of recreation and tourism in the state economies of the Colorado River Basin region is shown in **Figure 6**, which quantifies both the jobs created by and output multipliers of different industries on Bureau of Land Management (BLM) lands. Jobs/$1 M denotes the number of jobs created per one million dollars spent for the specified industry's related activities on BLM land. For instance in Colorado, $1 million spent in recreation on BLM lands generates 15.98 million spent in recreation on BLM lands generates 15.98 jobs vs. the same $1 million spent in grazing generating 11.85 jobs, in timber 10.83 jobs, and in minerals 6.14 jobs. Recreation consistently creates the most jobs per $1 million spent on BLM lands, with grazing in Utah (at 21.64 jobs/$1 M) being the notable exception. Recreation on BLM land creates more jobs, but its output multiplier is less than that of some other industries, especially timber.

Figure 6: BLM Jobs Created and Multipliers by Industry, 2011

	Recreation		Grazing		Timber		Minerals		Wind and Geothermal	
State	Jobs/$1 M	Output Multiplier	Jobs/$1 M	Output Multiplier	Jobs/$1 M	Output Multiplier	Jobs/$1 M	Output Multiplier	Jobs/$1 M	Output Multiplier
Arizona	17.53	1.84	13.31	1.91	13.47	2.97	6.64	1.62	9.72	1.24
California	15.80	2.03	14.05	2.35	13.46	2.58	7.32	1.92	10.02	1.95
Colorado	15.98	1.75	11.85	1.89	10.83	3.40	6.14	1.65	N/A	N/A
Idaho	18.24	1.53	11.24	1.73	11.14	1.94	7.08	1.46	N/A	N/A
Montana	18.12	1.53	13.30	1.81	8.30	1.97	7.14	1.47	N/A	N/A
Nevada	14.44	1.61	10.17	1.68	11.55	1.83	7.82	1.55	10.64	1.67
New Mexico	17.33	1.56	12.01	1.67	8.11	2.91	6.43	1.43	N/A	N/A
Utah	18.93	1.77	21.64	1.64	13.00	2.73	6.98	1.57	11.55	1.35
Wyoming	15.76	1.37	13.95	1.56	9.72	1.70	4.69	1.33	8.00	1.18

Source: Department of Interior Economic Report, June, 21, 2011.

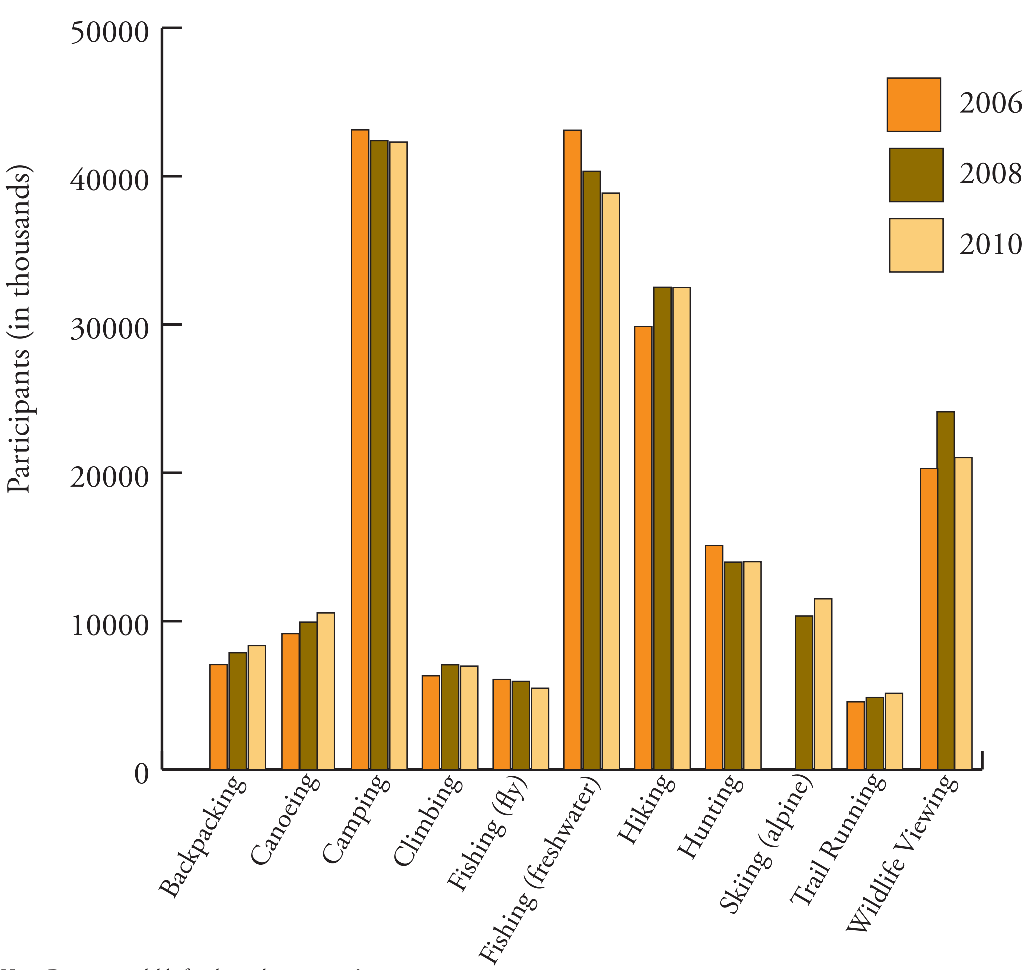
An output multiplier in the Impact Analysis for Planning (IMPLAN) model for a sector is defined as the total production in all sectors of the economy that is necessary to satisfy a dollar's worth of final demand for that sector's output.[13 14] This means that for an output multiplier of 1.2, for every $100 spent within a particular sector, there is $120 worth of economic benefit to the region when the secondary and tertiary impacts are included.

The data presented underpin the reality that recreation and tourism are very important facets to the economy of the Colorado River Basin. The Colorado River Basin remains a "resource-based" economy, but it is also highly dependent upon the water, environment, and other natural amenities that attract people to the region. The economic boom that is recreation and tourism faces an uncertain future, largely due to the immense challenges of water demands in the basin, soon to outpace supplies already put to "beneficial" uses. New and broader definitions of beneficial uses are required not only to underpin the region's environmental conditions, but as has been shown, to also maintain the tourism and recreation sector as an important part of a balanced regional economy. Population growth and climate uncertainty loom on the horizon as challenges, even threats, to the economic and environmental health of the basin.

First in the Nation

October 13, 2011: Only 100 days after closing on July 4th, Arapahoe Basin in Colorado became the first ski area to be open for every day of the season.[15] Though Las Vegas Ski and Snowboard Resort was the first in the nation to open—beating Colorado's Wolf Creek by 27 minutes—Arapahoe Basin, or A-Basin, was the first to offer skiing and snowboarding seven days a week.[16] Arapahoe Basin is able to achieve first-in-the-nation status because of a combination of high altitude—the area has a base elevation of 10,780 ft.[17]—and snowmaking ability. But with climate change and water shortages on the horizon, the landscape of skiing and other snow sports in the Colorado River Basin could greatly change over the next few decades.

Figure 7: Recent National Trends in Select Outdoor Activities



Note: Data not available for alpine skiing in 2006.
Source: Outdoor Recreation Participation Report 2011, Outdoor Foundation

Recent Trends in Recreation

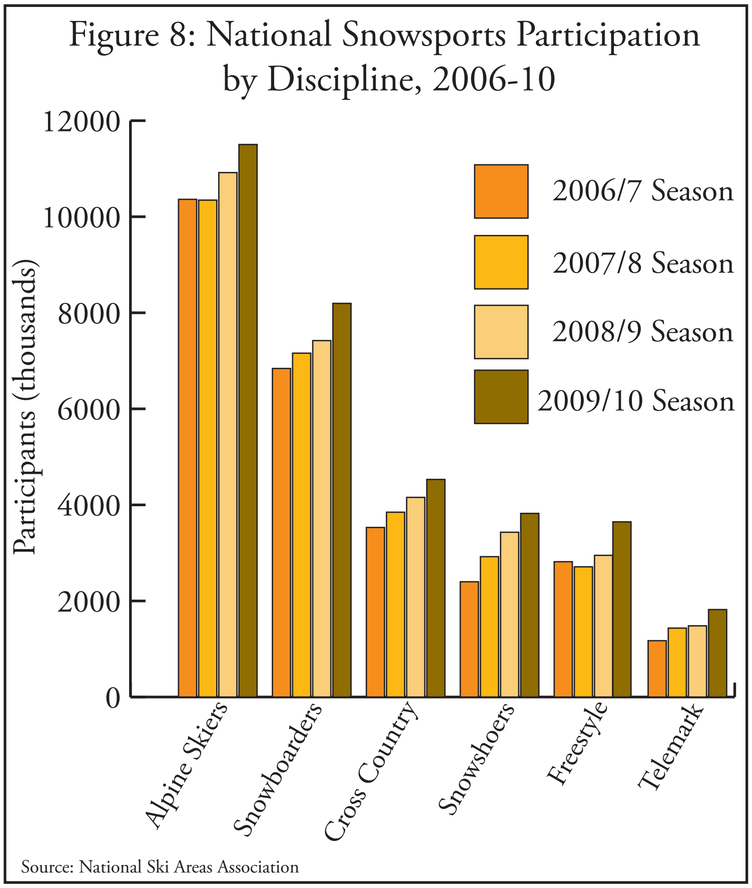
The recent economic downturn has led to a reduction in entertainment and discretionary spending; however, participation in many sectors of outdoor recreation have only been moderately affected or have even increased. **Figure 7** shows national participation levels for select outdoor activities. The relatively inexpensive activity of wildlife viewing saw a peak in 2008, but has since returned in 2010 to pre-recession levels of around 20 million. Other inexpensive outdoor recreation options, such as backpacking and canoeing, have seen a surge in popularity, while the equipment-heavy activities of fishing—both fly and freshwater angling—have decreased. Paradoxically, there has been an increase in Alpine skiing participation since the 2006-7 season from 10.36 million to 11.50 million participants in 2009-10.[18] This is in addition to an increase from 6.84 million snowboarders to 8.20 million during the same time.

Winter Wonderland: Snow Sports and the Colorado River Basin

Figure 8 notes the rise in popularity of snow sports nationally. In the 2009-10 season, over 21 million people—representing 7.5% of the over-6-years-old population—participated in the six outdoor experiences combined.[19] The continued growth of snow sports, however, may reach a zenith as the principal ingredient—snow—falls naturally in more restricted areas and more restricted time windows. Since effects of climate change, including unforeseen factors such as red snow, are being witnessed first-hand at ski areas and resorts, many related organizations are promoting varying degrees of climate mitigation and adaptation.

The National Ski Areas Association's (NSAA) Sustainable Slopes program aims "to be leaders among outdoor recreation providers by managing our [ski] business in a way that demonstrates our commitment to environmental protection and stewardship while meeting public expectations."[20] The NSAA further acknowledges that it is committed to improving the environment and ensuring that future generations will be able to enjoy ski areas. Numerous agencies and organizations, from the U.S. EPA to the Colorado Department of Public Health and Environment, have partnered with the NSAA. The Sustainable Slopes program has many goals, and acknowledges the need to reduce water and energy consumption, as well as mitigate effects on wildlife habitat.

In addition to the NSAA, other groups like the Ski Area Citizens' Coalition (SACC) monitor the environmental efforts of ski areas in the western U.S. Among those areas in the top-ten for best ski areas—receiving an "A" grade—three are within the Colorado River Basin (Aspen Highlands, Aspen Mountain and Buttermilk—all in Colorado) and six others lie outside of the basin but within basin states (including first place Squaw Valley in California and third place Deer Valley in Utah).[21] Of the ten worst environmental offenders—receiving a grade of "D" or "C"—three are also within the Colorado River Basin (Breckenridge Ski Resort in Colorado, Arizona Snowbowl in Arizona, and Las Vegas Ski and Snowboard Resort in Nevada). Four others on the "Worst Ten" list are outside of the basin but within one of the seven basin states.[22]



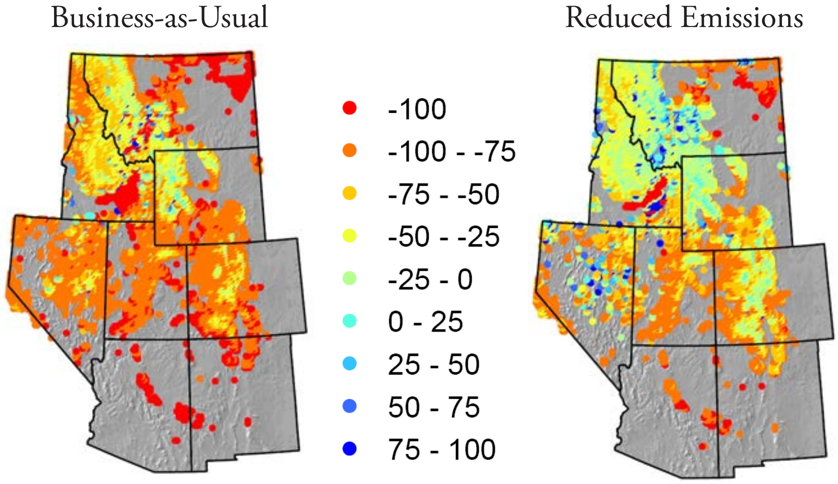
Aspen Skiing Company is a leader in addressing environmental concerns. They started in the late 1990s with recycling, philanthropy, and looking at their operational efficiency. In time, however, Vice President of Sustainability Auden Schendler noted that they realized that it was irrelevant without addressing the larger issues driving climate change.[23] "We decided to change the structure. We can do that because we're Aspen."[24]

Aspen Skiing Company decided "to tap the lever of Aspen": utilizing their influence as a destination for some of the wealthiest and most powerful people in the world in order to impact the larger conversation regarding climate change. Aspen installed a monitoring system in the largest suite, the one where former presidents and powerful CEOs stay. The visitors can see the real-time energy use of the biggest room there (which is also powered by a 5kw solar display), and policy-makers then have a direct link to their energy usage. "We can think of ourselves as an environmental organization as much as a corporation." "In a corporation in particular, you have to have CEO and ownership leadership,"[25] in order to promote environmental stewardship. Aspen has both.

Since the early 2000s, ski areas have been investing in alternative energy projects to reduce their carbon emissions.[26] In addition to photovoltaics and wind energy, Aspen Skiing Company is also pursuing using methane from coalmines as a source of power. Methane is approximately 30 times more efficient as a greenhouse gas than carbon dioxide,[27] so by burning it, power is acquired in a carbon-negative way as the methane is converted into carbon dioxide.[28] Another example of Aspen's influence is the Kimberly-Clark boycott. Kimberly-Clark did not employ sustainable forestry practices, so Aspen and many other companies boycotted their products.[29] The subsequent negative publicity for Kimberly-Clark resulted in a change in their policies.

Climate change mitigation efforts may not prove to be enough for ski areas to combat climate change: adaptation strategies must also be pursued. A 2006 paper by Daniel Scott and Geoff McBoyle[30] described some adaptation options for ski resorts. They divided these into two main categories: technological practices (snowmaking systems, slope development, operational practices, geo-engineering) and business practices (ski conglomerates, revenue diversification, marketing, transition to indoor ski areas). They also noted that government adaptations, including improved climate forecasting and subsidies for snowmaking, could be part of an adaptation strategy. Scott and McBoyle conclude by noting that a critical knowledge gap with regards to

Figure 9: April 1st Snowpack Percentage Change, 1976-2085



Source: Gregory Zimmerman, Caitlin O'Brady, and Bryan Hurlbutt. "Climate Change: Modeling a Warmer Rockies and Assessing the Implications." In The 2006 Colorado College State of the Rockies Report Card, edited by Walter E. Hecox, Bryan Hurlbutt, and Caitlin O'Brady, Colorado Springs: Colorado College, 2006, p. 94.

demand-side adaptation in the ski industry needs to be addressed, as there is uncertainty to the response of skiers and riders to climate change.

The 2006 Colorado College State of the Rockies Report Card carried out path-breaking analysis of projected impacts of climate change using down-sized global climate modeling. **Figure 9** reveals predicted April 1st snowpack percentage change from 1976-2085.[31] Following a "business-as-usual" path, where no steps are taken to mitigate climate change, results in large snowpack losses—upwards of 100%. The hardest hit ski areas in the basin will likely be the southernmost resorts—and those with less snowmaking abilities—such as Arizona Snowbowl and Las Vegas Ski and Snowboard. Telluride is predicted to be the hardest hit of the major resorts in the basin, losing 82% of April 1st snowpack from 1976-2085. A "reduced emissions" trajectory still reveals changes in predicted snowpack, but while lower latitudes/elevations generally show less of a decrease in snowpack, some higher latitudes and elevations show predicted increases. This decrease in snowpack could have a disastrous effect on the ski industry: the less snow available, the fewer people who are willing to ski.[32]

Small-scale climate mitigation projects do not address the larger issues brought on by climate change. The root problem is that if someone is under water- or food- stress, they won't ski. "It is the economic impacts of climate change that we fear."[33] Only will a stable, sustainable society that addresses climate change be able to enjoy the leisure of snow sports into the next century.

Rafting and other Outdoor Recreation in the Colorado River Basin

Commercial rafting does not usually have an in-stream water right in the Colorado River system. Instead, rafters rely upon either normal river flows, in the case of the Yampa in Colorado, or upon releases of water down the "pipeline" of the Colorado River to downstream users. The latter is the case on much of the Colorado and its tributaries. Rafting out of Glenwood Springs, Colorado, falls into this category; in order to generate power, water is released from Shoshone Dam, a hydroelectric diversion dam in Glenwood Canyon, at a minimum of 1,200 cubic feet per second (cfs).[34] Since Shoshone is a top-release dam, it does not have the negative temperature effects of a bottom-release dam like Glen Canyon: colder water increases the likelihood of hypothermia.

Despite not being a primary draw for tourists, rafting still is an important economic use of the Colorado River's natural amenity. On the Colorado River and its tributaries in the state of Colorado alone, the value of rafting has been estimated to be $114.5 million a year.[35] In 2001, over 22,000 people rafted the Grand Canyon, using limited permits granted by the National Park Service. This contributed $21.1 million to the local economy; however, more than half of the rafting-related expenditures were not captured by the local economy.[36] Rafting is not a primary economic draw, but rather a secondary one. People generally travel to the basin to visit a national park, for example, and decide to raft as a secondary activity.[37] As a result, the economic downturn has affected places like Moab, Utah.

Moab was the uranium mining capital of the United States from the 1950s until the collapse of the market in the 1980s. In an effort to reshape the local economy, the city

Encouraging Cooperation

There are 19 outfitters that run the river trips on the Green and Colorado in Canyonlands National Park. For much of the latter twentieth century, they helped each other out by timing their trips, but NPS began having rescue boats parked below some intense rapids—especially the famous "Big Drop" rapids. This created a safety net and acted as a disincentive to cooperation among the commercial outfitters. In 2011, the NPS began to focus instead on education and ramp safety checks. "We have been entirely successful,"[38] as boaters are more prepared for self-rescue, and outfitters have been timing their trips so they can help each other. Encouraging cooperation among outfitters to be able to handle a wide variety of river levels is especially important in Cataract Canyon, as river conditions are largely due to the natural flow of the Colorado. As Paul Henderson stated regarding the Colorado River through Cataract Canyon versus the Grand Canyon, "Theirs is on a faucet: ours is real."

council of Moab decided to aggressively pursue tourism-friendly policies. As a result, Moab—located near Arches and Canyonlands National Parks—became a haven for climbers, hikers, rafters, bikers, and sightseers. But with the "Great Recession" of the late 2000s, disposable income for the average American has declined. This adversely affects recreation-based economies. Because of this, localities are often looking to other sources of revenue to replace the lost tourism income. Some officials in Moab have started once again looking to the rich uranium deposits in the surrounding area as a possible cash cow. This could potentially bring the conflict between recreation and extraction-based economies to a head.[39]

With water rights being of the utmost importance in the Southwest, sustainable and non-consumptive uses of the Colorado River present good options for rural economic development. An understanding of the potentially adverse and constraining economic impacts that occur via substantial leakage of income out of communities and low wages, along with negative social impacts that can coincide with recreation and tourism, should temper future recreational development in rural communities. An increased awareness of factors that can limit the benefits of recreation and tourism development, however, will foster greater compatibility between national parks and their surrounding rural economies.[40]

John Wesley Powell saw the Colorado River Basin as a watershed, and he advocated that jurisdictional divisions should be made along natural watershed boundaries. This is not the case today, but thinking along these lines will prove beneficial in the future. Rafting and other forms of water-based recreation can encourage this type of thinking.[41] As raft guide Emily Brophy stated, "We are not the Green, the Colorado, the Yampa; we are a watershed."[42]

Resource Management in the National Park System

Resource management does not solely apply to visitors using the water and forests of a national park. The vistas, the night sky, the sound-scape, and even the odor-scape are also important resources to an area. Paul Henderson is the Assistant Superintendent of the Southeast Utah Group of the National Park Service (NPS) consisting of Arches National Park, Canyonlands National Park, Natural Bridges National Monument, and Hovenweep National Monument. He stated that in certain areas of Canyonlands National Park, the ambient noise is less than that of a professional recording studio shut off from outside ambient sounds[43] (< 20 decibel A-weighting (dBA)).[44] Development can affect the park experience. The sky-, odor-, and sound-scapes, along with the night sky—are all a part of the NPS experience: though mineral development might not occur directly on NPS lands, it can still adversely affect this experience.

Canyonlands National Park is operating on a 20+ year-old river management plan. The user limit of 8,000 people a year through Cataract Canyon is much less than the approximately 22,000 people who annually raft the Grand Canyon,[45] but unlike the Grand Canyon permits, where in some cases it can take years to acquire one, the user limit for Cataract Canyon has never been exceeded. The NPS spends over 10 times more per visitor on the river versus visitors to, say, the Island in the Sky district, an area in Canyonlands popular for its sightseeing. As a result, in 2011 Canyonlands instituted river permits to help recoup costs—no sense in making visitors subsidize river trips. "Is it fair for all park visitors to subsidize what is a specialized recreation use?"

Brendan Boepple, A fly-fisherman on the Blue River in Breckenridge, Colorado

From a recreation perspective, low flows are easier to manage because there are fewer potentially dangerous rapids. Since flows in the Colorado and Green Rivers change seasonally, the National Park Service has to maintain rescue craft capable of operating in a variety of conditions. If each of the parks in the Southeast Utah Group were an island and did not share services, it would be 30-40% more expensive to maintain the parks. Only a minority of visitors to national parks fully utilize all of the recreation opportunities present and it is only fair to assign at least some of the extra cost associated with their activities to these visitors. These same visitors, however, often have the greatest appreciation for national parks.

At the Black Canyon of the Gunnison National Park, about 250,000 people visit each year. Most of them, about 238,000, come, look at the canyon, and leave. These visitors remain largely unaffected by instream flows in the Gunnison. But the 12,000 visitors who hike down the canyon, usually to enjoy some of the best trout fishing in the world, are the ones with the greatest stake in the river. These are the people most likely to support or challenge policy changes.[46]

"Soft Use": Fishing and Hunting in the Basin

Fishing, unlike rafting, has been directly linked to being a primary draw for tourists.[47] Trout fishing and soft, non-consumptive use of waters can be used as a basis for boosting instream flows. There are primarily two types of fish in the basin: warm-water and cold-water. Many exotic cold-water species, including Rainbow, Brown, and Brook trout, have been introduced to the basin. These species do not come into conflict with the four warm-water endangered species in the basin: the Bonytail, the Colorado Pikeminnow, the Humpback Chub, and the Razorback Sucker. Cold-water fish habitats are generally in high mountain streams and lakes, whereas warm-water fish are in larger, lower reservoirs and rivers.

With man-made structures and climate change altering the hydrology of the basin, many cold-water sport fisheries are under threat. While several structures—notably the Glen Canyon Dam that created some of the best trout fishing in the world—have created or improved cold-water fisheries, many dams, culverts, and other such structures fragment fish habitat. This fragmentation degrades the health, restricts access to habitat, and can reduce the genetic viability of a species. Warming climate leads to earlier snowmelt and changes the temperature of spawning habitat. Increasing occurrences of wildfires and the spreading of diseases degrade habitats. A three degree Celsius increase in average July temperature would reduce the range of the Colorado River Cutthroat Trout (CRCT) further, confining it to ever-smaller, high-mountain streams and lakes.[48]

Climate change is a major threat to cold-water fisheries, but it is not the only one. Historically, the CRCT was found throughout most of the Colorado River Basin upstream from Glen Canyon. Trout Unlimited's Conservation Success Index, however, notes that only 16% of the watersheds within the historic range are now occupied by the CRCT. The issues affecting the CRCT mirror those faced by many native trout species in the region: competition from non-native trout, over-fishing, habitat degradation due to timber harvests, grazing and wildfires, and the fragmentation of habitat by dams, diversions, and other barriers (including culverts).[49]

There is a great discrepancy between penalties for disrupting species health of large mammals and fish. In Colorado, poaching a trophy bull elk carries a $10,000 Samson fine—an extra fine levied in order to provide a further disincentive for the illegal harvest of trophy bull elk, which are often some of the healthiest members of a species—in addition to about a $1,000 fine.[50,51] In many western states, game and fish are considered to be property of the state, and have associated fines for harvesting members of a species without state permission (be it in the form of a game tag and/or a fish/hunting license). While such poaching can be disruptive on a population—especially if it is widespread—the effects of one poaching incident are relatively small when compared to the effects of introducing exotic fish species. It takes only one breeding pair of an introduced exotic species potentially to decimate native populations, but fines associated with introducing exotic species into watershed are on the order of tens or hundreds of dollars, as opposed to thousands.[52]

Most state and federal fish and wildlife management agencies throughout the basin have long attempted to support both Endangered Species Act requirements and the desires of sport fishermen. Invasive species were removed from targeted waterways and relocated elsewhere. These exotic species, such as smallmouth bass and northern pike, are finding their way back into watersheds, resulting in ineffectual progress. Agencies have now begun to implement capture and kill programs.[53]

Hunting is another "soft-use" of the natural amenities of the Colorado River Basin. Hunting and recreational hiking are often portrayed as antithetical to each other, but studies have shown that environmental values, such as the need to preserve habitat and the desire for a "wilderness experience," are compatible.[54] Since hunting only indirectly uses water, in the form of water needing to be available for wildlife, it is another source of income for non-urban areas of the basin. Habitat loss, other stresses caused by climate change, and the scarcity of water may, however, reduce the opportunities for hunting. As habitat becomes more fragmented, the quantity of game that can be sustainably harvested is reduced.[55]

Agriculture and Recreation

Along many of the canals, and some storage reservoirs, within the Colorado River Basin there is a lot of winter camping. People park their RVs on the side of the canal and sit and fish all winter long. Senator Wash, a "storage" reservoir for excess flows, is a big attraction drawing thousands of campers and anglers (especially in the winter months) to the Imperial Valley of California, and is under management of the BLM.[56]

The Wellton-Mohawk Irrigation District in southern Arizona introduced carp to the canals as moss control. The public is not allowed to swim or boat in the canal, but “catch and release” fishing is allowed and managed by the Arizona Department of Game and Fish.[57,58] With the added bonus of increasing recreational opportunities, biological control methods, like introducing carp for moss control, can prove to be more efficient and cost effective than mechanical or chemical controls. Agriculture usage of water can provide recreation opportunities, from fish in canals to habitat for sport-game such as ducks, but often comes into conflict with the largest single source of tourism in the lower basin: Las Vegas.

The Desert Oasis: Las Vegas

The drier Lower Basin draws millions of people seeking sunshine but wanting the amenities of wetter climes. This can lead to a confrontation over water between tourist sectors and agriculture. Las Vegas, Nevada, has become a symbol of this. Forty-seven golf courses have been built in the Las Vegas area. Initially used as a way to sell houses, they were grossly overbuilt. There is currently, however, a moratorium on new golf courses.

But it is the casinos themselves that are often presented as the “bad guys” of the system. “Perception of water abundance is one of the primary tools of the gaming industry.” Hence, there are the glittering lights, relaxing spas, and magnificent water features. Resorts in Las Vegas, however, only account for 6.3% (2007)[59] of the consumptive use in the Southern Nevada Water Authority, but account for 70% of the economic benefit[60] in Clark County. Homeowners, rather, use the majority of the water. In 2007, single- and multi-family residential housing used 55% of the municipal water, while golf courses used 7.6%.[61]

Conclusion: Is the World Renowned Colorado River Basin “Playground” Under Threat?

This discussion about the future of recreation along the Colorado River and its tributaries is meaningless without placing it in the context of climate change. According to Auden Schendler, Vice President of Sustainability with Aspen Skiing Company, “It’s the economic impacts of climate change that we fear.”[62] Even if there is snow to ski on in 50 years, people from around the nation and world will not go on a ski trip unless their basic economic needs have been met and exceeded. Even if there is still enough water to raft down Cataract Canyon, no one will without the dispensable income to do so.

So is America’s Colorado River Basin playground under threat? In a word, yes. This threat stems from our increased reliance on the basin’s water for historically established “beneficial uses” by households, industry, and agriculture. It is derived from our current water management system that views the basin largely as a pipeline, one that divvies up water among the Upper and Lower Basin regions and for Mexico even though the highly volatile water flows historically average less than the allocated 16.5 million acre-feet (maf).[63] It is accentuated by resistance to new uses proposed for water: loosely termed “instream” flows for aquatic systems and adjacent riparian areas. With the increasing scarcity of water and the struggle to fulfill the additional demands people have expressed for Colorado River water, the “new” demands for water of threatened and endangered species needed for their survival must compete with firmly entrenched and well-financed entities hell-bent on squeezing more water “out” of the basin.

What can today’s youth bring to this debate and conflict? Elsewhere in this *Report Card* we discuss the results of a survey measuring the values of today’s college-age youth, compared with values of more established “water experts” throughout the basin. We are encouraged by the strength of support for less-traditional water uses in the basin, including instream flows and a desire to remedy the unmet shares of water for Native Americans and Mexico. Tough choices and trade-offs are on the horizon in all aspects of the basin. Yet, we are hopeful that a broader “systems thinking” will prevail, so that balance arises between human demands for water and products from the basin versus the needs of the hydrologic region for sufficient water to remain healthy and supportive of the types of recreation and tourism discussed in this section. Taken together, the various sections of this *Report Card* weave a fabric of solutions and perspectives for today’s youth and generations to come: we can have a healthy Colorado River Basin that supports vital economies without destroying vital hydrologic and environmental conditions that make the region world-class! We must keep it so.

[1] United States Bureau of the Census. North American Industry Classification System. *2008 County Business Patterns*. Total Employment and Total Private Earnings, 2008, accessed August 2, 2011, http://factfinder.census.gov/servlet/DatasetMainPageServlet?_program=EAS&_tabId=EAS2&_submenuId=datasets_5&_lang=en&_ts=313681690492.

[2] Mike Lee, “Water worries grow on Colorado River,” *San Diego Union-Tribune*, June 6, 2011, accessed July 28, 2011, http://www.signonsandiego.com/news/2011/jun/06/water-worries-grow-colorado-river/?page=2#article.

[3] Emily Brophy. Interview by author, Boulder, Colorado, June 30, 2011.

[4] United Nations World Tourism Organization, *World Tourism Barometer*, Vol. 8, No. 3, October 2010, accessed December 15, 2011, http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/unwto_barom10_3_en.pdf.

[5] United Nations World Tourism Organization, *World Tourism Barometer*, Vol. 9, October 2011, accessed December 15, 2011, http://dtxtq4w60xqpw.cloudfront.net/sites/all/files/pdf/unwto_barom11_october_excerpt.pdf.

[6] Richard J. Reeder and Dennis M. Brown, *Recreation, Tourism and Rural Well-Being*, United States Department of Agriculture, Economic Research Report No. (ERR-7) August 2005, accessed December 19, 2011, http://www.ers.usda.gov/Publications/ERR7/.

[7] Emil Dimantchev and Zoe Osterman. “Nature Based Recreation in the Rockies: The New Value of the Region’s Resources.” In *The 2011 Colorado College State of the Rockies Report Card*, edited by Walter E. Hecox, Russell H. Clarke, and Matthew C. Gottfried, Colorado Springs: Colorado College, 2011, p. 90-118.

[8] David McGranahan, United States Department of Agriculture. Economic Research Service, *Natural Amenities Drive Rural Population Change*, Agricultural Economic Report No. AER781, October 1999, accessed November 30, 2011, http://www.ers.usda.gov/Data/NaturalAmenities/.

[9] WebFinance, Inc., *North American Industry Classification System*, accessed November 30, 2011, http://www.businessdictionary.com/definition/North-American-Industry-Classification-System-NAICS.html.

[10] United States Bureau of the Census. *2007 Economic Census*. Accessed November, 2011, http://factfinder.census.gov/servlet/IBQTable?_bm=y&-geo_id=04000US32&-ds_name=EC0771SLLS1&-NAICS2007=71&-_lang=en.

[11] Dimantchev et al, “Nature Based Recreation in the Rockies: The New Value of the Region’s Resources.”

[12] Ibid.

[13] Department of Community Development and Applied Economics and Vermont Tourism Data Center, *IMPLAN Methodology for the Study of the Impact of Tourism on the Vermont Economy*, The University of Vermont, accessed December 13, 2011, http://www.uvm.edu/~snrvtdc/publications/implan_method.pdf.

[14] MIG, Inc. *IMPLAN Economic Modeling*, accessed December 13, 2011, http://implan.com/V4/Index.php.

[15] Hondo, “Arapahoe Basin Opens For The Season Today,” *Transworld Snowboarding*, October 13, 2011, accessed December 3, 2011, http://snowboarding.transworld.net/1000161220/news/arapahoe-basin-opens-for-the-season-today-october-13-2011/.

[16] Martin Griff, “Who’s on first? A-Basin and Killington. Who’s the mensch? Sunday River,” *NJ.com*, November 7, 2011, accessed December 3, 2011, http://blog.nj.com/skiing/2011/11/whos_on_first_a-basin_and_kill.html.

[17]Arapahoe Basin, *Fact Sheet—Winter 2011-2012*, accessed December 3, 2011, http://www.arapahoebasin.com/ABasin/about/fact-sheet.aspx.
[18]Snowsports Industries America, *2011 SIA Snow Sports Participation Report*, 2010.
[19]Ibid.
[20]National Ski Areas Association, *Sustainable Slopes: The environmental charter for ski areas*, 2005.
[21]Ski Area Citizens Coalition, *Top Ten*, accessed December 19, 2011, http://www.skiareacitizens.com/index.php?nav=top_ten.
[22]Ski Area Citizens Coalition, *Worst Ten*, accessed December 19, 2011, http://www.skiareacitizens.com/index.php?nav=worst_ten.
[23]Ben Elgin, "Little Green Lies," *Bloomberg Businessweek*, October 29, 2007.
[24]Auden Schendler. Interview by author, Aspen, Colorado, July 11, 2011.
[25]Ibid.
[26]Daniel Scott, Geoff McBoyle et al, "Climate Change and the Sustainability of Ski-based Tourism in Eastern North America: A Reassessment," *Journal of Sustainable Tourism*, 14, no. 4 (2006): 377.
[27]Henning Rodhe, "A Comparison of the Contribution of Various Gases to the Greenhouse Effect," *Science* 248, no. 4960 (June 8, 1990): 1219.
[28]John Gale and Paul Freund, "Coal-Bed Methane Enhancement with CO2 Sequestration Worldwide Potential," *Environmental Geosciences* 8, no. 3 (2001): 210-11.
[29]Auden Schendler, Aspen Skiing Company, letter to Thomas Falk, CEO Kimberly-Clark Corporation. March 5, 2007, accessed August 3, 2011, http://businessethicsnetwork.org/downloads/Kicking_Kleenex_Off_Mountain.pdf.
[30]Daniel Scott and Geoff McBoyle, "Climate change adaptation in the ski industry," *Mitigation and Adaptation Strategies for Global Change* 12, no. 8 (2007): 1411-31, http://cbtadaptation.squarespace.com/storage/Scott-CCadaptationintheskiindustry-1.pdf.
[31]Gregory Zimmerman, Caitlin O'Brady, and Bryan Hurlbutt. "Climate Change: Modeling a Warmer Rockies and Assessing the Implications." In *The 2006 Colorado College State of the Rockies Report Card*, edited by Walter E. Hecox, Bryan Hurlbutt, and Caitlin O'Brady, Colorado Springs: Colorado College, 2006, p. 99.
[32]Catherine Pickering et al, "Skiing Less Often in a Warmer World: Attitudes of Tourists to Climate Change in an Australian Ski Resort," *Geographical Research* (May 2010): 142.
[33]Schendler. Interview by author.
[34]Interview by author with raft guide, Glenwood Springs, Colorado, July 11, 2011.
[35]Joe Greiner and Jody Werner, *Commercial River Use in the State of Colorado 1988-2010*, Colorado River Outfitters Assocation, January 31, 2011.
[36]E.E. Hjerpe and Y. Kim, "Regional economic impacts of Grand Canyon river runners," *Journal of Environmental Management* 85, no. 1 (2007): 137-149.
[37]Emily Brophy. Interview by author.
[38]Paul Henderson. Interview by author.
[39]John Weischeit. Interview by author, Moab, Utah, July 13, 2011.
[40]Hjerpe et al, "Regional economic impacts of Grand Canyon river runners."
[41]Robyn Ceurvorst. Interview by author, Boulder, Colorado, June 30, 2011.
[42]Emily Brophy. Interview by author.
[43]Paul Henderson. Interview by author, Moab, Utah, July 14, 2011.
[44]National Park Service. Poster: "Sound Basics," Grand Canyon National Park.
[45]Ellen L. Jones et al, "An Analysis of Water Quality in the Colorado River, 2003-4; An Investigation Into Recurring Outbreaks of Norovirus Among Rafters," *Wilderness & Environmental Medicine* 20, no. 1 (2009): 6-13.
[46]Michael Dale. Interview by author, Black Canyon of the Gunnison National Park, Colorado, July 12, 2011.
[47]Emily Brophy. Interview by author.
[48]Trout Unlimited, *Healing Troubled Waters: Preparing Trout and Salmon Habitat for a Changing Climate*, October 2007, accessed July 26, 2011, http://www.tu.org/sites/www.tu.org/files/images/Healing-Troubled-Waters-Preparing-Trout-and-Salmon-Habitat-for-a-Changing-Climate.pdf.
[49]Trout Unlimited, *Conservation Success Index: A Strategic Approach to Fisheries and Watershed Conservation*, accessed December 18, 2011, http://www.tu.org/science/conservation-success-index.
[50]J & D Outdoor Communications, *Game Law Violations: Report from Colorado: The Samson Law*, accessed November 13, 2011, http://www.westernhunter.com/Pages/Vol02Issue24/glv.html.
[51]Colorado Revised Statutes 33-6-109 §3.4 (1998).
[52]Tom Chart. "The Colorado River Basin: Environmental Perspectives and Action." Panel discussion as part of the Colorado College State of the Rockies Speaker Series, Colorado Springs, Colorado, November 7, 2011.
[53]Ibid.
[54]A.C. Reis and J.E.S. Higham, "Recreation Conflict and Sport Hunting: Moving beyond Goal Interference towards Social Sustainability," *Journal of Sport & Tourism* 14, no. 2-3 (2009): 89-98.
[55]Nicole E. Heller and Erika S. Zavaleta, "Biodiversity management in the face of climate change: A review of 22 years of recommendations," *Biological Conservation* 142, no. 1 (2009): 14-32.
[56]Vince Brooks. Interview by author, Imperial, California, July 19, 2011.
[57]Ken Baughman. Interview by author, Wellton, Arizona, July 21, 2011.
[58]Arizona Game and Fish Department. *2011 & 2012 Fishing Regulations*. (2010): 20.
[59]Southern Nevada Water Authority, *Q4 2008 Indicator Brief*, Clark County Monitoring Program, 2008. p 14.
[60]Doug Bennett. Interview by author, Las Vegas, Nevada, July 18, 2011.
[61]Southern Nevada Water Authority, 2008.
[62]Schendler. Interview by author.
[63]Connie A. Woodhouse, Stephen T. Gray, and David M. Meko, "Updated streamflow reconstructions for the Upper Colorado River Basin," *Water Resources Research* 42, (2006).

David Spiegel

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.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Author:
Natalie Triedman (Colorado College class of '12) is a 2011-12 Student Researcher for the State of the Rockies Project.

Brendan Boepple

"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

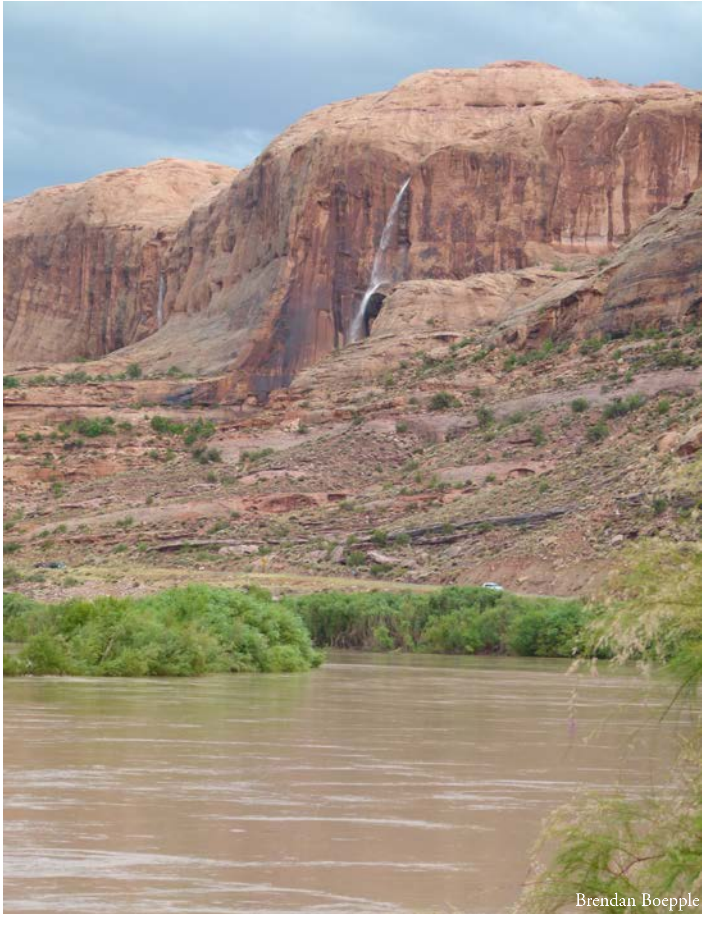
The Colorado River Basin is an environmental treasure that is an increasingly fragile system due to complex and diverse pressures. Human needs have historically taken precedence over environmental concerns when managing water and other natural resources. Natural organisms do not follow political boundaries, 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.



Brendan Boepple

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]

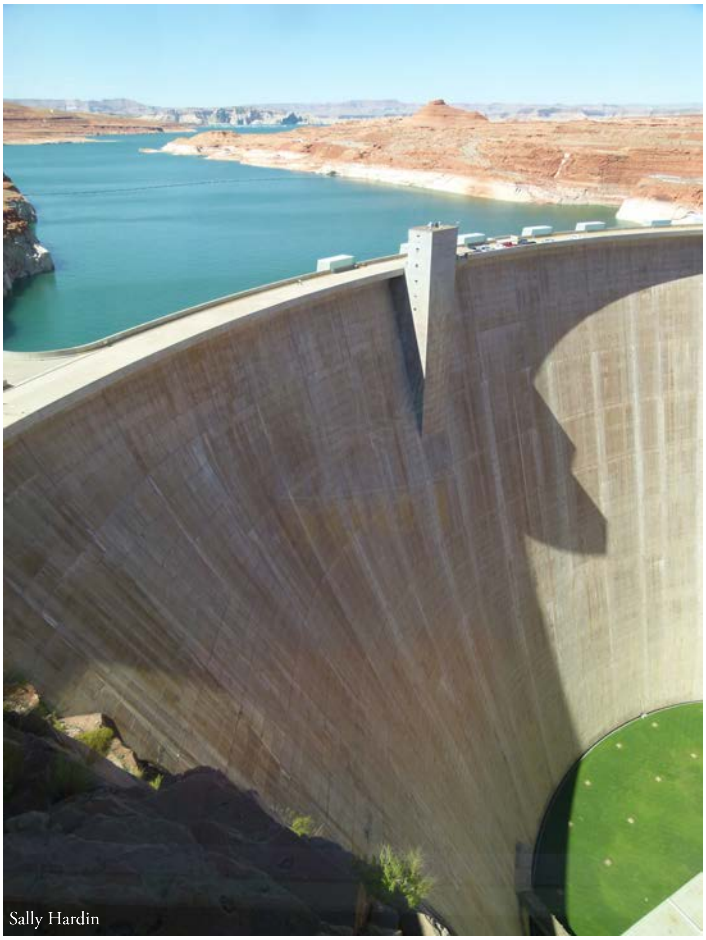
Rushing down the western slope of the state of Colorado, the river meets its fifth largest tributary, the Gunnison River. Prior to meeting at their confluence in Grand Junction, Colorado, the Gunnison winds through the Black Canyon of the Gunnison National Park, a unique area for flora and fauna alike. 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


Brendan Boepple

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.

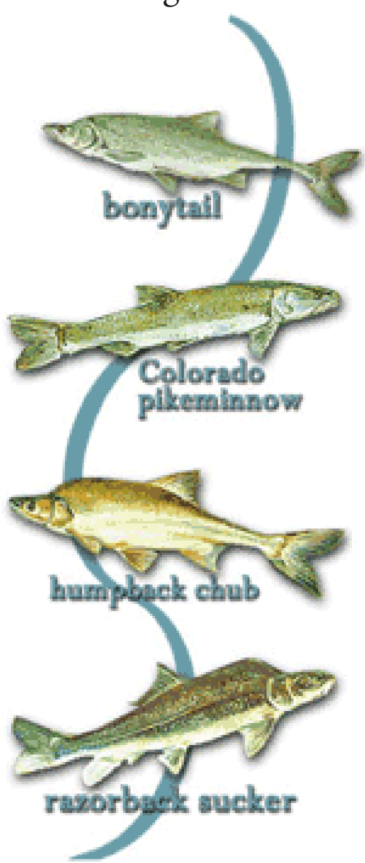
their competitive potential and their threat as predators. There are four endangered fish in the basin that have to compete with over forty nonnative fish for food and habitat, and must also face the additional threat of predation from nonnative species such as the northern pike, smallmouth bass, and 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]

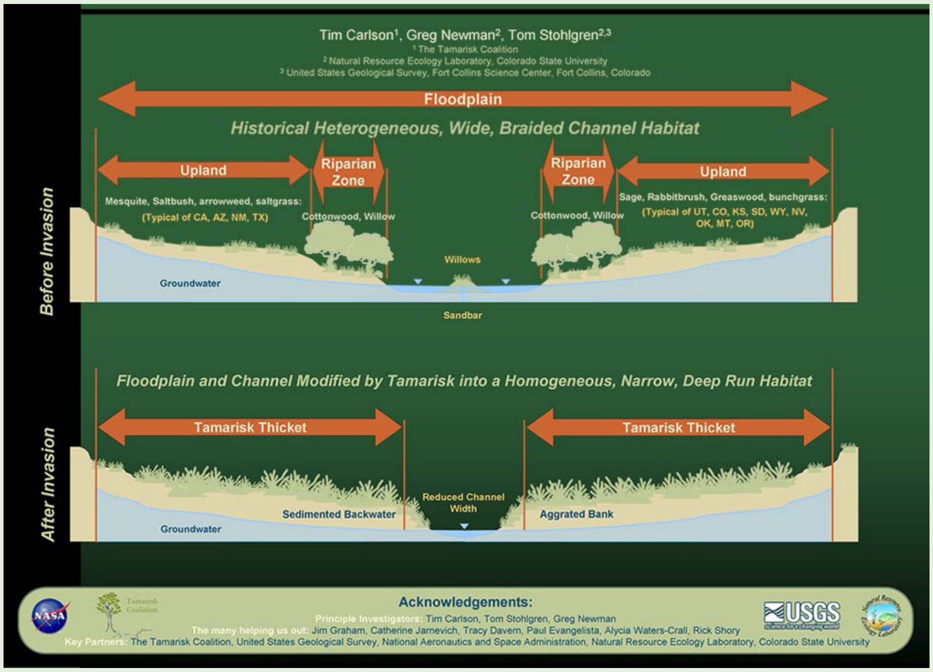
There are many anthropogenic factors that stimulate tamarisk growth. Infrastructure created to manage water along the river can interrupt natural flows that are essential for native species, but not as important for the tamarisk. Dams and water diversions have reduced spring floods so drastically that 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)

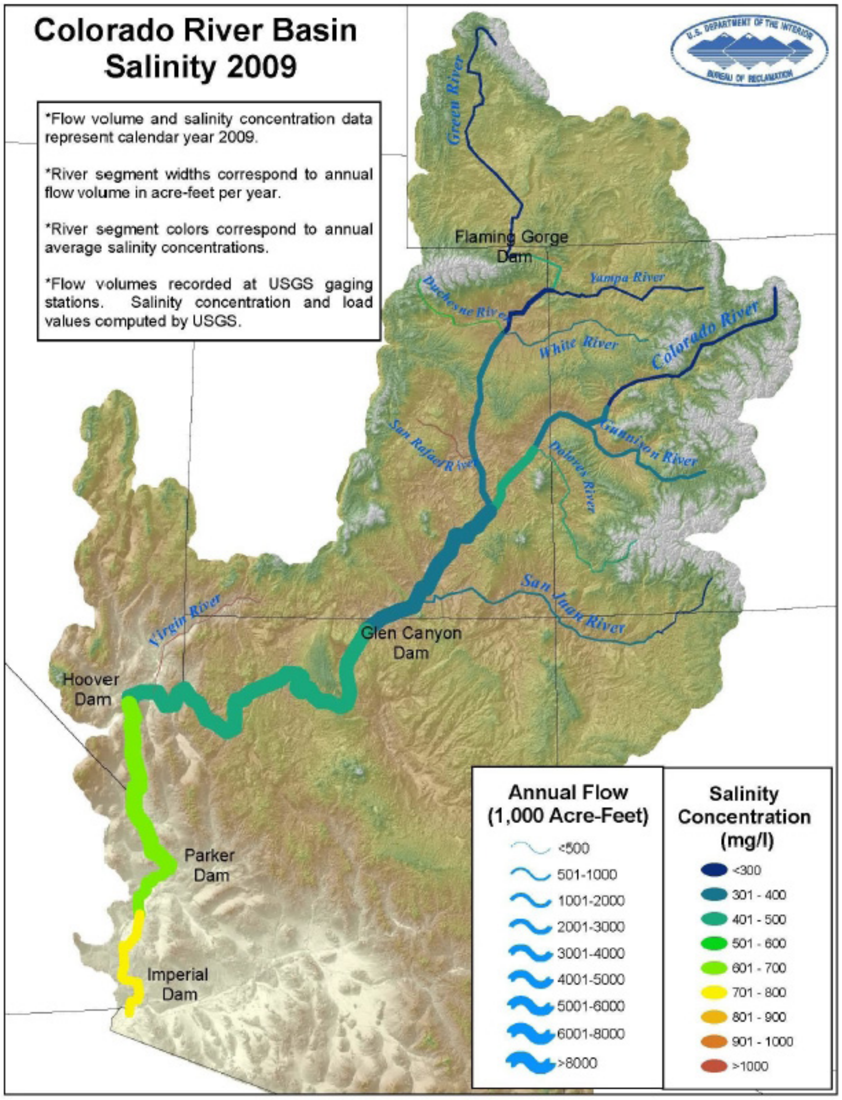
Salinity

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).

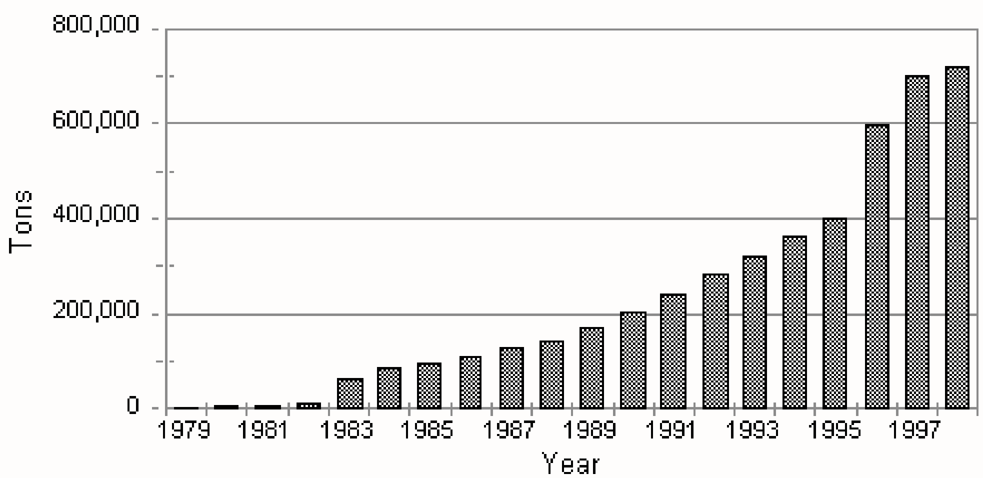
1960 1970 1980

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]

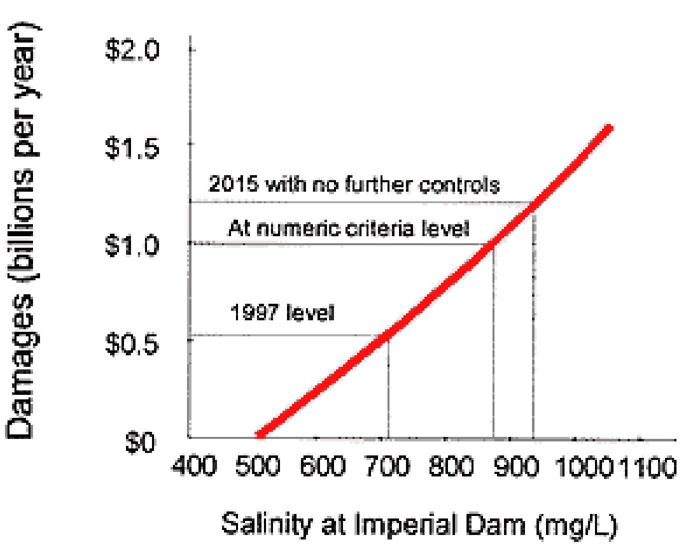
Ever since salinity emerged as a prominent issue in the 1960s, it has been a major environmental, political, and legal focus throughout the basin, which has led to decreased salinity levels despite the increasing water demand. The economic and political threats associated with high salinity levels have 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]

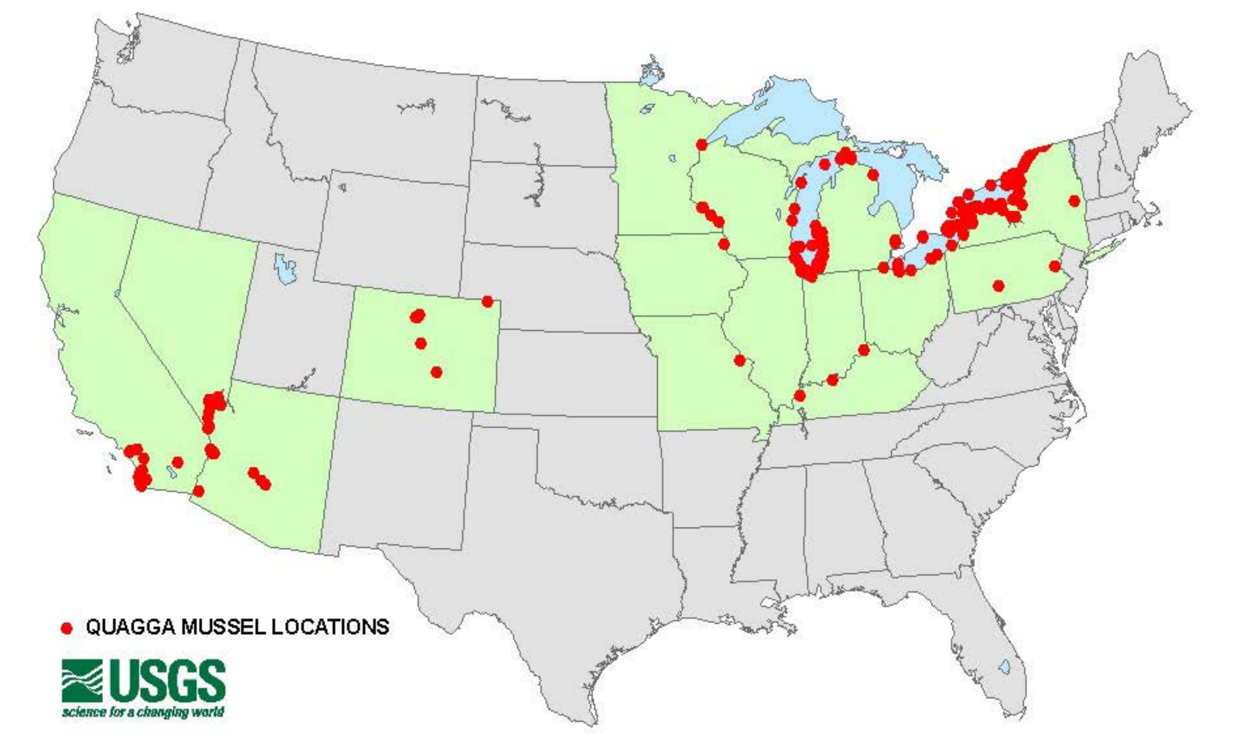
Conclusion: Nature Needs A Voice and an Assured Share of Water in the Basin

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

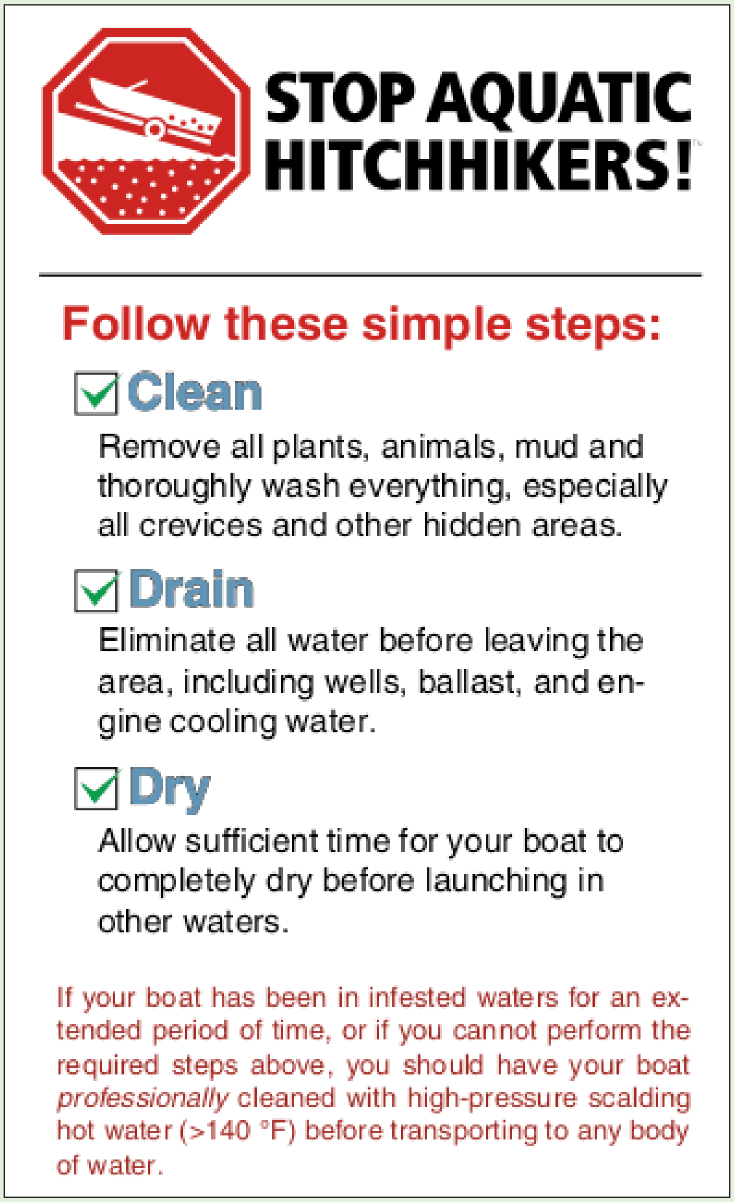
Source: Arizona Game and Fish Department, *AGFD Fishing Report,* http://www.azgfd.gov/artman/publish/printer_1123.shtml.

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.

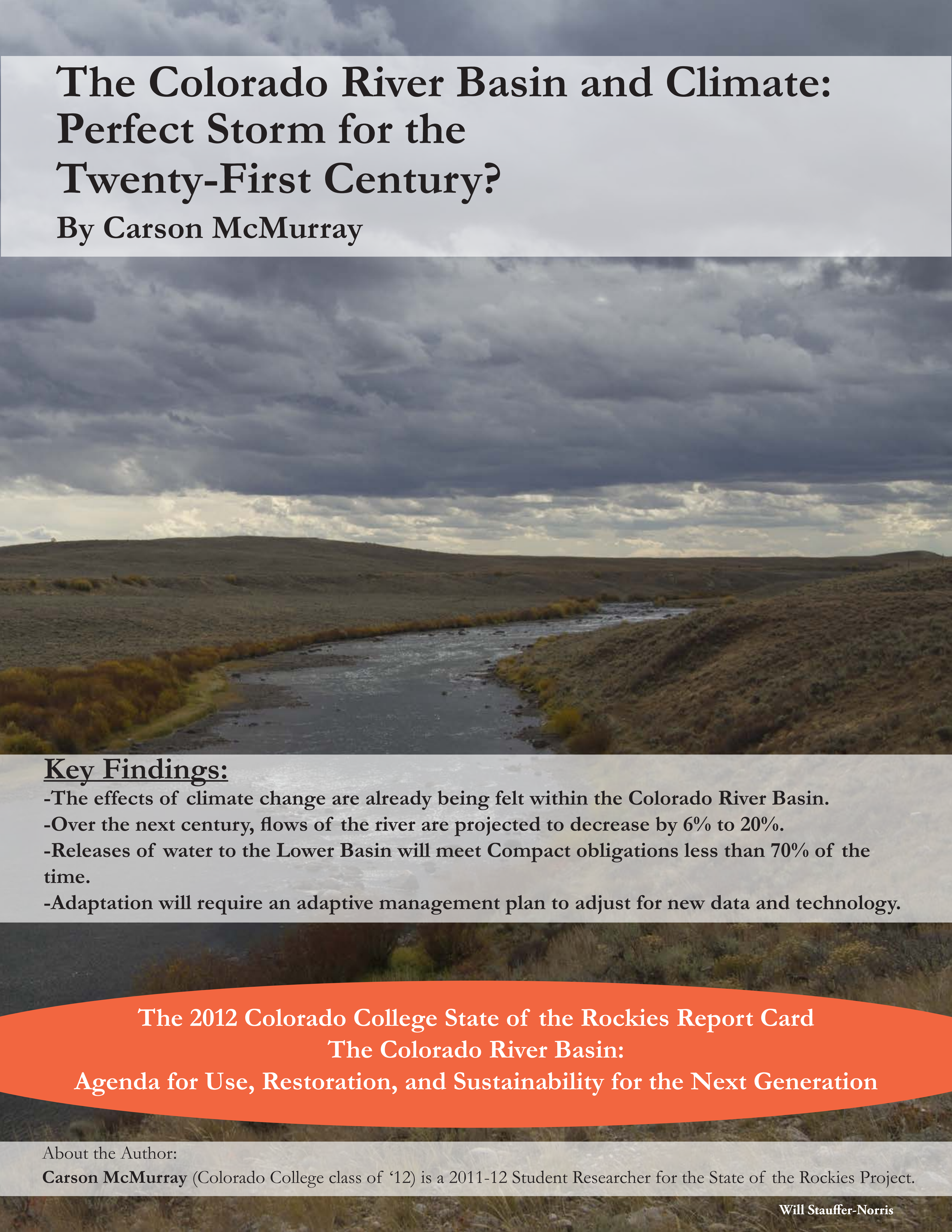
[1]Environmental Protection Agency, *Rivers and Streams*, accessed June 2011, http://www.epa.gov/bioiweb1/aquatic/rivers_and_streams.html.
[2]Western Resource Advocates, *Filling the Gap: Commonsense Solutions for Meeting Frontrange Water Needs*, accessed July 2011, http://www.westernresourceadvocates.org/gap/fillingthegap.pdf.
[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/hikinginnercanyon.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.coloradoriverrecovery.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.


Tara Hatfield

[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 Phreatypes 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 Phreatypes 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 Phreatypes 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.

The Colorado River Basin and Climate: Perfect Storm for the Twenty-First Century?

By Carson McMurray


Will Stauffer-Norris

Key Findings:

-The effects of climate change are already being felt within the Colorado River Basin.
-Over the next century, flows of the river are projected to decrease by 6% to 20%.
-Releases of water to the Lower Basin will meet Compact obligations less than 70% of the time.
-Adaptation will require an adaptive management plan to adjust for new data and technology.

The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

About the Author:
Carson McMurray (Colorado College class of ‘12) is a 2011-12 Student Researcher for the State of the Rockies Project.

"The more we can think about innovations and solutions from science, from policy, and from practice, the more we open up the debate right now and allow ourselves to consider new ways of doing business; better when that crisis eventually faces us that we'll be able to adapt and move forward."

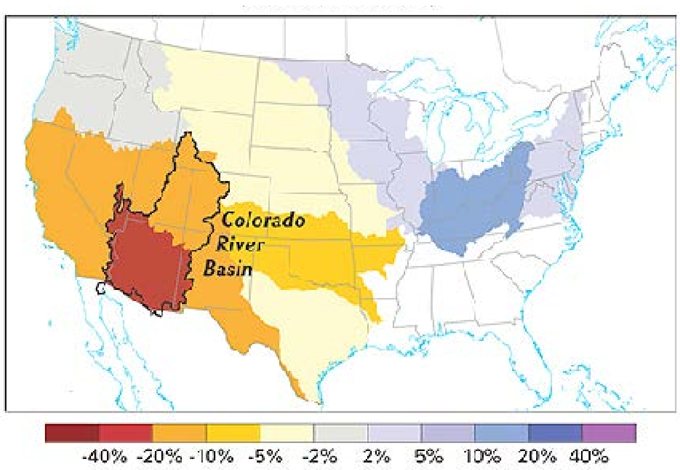
-Beth Conover, editor of *How the West Was Warmed* speaking at the Colorado College, December 5th, 2011 as part of the State of the Rockies Project Speakers Series

Introduction

The Colorado River Basin was once one of the most rugged and vast regions of the United States. From the bitterly cold headwaters to the maze of canyons, the Colorado River was in control. The thought of humans impacting or influencing the raging river was unimaginable 100 years ago. Today, the Colorado River is managed by seven states and two federal government agencies for uses ranging from agriculture to municipalities. With the construction of dams, irrigation canals and vast cities, the once wild Colorado River has largely been tamed by massive dams such as Hoover and Glen Canyon Dams. As humans move into the future, we must now deal with global warming, which threatens all aspects of the lifeline of the Southwest.

As climate change effects begin to surface after years of unsustainable greenhouse gas emissions, the southwestern United States, specifically its hydrology, will be drastically affected. In a review of 19 global climate models by the Intergovernmental Panel on Climate Change (IPCC), the group noted "there is a broad consensus amongst climate models that this region will dry significantly in the 21st century and that the transition to a more arid climate should already be underway."[1] The Bureau of Reclamation has also found consensus among federal climate models that predict a significant decrease in water availability by the end of the twenty-first century.[2] The predicted reduction in annual runoff between 2041-2060 for the Colorado River Basin is between 6% and 20%, depending on the location within the basin. This is by far the largest reduction in the continental United States (**see Figure 1**).[3] This diverse region ranges from 14,000 foot snowcapped mountains to some of the driest deserts in the United States, making the projected impacts of climate change even more difficult to discern. However, there is consensus that temperatures will rise and precipitation patterns will change, increasing the difficulty of managing a river that is already over allocated.

Figure 1: Average Projected Changes in Annual Runoff, 2041-2060 (selected river basins)

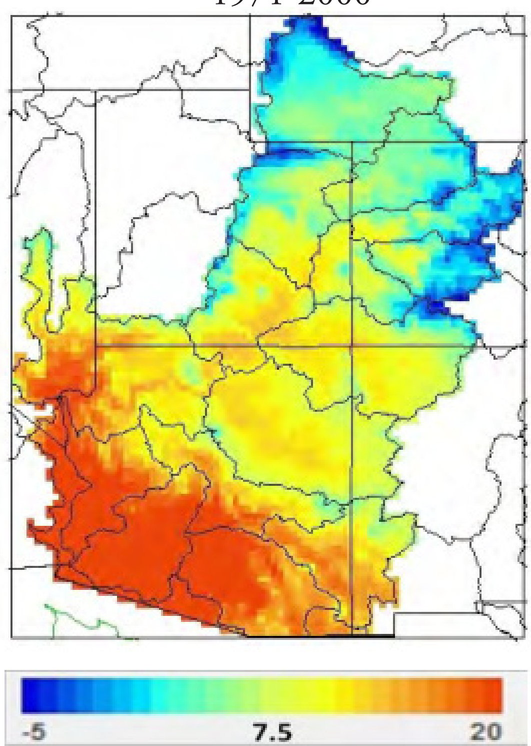


Source: National Geographic

Historical Climate Data: A Story of Variability

The temperature profile shown in **Figure 2** exemplifies the diversity of the Colorado River Basin. The high elevation headwaters' annual average temperature is -5°C compared to the lowlands where temperatures annual average is nearly 20°C. The annual temperatures only tell half the story as both the high elevation headwaters and lowlands experience extreme hot and cold depending on the season due to the large differences in altitude and mid-continent latitude range.

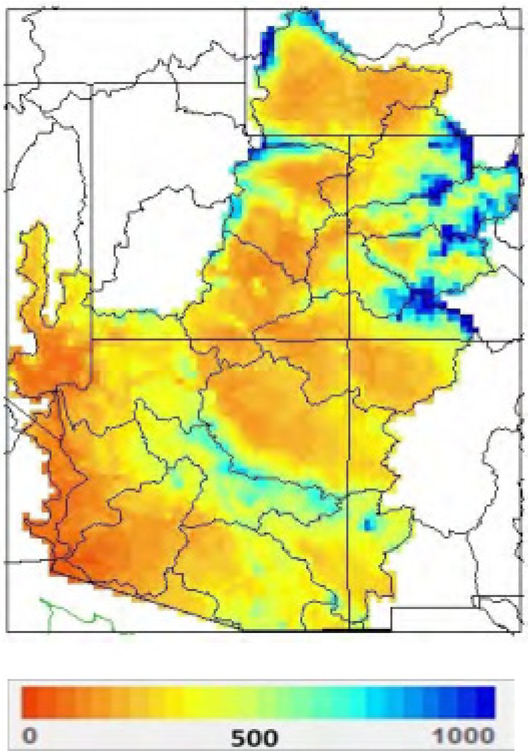
Figure 2: Average Annual Temperature (C°), 1971-2000



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

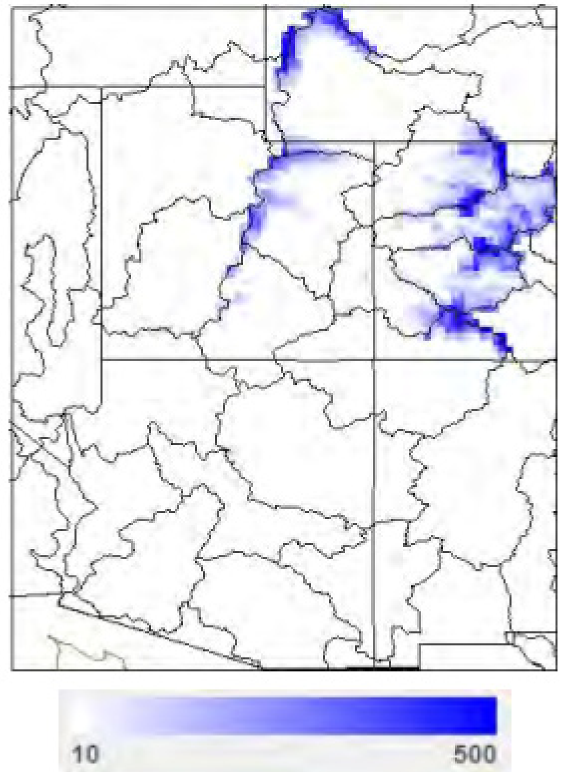
Annual precipitation patterns mimic the temperature variability as certain areas of the headwaters receive 1,000 millimeters (39 inches) of precipitation annually and the lowlands receive under 5 mm (.2 inches) in some areas (**see Figure 3**). The entire basin averages 354 mm of precipitation annually,[4] which is the definition of a semiarid desert (250 mm and 500 mm annually).[5] The headwaters, which are 15% of the land mass of the Colorado River Basin, receive 85% of the total water, the majority falling as snow during the winter and spring months.[6] The snow water equivalent (SWE) illustrates the dependence of the river flow on snowfall (**see Figure 4**). Peak runoff occurs between April and July, depending on snowpack and temperature, and fuels the classic mountain flow regime of the Colorado River.[7] The hydrograph for Lee's Ferry, before creation of Glen Canyon Dam, also shows that snowpack melting is the primary source of Colorado River water when the peak discharge is during the prime snow melting months of May, June, and July (**see Figure 5**).

Figure 3: Average Annual Precipitation (mm), 1971-2000



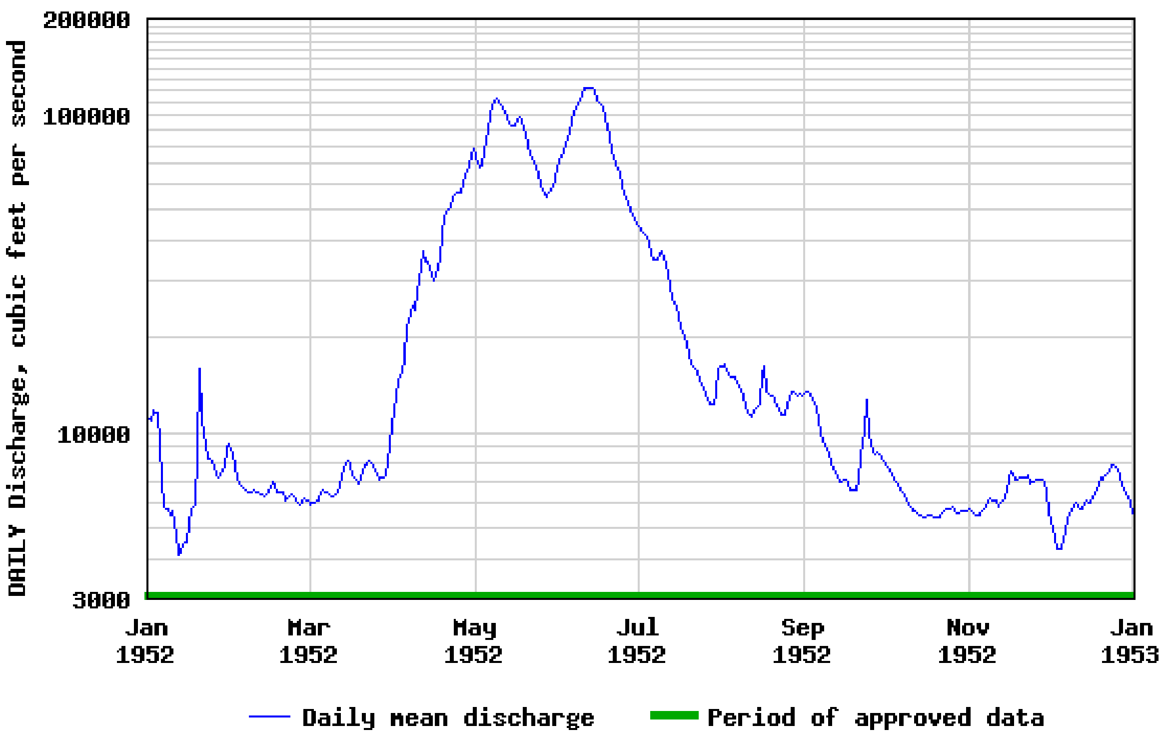
Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Figure 4: Average Annual March SWE (mm), 1971-2000



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Figure 5: USGS Lee's Ferry Hydrograph of 1952 before creation of Glen Canyon Dam

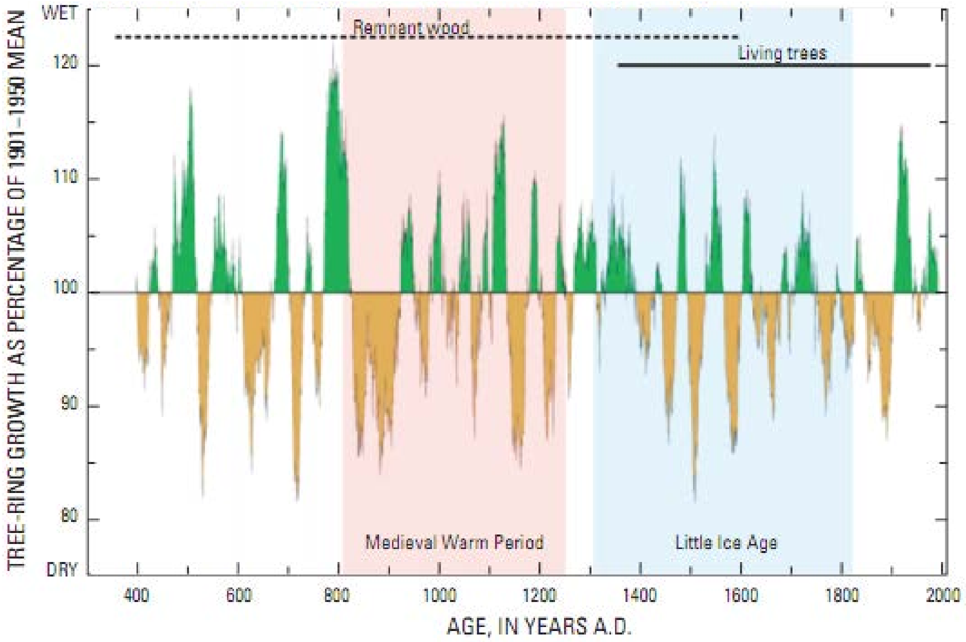


Source: U.S. Geological Survey, "Effects of Climate Change and Land Use on Water Resources in the Upper Colorado River Basin," *Fact Sheet 2010-3123,* January 2011.

Another aspect of the Colorado River flow regime is the variability of the basin. Located in an interior region, away from the consistency of maritime climates, the existence of generally arid climates makes the Colorado River Basin particularly susceptible to climate variability. Tree ring data dating back to the year 400 A.D. shows the extreme precipitation variations that can last for extended periods, notably the extended droughts that occurred during the Medieval Warm Period (**see Figure 6**).[8] The potential natural 40% annual difference in precipitation in the headwaters causes concern for a river system that is dependent on snowmelt for the majority of its water.

Temperature and precipitation affect the runoff, evaporation, runoff efficiency, and the percentage of precipitation that leaves the watershed as runoff, all of which combine to determine stream flow (**see Figures 7, 8, 9**). The average runoff is 45 mm/yr, which equates to a runoff efficiency of 13%, a low efficiency due to the arid climate and soils, which hold the water before it evaporates.[9] For comparison the average runoff efficiency for a temperate climate that receives 900 mm of precipitation annually is 45%.[10] The Colorado River Basin headwaters, with high precipitation and lower temperatures, provide a runoff efficiency of 20%, compared to the region's lowland's runoff efficiency of 0% to 5%. This once again highlights the importance of the headwaters on the entire Colorado River Basin, with most of the annual runoff contributed by headwater streams in Colorado, Wyoming, and Utah.[11]

Figure 6: Climate reconstruction from tree rings in Eagle, Colorado, showing yearly variability in precipitation



Source: U.S. Geological Survey, "Effects of Climate Change and Land Use on Water Resources in the Upper Colorado River Basin," *Fact Sheet 2010-3123,* January 2011.

Figure 7: Average Runoff Efficiency, 1971-2000

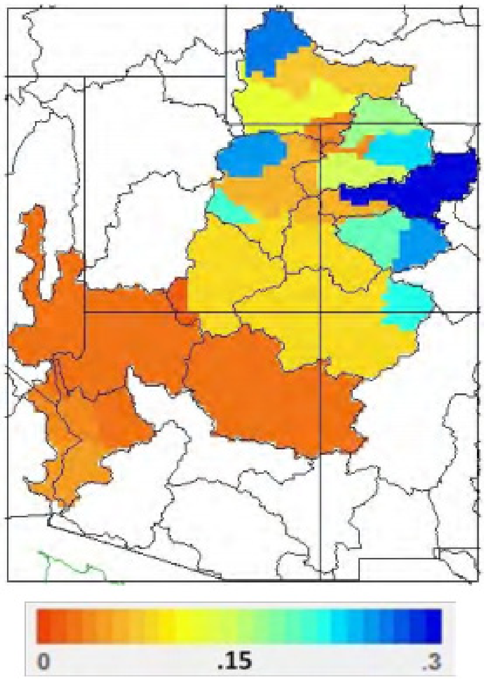


Figure 8: Average Annual Evapotranspiration (mm), 1971-2000

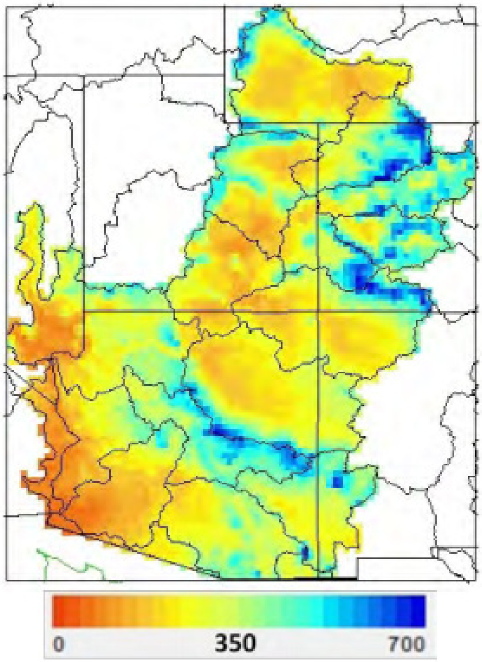
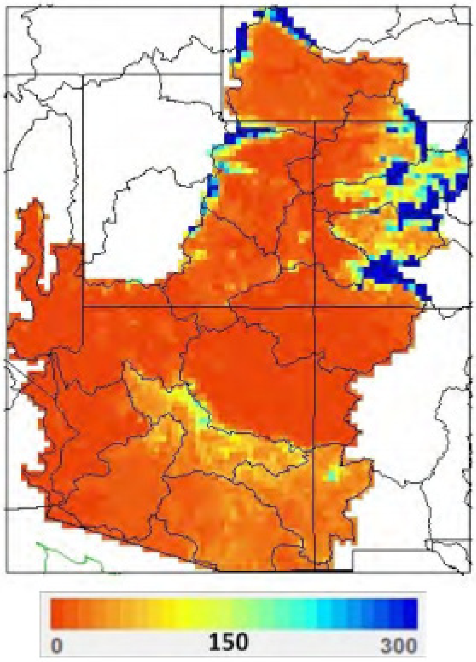
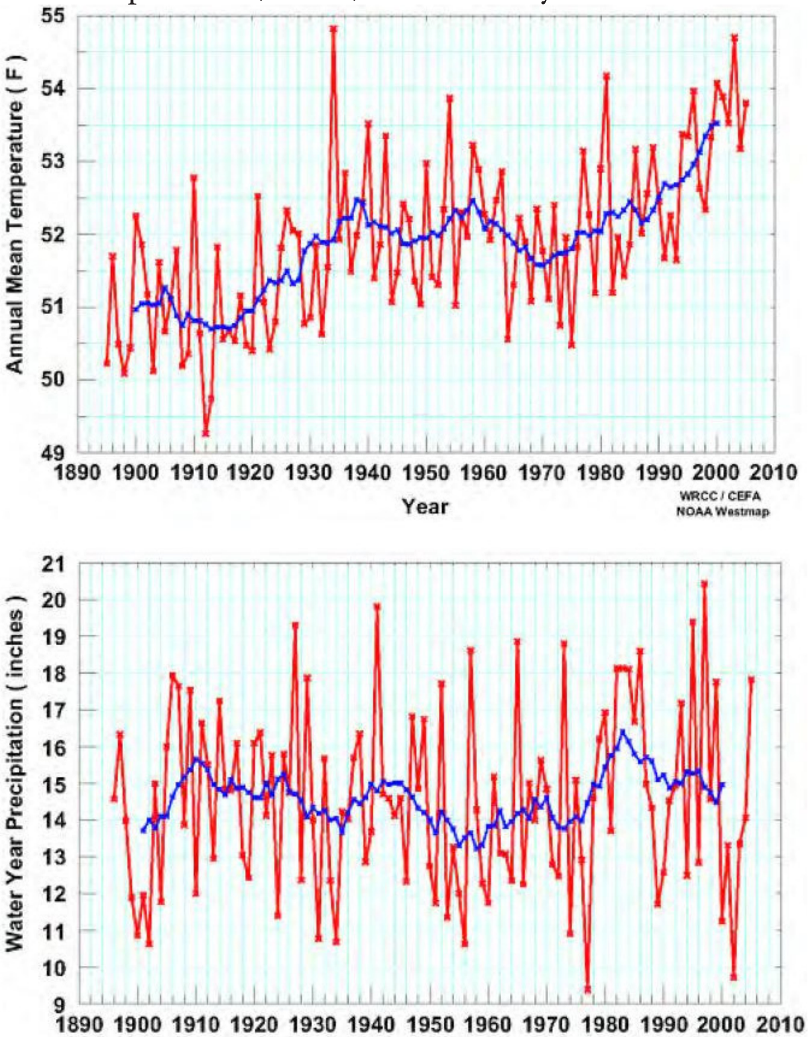


Figure 9: Average Annual Runoff (mm), 1971-2000



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Figure 10: Average Annual Air Temperature (F) and Precipitation (inches) at Lees Ferry, 1895-2005

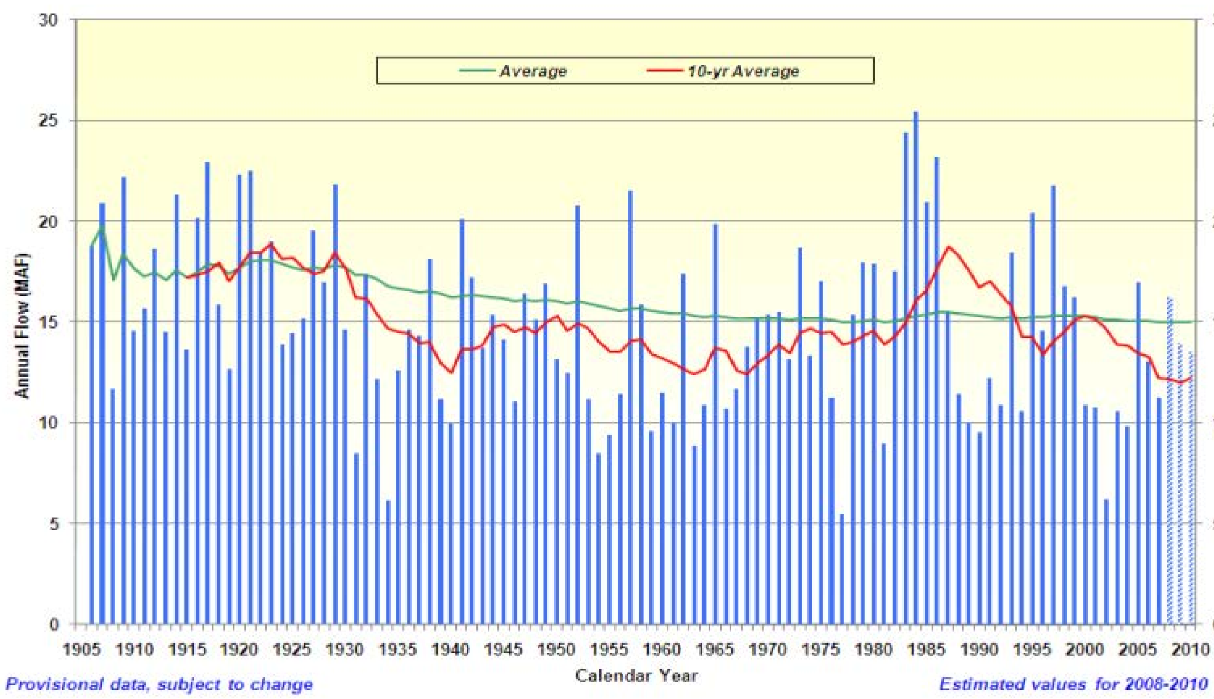


Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Whether anthropogenic or natural, climate change has already begun in the Colorado River Basin. Since the late nineteenth century, temperatures have risen nearly 1.4° Celsius, which exceeds levels of natural climate change with very high statistical confidence.[12] The annual average temperature has increased nearly 2°C at Lee's Ferry, the dividing point between the Upper and Lower basin, since recording started in 1906 (**see Figure 10**). While temperature has shown marked increase, year-to-year precipitation has not changed significantly, but extreme annual variation is evident (**see Figure 10**). This small rise in temperature and the presence of droughts made the 2000-2010 the lowest runoff period in recorded history.[13]

The natural stream flow of the Colorado River varies significantly annually, but in recent years has been extremely low. Whether this is attributable to anthropogenic climate change is debatable, but the average natural flow, measured at Lee's Ferry, was 15.1 million acre-feet (maf) annually from 1906-2005 with a maximum of 25.5 maf and minimum of 5.5 maf.[14] Compare this data to the period of 2000 to 2008 when the average natural flow was 11.7 maf and the severity of the situation becomes apparent. The steady decline in average natural stream flow at Lee's Ferry is beginning to threaten the Colorado River Compact and stress the already tenuous relations among managers of the basin (**see Figure 11**).

Figure 11: Natural Flow of the Colorado River Calculated at Lees Ferry, 1905-2005

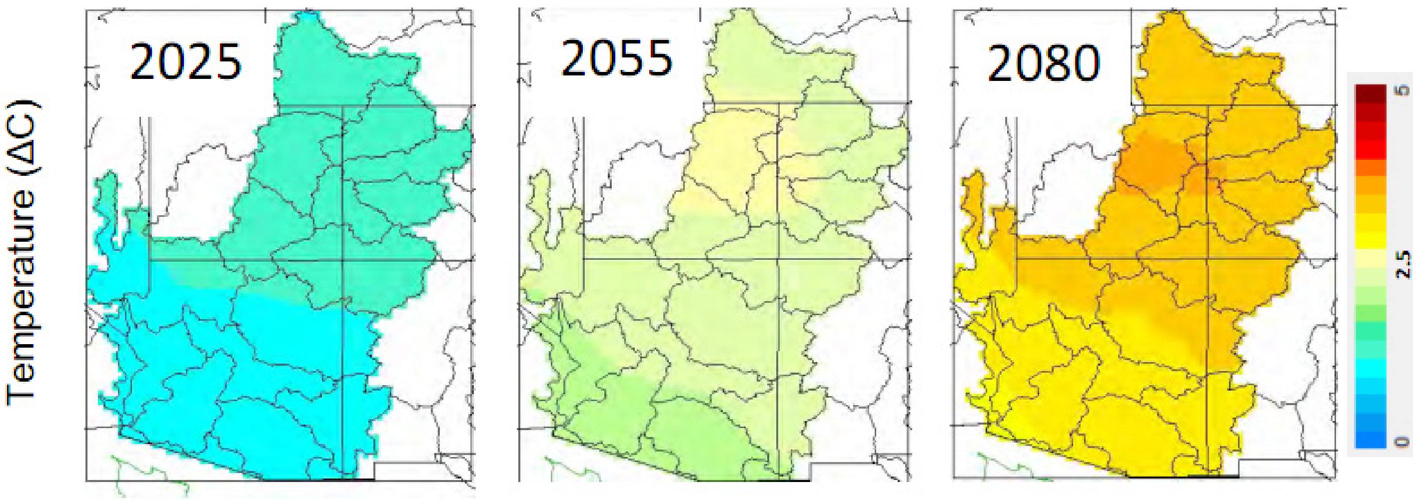


Source: U.S. Bureau of Reclamation, "Planning Hydrology based on Blends of Instrumental Records, Paleoclimate, and Projected Climate Information," A presentation from: *Workshop on Nonstationarity, Hydrologic Frequency Analysis, and Water Management,* Boulder, CO, January 13-15, 2010.

What is Climate Change in the Colorado River Basin?

As atmospheric greenhouse gas concentrations continue to increase, the effects of climate change on the Colorado River Basin will also respond to climate forcing. Current predictions from downscaled global climate models with a "business as usual" rate of greenhouse gas emissions predict a temperature increase of 1°C by 2025, 1.7°C by 2055, and 2.4°C by 2085[15] (**see Figure 12**). The temperature increase will be the largest in the Upper Basin, where the majority of the precipitation falls. This is potentially dangerous because the high alpine areas, which are the largest contributor of water to the basin, are particularly vulnerable to climate change, although the vulnerability is partly due to the uncertainty of climate change on these high elevation areas.[16]

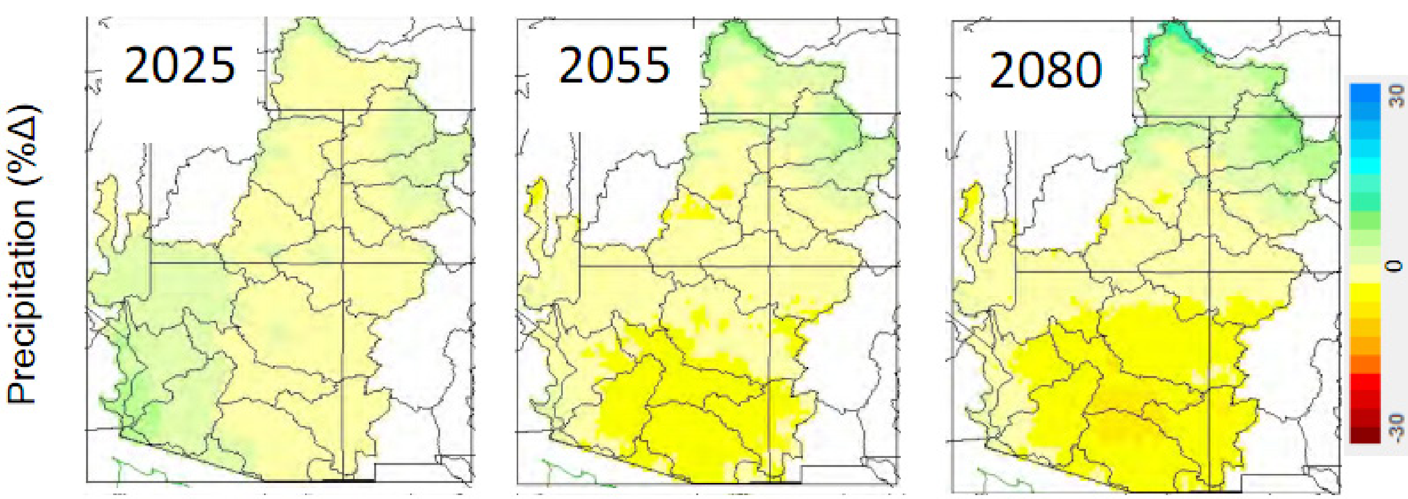
Figure 12: Mean Predicted Change in Temperature (°C)



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Climate change effects on precipitation will not be as noticeable as its effect on temperature because of the complex systems that govern precipitation. The predicted decrease in precipitation is 10 mm/yr (3%) by 2025, 20 mm/yr (6%) by 2055, and 10 mm/yr (3%) by 2085[17] (**see Figure 13**). The location of precipitation will undergo a more drastic change than the amount, as the Lower Basin will become more arid with northern Arizona receiving 15% less water, and the headwaters area receiving more water, an increase of up to 10%.[18]

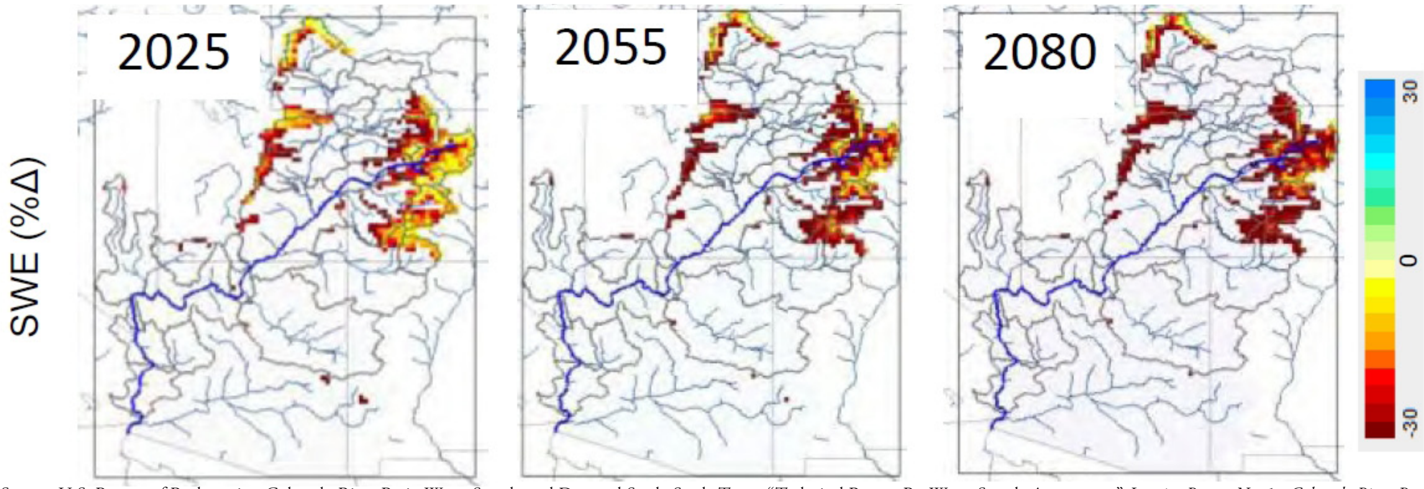
Figure 13: Mean Predicted Change in Precipitation



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Will Stauffer-Norris, Bald eagle on Lake Powell with the Navajo coal plant

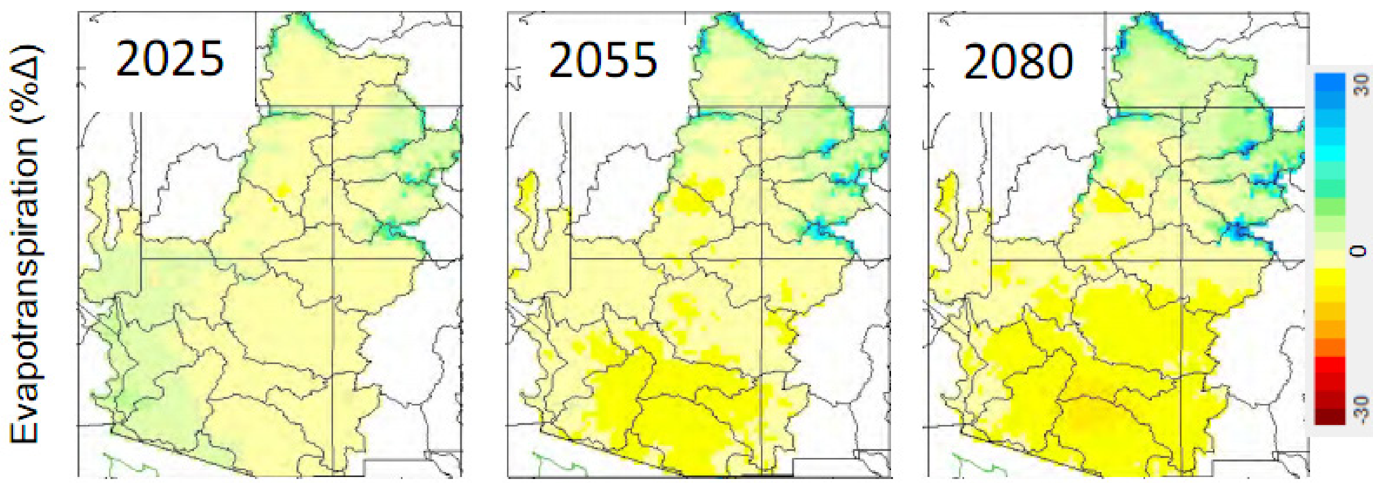
Figure 14: Mean Predicted Snow Water Equivalent (April 1st)



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

The main source of water, snowpack, will be impacted greatly by the increase in temperature and change in precipitation. Although the headwaters will receive slightly more precipitation, the increased temperature will result in a drastic decrease in the snow water equivalent, as shown in **Figure 14**. April 1st snow water equivalent, normally the largest amount of snow during the hydrologic year, from October 1st to September 30th, will decrease by 24% by 2025, 29% by 2055, and 30% by 2085.[19] The reason for this drastic decrease in snow water equivalent is the increase in temperature, leading to more precipitation falling as rain rather than snow, and a potential decrease in winter and spring precipitation[20][21](**see Figure 15**). The area hit hardest by these changes will be the lower elevation alpine areas because of their natural proximity to the boundary between snow and rain and the greater chance of the ground being exposed by snowmelt.[22]

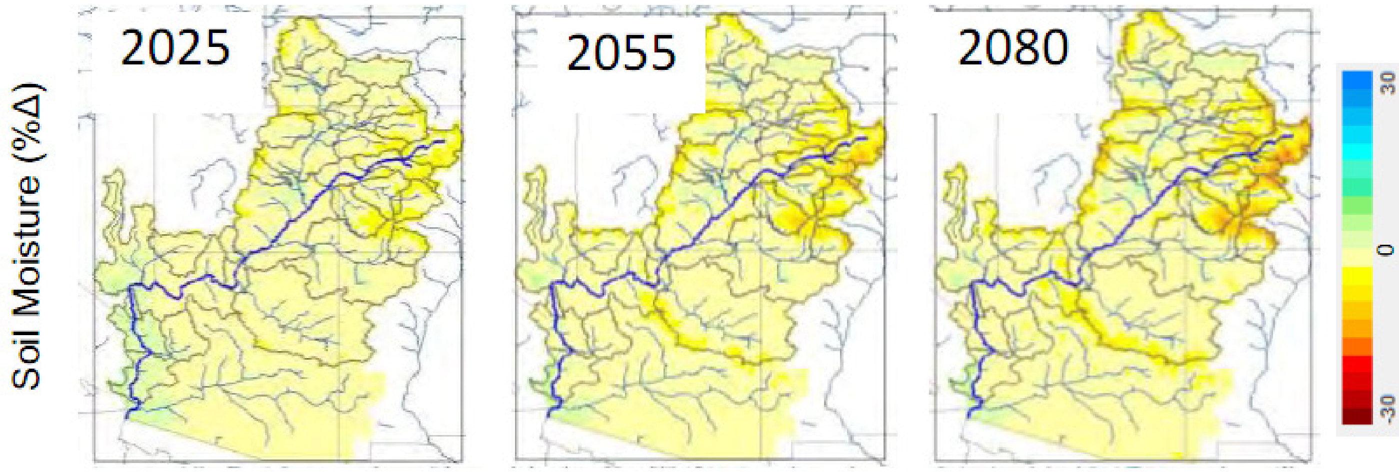
Figure 15: Mean Predicted Change in Evapotranspiration



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

Dominique Saks

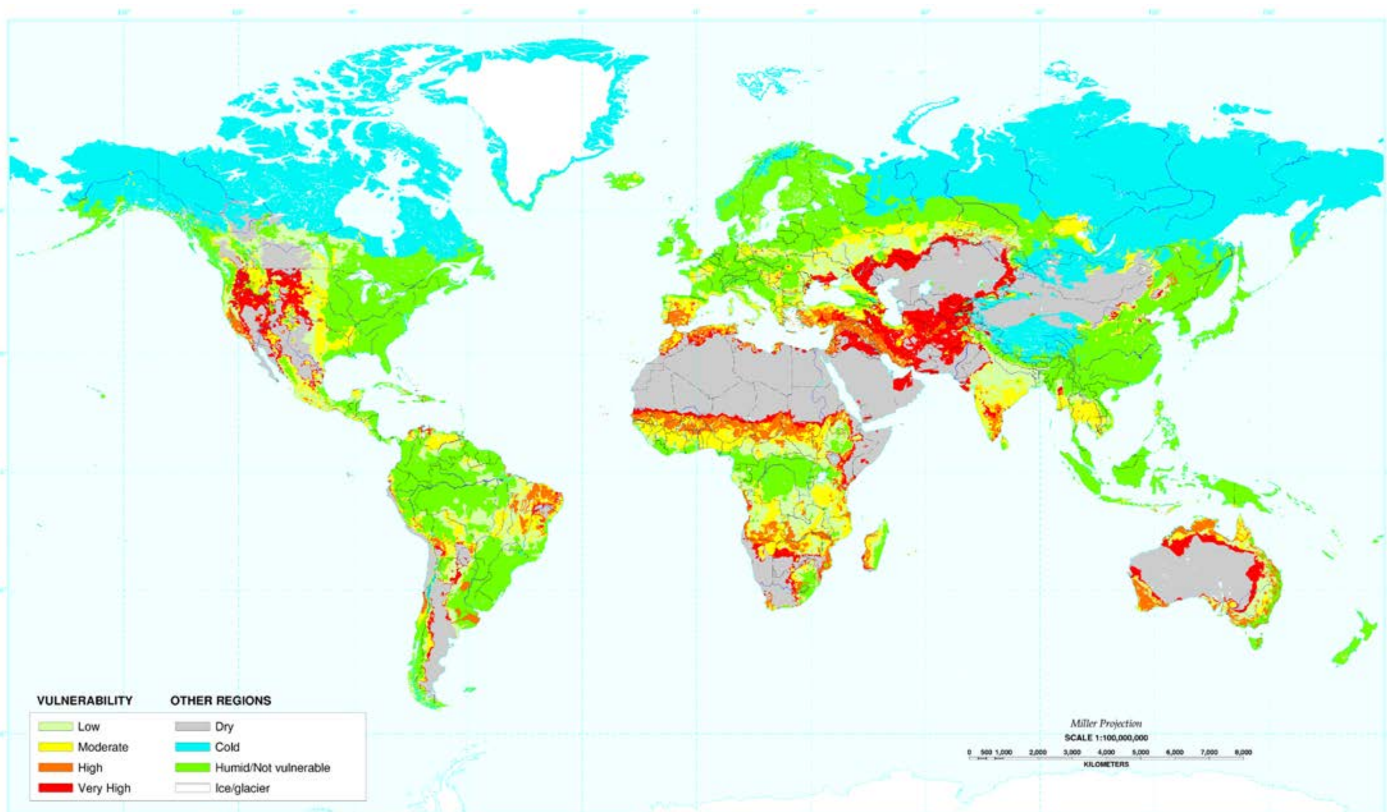
Figure 16: Mean Predicted Change in Soil Moisture (June 30th)



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

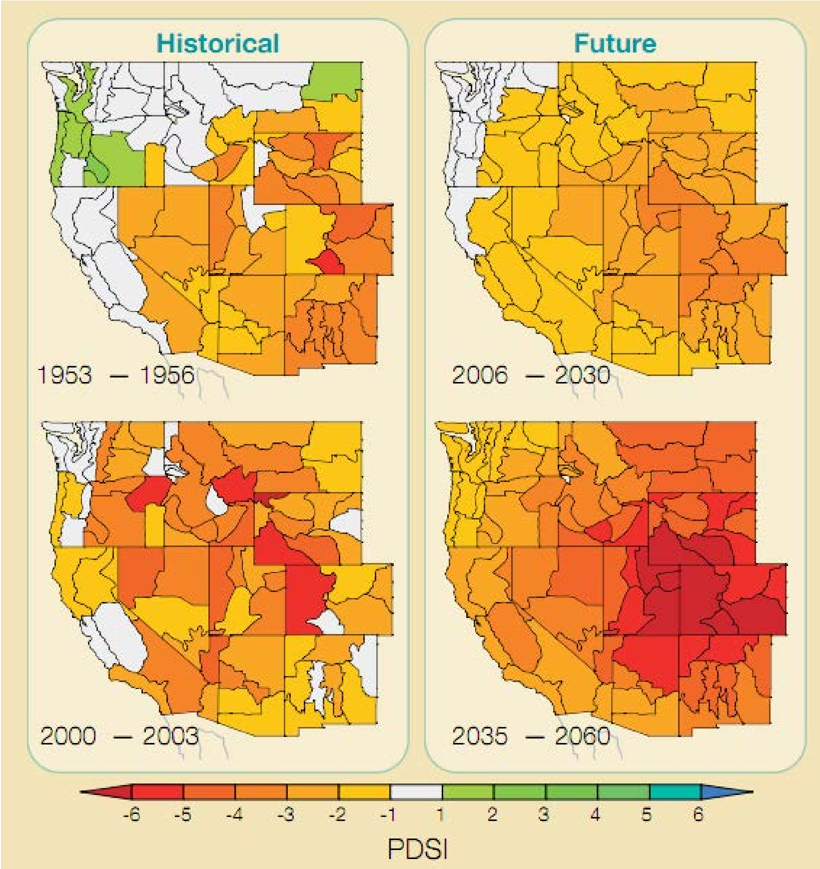
The increased projected temperature will also affect the soil moisture, which is an important factor in runoff. Already arid soils of the Colorado River Basin, especially the Lower Basin, are not predicted to dry significantly but the more moist soils of the Upper Basin will see a significant decrease in soil moisture (**see Figure 16**). The drier Upper Basin soils are predicted to result in reduced runoff due to greater percolation into the groundwater and absorption into the surface soils. The result is a predicted increase in desertification of the Upper and Lower Basins (**see Figure 17**).

Figure 17: Global Desertification Vulnerability



Source: U.S. Department of Agriculture Natural Resources Conservation Service, *Global Desertification Vulnerability Map*, accessed March 22, 2012, http://soils.usda.gov/use/worldsoils/mapindex/desert.html.

Figure 18: Palmer Drought Severity Index (PDSI)



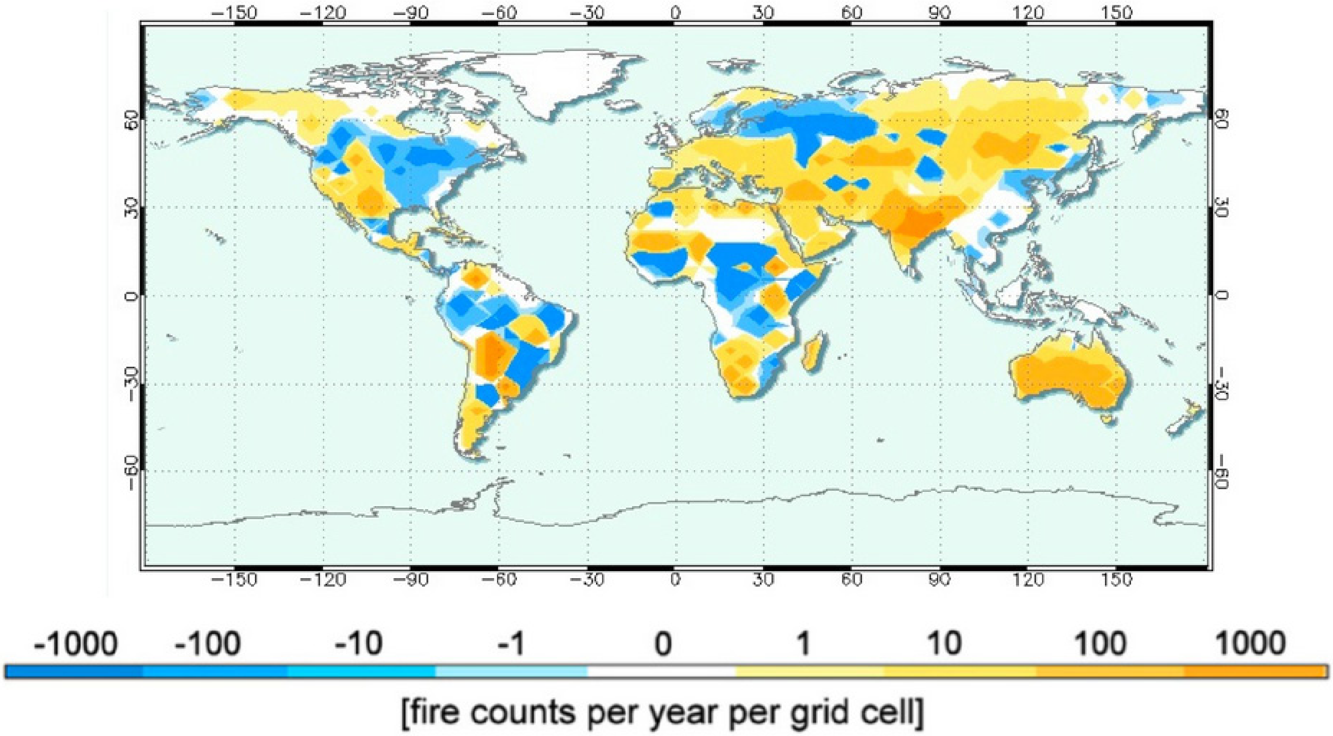
Note: Values less than -3 dente serve drought conditions

Source: Martin Hoerling and Jon Eischeid, "Past Peak Water in the Southwest," accessed March 22, 2012, http://wwa.colorado.edu/climate_change/docs/hoerling%20past%20peak%20water%20in%20press.pdf.

The lower precipitation, higher temperature, and desertification will create basin-wide drought conditions. The Palmer Drought Severity Index (PDSI), created by Walter Palmer in the 1960s, determines dryness using temperature and precipitation data. Between the years 2035 and 2060, the Upper Basin's moisture balance is predicted to be similar to the worst drought on record (**see Figure 18**). This expected desertification is potentially dangerous due to the feedback cycles that could result due to a drier climate. As Auden Schendler, the vice president of sustainability at Aspen Skiing Company, stated "It isn't the warmer temperature or lower precipitation that scare us; the potential feedback loops of climate change are what keep us up at night."[23]

One of the most concerning feedbacks is the increased number and severity of fires. Under current greenhouse emission rates over coming decades, the fire risk in the West is predicted to increase by 30% to 60% by the end of the twenty-first century; even with reductions in emissions, the Southwest is extremely vulnerable to wildfires (**see Figure 19**).[24] Wildfires have the potential to create a feedback loop of their own due to the decrease in albedo, the reflectivity of a surface, and the reduction in vegetation. Reduced albedo would lead to land surfaces absorbing additional incoming solar radiation, therefore increasing basin temperatures, and leading to greater fire risk. Larger or more frequent fires could also lead to extremely unstable soils, which can easily lead to sedimentation or airborne dust.

Figure 19: Regional Projected fire activity changes under maximum emission scenario



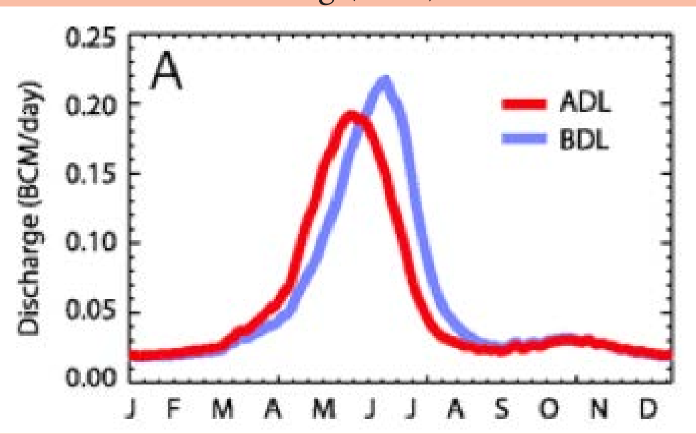
Source: U.S. National Aeronautics and Space Administration, accessed March 22, 2012, http://www.nasa.gov/images/content/492951main_Figure-3-Wildfires.jpg.

Case Study: Dust on Snow

The measureable temperature effects of climate change could produce significant runoff effects on the Colorado River Basin, but the feedback cycles are what frighten the experts. As Auden Schendler, the Vice President of Sustainability at Aspen Skiing Company stated "the potential feedback loops of climate change are what keep us up at night."[25] One of the most dangerous feedbacks for the Colorado River Basin is desertification and the resulting dispersion of dust on snow. Water in the Colorado River Basin is largely dependent on snowpack from winter months melting slowly into spring and summer. It represents over 80% of the total water supply in the basin, and variability of high alpine zones to climate change make dust on snow a potentially devastating feedback loop.[26 27] The dust increases the absorption of solar energy due to its lower albedo, the reflectiveness of a surface, therefore decreasing runoff and an earlier peak runoff.[28]

The source of the dust that falls on the Colorado River headwaters comes from the Colorado Plateau and Basin areas due to agricultural uses that disturb the sensitive soils.[29] This has resulted in a increase of solar energy absorbed by 25-50 watts per square meter (W/m^2) in the eastern central Colorado River Basin, which when compared to the increase of energy due to greenhouse gases (2 W/m2), illustrates the impact of dust on snow.[30] This influx of energy has resulted in a 27-35 day reduction in snow coverage compared to snow without dust in the Colorado headwaters.[31] Extrapolated to the entire Upper Basin, the predicted flows at Lee's Ferry show significant decreases in timing, on average three weeks earlier, and amount of runoff, one billion cubic meter or approximately 5% of the yearly average (**see Figure 20**).[32]

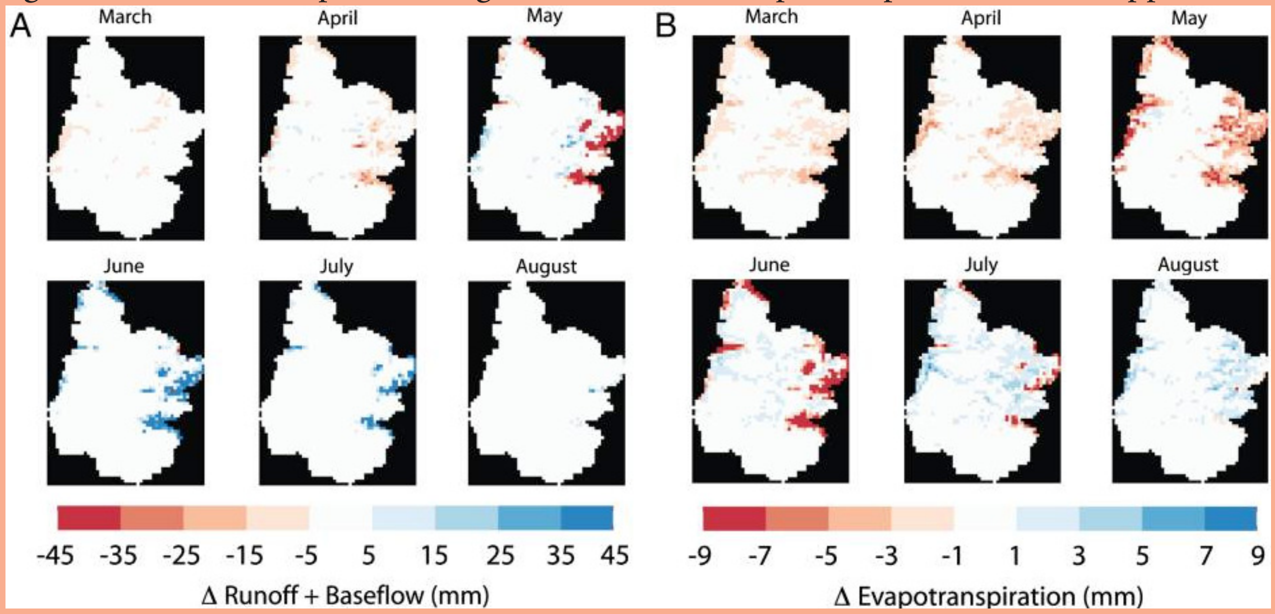
Figure 20: Differences in runoff timing and volume between After Dust Loading (ADL) and Before Dust Loading (BDL) dust scenarios.



These decreases in amount of runoff and changes in timing have the potential to cripple the Upper and Lower Basins of the Colorado River. The lower amount of runoff will stress an already over-allocated watershed and as loss of vegetative cover increase so will the desertification of the basin. The earlier snowmelt will also have feedback impacts in the basin by increasing the amount of evaporation of the water in streams and reservoirs and increasing evapotranspiration in the headwater areas due to sublimation, water transforming from snow to water vapor and evaporating, and liquid water in the snowpack reaching plant life therefore being respired (**see Figure 21**).[33] Dust on snow is also vulnerable to changes in vegetation density throughout the basin, as the widespread existence of plants provides much needed stability to soils.

Although the role of dust on snow is well documented, research is needed on the effects of lower melt water runoff in the basin. This potential feedback loop will threaten the basin's main water supply and cause disastrous results downstream. Current research initiatives, such as the Colorado Dust on Snow Program, are trying to discover the complex relations between snow, dust, and the Colorado River water.

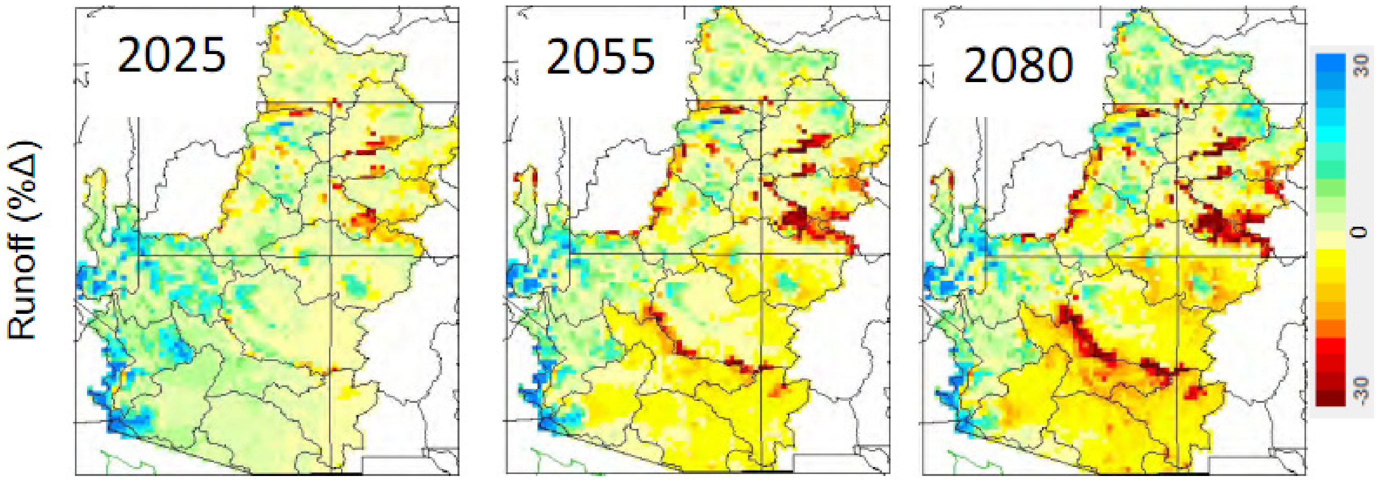
Figure 21: Simulated spatial changes in runoff and evapotranspiration in the Upper Basin



Note: (A) Spatial change in monthly average runoff (BDL–ADL) for March–August. (B) Spatial change in monthly average ET (BDL–ADL) for March–August. Note the difference in scales. Representation of runoff and ET in terms of depth (mm) is traditional for these studies and can be thought of as the depth of water across the entire grid cell. Each cell's volume of runoff or ET comes from multiplying this depth by the area of the cell.

Source: Figures from Thomas Painter, "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," Proceedings of National Academy of Sciences 107, no. 40 (2010): http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2951423/.

Figure 22: Mean Predicted Runoff Change



Source: U.S. Bureau of Reclamation Colorado River Basin Water Supply and Demand Study Study Team, "Technical Report B - Water Supply Assessment," *Interim Report No. 1 - Colorado River Basin Water Supply and Demand Study,* June 2011.

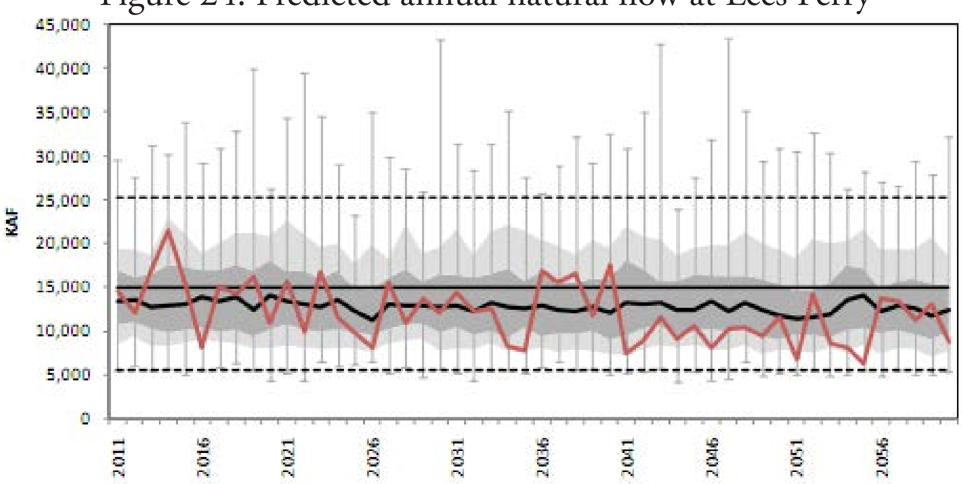
All of these results of climate change will combine to reduce runoff basin wide by a projected 6 mm/yr (14%) in 2025, 8 mm/yr (18%) in 2055, and 8 mm/yr (18%)[34] (**see Figure 22**). The hardest hit areas will be the headwaters and the mountains in central Arizona due to higher temperatures and reduced precipitation in this area. The lower runoff will drastically reduce stream flows through the basin as runoff represents the majority of water that constitutes stream flows in the Colorado River Basin.

Figure 23: Project changes in Colorado River Basin stream flow by mid-21st Century

Study	Global circulation models (runs)	Spatial scale	Temperature	Precipitation	Year	Runoff (flow)	Risk estimate
Christensen and others (2004)	1 (3)	VIC model grid (~8 mi)	+3.1°F	-6%	2040-69	-18%	Yes
Milly (2005) replotted by P.C.D. Milly	12 (24) (~100-300 mi)	CGM grids --	--		2041-60	-10% to -20% 96% model agreement	No
Hoerling and Eischeid (2007)	18 (42)	NCDC Climate Division	+5.0°F	~0%	2035-60	-45%	No
Christensen and Lettenmaier (2007)	11 (22)	VIC model grid (~8 mi)	+4.5°F (+1.8 to +5.0)	-1% (-21% to +13%)	2040-69	-6% (-40% to +18%)	Yes
Seager and others (2007)	19 (49)	CGM grids (~100-300 mi)	--	--	2050	-16% (-8% to -25%)	No
McCabe and Wolock (2007)	--	USGS HUC8 units (~25-65 mi)	Assumed +3.6°F	0%	--	-17%	Yes
Barnett and Pierce (2008)	--	--	--	--	2057	Assumed -10% to -30%	Yes

Source: U.S. Geological Survey, "Effects of Climate Change and Land Use on Water Resources in the Upper Colorado River Basin," Fact Sheet 2010-3123, January 2011.

Figure 24: Predicted annual natural flow at Lees Ferry



Note: Predicted annual natural flow at Lees Ferry. Median (line) 25th-75th percentile band (dark shading) 10th-90th percentile band (light shading) maximum (whiskers) selected individual realization (red line) and 1906-2007 observed mean, min, max (dashed lines)

Source: Christensen, Niklas S. "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." Climate Change 62, no. (2004): 337-363.

Many climatologists have modeled the expected changes in the Colorado River Basin with consensus on reduced flows, but the magnitude of the change is still being debated. These projections range from a 6% to 45% reduction in flow, with a consensus on a 15% to 20% decline by 2050 (**see Figure 23**).[35] The projected annual natural flow at Lee's Ferry shows that the variation of yearly flows will also be a factor that needs to be incorporated into future management (**see Figure 24**).

The Future of Climate Change in the Colorado River Basin: What do the Projections Mean?

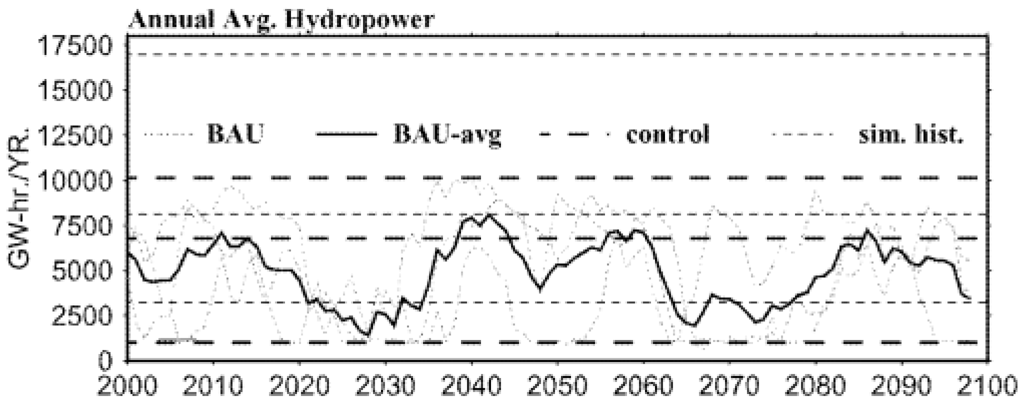
The effects of a modified climate will drastically change the way the Southwest uses Colorado River water. As a primarily rural, agricultural area, 78% of water is used for agriculture. Expected increased temperatures and decreased water availability have the potential to negatively affect the agricultural economy by raising the price of water high enough for lower value crops to become unprofitable.[35] The main culprit will be higher evapotranspiration and lower soil moisture due to increased temperatures, particularly for water-intensive crops. The effects on agriculture are disputed, but most agree that crops will require more water than they currently need to grow; however, there is a possibility of shorter time required for crops to mature due to the higher concentrations of carbon dioxide in the atmosphere.[36] Whether the predicted beneficial aspects of climate change occur or not, the agricultural sector is facing an uphill battle because of the reduced water availability and the increase in water needed for growing crops due to higher temperatures.

Just as the average annual temperature will rise, the yearly variation will increase. Coupled with lower water availability, these variables have the possibility to affect agriculture. The low flow years could potentially result in farmers having to fallow their fields or abandon crops due to insufficient water. This will only become more prevalent as the Southwest's population continues to grow and water storage becomes scarcer. In southern California, one of the largest consumers of Colorado River water for agriculture, there is a predicted 29% decrease in water deliveries due to projected climate change.[37] The other primary agricultural activity is ranching, which is just as susceptible to climate change as farming due to the necessity of water to grow feed, as well as provide water for livestock.[38]

With the increased demand and decreased supply of water in the West, the cost of water will most likely increase. This increase is particularly dangerous to the agricultural sector for multiple reasons, including the large volume of water utilized by crops and the decreased irrigation efficiency association with increased evapotranspiration. Experts predict a loss of $300 million per year in California's agricultural districts that rely on Colorado River water by midcentury, related directly to the effects of climate change.[39]

Another major economic sector of the Colorado River Basin is hydropower electricity generation by basin dams. Currently the major dams of the Colorado River and its tributaries, primarily Glen Canyon and Hoover Dams, have the ability to produce over nine billion kilowatt hours per year (kWhr/yr).[40] Due to increased evapotranspiration and sedimentation behind dams, there is a predicted 53% decrease in hydropower production by the year 2080 (**see Figure 25**).[41] This decrease in power, combined with the probable increase in energy prices, will have a significant economic effect on the Southwest. Many industries and municipalities are reliant on relatively cheap hydropower to provide services. An example of this is the Wellton Mohawk Irrigation District, a 65,000-acre agricultural zone in western Arizona. The agricultural operations only remain profitable due to the cheap power provided by Parker Dam, which allows them to pump water uphill to their fields.[42]

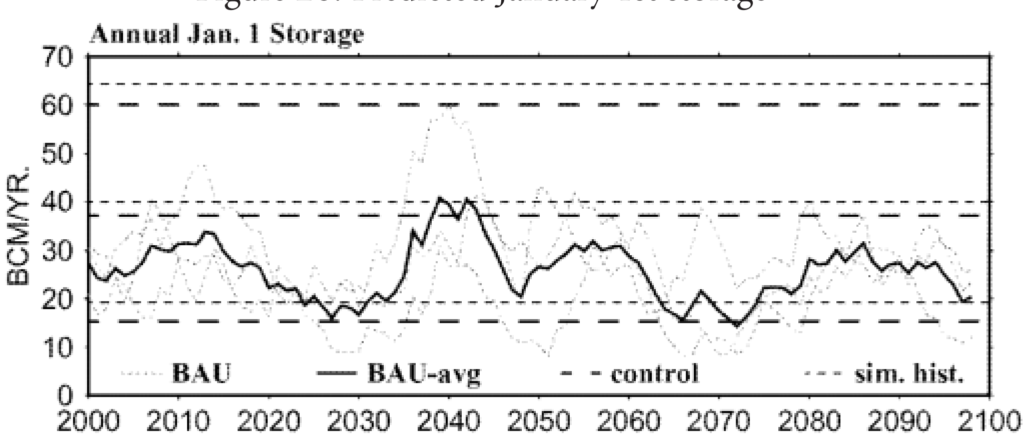
Figure 25: Predicted total annual hydropower production



Source: Christensen, Niklas S. "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." Climate Change 62, no. (2004): 337-363.

Storage capacity is another aspect of the Colorado River Basin that is vulnerable to climate change. A 10% to 20% reduction in annual flow has a predicted 30% to 60% reduction in annual storage.[43] Currently the maximum storage of all the dams in the Colorado River Basin is 60 maf since Lake Powell filled in 1983.[44] The predicted average annual storage for the years 2010-2039 is 20.08 maf (33% of potential storage), 2040-2069 is 21.91 maf (36%), and 18.99 maf (32%) for 2070-2099 (**see Figure 26**).[45]

Figure 26: Predicted January 1st storage



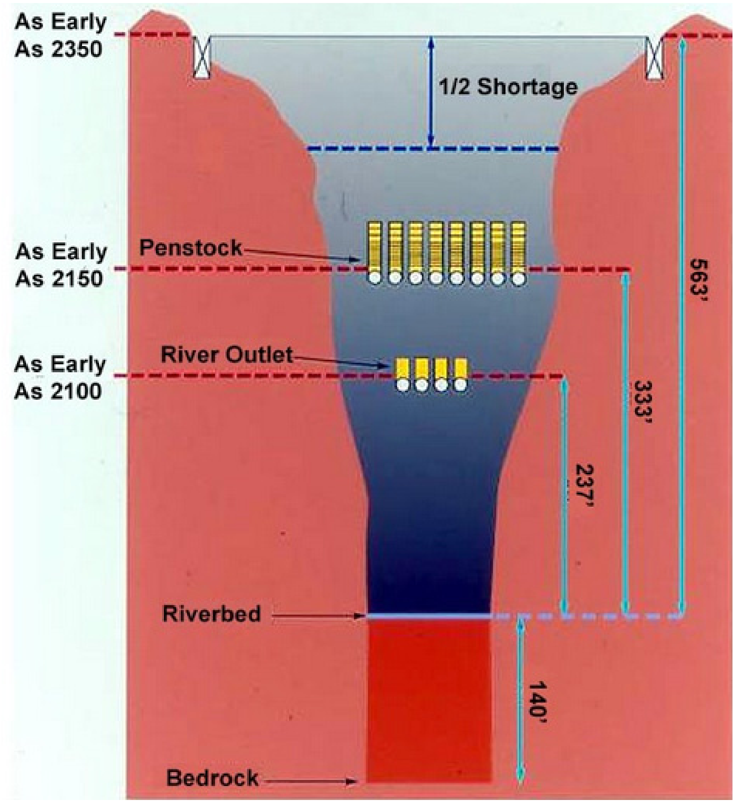
Source: Christensen, Niklas S. "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." Climate Change 62, no. (2004): 337-363.

The cause for this large decline in average storage is mainly due to increased evaporation with higher temperatures. Due to the arid climate and large surface areas of the reservoirs, evaporation currently accounts for a 1.4 maf/yr loss from the large dams on the Colorado River, more than four times the consumptive water usage of Nevada.[46] As temperature increases the evaporative loss will continue to grow, further depleting the storage capabilities of the Colorado River. Another effect of rising temperatures is peak runoff occurring earlier in the year, therefore allowing more time for the water to evaporate. The increased temperatures are responsible for an increase of 2 watts per square meter (W/m2) that has the potential to significantly alter the timing of peak runoff.[47] The increased exposure of snowmelt to the desert climate will result in an increase in evaporative losses.

The other element affecting the reservoirs on the Colorado River is sedimentation. Natural sediment loads once were carried all the way to the Gulf of California, creating the Colorado River Delta. As dams were installed in the basin, sediment began settling to the bottom of reservoirs, a process that slowly reduces storage capacity of the reservoirs from the bottom up. The largest recipient of sediment on the Colorado River is Lake Powell behind Glen Canyon Dam. Receiving over 100 million tons of sediment annually, the equivalent of nearly 30,000 dump trucks per day, the Glen Canyon Dam could be unable to produce power by 2150 and completely filled by 2350 (**see Figure 27**).[48]

Ultimately the effects of climate change will result in difficulties to meet Colorado River Basin Compact requirements. The anticipated chance of releasing 8.23 maf annually at Lee's Ferry, the required amount from the Upper to Lower Basin, will only be met 59% of the time from 2010-2039, 72% of the time in 2040-2069, and 79% of the time in 2070-2099 (**see Figure 28**).[49] The average release is predicted to drop from 9.5 maf/yr to 7.9 maf/yr during the twenty-first century.[50 51] The water delivery agreement with Mexico will also be tested, as the average release will drop to 0.9 maf/yr, well under the 1.5 maf/yr they are allocated.[52] The chance of fulfilling 1.5maf is predicted to decline to 24% of the time from 2010-2039, 46% chance in 2040-2069, and 25% chance in 2070-2099 (**see Figure 29**).[53]

Figure 27: Potential Sedimentation in Lake Powell behind Glen Canyon Dam



Source: Glen Canyon Dam Institute Archives

Figure 28: Simulated average annual release from Glen Canyon Dam to the Lower Basin and probability that release targets are met for simulated historical, control, BAU Periods 1-3

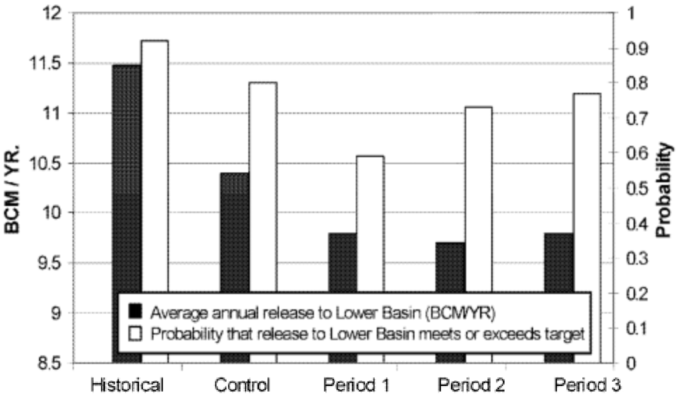
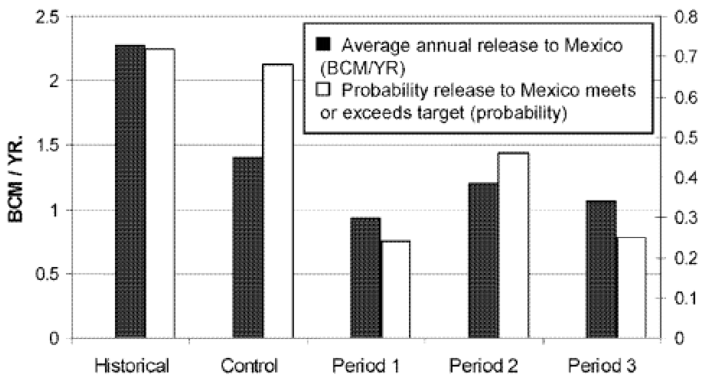
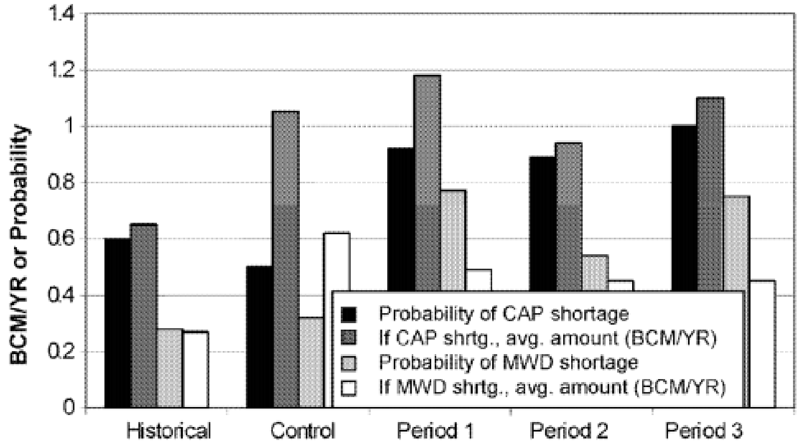


Figure 29: Simulate average annual release from Imperial Dam to Mexico and probability that release targets are met for simulated historical, control, BAU Periods 1-3



Source: Christensen, Niklas S. "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." Climate Change 62, no. (2004): 337-363.

Figure 30: Probability of a delivery shortage to Central Arizona Project and metropolitan Water District; and average amount of shortages for simulated historical, control, and BAU Period 1-3 simulations



Source: Christensen, Niklas S. "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin." Climate Change 62, no. (2004): 337-363.

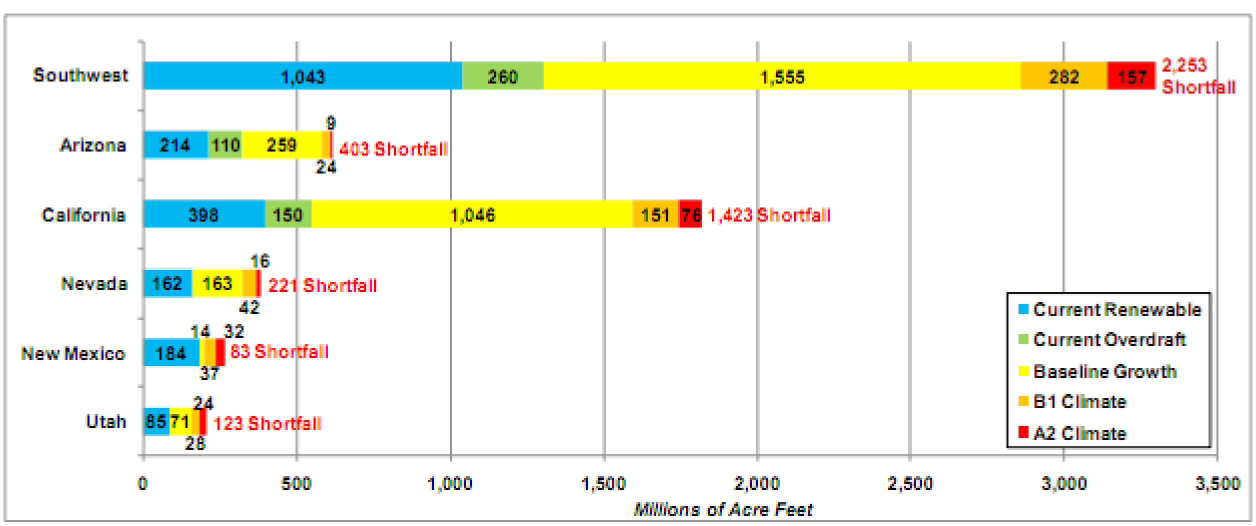
Along with stressing the Compact, lower water availability will stress the metropolitan areas of Los Angeles, Las Vegas, and Phoenix. These water districts have restrictions that are based upon the level of the large reservoirs, mainly Lake Mead. Level 1 shortages, which entails the diversifying of water sources through ground water exploration and Central Arizona Project receiving 288,000 less acre feet per year, are expected to occur 92% of the time during 2010-2039, 89% of the time during 2040-2069, and 100% of the time during 2070-2099 (**see Figure 30**).[54 55 56] The more restrictive Level 2 shortages, which include a Central Arizona Project receiving 360,000 less acre feet per year and basin-wide discussion on water conservation action, will need to be implemented 77% of the time during 2010-2039, 54% of the time during 2040-2069, and 75% of the time during 2070-2099.[57 58 59]

Although the majority of the water falls in the Upper Basin, the Lower Basin is allocated 7.5 maf/yr by the Compact. This is a potentially dangerous situation for the Upper Basin because under current agreements, the Lower Basin states maintain that the Upper Basin is still required to release on average 7.5 maf/yr to fulfill the Compact. This issue of obligation to deliver- or on the other hand- an obligation not to deplete is hotly debated and will surely become a major aspect of water negotiations in the future.[60] The result may be that the Upper Basin is forced to use its present perfect rights, the Upper Basin's water rights prior to the Compact in 1922, which are estimated around 2.2 maf/yr.[61]

The predicted decrease in Colorado River water availability will put pressure on water users to find alternative sources of water. However, the problem remains: what will be the potential effect of climate change on other sources of water? The largest alternative source of water is fresh groundwater, replenishment of which is extremely vulnerable to the increase in temperature and other aspects of climate change. The expected fresh groundwater use for the Southwest shows the unsustainable predicted increase in withdrawals and how climate change will affect the fresh groundwater reserves (**see Figure 31**).[62]

The other potential source of water for the Colorado River Basin is the importation of water from nearby watersheds suggested by many decision makers within the basin.[63] This idea is limited by a few factors, as most of the surrounding area is extremely arid and has little water to offer, population is growing in the western U.S., climate change will likely adversely affect these sources, as well as the huge costs associated with transferring water.

Figure 31: Predicted Southwestern states groundwater use under a 'baseline' scenario of current climate change conditions combined with expected population and income growth; and under two climate change scenarios, comparing a mild (B1) and more serve (A2) climate forecast.



Source: Frank Ackerman and Elizabeth A. Stanton "The Last Drop: Climate Change and the Southwest Water Crisis." Stockholm Environment Institute, February 2011.

Adaptation to Climate Change in the Colorado River Basin

Projected climate change will have a significant effect on the Colorado River Basin. The question is how will the Southwest adapt to these changes? The rising temperatures, increased water variability, and desertification will stress an already fragile basin to new levels. The most important change for the basin is to install a fully adaptive management system, a structure process of decision making in the face of uncertainty by using knowledge gained to develop better management practices, which can cope with the drastic changes of climate change and the constant influx of better information (**see Figure 32**). This circular approach will ensure the inclusion of the most current data and stakeholders that will be essential in combating an extremely complex and changing problem.

Figure 32: Adaptive Management Cycle

Source: Conservation Measures Partnership, *Open Standards for the Practice of Conservation, Version 2.0*, October 2007, accessed March 27, 2012, http://www.conservationmeasures.org/wp-content/uploads/2010/04/CMP_Open_Standards_Version_2.0.pdf.

In addition to a new management plan, new technologies to offset the increased temperature and evaporation are needed. As the primary water user, agriculture's involvement in implementing new water efficient practices is essential. Some progress has been made in the last few years that can be extrapolated to the entire basin. For example, lining irrigation canals can prevent water from seeping into the groundwater. The largest canal-lining project was the lining of 23 miles of the All-American Canal. This project saves over 70,000 acre feet annually from entering the groundwater table and similar projects have potential to save valuable surface water.[64] This prevention of surface water entering the groundwater table can also be seen as restricting the replenishment of groundwater reserves.

Another way to offset the increased evaporation is storing water underground. Artificially replenishing aquifers is currently being done by a number of water districts. Southern Nevada Water Authority's artificial aquifer replenishment program stores water during the wet months and extracts it during the dry; annual average artificial replenishment is 13 to 18 feet.[65] A similar project has been operating in central Arizona for nearly 15 years now and represents the largest artificial aquifer replenishment with a potential 376,000 acre-feet per year of water being replenished.[66] There are many large, mainly depleted aquifers in the Lower Basin that could be refilled during extreme high water years or by undesirable water such as water from a grey or brown system.[67] Underground storage is attractive because it eliminates evaporative loss, which is responsible for 3% to 5% loss of water stored annually in Lake Mead.[68] The drawback of underground storage is the amount of energy required to pump water into the ground.

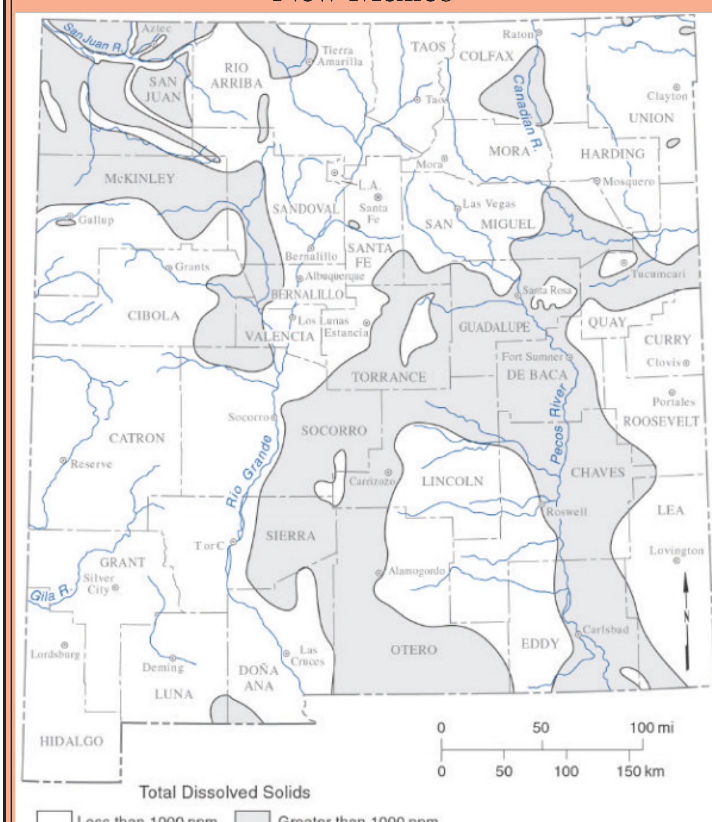
Some of the proposed new sources of water are controversial and none are more debated than cloud seeding, the practice of introducing silver iodine or dry ice into the atmosphere to condense gaseous water into liquid. Some American states have been cloud seeding for years to offset the effects of droughts and increase agricultural production or decrease the intensity of storms.[69] In 2006, the state of Wyoming started a pilot project of cloud seeding over the Medicine Bow, Sierra Madre, and Wind River mountain ranges to evaluate the effectiveness of cloud seeding.[70] The economic analysis of the potential revealed that a 10% increase in snowpack as a result of cloud seeding would equate to $2.4 to $4.9 million of water.[71] Comparing the price of water, purchased from the High Savery Dam at $158.93 per acre foot versus cloud seeding costs of $6.60 to $13.00 per acre foot, shows the massive potential for cloud seeding in the West.

Importing water from outside the Colorado River Basin occurs rarely, but currently the prospects of increased precipitation in other regions have sparked the idea. Certain areas, especially flood-prone ones like the Mississippi, would benefit in transferring some of their water west to the Front Range of Colorado, which currently relies heavily on Colorado River water through trans-mountain diversion.[72] The obstacle is the cost of infrastructure to deliver the water nearly 1,500 miles away. The energy required to move water up nearly 5,000 feet would also be extremely expensive and currently impractical. Other ideas including piping water south from the Northwest, but the large mountain ranges in between make this an unlikely solution as well.

Case Study: Desalination

As the need for new sources of water increases, due to depletion of fresh water, desalination of brackish groundwater has potential to provide the Lower Colorado River Basin with a viable and extensive source of water. There are over 1.5 billion acre-feet of brackish groundwater, defined as containing 1,000 to 10,000 milligrams per liter (mg/L) of dissolved solids, in Arizona and New Mexico alone (**see Figure 33, 34**).[73] [74] This vast amount of brackish water could provide the entire Lower Basin with 200 years of its apportionment, 7.5 million acre-feet. The groundwater is also being replenished by agricultural runoff, which accounts for 78% of water use throughout the basin, making desalination of brackish groundwater a potentially sustainable water supply. The major obstacle for desalination is the energy required for treatment and large infrastructure required to supply a substantial amount. Recent developments in new desalination technologies have reduced the cost of desalinating low salt concentration water, 1,000 to 5,000 mg/L of total dissolved solids, to $325.85 to $977.55 per acre foot of water, compared to the average of $700.00 per acre foot now paid for municipal water in parts of the Lower Basin or as low as $15 for agricultural water.[75] [76] [77]

Figure 33: Map of brackish water reserves in New Mexico



Source: Peggy Johnson, "Hydrogeological Mapping and Assessment of Saline Aquifers," New Mexico Groundwater Assessment Program Workshop (2004): 11, http://web.archive.org/web/20100604122806/http://wrri.nmsu.edu/conf/brackishworkshop/presentations/johnson.pdf.

Figure 34: Map of brackish water reserves in Arizona

Source: Edwin McGavock, "Desalination of Brackish Groundwater in Arizona," Errol L. Montgomery & Associates Inc. (2008): 1.

The potential uses of desalinated brackish water are numerous and the water can be treated to precise concentrations of dissolved solids to reduce cost when water quality is not as important, for example, in mining or energy production water use. Increasing and diversifying domestic water supplies is particularly attractive to metropolitan areas within the Colorado River Basin, due to their water rights being junior to agricultural water rights and recent population growth. Currently, Las Vegas, Phoenix, and Tucson are evaluating groundwater desalination opportunities and smaller cities such as Scottsdale and Abilene have already built desalination plants for groundwater.[78] The plants can range from 10 million gallons per day (30 acre-feet per day) to 30 million gallons per day (90 acre-feet per day), which would provide a significant portion of municipal uses.[79]

Another potential benefit of building desalination plants is the possibility of having to desalinate Colorado River water to comply with Total Maximum Daily Load (TMDL), a subsection of the Clean Water Act that designates the maximum total dissolved solids for wastewater treatment or industrial uses.[80] Although not currently being implemented in the Colorado River Basin, there is that possibility due to the impacts of possible future oil shale production and present agricultural runoff, which both influence water quality.

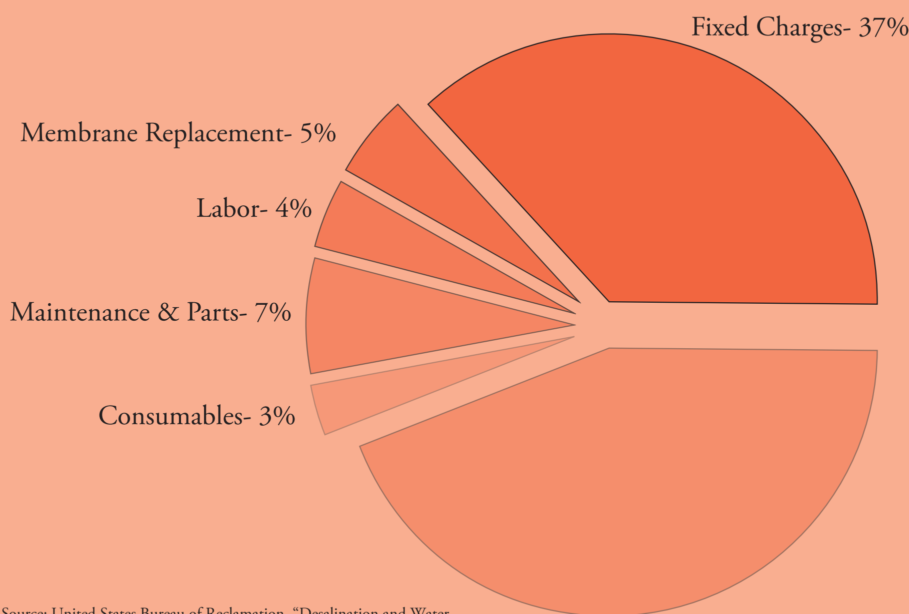
While desalination of groundwater has promise to provide a large enough water source to adapt to reduced water runoff due to climate change, it still has its flaws. The major flaw is the energy use and cost (nearly seven to eight times the cost of fresh water treatment) needed to pump the brackish water through reverse osmosis membranes (**see Figure 35**).[81] This large energy need is likely to be met by fossil fuels, which will only increase the concentration of greenhouse gases, exacerbating the climate change issue, or by large solar plants, which are currently extremely expensive. Disposal of the waste product, an extremely salty slurry, which is between 25% and 40%of the input, provides another expense and environmental issue.[82]

Figure 35: Cost of water treatment options

Treatment cost for fresh water from a conventional water treatment plant	$0.30-0.40/1000 gallons
Reclaimed water for industry in Southern California	$2.22/1000 gallons
Treatment cost for desalinated brackish water for residential use	$1-3/1000 gallons
Treatment cost desalinated seawater	
Santa Barbara, CA (1992)	$5.50/1000 gallons
Cyprus-2 (1999)	$3/1000 gallons
Tampa Bay (2001)	$2.08/1000 gallons

Source: United States Bureau of Reclamation, "Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee," (2003): 52.

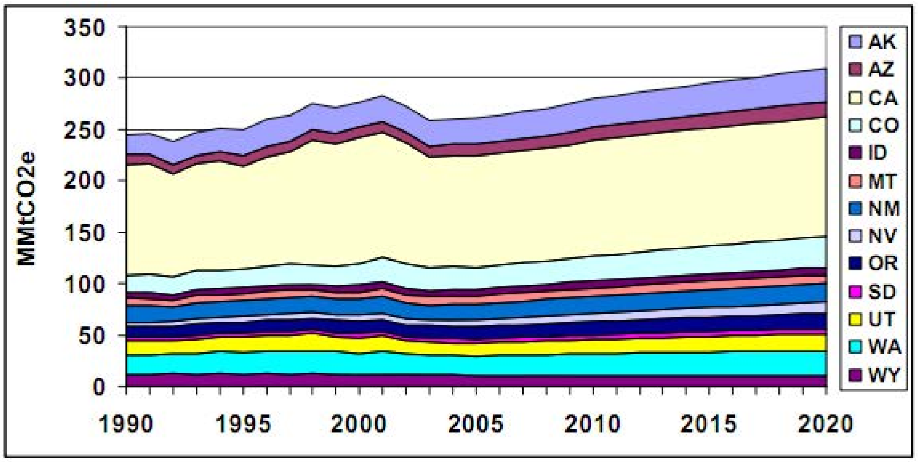
Figure 36: Potential reductions in desalination process



Source: United States Bureau of Reclamation, "Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee," (2003): 56.

In 2003, the Bureau of Reclamation, along with consultants, released the *Desalination and Water Purification Technology Roadmap*, with the aim to increase technology development and awareness of desalination opportunities. The report details the cost breakdown of desalination and the possible reductions in energy use and maintenance cost that could make desalination a viable alternative to Colorado River water (**see Figure 36**).[83] The extensive report illustrates the belief, despite the current issues of desalination, that brackish groundwater is a promising future water source in the Southwest.

Figure 37: Current and predicted carbon dioxide emissions in the Western United States



Source: Center for Climate Strategies and Western Regional Air Partnership "Greenhouse Gas Emission Inventories and Forecasts for Nine Western States," accessed March 22, 2012, http://www.epa.gov/ttnchie1/conference/ei16/session3/roe.pdf.

global scale of reductions in carbon discharge into the atmosphere required to reduce its impacts. As the ultimate "tragedy of the commons," global climate change will require the cooperation of all countries, and ultimately all people. A bottom-up approach is unlikely to be successful because the near-term effects of climate change will not be significant enough to impact the lives of humans until the globe is beyond the tipping point of climate change, meaning feedback cycles have begun that are extremely difficult to stop.[90] This dilemma puts the burden on governments to foresee the effects of climate change and take the necessary steps to mitigate climate change.[91]

Mitigation of Climate Change: What can the Next Generation Do?

Adaptation presents the most achievable approach due to the uncertainty of climate change, but mitigation by reducing greenhouse gas concentrations in the atmosphere is the only true solution. Currently the western United States emits 250 million metric tons of carbon dioxide and this figure is expected to grow (**see Figure 37**).[84] Although the Rockies region has vast reserves of traditional fossil fuel energy sources, including coal, natural gas and oil, use of these fossil fuels will only continue to contribute to climate change.

In order to slow the rate of emissions, the Colorado River Basin, in particular, and the United States, in general, need to maximize use of renewable energy resources. The potential for renewable energy sources such as wind, solar, and biomass is vast (**see Figure 38**). Capitalizing on these resources in the Rockies region alone could potentially reduce carbon dioxide emission by 87 million metric tons per year or nearly 34% of America's carbon dioxide emissions.[85 86 87]

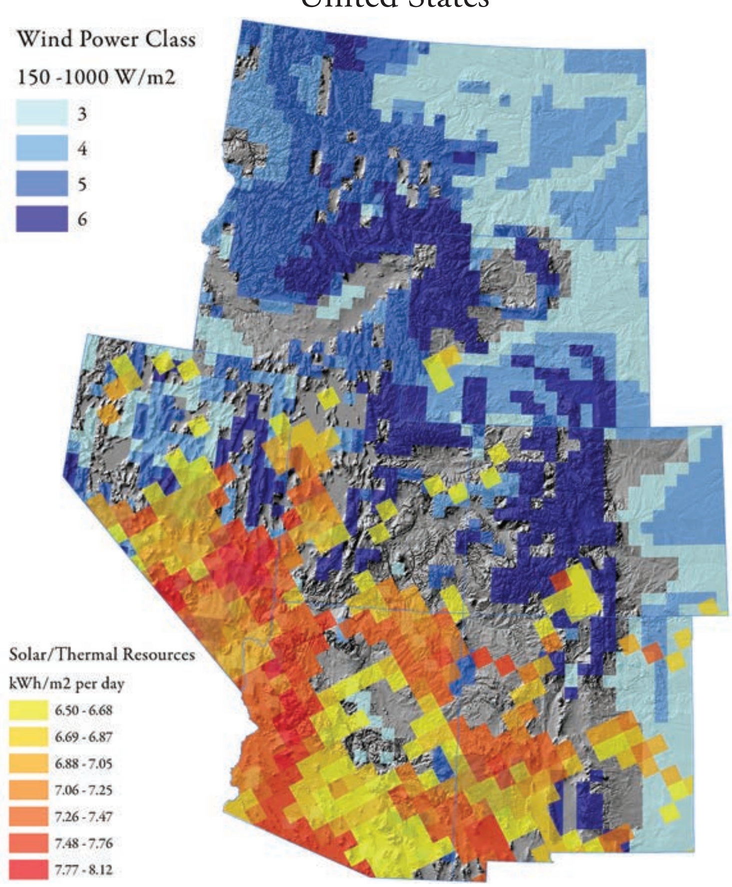
Carbon sequestration of emissions from continued use of fossil fuels has recently gained steam due to the limitations of renewable energy and sequestration's effectiveness in combating climate change. The relatively arid climate of the Colorado River Basin limits the potential for sequestration through biomass, but the large underground petroleum fields and saline aquifers provide ample space for possible underground sequestration. Geo-sequestration, the process of injecting carbon dioxide into old oil wells or aquifers, has proven to be effective and plausible on a large scale in the United States, with over 6,000 square miles of rock formations having been mapped for sequestration purposes.[88] There are potentially dangerous side effects of carbon sequestration, primary the risk of release during an earthquake or seismic event and the destabilization of geology by the pressure of inputting gases.[89]

Mitigation of climate change is a daunting task for a multitude of reasons, but none are bigger than the

Conclusion: Will the Twenty-First Century be Nasty?

The Colorado River Basin stands at a crossroad today. Water demand has recently exceeded supply, deliveries to Native Americans and Mexico are problematic, and infrastructure is slowly becoming outdated and inefficient. As these evident problems persist, the looming threat of climate change must be added to discussions and basin-wide management. Without careful planning for climate change adaption and lobbying for mitigation, the decrease in stream flow due to climate change will overwhelm all other issues. The

Figure 38: Renewable energy potential in the Western United States



Source: Department of Energy, National Renewable Energy Lab conservative estimate for stream flow decrease by mid-century of 6% would still threaten the entire basin, from agriculture to municipalities.

Offsetting such a formidable challenge cannot be done in years, decades, or even centuries, but will take constant adaptation to changes in climate and water needs. This flexible adaptive management approach will continually challenge the current Law of the River, and the necessary changes cannot be enacted overnight. While the shortsighted problems of water supply for this year's crops or cities are necessary issues, without a long-term management plan that includes adapting to and mitigating climate change, the basin will inexorably move towards crises. The Colorado River represents the lifeline of the Southwest to over 30 million people. Without consideration of climate change and its effect on water availability, the once productive Southwest will return to its desert roots.

What can today's youth do in the face of such challenges? Traditional approaches to water management in the Colorado River Basin must become more flexible at a minimum, and may even need to be replaced by new management guidelines and legal constructs. The section of this *Report Card*: "Laws of the Colorado River Basin: Obsolete or Flexible for a Sustainable Future?" faces this conundrum head-on. In addition, the results of the Rockies Project's survey of college-age youth opinions about Colorado River Basin issues and management bring fresh perspectives to the debate. In the end, it is vital that today's youth become engaged and involved in how our precious natural resources in the basin are managed, for they will soon inherit the results!

[1]Richard Seager, "Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America," *Science*, no. 316 (2007): 1181 http://www.sciencemag.org/content/316/5828/1181.short.
[2]United States Bureau of Reclamation. *SECURE Water Act Section 9503(3): Reclamation Climate Change and Water Report to Congress*. 2011, 7.
[3]Jonathan Waterman, *Colorado River Basin: Balancing a Limited Supply with an Increasing Demand* . Accessed June 20th, 2011, http://www.environment.nationalgeographic.com/environment/freshwater/colorado-river-zoomifier/.
[4]Niklas Christensen, "The Effects of Climate Change on the Hydrology and Water Resources of the Colorado River Basin," *Climatic Change* 62, no. 1-3 (2004): 350, http://www.springerlink.com/content/t66120x0hw672395/.
[5]USGS Publication "What is a Desert." Accessed August 3, 2011, http://pubs.usgs.gov/gip/deserts/what/.
[6]United States Bureau of Reclamation. *SECURE Water Act Section 9503(3): Reclamation Climate Change and Water Report to Congress*. 2011, 18.
[7]Ibid., 23.
[8]Ibid., 24.
[9]Niklas Christensen, Climatic Change, 350.
[10]*The Times Atlas of the World*. London: Times Books in collaboration with John Bartholomew & Son, 1985.
[11]Niklas Christensen, *Climatic Change*, 338.
[12]Martin Hoerling, "Past Peak Water in the West," *Southwest Hydrology* 6, no. 1 (2007): 2, http://wwa.colorado.edu/climate_change/docs/hoerling%20past%20peak%20water%20in%20press.pdf.
[13]United States Bureau of Reclamation. *SECURE Water Act Section 9503(3): Reclamation Climate Change and Water Report to Congress*. 2011, 23.
[14]Ibid, 18.
[15]Niklas Christensen, *Climatic Change*, 337.
[16]Philip Mote, "Declining Mountain Snowpack in Western North America," *American Meteorological Society* 86, no. 1 (2005): 42, http://www.livingrivers.org/pdfs/LRlibrary/ClimateDocs/MoteHamletClarkLettenmaier.pdf.
[17]Niklas Christensen, *Climatic Change*, 347.
[18]Ibid.
[19]Ibid.
[20]Ibid.
[21]Arumugam Sankarasubramanian, "Climate Elasticity of Streamflow in the United States," *Water Resources Research* 37, no. 6 (2001): 1771, http://engineering.tufts.edu/cee/people/vogel/publications/climate-elasticty.pdf.
[22]Ross Brown "Northern Hemisphere Snow Cover Variability and Change 1915-97," *American Meteorological Society* 13, no. 1 (2000): 2339, http://journals.ametsoc.org/doi/pdf/10.1175/1520-0442%282000%29013%3C2339%3ANHSCVA%3E2.0.CO%.
[23]Auden Schendler. Interview by Author, Carson McMurray, Aspen, Colorado, July 11, 2011.
[24]Olga Pechony, "Driving Forces of Global Wildfires over the Past Millennium and the Forthcoming Century," *Proceedings of National Academy of Sciences* 107, no. 45 (2010): 19169, http://www.pnas.org/content/107/45/19167.full.pdf+html.


Brenna Swift

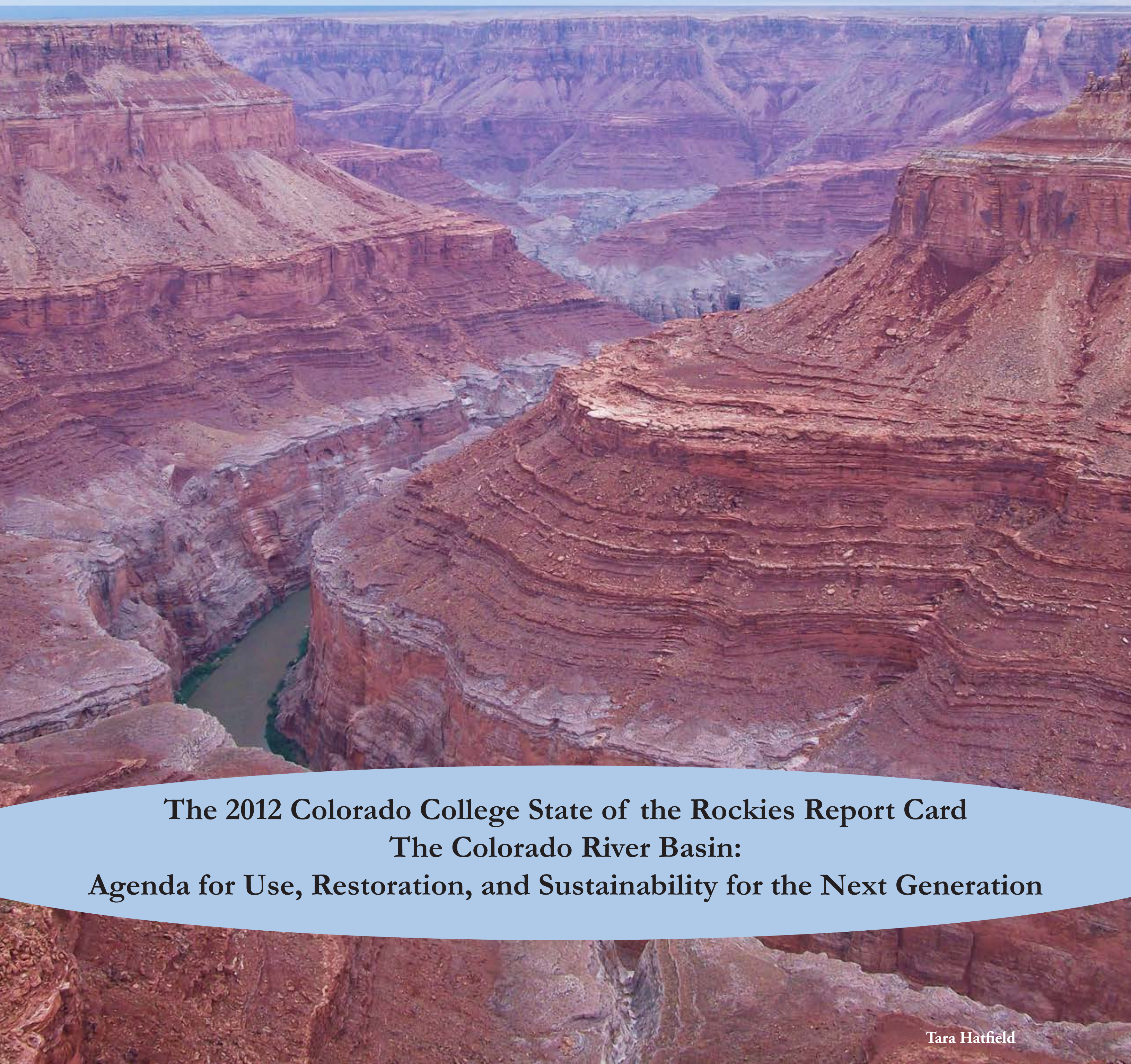
[25]Auden Schendler. Interview by Author, Carson McMurray, Aspen, Colorado, July 11, 2011.
[26]United States Bureau of Reclamation, *SECURE Water Act Section 9503(3): Reclamation Climate Change and Water Report to Congress*. 2011, 18.
[27]Philip Mote, "Declining Mountain Snowpack in Western North America," *American Meteorological Society* 86, no. 1 (2005): http://www.livingrivers.org/pdfs/LRlibrary/ClimateDocs/MoteHamletClarkLettenmaier.pdf.
[28]Thomas Painter, "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," *Proceedings of National Academy of Sciences* 107, no. 40 (2010): http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2951423/.
[29]Thomas Painter, "Impact of Disturbed Desert Soils on Duration of Mountain Snow," *Geophysical Research Letters*, 34, no. 6 (2007): http://www.agu.org/pubs/crossref/2007/2007GL030284.shtml.
[30]Ibid.
[31]Ibid.
[32]Thomas Painter, "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," *Proceedings of National Academy of Sciences* 107, no. 40 (2010): http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2951423/.
[33]Ibid.
[34]Niklas Christensen, *Climatic Change*, 350.
[35]Douglas Kenney, "Rethinking the Future of the Colorado River: Draft Interim Report of the Colorado River Governance Initiative," Western Water Policy Program, (2010): 109, http://www.rlch.org/archive/wp-content/uploads/2010/12/CRGI-Interim-Report.pdf.
[36]David Lobell, "Global Scale Climate-Crop Yield Relationship and the Impacts of Recent Warming," *Environmental Research Letters* 2, no. 1 (2007): 6, ftp://ftp-gem.jrc.it/evahugh/NPK/climate/Climate%20Lobel%20climateandyields%202011.pdf.
[37]Josué Medellín-Azuara, "Adaptability and adaptations of California's water supply system to dry climate warming," *Climatic Change* 87, no. 1(2008): S80, http://www.springerlink.com/index/10.1007/s10584-007-9355-z.
[38]Hallie Eakin, "Climate Variability and the Vulnerability of Ranching in Southeastern Arizona: A Pilot Study," *Climate Research* 21, no. 3(2002): 271, http://www.southwestclimatechange.org/node/483.
[39]Frank Ackerman, "The Last Drop: Climate Change and the Southwest Water Crisis," Stockholm Environment Institute-U.S. Center (2011): 5, http://sei-us.org/Publications_PDF/SEI-WesternWater-0211.pdf.
[40]Bureau of Reclamation, *Power Distribution*, accessed August 4, 2011, http://www.usbr.gov/lc/hooverdam/parkerdam.html.
[41]Niklas Christensen, *Climatic Change*, 357.
[42]Ken Baughman. Interviewed by Author, Carson McMurray, Wellton, Arizona, July 24, 2011.
[43]EPA, " The Colorado River Basin and Climate Change: The Sensitivity of Stream Flow and Water Supply to Variations in Temperature and Precipitations," *Policy, Planning and Evaluation*, (1993).
[44]Colorado River Water Users Association, *The Colorado River*. Accessed December 12, 2011, http://www.crwua.org/ColoradoRiver/RiverUses/Reclamation.aspx.
[45]Niklas Christensen, *Climatic Change*, 353.
[46]Jonathan Waterman, *Colorado River Basin: Balancing a Limited Supply with an Increasing Demand.*
[47]Thomas Painter, "Response of Colorado River Runoff to Dust Radiative Forcing in Snow," *Proceedings of National Academy of Sciences* 107, no. 40 (2010): 1, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2951423/.
[48]Glen Canyon Institute, *Glen Canyon Dam and Sediment*, Accessed September 1, 2011, http://www.glencanyon.org/library/sediment.php.
[49]Niklas Christensen, *Climatic Change*, 354.
[50]*Lake Powell Daily Averages Since 1980*, accessed November 11, 2011, http://lakepowell.water-data.com/index2.php.
[51]Niklas Christensen, *Climatic Change*, 354.
[52]Ibid., 355.
[53]Ibid.
[54]Ibid., 356.
[55]Carol Zimmerman, "Challenges Facing CAP Water Supplies" Central Arizona Water Conservation District. (2011): http://www.sahba.org/WeeklyUpdate/CAPPresentation1-24-11.pdf.
[56]Southern Nevada Water Authority, "Water Resource Plan 09: Chapter 4: Meeting Demands During Shortage" (2009): http://www.snwa.com/assets/pdf/wr_plan.pdf.
[57]Niklas Christensen, *Climatic Change*.
[58]Carol Zimmerman, "Challenges Facing CAP Water Supplies."
[59]Southern Nevada Water Authority, "Water Resource Plan 09: Chapter 4: Meeting Demands During Shortage" (2009): 48-49.
[60]Center for Natural Resource & Environmental Policy at The University of Montana, "Thinking Like a River Basin: Leaders' Perspective on Options and Opportunities in Colorado River Management" (2011): 20-21.
[61]Niklas Christensen, *Climatic Change*, 344.
[62]Frank Ackerman "The Last Drop: Climate Change and the Southwest Water Crisis" Stockholm Environment Institute-U.S. Center (2011): 5, http://sei-us.org/Publications_PDF/SEI-WesternWater-0211.pdf.
[63]Craig Rowe, "When it comes to importing water, nothing seems too extreme," *High Country News*, September 29, 2011, http://www.hcn.org/wotr/when-it-comes-to-importing-water-nothing-seems-too-extreme.
[64]Imperial Irrigation District, *All-American Canal Lining Project*, Accessed November 1, 2011, http://www.iid.com/index.aspx?page=181.
[65]Betsy Woodhouse, *What about the "R" in ASR*, accessed August 10, 2011, http://www.swhydro.arizona.edu/archive/V7_N3/feature6.pdf.
[66]Central Arizona Project, *Recharge Program*, accessed December 10, 2011, http://www.cap-az.com/Operations/RechargeProgram.aspx.
[67]Bureau of Reclamation, *Phoenix Metropolitan Water Reclamation and Reuse Project*, accessed December 10, 2011, http://www.usbr.gov/lc/phoenix/programs/progdescon.html.
[68]Jonathan Waterman, *Colorado River Basin: Balancing a Limited Supply with an Increasing Demand* .
[69]Climate Education for Agricultural, *Cloud Seeding*, accessed September 12, 2011, http://hatteras.meas.ncsu.edu/secc_edu/CloudSeeding.
[70]National Center for Atmospheric Research, *Wyoming Cloud Seeding Experiment begins this month*, accessed September 11, 2011, http://www.eurekalert.org/pub_releases/2006-01/ncfa-wcs012606.php.
[71]Ibid.
[72]Peter Gleick, "Zombie Water Projects (Just when you thought they were dead)," *Forbes*, December 8, 2011.
[73]Edwin McGavock, "Desalination of Brackish Groundwater in Arizona," Errol L. Montgomery & Associates Inc. (2008): 1, http://www.elmontgomery.net/documents/ahsDesalination-Abstract.pdf.
[74]United State Bureau of Reclamation, "New Mexico Brackish Groundwater Assessment Program Workshop; Report of Findings and Recommendations," (2004): 1, http://wrri.nmsu.edu/conf/brackishworkshop/report/NMBWWreport_FINAL.pdf.
[75]United States Bureau of Reclamation, "Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee," (2003): 52.
[76]Kathryn Kranhold, "Water, Water Everywhere… Seeking Fresh Sources California Turns to Salty Pacific, but Desalination Plants Face Criticism on Environment, Costs," Wall Street Journal, January 17, 2008, sec. B.
[77]WG Harner, "The Cost of Water and Water Markets in Southern California, USA," WIT Transactions on Ecology and the Environment 103, no. 1 (2007): http://library.witpress.com/pages/PaperInfo.asp?PaperID=17561.
[78]Mike Hightower, "Desalination Technology Development and Potential Application in New Mexico," Sandia National Laboratories (2004): 226, http://www.unm.edu/~cstp/Reports/H2O_Session_4/4-6_Hightower.pdf.
[79]Ibid.
[80]Ibid.
[81]United States Bureau of Reclamation, "Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee," (2003): 56.
[82]Mike Hightower, "Desalination Technology Development and Potential Application in New Mexico," Sandia National Laboratories (2004): 228, http://www.unm.edu/~cstp/Reports/H2O_Session_4/4-6_Hightower.pdf.
[83]United States Bureau of Reclamation, "Desalination and Water Purification Technology Roadmap: A Report of the Executive Committee," (2003).
[84]Stephen Roe, "Greenhouse Gas Emissions Inventories and Forecasts for Nine Western States," *EPA International Emissions Inventory Conference*, (2007): 5, http://www.epa.gov/ttnchie1/conference/ei16/session3/roe.pdf.
[85]EPA, *Calculation and References*, accessed September 20, 2011, http://www.epa.gov/cleanenergy/energy-resources/refs.html.
[86]Stephen Roe, *EPA International Emissions Inventory Conference*.
[87]Jeremiah Cox and Anna Johnson, "Infrastructure," *The 2010 Colorado College State of the Rockies Report Card*, edited by Walt Hecox, Colorado College, Colorado Springs, (2010): 72.
[88]LiveScience Staff, *Rocks Found That Could Store Greenhouse Gas*, accessed September 22, 2011, http://www.livescience.com/3364-rocks-store-greenhouse-gas.html.
[89]Louis Bergeron, *Earthshaking possibilities may limit underground storage of carbon dioxide, says Stanford geophysicist*, accessed December 8, 2011, http://news.stanford.edu/news/2010/december/zoback-sequestration-quake-121410.html.
[90]Auden Schender. Interview by Author, Carson McMurray, Aspen, Colorado, July 11, 2011.
[91]Ibid.

Managing the Colorado River Basin: An Agenda for Use, Restoration, and Sustainability

An Open Letter

From the 2011-12 Colorado College State of the Rockies Project Student Researchers:

Sally Hardin, Warren King, Carson McMurray, Ben Taber, Natalie Triedman



The 2012 Colorado College State of the Rockies Report Card
The Colorado River Basin:
Agenda for Use, Restoration, and Sustainability for the Next Generation

Tara Hatfield

March, 2012

Dear Colorado River Basin Water Users, Experts, and Enthusiasts:

The Colorado River Basin has stood out over the centuries as a subject of fascination and intrigue. The **"age of exploration"** dating back centuries witnessed explorers in search of riches from golden cities to cross-continental routes, with the feats of explorer John Wesley Powell magnified in publications and hearings. The **"age of construction"** has similarly provided boundless fascination as human ingenuity and massive amounts of financial capital proceeded to literally "conquer" a massive river for flood prevention, water diversion and storage, as well as transmountain diversion. Many people will endlessly be in awe at the towering Glen Canyon and Boulder Dams with their sprawling Lake Powell and Lake Mead reservoirs, once full but today ironically looking more like partially full bathtubs with dirty rings. The Central Arizona Project similarly is an engineering wonder.

But today we enter into a new age- one we call the **"age of conservation"** for a river and its basin once seen as a boundless water supply that is now being overwhelmed by growing water demands, even as projected average annual supplies shrink. A century of legal definition for "beneficial uses" was formed in the earlier thinking that the basin and its waters would be boundless, there to be diverted and put to "human" use. However, society's values are changing and current water uses and tactics no longer suffice for a future generation that increasingly calls for a different approach for a river "standing through time" as an example of humans wisely using its water while providing for nature's complex beauty and balance.

We represent that "future generation" and through intensive research and observation we have earned "standing" in discussions about the Colorado River's future. In this letter we present **Five Actions** we find are essential if this national, even global, natural wonder is to stand tall and remain dynamic throughout our lives and those of our children. We are convinced that exciting changes are underway "at the margins" of these immense problems and challenges. Aggressive water conservation measures in the West's urban areas are proof we can meet the "frugal" needs of growing urban areas, but not the "frivolous" wants. Experiments with water banking and rotational crops in agriculture convince us that the "old" techniques of flood irrigation in a "use it or lose it" legal structure can be replaced with conservation that does not threaten our ability to grow crops in sustainable agricultural areas of the Rockies. All of these actions will take changes in legal structure and administration, as well as large amounts of new capital. However, if we once found literally billions of dollars in the **"age of construction"** then we know with immense will and perseverance we can fund the **"age of conservation."** And the outcome will gradually result in the Colorado River and its tributaries, as well as the delta, having a reasonable but essential "share" of nature's bounty in the form of sustainable flows all the way to the sea.

Here are the **five actions** we recommend so that a viable, living Colorado River Basin exists, even thrives for our children:

- **Action 1:** Recognize the finite limits of the river's supplies and pursue a "crash course" in conservation and water redistribution that sustains current users while leaving water in the river.
- **Action 2:** Modify and amend the "Law of the River" to build in cooperation and flexibility.
- **Action 3:** Embrace and enshrine basin-wide "systems thinking" in the region's management of water, land, flora and fauna, agriculture, and human settlements.
- **Action 4:** Give "nature" a firm standing in law, administration, and use of water in the basin.
- **Action 5:** Adopt a flexible and adaptive management approach on a decades-long basis to deal with past, present, and projected future variability of climate and hydrology.

Each **action** is explained in greater detail at the end of this section, where we collect together the conclusions each of our research efforts has developed and published as a section in this *2012 Colorado College State of the Rockies Report Card*. However, first we summarize two public opinion surveys conducted recently about the Colorado River Basin and its proper management. One examines the opinions of "water experts" and another, conducted by the Colorado College State of the Rockies Project, surveys college-age students. Findings from both put our recommended actions in context and validate their reasonableness and validity.

The Evidence from a Survey of College-Age Youth Contrasted with Opinions of Water Experts

How can young people understand the complexities of a massive system like the Colorado River Basin? Are they prepared to grapple with nine decades of enshrined laws and regulations that form the Law of the River? Might they take immature stances on issues that deeply affect existing groups with vested interests in the basin?

In anticipation of such questions being asked, part of our 2011-12 research on the management of the Colorado River Basin has been a survey offered to college faculty throughout the basin for use by students in their courses. We structured the survey as a companion to an "Overview of the Basin," (see page 24-31) which was carefully written and peer reviewed so that college students taking the survey would first have access to the history, operation, and challenges to the basin that abound. Over six months a total of 197 college-age students completed the survey. Four-fifths of respondents were 18-24 years of age; 60% male vs. 40% female; 81% Caucasian; all but 10% undergraduates; and a majority whose home state is in the Rockies region.

To provide a comparison to these views of youth, we obtained permission to report on the results of a similar survey of "water experts" conducted by the Colorado River Governance Initiative and contained in a December, 2010 Report: *Rethinking the Future of the Colorado River*, a part of the Water Policy Program at the University of Colorado-Boulder Law School. A total of 184 people answered the anonymous survey, half water managers/government officials, 30% water professionals, and the rest water users, citizens, and members of non-governmental organizations.

What about the adequacy of the current "Law of the River?" Among college-age respondents, 90% responded that a new body of laws and regulations should be created to meet new challenges facing the basin in the 21st century. Among "water expert" respondents only 20% agreed that no changes are needed, the current Law of the River being adequate. Another 70% called for minor to significant changes and only 10% called for a fundamental restructuring. Thus, youth and experts alike in large majorities believe that changes are needed in the Law of the River. The survey of "water experts" went one step further and asked when water demand will exceed supply in the basin, thus helping trigger need for changes in management. Nearly 40% believe that demand already exceeds supply, another 23% believe that will be the case by 2020 and another 21% believe so by 2050.

"I think that the younger generation needs to be more involved in all aspects of the future of the Colorado River Basin. Too often are we told that the older generation is sorry for what they are giving us, but we have so little say in changes... at least in an accessible manner. Few young people will search it out. There needs to be more outreach, more education on the matter, and more involvement of students and young adults all around. Combine the resources we have from everyone out there to make the best change possible!"
- College-age poll respondent

"Things change over time. It's been almost 90 years since the Colorado River Compact was set. The world has made some big changes since then."
- College-age poll respondent

How can the basin be fixed? Priority for conservation efforts in the face of a severe shortage of water in the basin received the highest ranking among college-age respondents, with depletion of reservoirs and efforts to augment supply falling lower in priority. Among "water experts" asked to rank solutions, technology to reduce waste (efficiency) and desalination were ranked highest, followed by improved intra-state management and infrastructure updates and expansions.

In handling unmet Native American water rights within an over-allocated basin, college- age respondents interestingly chose recreation as the first use that might be curtailed, followed by industry, municipal use, electric power, and then agriculture; meeting the needs of Mexico and environmental flows were last in line to offer up some water.

Pursuit of efficiency rather than basin augmentation is a strong measure of where college-age respondents come down on conservation of water. They strongly chose pursuit of degrees of efficiency (nearly 95%) over degrees of augmentation. Similarly among "water experts," augmentation ranked lowest as a solution to basin challenges; this means that cloud seeding, vegetation management, and imports from other basins were ranked last.

"Water augmentation on a large scale by whatever means will be very expensive. Conservation has a limit, but I do not think we are even close to that at this point. Managed population growth is a key to the West's water issues."
- "Water expert" poll respondent

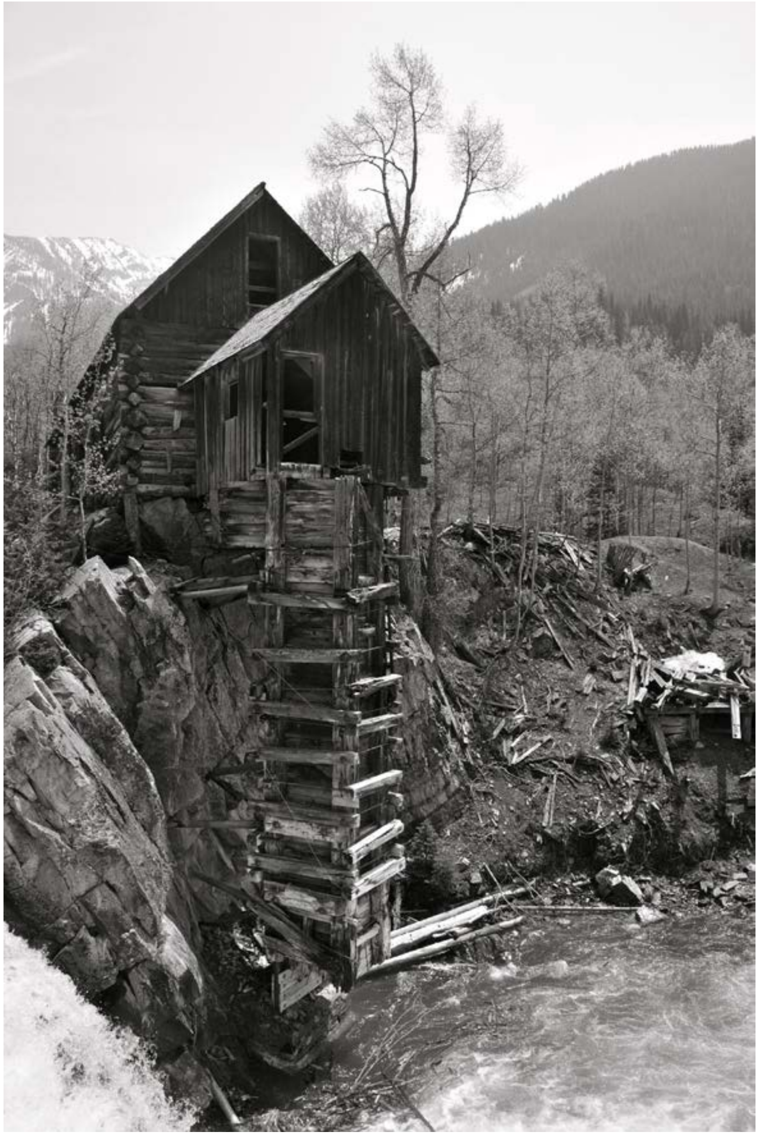
"A healthy environmental flow helps to ensure the health of species living in the river. In addition it protects the recreational uses of the river."
- College-age poll respondent

Water for nature registers strongly with college-age respondents; 93% replied that even in the face of extreme water shortage there should be assured environmental flows.

What are the major challenges to managing the basin? In the college-age survey population growth was seen as most serious, then climate change, salinity/water quality, water diversion, and then endangered species. Interestingly Native American water rights and Mexican treaty rights were seen as less of a challenge.

We present this brief glimpse of these two surveys to demonstrate that college-age respondents in some cases closely agree with "water experts" on the major issue of adequacy of the Law of the River. In other cases, priorities of youth are supportive of traditional uses of water in the basin, even ranking "unmet" needs lower than traditional uses for agriculture, industry, and municipalities. Even with only a brief overview of the Colorado River Basin and their class materials and discussion, college-age respondents demonstrate a maturity and sensitivity in prioritizing basin challenges and recommending solutions. This is good news since these young people will soon be part of a generation both inheriting the basin and being challenged to manage it sustainably.

Demographics, Economy, and Agriculture Depend on Water Storage and Diversion: Is it a Zero Sum Game?
by:
Sally Hardin


Leah Lieber

Conclusion: Is the Colorado River Basin Faced with a Zero Sum Struggle?

Decades of immense human ingenuity and vast sums money have been invested in “taming” the Colorado River. is often seen as one of the human wonders of the world: carv- out immense reservoirs backed up behind gigantic dams, while version structures carry water hundreds of miles from river itself to fertile agricultural regions and urban areas even yond the hydrologic boundaries of the basin. A steady sup- of water over the decades, varying by the year according drought conditions, is now rapidly being disrupted by grow- demand for water to be put to “beneficial” uses. Colliding with traditional definitions of “beneficial uses,” new demands arise maintaining instream flows to protect the fragile riparian areas and vast public lands of the region.

Many believe that the height of human engineering the basin is nearing an end, with a few remaining propos- als for massive diversion increasingly being challenged by vironmental concerns. The result: a situation that increasingly existing users against one another, as urban areas seek to obtain ter dedicated to agriculture, and out-of-basin demands seek remaining surplus or unused allotments to individual states.

We have traced the thread of human development the Colorado River Basin in this section, with the purpose seeking answers to what many argue is now a zero sum game. ditional water obtained by urban areas must now come from a decline in water use by agriculture (potentially signaling decline in agricultural production itself). Any further water di- sions, even pursuing remaining surplus allotments to individ- states, must come at the expense of diminished instream flows, thus harming further rivers and their associated flora and fauna.

Should today’s youth look at this collision of steady and perhaps dwindling water supplies, as climate changes occur, against rising human demands as the ultimate threat to the basin as we know it? Or are we witnessing in the vibrant experiments discussed above innovative opportunities for new techniques of water sharing and conservation? The tentative answer we reach as Colorado College State of the Rockies Project student researchers is that the future sustainability of the Colorado River Basin remains to be determined. Encouraging signs of conservation and water sharing techniques give hope that our children will inherit a vibrant Colorado River. Water use in the Colorado River Basin need not be a zero sum game. On its current trajectory, it could certainly be classified as such. However, we are encouraged by promising alternatives for water conservation, reuse, and sharing of this scarce resource that together have the power to alter this path of destruction.

Action 1: Recognize the finite limits of the river’s supplies and pursue a “crash course” in conservation and water redistribution that sustains current users while leaving water in the river.

Laws of the Colorado River Basin: Obsolete or Flexible for a Sustainable Future?
by:
Warren King

Concluding Remarks

While the issues that remain, such as the unexpected future of the Cienega de Santa Clara, declining native fish populations, and under-served Indian reservations all highlight the rigidity of the Law of the River, one can just as easily look at the minutes created by the IBWC, the water sharing programs established in Arizona and Nevada, and the 2007 Shortage Guidelines as examples proving that disputes and issues can be resolved using the existing framework of the Law of the River and the

Compact. What may be most important to acknowledge is what Southern Nevada Water Authority President Patricia Mulroy stated: “The Compact inextricably binds them [the basin states] together in a framework that is as rigid or as flexible as the parties as a whole desire.” That is to say, it may not be necessary to choose between stringently adhering to the Law of the River and creating a new Compact. What is most important is the political will of those involved to cooperate. However, given the issues that have arisen, and those that are destined to come, might it not be time to formalize this spirit of cooperation that Patricia Mulroy so vehemently defends? What is needed at this point is an amendment or an addition to the Law of the River, which will take into account the enduring issues and formalize a process for discussion and action on those existing and forthcoming issues.

Action 2: Modify and amend the Law of the River” to build in cooperation and flexibility.

Melissa Kolano

Recreation in the Colorado River Basin:
Is America’s Playground Under Threat?
by:
Benjamen N. Taber

Conclusion: Is the World Renowned Colorado River Basin “Playground” Under Threat?

This discussion about the future of recreation along the Colorado River and its tributaries is meaningless without placing it in the context of climate change. According to Auden Schendler, Vice President of Sustainability with Aspen Skiing Company, “It’s the economic impacts of climate change that we fear.” Even if there is snow to ski on in 50 years, people from around the nation and world will not go on a ski trip unless their basic economic needs have been met and exceeded. Even if there is still enough water to raft down Cataract Canyon, no one will without the dispensable income to do so.

So is America’s Colorado River Basin playground under threat? In a word, yes. This threat stems from our increased reliance on the basin’s water for historically established “beneficial uses” by households, industry, and agriculture. It is derived from our current water management system that views the basin largely as a pipeline, one that divvies up water among the Upper and Lower Basin regions and for Mexico even though the highly volatile water flows historically average less than the allocated 16.5 million acre-feet (maf). It is accentuated by resistance to new uses proposed for water: loosely termed “instream” flows for aquatic systems and adjacent riparian areas. With the increasing scarcity of water and the struggle to fulfill the additional demands people have expressed for Colorado River water, the “new” demands for water of threatened and endangered species needed for their survival must compete with firmly entrenched and well-financed entities hell-bent on squeezing more water “out” of the basin.

What can today's youth bring to this debate and conflict? Elsewhere in this *Report Card* we discuss the results of a survey, measuring the values of today's college-age youth compared with values of more established "water experts" throughout the basin. We are encouraged by the strength of support for less-traditional water uses in the basin, including instream flows and a desire to remedy the unmet shares of water for Native Americans and Mexico. Tough choices and trade-offs are on the horizon in all aspects of the basin. Yet, we are hopeful that a broader "systems thinking" will prevail, so that balance arises between human demands for water and products from the basin versus the needs of the hydrologic region for sufficient water to remain healthy and supportive of the types of recreation and tourism discussed in this section. Taken together, the various sections of this *Report Card* weave a fabric of solutions and perspectives for today's youth and generations to come: we can have a healthy Colorado River Basin that supports vital economies without destroying vital hydrologic and environmental conditions that make the region world-class! We must keep it so.

Action 3: Embrace and enshrine basin-wide "systems thinking" in the region's management of water, land, flora and fauna, agriculture, and human settlements.

Environment and Ecology of the Colorado River Basin
by:
Natalie Triedman

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

Diversions on the Colorado River 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. 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 trade-offs, but remains confident compromise is possible. We repeat where we started this section: We are all stakeholders, and the stakes are high!


Kim Sundermeyer

Action 4: Give "nature" a firm standing in law, administration, and use of water in the basin.

The Colorado River Basin and Climate:
Perfect Storm for the Twenty-First Century?
by:
Carson McMurray

Conclusion: Will the Twenty-First Century be Nasty?

The Colorado River Basin stands at a crossroad today. Water demand has recently exceeded supply, deliveries to Native Americans and Mexico are problematic, and infrastructure is slowly becoming outdated and inefficient. As these evident problems persist, the looming threat of climate change must be added to discussions and basin-wide management. Without careful planning for climate change adaption and lobbying for mitigation, the decrease in stream flow due to climate change will overwhelm all other issues. The conservative estimate for stream flow decrease by mid-century is 6%, which would still threaten the entire basin, from agriculture to municipalities.

Offsetting such a formidable challenge cannot be done in years, decades, or even centuries, but will take constant adaptation to changes in climate and water needs. This flexible adaptive management approach will continually challenge the current Law of the River, and the necessary changes cannot be enacted overnight. While the shortsighted problems of water supply for this year's crops or cities are necessary issues, without a long-term management plan that includes adapting to and mitigating climate change, the basin will inexorably move towards crises. The Colorado River represents the lifeline of the Southwest to over 30 million people. Without consideration of climate change and its effect on water availability, the once productive Southwest will return to its desert roots.

What can today's youth do in the face of such challenges? Traditional approaches to water management in the Colorado River Basin must become more flexible at a minimum, and may even need to be replaced by new management guidelines and legal constructs. The section of this *Report Card* entitled "Laws of the Colorado River Basin: Obsolete or Flexible for a Sustainable Future?" faces this conundrum head-on. In addition, the results of the Rockies Project's survey of college-age youth opinions about Colorado River Basin issues and management bring fresh perspectives to the debate. In the end, it is vital that today's youth become engaged and involved in how our precious natural resources in the basin are managed, for they will soon inherit the results!

Action 5: Adopt a flexible and adaptive management approach on a decades-long basis to deal with past, present, and projected future variability of climate and hydrology.

Leo Tonozzi, Glenwood Springs kayak park

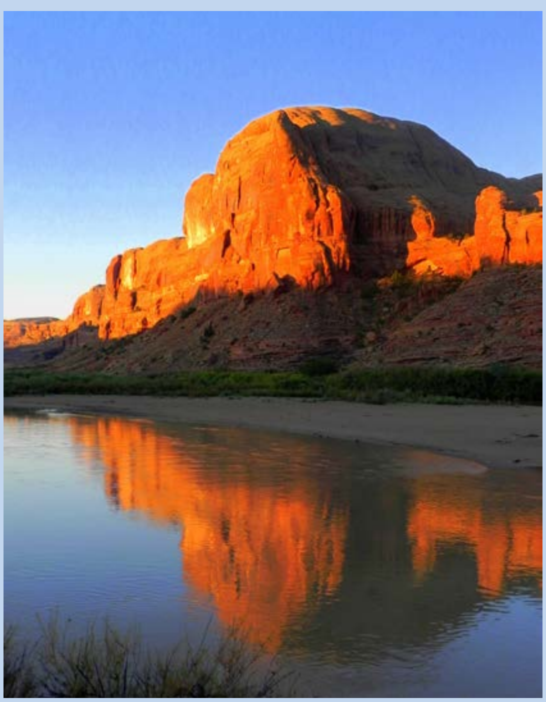
Jerry Brockway

Priscilla Engeln

All of the photos used in this section of the *Report Card* are from the 2011-12 Rockies Project *Save the Colorado River Basin* Banner Photo Contest or the 2012 Rockies Project Student Photo Contest. Thanks to all of those who participated and took the time to tell us what they value in the Colorado River Basin.

Veronica Spann

Walt Hecox



Colleen Cahill

John Nestler

Emily Cleveland

Special thanks to:

Steve Weaver for his annual contribution of the cover photo and for judging submissions in the student Rockies photo contest.

Brendan Boepple is the program coordinator for the 2011/2012 State of the Rockies Project. Originally from Wilton, Connecticut, Brendan graduated from Colorado College May 2011 with a Political Science major and an Environmental Issues minor. While growing up Brendan developed a love for the outdoors and the environment as his family traveled to many national parks and he later worked with environmental organizations like Trout Unlimited and his local conservation land trust. He spent the fall semester of 2009 studying International Relations in Geneva, Switzerland, and hopes to eventually pursue a career in foreign policy. His interests include skiing and fly-fishing, two activities that drew him to the Rocky Mountain region.

Matthew C. Gottfried is the GIS Technical Director at Colorado College and the 2011/12 technical liaison for the State of the Rockies Project, overseeing tasks including data assimilation, GIS analysis, and logistics management. He received his B.S. (1999) in Field Biology and Environmental Studies from Ohio Northern University and his M.A. (2005) in Geography and Planning from University of Toledo where his focus was on land use planning and GIS. Matt's regional research focus includes studying the biogeography of critical species, land use planning, and conservation management practices of local natural resources.

Sally Hardin is a student researcher for the 2011/12 Rockies project. From Takoma Park, Maryland, Sally will graduate in May 2012 with a major in Environmental Policy and a double minor in Music and African Studies. Growing up near the Shenandoah Mountains and the Potomac River, she fell completely in love with the outdoors but quickly saw the destruction that excessive human presence inflicts on this environment. Sally spent the first semester of last year studying Wildlife Management in Kenya and Tanzania, and was fascinated to see the similarities and differences in socio-environmental issues between East Africa and the American West. In her free time, Sally loves to run, rock climb, and play the tuba.

Walter E. Hecox is professor of economics and environmental science, and project director for the State of the Rockies Project at Colorado College, Colorado Springs, Colorado. Walt received his B.A. degree from Colorado College (1964) and an M.A. (1967) and Ph.D. (1970) from Syracuse University, Syracuse, New York. He teaches courses in ecological economics and sustainable development. He has conducted research and taken leave to work for the World Bank, U.S. Agency for International Development, U.S. Department of Energy, and Colorado Department of Natural Resources. He is author of *Charting the Colorado Plateau: an Economic and Demographic Exploration* (The Grand Canyon Trust, 1996), co-author of *Beyond the Boundaries: the Human and Natural Communities of the Greater Grand Canyon* (Grand Canyon Trust, 1997), and co-editor of the Colorado College State of the Rockies Report Cards.

Warren King is a student researcher for the 2011/2012 State of the Rockies Project. Originally from Essex, Connecticut, Warren is an Environmental Policy major. He developed his love for the environment at an early age while taking summer camping trips with his family. He spent his junior year assisting Professor Walt Hecox with various research assignments, and intends to pursue a law degree following his graduation from CC May 2012. His interests include skiing, backpacking, and participating on Colorado College's varsity men's soccer team. It was these activities that drew him to the Rocky Mountain region.

Carson McMurray is a 2011/2012 student researcher from Chapel Hill, North Carolina, and will graduate in May 2012 with a degree in Environmental Science. His interests in environmental issues originate from his family's obsession with fishing and have grown during his time at Colorado College. Carson specializes in work with GIS mapping and has combined this specialization with his environmental studies to help people see environmental issues through a new perspective. In his spare time, he enjoys playing sports, mountain biking and, of course, fishing.

Zak Podmore is a field researcher for the 2011/2012 State of the Rockies project. He grew up in Glenwood Springs, Colorado where he came to appreciate the waters of the Rocky Mountains over the course of a childhood shaped by winters skiing on mountain slopes and summers floating through the arid sandstone canyons of the San Juan, Dolores, Green, and Colorado Rivers. A long-time kayaker and rafter, Zak's love of wilderness rivers has taken him to Mexico, Canada, Ecuador, and throughout the American West. This winter he hopes to gain a deeper understanding of the Colorado River basin by researching the water issues currently facing Southwestern communities and by exploring the rivers that fuel them. He graduated from CC in May of 2011 with a degree in Philosophy and a minor in Psychoanalysis.

Will Stauffer-Norris is a field researcher for the 2011/2012 State of the Rockies project. He was born in Moscow, Idaho, grew up in Blacksburg, Virginia, and graduated from Colorado College in May 2011 with an Environmental Science degree. Starting from early childhood float trips in Idaho, Will has paddled rivers in the U.S., Canada, Chile, and Argentina. He intends to combine his passions for wild rivers, visual art, and adventure to document environmental issues surrounding the Colorado River for the 2011-12 Rockies Project.

Alex Suber is the State of the Rockies videographer and a member of the Colorado College class of 2015. He was born and raised in the hills of Northern California and later moved to Highland Park, Illinois. This past summer Alex interned for Bitter Jester Creative, a documentary film company, while also working on his own documentary. Alex has no idea what he will major in, but has a strong passion for environmentalism and cinematography. These two interests have led him to become involved with the State of the Rockies Project. When he's not making a movie, Alex enjoys playing the banjo, hiking, and working at the farm.

Ben Taber is a student researcher for the 2011/12 State of the Rockies Project and a Colorado Springs native. A graduate of Coronado High School, he will graduate from Colorado College in May 2012 with a degree in Physics and a Mathematics minor. He is a varsity Cross Country and Track athlete. Politically active, Taber was elected to the 2008 Democratic National Convention, interned in the U.S. Senate, and Co-Chairs the CC Democrats. He is interested in trail running, fishing and camping, and desires to pursue a synthesis between science and policy.

Natalie Triedman is a student researcher for the 2011/2012 State of the Rockies Project. Originally from Providence, Rhode Island, Natalie will graduate in May 2012 with a degree in Global Health. Natalie's interest in conservation and sustainable living began during a semester abroad at the Island School, a program that focuses on environmental studies and sustainability through experiential learning. She spent the fall of 2010 studying public health in Arica, Chile, and is excited to contribute a unique perspective to the State of the Rockies Project during 2011-12.

Stephen G. Weaver is an award-winning photographer with over 30 years experience making images of the natural world and serves as technical director for the Colorado College geology department. Educated as a geologist, Steve combines his scientific knowledge with his photographic abilities to produce stunning images that illustrate the structure and composition of the earth and its natural systems. As an undergraduate geology student, he first visited the Rocky Mountains where he fell in love with the mountain environment and the grand landscapes of the West. Steve currently photographs throughout North America with a major emphasis on mountain and desert environments. His use of a 3x5 large format view camera allows him to capture images with amazing clarity and depth.

The Colorado College State of the Rockies Project

Students Researching, Reporting, and Engaging:

The Colorado College *State of the Rockies Report Card*, published annually since 2004, is the culmination of research and writing by a team of Colorado College student researchers. Each year a new team of students studies critical issues affecting the Rockies region of Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming.

Colorado College, a liberal arts college of national distinction, is indelibly linked to the Rockies. Through its Block Plan, students take one course at a time, and explore the Rockies and Southwest as classes embark in extended field study. Their sense of "place" runs deep, as they ford streams and explore acequias to study the cultural, environmental, and economic issues of water; as they camp in the Rocky Mountains to understand its geology; as they visit the West's oil fields to learn about energy concerns and hike through forests to experience the biology of pest-ridden trees and changing owl populations. CC encourages a spirit of intellectual adventure, critical thinking, and hands-on learning, where education and life intertwine.

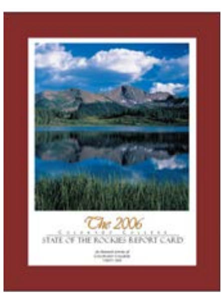
The Colorado College State of the Rockies Project dovetails perfectly with that philosophy, providing research opportunities for CC students and a means for the college to "give back" to the region in a meaningful way. The *Report Card* fosters a sense of citizenship for Colorado College graduates and the broader regional community.

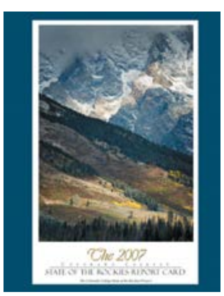
Research
During summer field work, the student researchers pack into a van and cover thousands of miles of the Rocky Mountain West as they study the landscape, interview stakeholders, and challenge assumptions. Back on campus, they mine data, crunch numbers, and analyze information.

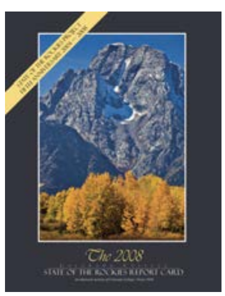
Report
Working collaboratively with faculty, the student researchers write their reports, create charts and graphics, and work with editors to fine-tune each *Report Card* section. Their reports are subjected to external review before final publication.

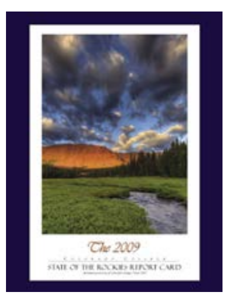
Engage
Through a companion lecture series on campus, the naming of a Champion of the Rockies, and the annual State of the Rockies Conference, citizens and experts meet to discuss the future of our region.

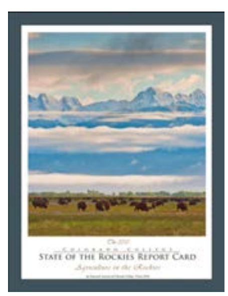
Each *Report Card* has great impact: Media coverage of *Report Cards* has reached millions of readers, and the 2006 report section on climate change was included in a brief presented to the U.S. Supreme Court. Government leaders, scientists, ranchers, environmentalists, sociologists, journalists, and concerned citizens refer to the Colorado College *State of the Rockies Report Card* to understand the most pressing issues affecting the growing Rockies region.











Printed on recycled paper

www.stateoftherockies.com

The Colorado College State of the Rockies Project
14 E. Cache La Poudre St.
Colorado Springs, CO 80903
Rockies@coloradocollege.edu (719) 227-8145

Recyclable material printed with organic inks