Sonorensis

ARIZONA-SONORA DESERT MUSEUM

2014

Sonorensis

ARIZONA-SONORA DESERT MUSEUM

2014

Volume 34, Number 1
Winter 2014
The Arizona-Sonora Desert Museum
Co-founded in 1952 by
Arthur N. Pack and William H. Carr

Sonorensis is published as a benefit to the Arizona-Sonora Desert Museum membership as a resource for furthering understanding of the Sonoran Desert Region. 2021 N. Kinney Road, Tucson, Arizona 85743.

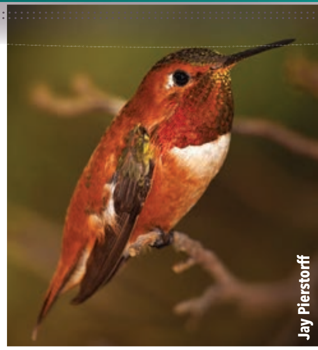
Visit us at www.desertmuseum.org

Cover: A view from Rancho Los Fresnos, across a small reservoir, just south of the U.S.-Mexico border. This important grassland habitat, with the headwaters to the Rio San Pedro, is managed by Naturalia and The Nature Conservancy. It is largely ungrazed, and natural fire regimes are returning. Photo by Sky Jacobs.

Back cover: Aerial view of the Colorado River during a pulse flow (upper left) snaking its way through the Delta into the upper estuary. The river's locally known "kidney" area can be seen on the right. Photo by Francisco Zamora, Sonoran Institute with aerial support from LightHawk.

Thanks to all the photographers and organizations who contributed photos for this issue of Sonorensis.

Photos on this page, above: Rufous hummingbird *(Selasphorus rufus)*; Mexican garter snake *(Thamnophis eques megalops)*.


Jay Pierstorff


Tom Brennan

Contents

1-2 Introduction
Linda M. Brewer

3-8 The Colorado
Kerry Schwartz

9-12 The River People on the Gila
Henrietta Lopez & David DeJong, Ph.D.

13-17 Requiem for the Santa Cruz River and Other Reflections
Julio Betancourt, Ph.D.

18-23 Aquatic Architects at Work: The Return of Beaver to San Pedro Riparian National Conservation Area
Marcia Radke

24-28 On the Rivers of Sonora, Mexico
Sky Jacobs

29 Recommended Readings

REFLECTIONS ON OUR *Desert Rivers*

INTRODUCTION

Linda M. Brewer
ASDM Press Editor

In the arid West, water wars and water negotiations are both notorious and vitally consequential to people and wildlife. Water is tied to almost every resource we use or reap—plumbing systems, crops, mineral extraction, electrical generation, digital communications, etc.—as well as to trees and other vegetation that cleanse the air, organisms that recycle dead organic matter into substrates for new life, and a full ecosystem that provides natural resources for us and other living beings. Especially in arid lands, rivers are veins of ecological gold, with an impact far beyond the ground they cover. About half of all breeding birds in the southwestern United States depend on the narrow ribbons that are riparian corridors, which represent just 1 percent of the land. In the Sonoran Desert, 85 percent of wildlife species depend on surface water or an associated riparian habitat in some phase of their life cycle.

In this issue of *Sonorensis,* we tell the story of our rivers, because the story of rivers in the Sonoran Desert is largely a story of "rivers no more." On the following pages, scientists and historians tell us about the interplay of people and water along the Colorado, Gila, Santa Cruz, and San Pedro River in Arizona, as well as the Yaqui, Altar, Aros, Bavispe, and other Sonoran rivers—from personal explorations, to water allocations, to restoration.

The need for new water policies and riparian restoration has become increasingly clear over the last few decades. In 2004, comparing historical and current data, The Nature Conservancy estimated that 35% of Arizona's natural perennial flowing rivers had already been lost or altered. Of the many miles of once free-flowing water in the Colorado, Gila, Salt, and Verde Rivers more than 90% have been lost. And loss of surface flow has also been significant in the rivers of Sonora. In this issue of *Sonorensis* you will read about what that meant to the "River People," the Akimel O'otham and Pee Posh along the Gila. Water is vital.

LIKE FISH IN A RIVER

Gila topminnow *(Poeciliopsis occidentalis)*
Fish illustrations by Rachel Ivanyi.

Perhaps the status of our fishes best illustrates the state of our rivers. About three dozen native species, most of the historical cast, are still hanging on in the Sonoran Desert Region, but their presence is tenuous—in part due to habitat loss, and in part because our rivers also now host at least twice as many introduced or nonnative fish and amphibian species that compete with or prey on the natives.

Modern technologies and policies that encouraged dam building, diversions, and withdrawals from the underground aquifers have changed natural cycles of flow and sedimentation, as well as water temperatures of rivers—changing the habitat to which native fish are adapted. Between habitat conversion and the introduction of game fish and other exotic species, native fish populations north of the international border have almost collapsed, and pressures are increasing on them in Sonora as well. Many are federally listed as endangered.

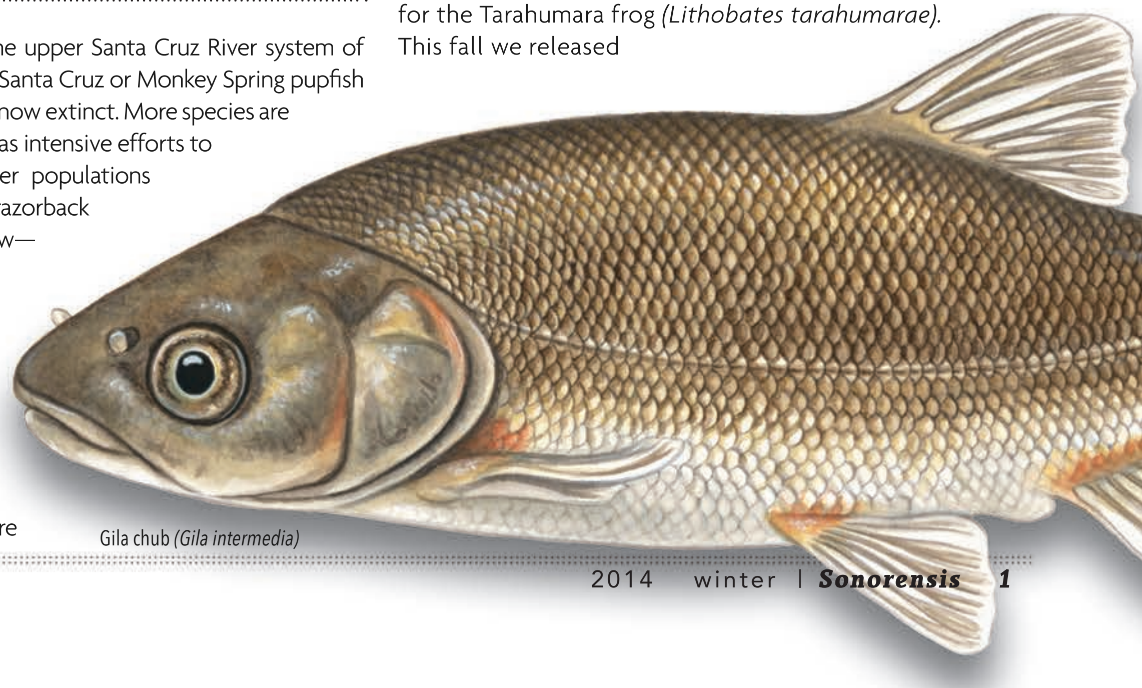
About a dozen native fish species in the region are not yet listed as threatened or endangered. The longfin dace *(Agosia chrysogaster)* is still widespread; the desert sucker *(Pantosteus clarkii)* is abundant in a more limited range, while in Sonora, the Sonoran Chub *(Gila ditaenia)* is relatively common. The beautiful shiner *(Cyprinella formosa),* Yaqui sucker *(Catostomus bernardini),* and Yaqui catfish *(Ictalurus pricei)* are still present in Sonora in spite of issues with water pollution in the Río Yaqui watershed, but they have been extirpated north of the border.

Among the twenty-odd Arizona fish species that are federally listed as endangered or threatened are three Colorado River fishes—the bonytail chub *(Gila elegans),* Colorado pikeminnow *(Ptychocheilus Lucius),* and razorback sucker *(Xyrauchen texanus).* Also listed are the loach minnow *(Tiaroga cobitis)* and Yaqui chub *(Gila purpurea),* which inhabit streams at somewhat higher elevations. Many of those streams no longer flow regularly, and few support large populations of native fishes, while nonnative species have become common. Even populations of the relatively large and aggressive Sinaloa cichlid *(Cichlasoma beani),* which had been thriving in Mexico, are now in decline, largely due to introduced sunfishes and other nonnatives. The desert pupfish *(Cyprinodon macularius)* and Sonoyta (or Quitobaquito) pupfish *(C. eremus),* true desert stream dwellers, are still extant, but barely. (The Desert Museum currently maintains a small population of desert pupfish to assure a source for emergency reintroduction, but no longer actively breeds them.)

OTHER AQUATIC AND RIPARIAN OBLIGATE SPECIES—INCLUDING SALAMANDERS, FROGS, AND RIPARIAN REPTILES—ARE ALSO LOSING GROUND AS OUR RIVERS LOSE WATER.

Once common in the upper Santa Cruz River system of Arizona and Sonora, the Santa Cruz or Monkey Spring pupfish *(Cyprinodon arcuatus)* is now extinct. More species are expected to follow suit, as intensive efforts to introduce and/or bolster populations of natives—including razorback sucker and loach minnow—have met with little long-lasting success. Introduced mosquitofish, catfish, sunfish, shiners, bass, and nonnative trouts and minnows are already well established and are taking their place. What kind of ecological cascade effect will result, we won't know for some years to come. The same can be said for other introduced species in riparian corridors—species like tamarisk, a tree from Asia that has replaced significant stands of cottonwood-willow riparian forest favored by migratory birds, but which now is being used by some native species. Some introduced species, however, may displace so much biodiversity that the ecosystem becomes impoverished for our children and grandchildren.

Other aquatic and riparian obligate species are also losing ground as our rivers lose water, including salamanders, frogs, and riparian reptiles. In fact, the Desert Museum has made great efforts to safeguard some of these species. For the last four years we have bred the Mexican gartersnake *(Thamnophis eques),* working in collaboration with the U.S. Fish and Wildlife Service and the Arizona Game and Fish Department to reintroduce these now federally threatened animals once common along our major waterways. Also, for the last 20 years, the Desert Museum has maintained a breeding program for the Tarahumara frog *(Lithobates tarahumarae).* This fall we released



Gila chub *(Gila intermedia)*

Above, left to right: close up of North American beaver *(Castor canadensis)*; Colorado River fishes – Top row, left to right, humpback chub *(Gila cypha)*, bonytail chub *(Gila elegans)*, razorback sucker *(Xyrauchen texanus)*; center, woundfin *(Plagopterus argentissimus)*; bottom, Colorado pikeminnow *(Ptychocheilus lucius)*. Illustration by Rachel Ivanyi; Tarahumara frog tadpoles *(Lithobates tarahumarae)* emerging from an egg mass at the Arizona-Sonora Desert Museum; white-nosed coati *(Nasua narica)*.

nearly 800 tadpoles and froglets. But the upshot is, riparian species need riparian habitat.

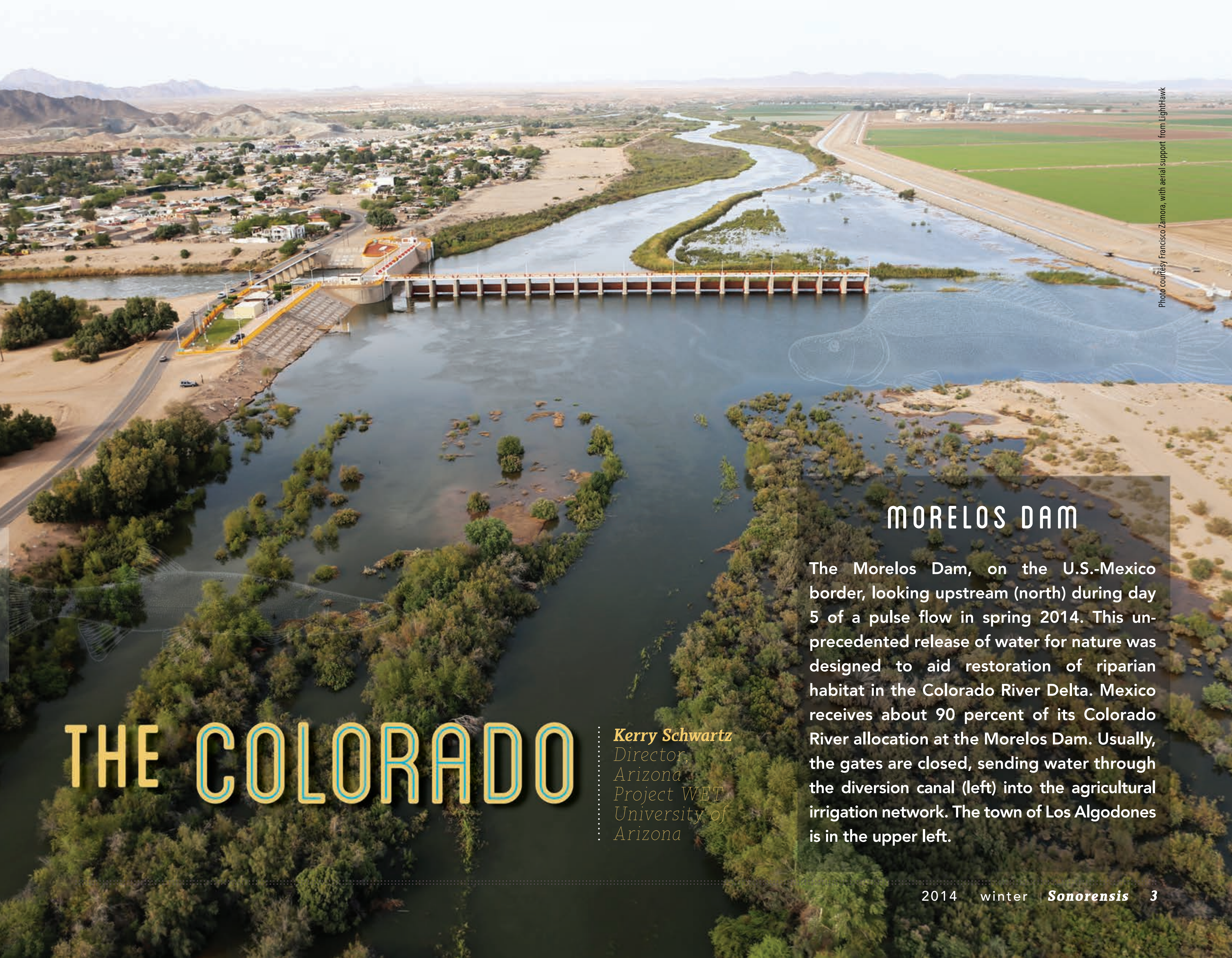
RIPARIAN-AVIAN CONNECTIONS

Migratory birds are dependent on green, flowering riparian highways that offer pollen, nectar, and insects. This nutritious buffet is sustained by the availability of water, even, to some degree, along intermittent streams, where it may flow consistently above ground only seasonally.

The San Pedro River, where beaver have been introduced in an effort to slow flow, increase surface water, raise the water table, and enrich species diversity (see “Aquatic Architects,” page 18), is a major migratory highway. The upper San Pedro alone provides for 400 species of resident or migratory birds—including the rare yellow-billed cuckoo *(Coccyzus americanus)* and southwestern willow flycatcher *(Empidonax trailli)*—as well as around 85 mammal, 50 reptile and amphibian, 14 fish species (6 of which are natives), and nearly 180 species of butterflies. Ocelot and coati have traipsed these leafy corridors, not to mention bats that fly the cool air above.

Surface flows in the San Pedro River have been decreasing for decades in spite of long-term conservation efforts by various private, nonprofit, and governmental groups. Much of this loss is tied to groundwater pumping for agriculture, nearby housing developments, and the surrounding communities. This is not an isolated instance. As you will see in the following articles, our cities and towns and industries are impacting all our rivers. The desert’s natural water supply is not adequate to support large populations of *Homo sapiens*. However, people and communities are recognizing the value of healthy riparian ecosystems and doing requisite science, politics, and business in an attempt to preserve and restore them. We have learned that wise management and a little water, applied in the right way, can have a large effect. As you are asked to vote on or otherwise consider water issues in the future, we hope you will remember that a little water for nature can have tremendous returns.

As the desert web of life loses more strands, the fabric of the ecosystem becomes more impoverished and, thus, less resilient to climate change and other assaults, less able to provide for us and the natural community. So discussion about water use and water conservation cannot be an elephant in the room. Every water decision we make impacts the ability of the Sonoran Desert to sustain us and the rest of our ecosystem. With effort, and some compromise, we can find creative ways to reallocate, re-use, and restore. S



THE COLORADO

Kerry Schwartz
Director, Arizona Project WET, University of Arizona

MORELOS DAM

The Morelos Dam, on the U.S.-Mexico border, looking upstream (north) during day 5 of a pulse flow in spring 2014. This unprecedented release of water for nature was designed to aid restoration of riparian habitat in the Colorado River Delta. Mexico receives about 90 percent of its Colorado River allocation at the Morelos Dam. Usually, the gates are closed, sending water through the diversion canal (left) into the agricultural irrigation network. The town of Los Algodones is in the upper left.

Photo courtesy Francisco Zamora, with aerial support from LightHawk

Above: Horseshoe Bend of Colorado River near Page, Arizona. Colorado River fish illustrations courtesy of Rachel Ivanyi, unless otherwise noted. Bonytail chub illustrations (right and on page 6), by Ken Wintin.

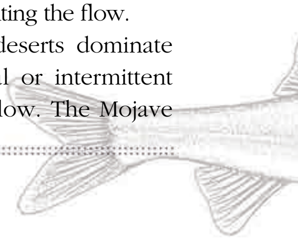
THE COLORADO

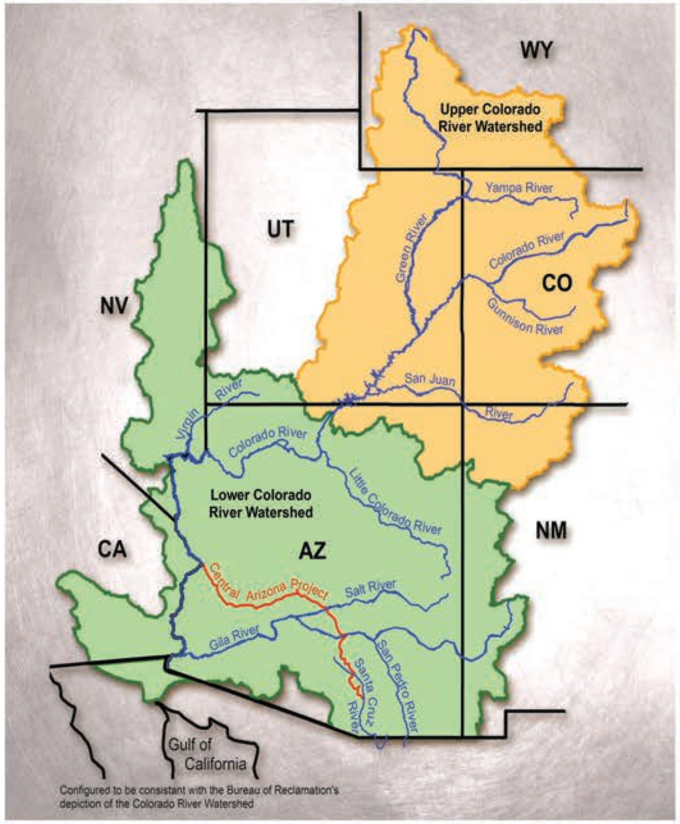
The Colorado River is so much to so many. It is tap water in Tucson, trout streams on the Rockies western slopes, lettuce in Yuma, an erosive force in the story of the Grand Canyon, golfing on the greens in Scottsdale, a surreal houseboat experience at Lake Powell, and world class whitewater through Cataract Canyon. All of us know some of this story, but the story starts a century ago, is hidden in remote, roadless places, and changes with the passing of time.

The Colorado River travels from the 14,000-foot peaks of the Rockies, 1,450 miles across the arid Southwest—a land that averages less than 20 inches of rain per year—to its delta at the Sea of Cortez (Gulf of California). Its watershed covers portions of six states and nearly all of Arizona. The eastern boundary follows the Continental Divide from the Wind River Range in western Wyoming down the spine of the Rockies and connects the dots between New Mexico's Carson, Santa Fe, Cibola, and Gila National Forests. The western boundary follows lower mountain ranges through central Utah, juts into Nevada along the White River, and traverses dry hills on the western edge of California. The land is canyon country, towering sky islands, and fantastical desert containing world renowned gems of the National Park system: Dinosaur, Arches, Canyonlands, Zion, Mesa Verde, Grand Canyon, Painted Desert, Petrified Forest, and Saguaro. To truly know the United States of America, you'd need to know these places.

Conifer forests dominate the river's headwater regions in both the Rockies, where the Colorado originates, and the Wind River Range, the birthplace of the Green River. The Gunnison, Dolores, Duchesne, and Price tributaries flow in to these major rivers. The Colorado Plateau in northern Arizona and the Four Corners region with Utah, Colorado, and New Mexico is central to the watershed. It showcases vast landscapes painted by their own geology. Juniper and piñon trees grow at the higher elevations. The confluence of the Colorado and San Juan Rivers is here, too, in Canyonlands. The San Juan collects runoff from southern Colorado and New Mexico, augmenting the flow.

Below the plateau, three distinctive deserts dominate the watershed. Rivers here are ephemeral or intermittent negligible contributors to the Colorado's flow. The Mojave






Kerry Schwartz

Above, left to right: map of Colorado River watershed; Lee's Ferry, in Glen Canyon, Arizona, has historically been an important river crossing and is a launching area for white-water rafting trips in the Grand Canyon.

Desert in Nevada, California, and westernmost Arizona is home to the distinctive Joshua tree. In the Chihuahuan Desert, straddling the border with Mexico in the southeast, *Agave lechuguilla* is endemic. The verdant Sonoran Desert dominates the rest of southern Arizona all the way down to the Colorado's mouth at the Sea of Cortez in Mexico. Saguaros and mesquite trees are indigenous here.

If the watershed is the body, then the rivers are the arteries through which flows its life-giving liquid. Though better known for saguaros, arches, and canyons, the Southwest thrives because of the Colorado River and its tributaries. Historically flashy, the river raged red in one season and only trickled in another. Human ingenuity and a pioneering spirit changed all of that over a century ago.

HISTORY

Forward-thinking settlers of the Southwest knew that water would fuel every endeavor in this dry land. They set out in the early 1900s to quantify and allocate the waters of the Colorado River. Agriculture was already thriving in Arizona and California, and these states were eager to ensure that upper watershed states couldn't cut off their supply. According to annual streamflow data, Colorado River baseflow was 17.3 million acre-feet. An acre foot is 325,851 gallons, the amount that a couple of households might use in a year. After vigorous negotiation among the states in 1922, the Colorado River Compact set 7.5 million acre feet for the upper basin—Colorado, Wyoming, Utah, and New Mexico—and the same amount for the lower basin—Arizona, California, and Nevada. This left 2.3 million acre feet in the river. When all seven states reconvene in 1925 to sign the Compact, Arizona does not sign.

History informs the present and this moment was no different. Long before 1922, Arizona had been formulating plans to irrigate the Salt River Valley for year-round production. In the 1902 Water Reclamation Act, the federal government had agreed to work with Arizona to build the largest masonry dam in the country at the time. President Theodore Roosevelt dedicated Roosevelt Dam in 1911 and pressed the button to let the now-regulated water flow through the hydroelectric generating system and into the Phoenix Valley. Full-scale development of central Arizona had begun and the

Kerry Schwartz

EDI

ancient Hohokam canal footprint was brought back to life to make the desert flourish. Herein lies the reason that Arizona didn't sign the Compact. They didn't want their tributaries, like the Salt River, to count in their Colorado River allocation. It was already theirs, reclaimed for human use.

Fast-forward four decades. Arizona comes back to the negotiating table. The six-reservoir water supply system of the Salt River Project had not provided enough water for the phoenix emerging from the desert floor. Central and southern Arizona and a booming agricultural complex needed more water to ensure their futures. The 1964 Supreme Court case (Arizona versus California) is decided; Arizona's tributaries are not counted in its 2.85-million-acre-foot allocation and the federal government agrees to build the Central Arizona Project (CAP), a 336-mile canal that runs uphill from Lake Havasu to Tucson. But, there is a price. Arizona accepts Junior Water Right status on the river for all water transported in the CAP canal. With that concession, Central Arizona could now take full advantage of the water stored behind Hoover Dam (completed in 1936) and Glen Canyon Dam (completed in 1966).

Arizona is not the only one utilizing the waters of the Colorado for growing cities and agriculture. High in the Rockies, the Big Thompson Project transports water over the mountains to Denver. Flaming Gorge Dam impedes the flow of the Green River for use in Wyoming and Utah. The Central Utah Project delivers water to Salt Lake City west of the Wasatch Front. Lake Powell floods the canyon lands of southeast Utah covering a surface area of 266 square miles. The shining city of Las Vegas is sustained wholly by the storage at Lake Mead, which also regulates flow to the Lower Basin states. The Metropolitan Water District (diverting water to Los Angeles and San Diego) and Central Arizona Project (to Phoenix and Tucson) both draw from Lake Havasu. Imperial, Coachella, Yuma, and Wellton-Mohawk Irrigation Districts serve thriving agricultural areas along the river in southern California and Arizona.

Burgeoning economies all celebrated the "renewable water supply." But further study unveils looming challenges. Using tree ring data to reconstruct the streamflow record back to 1520, University of Arizona (UA) dendrochronologists estimate that the average annual Colorado River flow is more accurately

Far Left: The Theodore Roosevelt Dam, on the Salt River northeast of Phoenix, was completed in 1911 and expanded in the late twentieth century. It provides irrigation water, flood control, and hydroelectric power.

Center: The Central Arizona Project (CAP) was designed to bring about 1.5 million acre-feet of Colorado River water per year to Pima, Pinal, and Maricopa Counties.

Right: The Colorado River in Mexico, looking northwest (upstream), about 20 miles from the Gulf of California. Grey-blue herons, great egrets, and salt grass can be seen here.

Photo courtesy Francisco Zamora, with aerial support from LightHawk

13.5 million acre feet rather than the 17.3 million acre feet previously estimated. In the reconstructed data, the 20 years prior to 1922 is one of the wettest periods on record, long periods of drought appear to be normal, and mega-droughts of 50 years are evident. Today, the Colorado River Watershed marks its fourteenth year of drought, and the baseflow based on the long-term record appears to be more plausible.

As challenges arise, forward-thinking individuals try to address them. Shortage-sharing agreements were set in 2007 by the Colorado River basin states and the federal government. Again, history informs the present. CAP, as the junior priority holder, will take the largest reductions in its allotment. Reductions are triggered by the water level at Lake Mead (at 1075 feet CAP reduction is 320,000 acre-feet, at 1050 it's an additional 400,000 acre-feet, and at 1025 it's another 480,000). As of June 26, 2014, the Lake Mead water level was 1083 feet above sea level. These reductions will eliminate water going to the Arizona Water Banking Authority and cut in half the current allotment to non-Indian agriculture in central Arizona. Municipal supplies are not yet on the chopping block. Yet most acknowledge that reductions alone will not stop Lake Mead's decline without greater snowpack levels. Climate predictions for the Southwest suggest that the region will continue to warm, making plentiful snowpack unlikely, but communities are working to reduce demand, minimize system losses, and find other ways to augment water supplies. The spirit of human ingenuity lives on in the Colorado River Watershed.

THE DELTA

What of Mexico and the Colorado River Delta? Mexico, by the treaty of 1944, is entitled to 1.5 million acre feet of the Colorado River. Like the basin states, Mexico uses this water for agriculture and transports water outside of the watershed for urban use. With 16.5 million acre feet of water now allocated, the Colorado River almost never makes it to the Sea of Cortez. Fresh water and nutrients no longer contribute to the sea's ecosystems and the delta is barren and desiccated.

Decades ago, the Colorado River Delta covered 3,125 square miles of flourishing wetland habitat for abundant plants and animals, including 380 species of birds. Aldo Leopold described it this way in 1922: "… on the map the delta

Photo courtesy Francisco Zamora, with aerial support from LightHawk

Left: The Colorado River as it approaches the crest of a sand bar that physically separates the river from the intertidal channels of the Gulf of California in the upper part of the estuary. Much of the pulse flow soaked into river areas upstream, but the fact that a small amount reached this far provides hope that the river may one day be reconnected with the sea.

Below: Yellow-footed gulls *(Laurus livens)*, a species endemic to Gulf of California.

Rick Brusca

was bisected by the river, but in fact the river was nowhere and everywhere for he could not decide which of a hundred green lagoons offered the most pleasant and least speedy path to the Gulf. So he traveled them all and so did we."

In the midst of acknowledged deficit on the Colorado River, ecologists and water managers recognize the value of a functioning delta. This past spring a landmark agreement between Mexico and the United States came to fruition as a pulse flow of 105,392 acre-feet (half from each country) gushed through Morelos Dam at the international border, stunning residents accustomed to a dry riverbed. Minute 319 of the 1944 treaty is an unprecedented model for water-sharing agreements and a "dream come true" for delta and Sea of Cortez advocates. The "pulse flow" mimicking spring floods enabled tens of thousands of cottonwood and willow seedlings to be planted. Water purchased from Mexican farmers will sustain them over the next four years.

At a restoration site midway between the border and the sea, with a group from the UA and Arizona-Sonora Desert Museum, I had the opportunity to work alongside citizens of Mexico, planting trees. There on our knees in powdery soil under the blazing sun, dropping seedlings in holes made with sticks, V-formations of white pelicans suddenly filled the blue sky. The Sea of Cortez was near. We are reminded in so many ways of life's resiliency. Aspirations to sustain the Colorado River and its people are evident throughout history. Through our actions, we continue to write the story of this great river. S

WATER FOR NATURE

A collaborative program known as "Conserve to Enhance," or C2E, encourages people to reduce water use and donate their savings to riparian restoration. There are active C2E programs throughout the Colorado River Basin. For more information go to: http://conserve2enhance.org/.

THE *River People* ON THE GILA

Henrietta Lopez & David DeJong, Ph.D.
Pima-Maricopa Irrigation Project,
Gila River Indian Community

EDI

Our Community is home to two separate and culturally distinct people: the Akimel O'otham ("River People"), also known as the Pima, and the Pee Posh ("People"), also known as the Maricopa. The Pee Posh, who originally lived along the Colorado River, are a Yuman-speaking people related to the Mohave, Quechan, and other Yuman tribes in western Arizona. The Pee Posh here began arriving in central Arizona in the early 1800s, when they confederated with the Akimel O'otham. Together we agreed to provide for our mutual defense and prosperity. The Akimel O'otham have lived in the Gila and Salt River Valleys since time immemorial and are descended from the prehistoric Huhugam civilization (also known as the Hohokam culture) that prospered throughout south central Arizona during a time when the river continually flowed.

The Gila Valley has a long history of human occupation, encompassing what archaeologists refer to as nine periods, each of which is characterized by unique cultural attributes. Our earliest ancestors are known as Paleo-Indians, a nomadic, hunting people who used spear points to hunt big-game animals and who lived in these valleys more than 12,000 years ago. Eventually our ancestors began growing corn in the fertile lands along the Gila River and its tributaries.

Ancient Gila River Cultures

8,500 BC

Ancestors of the Gila River Indian Community were hunting smaller animals and foraging on the wide diversity of plants that grew at that time. By about 4,000 years ago they began harvesting many of these edible plants. They used metates and manos (grinding stones) to prepare them for eating and began living in semi-permanent villages.

ARCHAIC PERIOD (1,500 BC–AD 150)

They were growing corn and storing it in large facilities for long periods of time.

EARLY FORMATIVE PERIOD (AD 150–650)

They expanded their agricultural efforts. During this period they also began using floodwater irrigation.

PIONEER PERIOD (AD 650–750)

A distinct Huhugam himdag appeared, with its arts and culture evidenced in the archaeological excavations of Snaketown. The development of large-scale irrigation agriculture began.

COLONIAL PERIOD (AD 750–950)

The Huhugam expanded throughout the river valleys of central Arizona, including the Salt, Gila, Verde, and Santa Cruz Rivers. During the late Colonial period the number and size of Huhugam settlements increased. Ball courts, canal networks, and the use of non-irrigation check farming were all employed.

SEDENTARY PERIOD (AD 950–1150)

The Huhugam settlements congregated along rivers and streams.

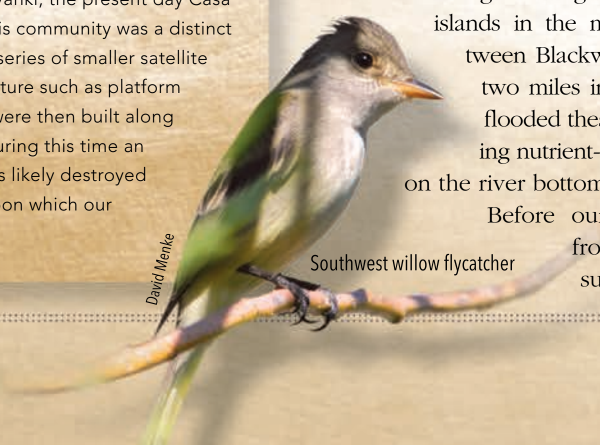
CLASSIC PERIOD (AD 1150–1450)

During this period of Huhugam history, settlements became more hierarchal. Villages with one or more walled residential compounds and one or more platform mounds were developed. At this time our ancestors built Sivan Vahki, the present day Casa Grande Ruins National Monument. This community was a distinct irrigation community consisting of a series of smaller satellite villages that included public architecture such as platform mounds and ball courts. The villages were then built along a single canal or irrigation system. During this time an extended drought and flood conditions likely destroyed or reduced the irrigation systems upon which our ancestors relied.

Between 1450 and the arrival of the Spanish, our people continued to live in scattered settlements along the Gila River and its tributaries, extending from the San Pedro River Valley to the Gila River west of the Gila bend. Small, loosely clustered homes were organized into politically autonomous, agriculture-based villages, each of which was self-sufficient. Early on our ancestors practiced floodwater irrigation, and later developed an irrigation distribution system as well.

The Historic period began with the arrival of the Spanish priest Father Kino in 1694 and marked the beginning of centuries of dramatic change to the landscape of our Community. Our environment, especially the plants and animals, and our villages have been altered by the loss of our water. While the Spanish explorers introduced land-use changes (including cattle ranching and wheat farming) that brought about degraded habitat and water loss, their recorded words help us reconstruct what our environment once looked like. Jesuit priest Father Eusebio Kino was the first known European to visit our villages, describing “large cottonwood groves” along the Gila River. Further west, he observed our people “sustaining themselves with the abundant fish and with their maize, beans, and calabashes.” Passing through our villages, Kino was given “so much and so very good fish” from our ancestors. Sometime later, Jacobo Sedelmayr, another priest, passed through our villages and noted “broad acres of cultivation of crops” as well as “broad savannas of reed grass and clumps of willow and a beautiful spring with good land for pasture.”

Our land was a rich environment centered on the flowing Gila River and its tributaries, which provided water for drinking and irrigating. There were once eight islands in the mainstream of the Gila between Blackwater and Pima Butte, some two miles in length. The river typically flooded these lands every year, depositing nutrient-rich sediment on them and on the river bottomlands.



Southwest willow flycatcher

David Menke

Before our water was taken away from us in the later 1800s and subsequent floods changed

Courtesy of the National Archives

A farmer from the Gila River Indian Community clears brush in anticipation of water to irrigate new fields in 1936 .

the channel of the river, the Gila River ran broad and shallow. There were many cienegas or low-lying wetlands along the rivers we lived beside, with the largest on the Santa Cruz River between Maricopa Wells and the village of Santa Cruz. There were meadows of salt grass, sacaton, and other native grasses. The area northwest of Bapchule was thick with vegetation, once called “Louisiana” because it resembled a bayou.

The Gila River was also home to thousands of beaver. By constructing dams, these animals helped slow rapid rain runoff in the river and its tributaries. When the beaver disappeared from the river system in the early 1800s, the diversity and abundance of other animals and birds suffered as well. As in any landscape, and not the least in a fragile desert environment, a cascade of effects can occur with any change in the system.

Draping the river was a thick canopy of cottonwoods and willows. Many a traveler who passed through our villages described how the river was “told a long way off by the green cottonwoods which fringe its banks.” The riparian woodlands were once so thick that they obscured the view of the river.

HARVESTING THE LAND

Away from the river were large bosques (forests) of screwbean and honey mesquite. These trees lived on the low alluvial plains along the Gila, Salt, and Santa Cruz Rivers and the many washes feeding them. Mesquite wood helped our people build good sturdy homes and was used for heating and cooking by our women. Mesquite beans were harvested and stored in large arrowweed baskets. The protein- and carbohydrate-rich flour made from these beans was used for bread, pudding, and a number of other foods. Little rain did not affect the ability of these trees to produce fruit, as their root system extended deep into the water table below the surface. When our water was taken away and the water table dropped, many of these trees began dying. As a result, mesquite is no longer our "staff of life."

We have always seen ourselves as part of the desert. This means we have always lived with the land. Until little over a hundred years ago, desert foods provided by the creator accounted for most of our diet. There were nearly sixty native plants, not including thirty later introduced by Europeans and Americans, that were harvested and eaten at various times by our people. These natural "greens" were an important part of our diet. We always had a plentiful supply of food and were willing to share with those in need.

But it is irrigated crops for which the Akimel O'otham and Pee Posh were best known. We grew at least six major food crops: corn, squash and pumpkins, tepary beans, lima beans, grain amaranth, and grain chenopod. All of these could be easily stored for later use. With irrigation, these crops were grown in a region where rainfall is very sparse. We diverted water from the river by building brush dams. Head gates, or diversion points from the river, were usually located several miles upstream from our fields.

Our lands along the Gila were formally recognized by an act of Congress on February 28, 1859. The United States acknowledged our loyalty "and the many kindnesses heretofore rendered" by our people. By the 1860s, our wheat was in demand throughout the territory, sold as far north as the mining districts of Prescott and as far south as Magdalena, Sonora.

WATER! WATER! WATER!

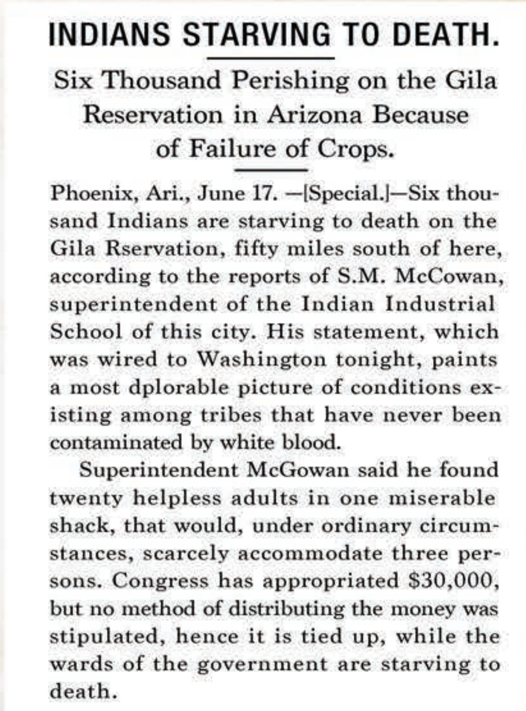
When the Arizona Territory was organized in 1863, Charles Poston, the first superintendent for Indian Affairs for the territory, wrote the Commissioner of Indian Affairs that the most important consideration of our people was "Water! Water!!! Water!!" If "in the eager rush for farms and city sites, the land [above us should be settled by emigrants and our water supply reduced there would be] discontent and disturbance." Nonetheless, upstream diversion of the Gila River by new settlers was allowed to continue.

The years between 1880 and 1920 were years of famine, but the years from 1892 to 1904 were years of starvation. Deprived of water, many of our people cut mesquite to sell as firewood in nearby towns in order to provide food for their families. In the process, nearly 100,000 acres of trees were clear-cut. The Calendar Stick of Juan Thomas of Blackwater recorded this hardship: "The river practically dry. The Blackwater Indians were forced to leave homes to sell wood."

Our leaders appealed to government officials. In March 1901, Antonio Azul, the last Pima Chief, wrote: "We have had very poor or no crops for the past three years. About two thousand of us are not likely to raise any wheat this year, because we have no water…. Our horses and cattle are dying for want of food and [having] nothing to feed them we cannot work them…. Many of our people have not enough to eat and to wear and don't know what to do for a living." By 1901, Congress was discussing a national reclamation act, and most government leaders believed the first federal reclamation project would be on the Gila River for our benefit. In 1903, the government decided to build the dam on the Salt River where Roosevelt Dam is today. Despite a $100,000 appropriation by Congress in 1907 to bring water to our land, we did not receive any water from this new reclamation project.

The Reclamation Service—and after 1913, the Indian Service—did begin construction on a series of irrigation projects designed to protect our rights to the water. While much money was expended and miles of canals were built, a lack of water doomed these projects, and we struggled to farm. Some of our men continued farming despite inadequate water, showing the resolve of our people.

In 1911, Antonito Azul penned a "Pima Appeal for Justice." It was sent to all members of Congress and newspapers across the country. It was a story of the wrongs against our people and a plea for correcting an injustice. While, in 1916, Arizo-



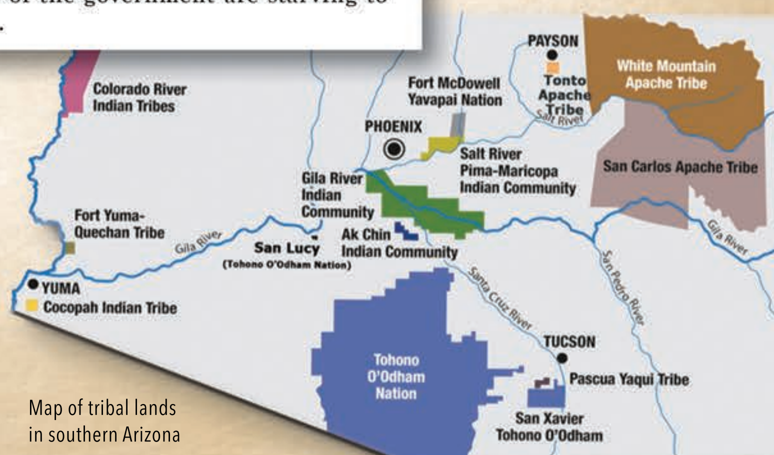
INDIANS STARVING TO DEATH.

Six Thousand Perishing on the Gila Reservation in Arizona Because of Failure of Crops.

Phoenix, Ari., June 17. —[Special.]—Six thousand Indians are starving to death on the Gila Rservation, fifty miles south of here, according to the reports of S.M. McCowan, superintendent of the Indian Industrial School of this city. His statement, which was wired to Washington tonight, paints a most dplorable picture of conditions existing among tribes that have never been contaminated by white blood.

Superintendent McGowan said he found twenty helpless adults in one miserable shack, that would, under ordinary circumstances, scarcely accommodate three persons. Congress has appropriated $30,000, but no method of distributing the money was stipulated, hence it is tied up, while the wards of the government are starving to death.

A news article in the Chicago Tribune from June 19, 1900.



Map of tribal lands in southern Arizona

Courtesy of Arizona State Library Archives na Senator Henry Ashurst and Representative Carl Hayden convinced Congress to authorize several diversion dams to deliver water first and foremost to the reservation for our use, water was not forthcoming.

After many years of lobbying by our people, as well as the Presbyterian Church and other Indian rights groups, Congress finally constructed Coolidge Dam, and created the San Carlos Reservoir. Completed in 192 8, the dam was hailed as "the savior of the Pimas." But the dam—and the San Carlos Irrigation Project that accompanied it—had only limited success. While it was to provide us with water before all other users, our water was given away once again when U.S. attorneys gave the surrounding and upstream farmers a share of our time immemorial priority water rights in disregard of state water laws. We objected to this decision and, in June of 1935, our leaders rode on horseback to Tucson to stop this give-away of our water. Our leaders were made to wait in the hall when the judge accepted Globe Equity Decree 59, ignoring our pleas.

In the meantime, the Indian Service began clearing 50,000 acres of land, destroying nearly 2 million mesquite, palo verde, ironwood, and acacia trees in preparation for agriculture using the water we thought would arrive with the completion of Coolidge Dam.

The San Carlos Irrigation Project sought to irrigate land outside the traditional areas we farmed, but much of it was too alkaline for agriculture, and more than half proved unsuitable for farming and was abandoned, requiring another 26,000 acres to be cleared. Today, one can find abandoned irrigation structures in the desert as a result of these Indian Service projects.

Our leaders adopted a two-pronged approach to restore our water using both litigation and negotiation. In 1976, the General Water Adjudication hearings began, with all water rights in Arizona to be decided. In 1983, we were allowed to represent ourselves in the Globe Equity 59 Action, in an effort to stop upstream diverters from using our water, but every time upstream farmers were required to reduce their diversions, they increased their upstream groundwater pumping, reducing surface flow. In 2002 the Arizona Supreme Court issued a ruling defining subsurface flow. Our day in court had arrived. A trial was held in 2002, and this time we did not have to sit in the hall outside the courtroom as we did in 1935. We demonstrated—just as independent observers had confirmed—that Globe Equity 59 covered upstream agricultural wells.

At the same time, we continued to work with outside parties for the return of our water. A severe drought in 1990 led us to build an interconnect to the Central Arizona Project (CAP), and two years later we reached an agreement with the federal Bureau of Reclamation to deliver 173,100 acre-feet of CAP water to the reservation, which very likely saved the agricultural economy of our community.

As we worked for the return of our water, we entered into a self-governance compact with the United States Government. In 1995, we became the first Indian tribe in the country to put an irrigation system under self-governance. The Pima-Maricopa Irrigation Project (P-MIP) is a tribal program funded by the Bureau of Reclamation. By 1998, we had commemorated the P-MIP system with a groundbreaking ceremony.

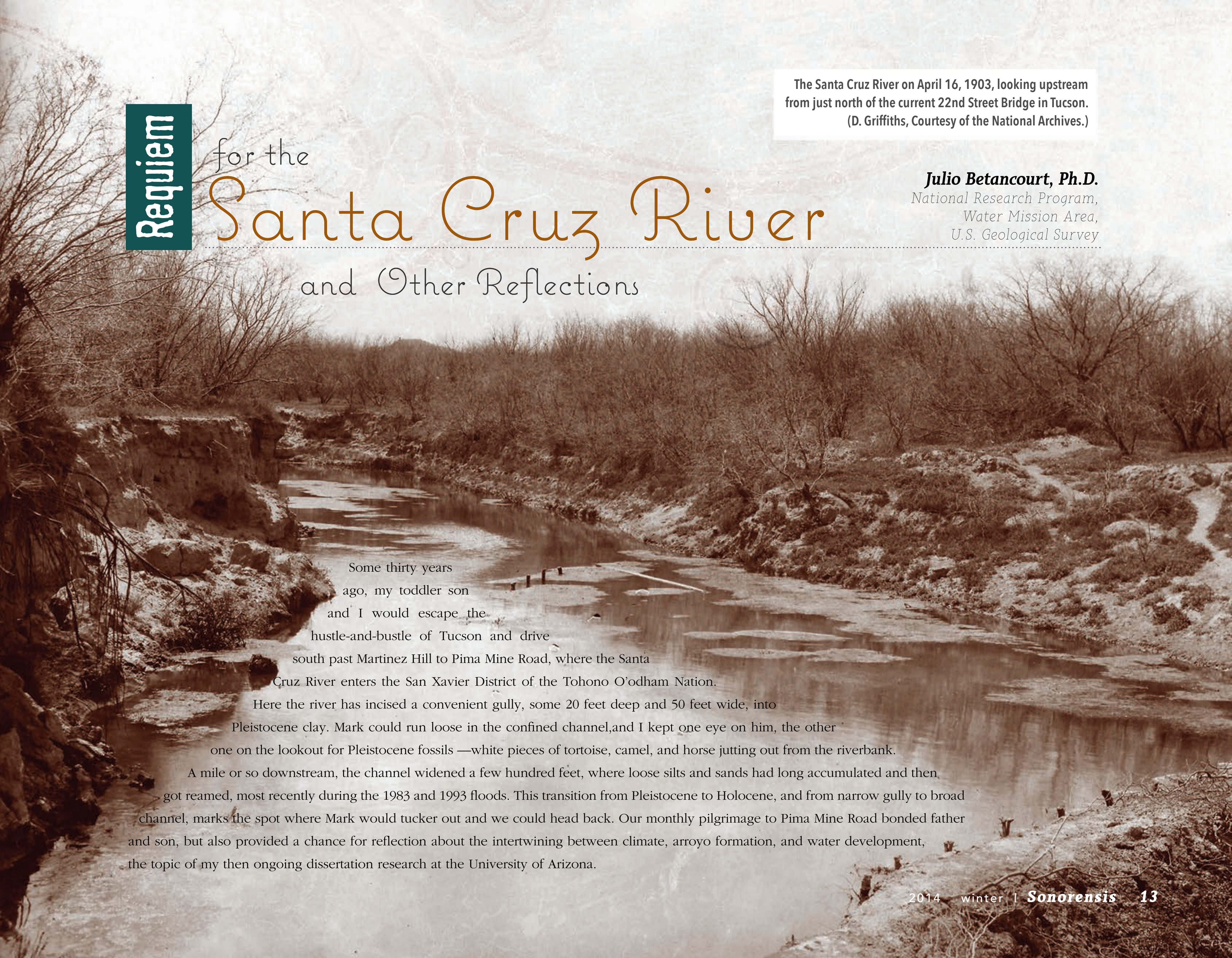
On December 10, 2004, President George W. Bush signed the Arizona Water Settlements Act of 2004. This restored 653,500 acre-feet of water annually to our Community. After a century of limited farming, the future is looking bright for our Community. We are coming full circle to rebuild our agricultural heritage with our children—the primary beneficiaries. The future holds great promise for them, as with the long-awaited restoration of our water, we can rebuild our agrarian heritage and once again enjoy the fruits of our labor. Our successful effort to restore our water demonstrates our resolve to once again become the industrious agriculturalists of the desert.

The Gila River sustained our agricultural economy. But it did much more. It sustained a way of life built around a lush riparian habitat. With water we can reestablish riparian habitat areas along the delivery system that will provide boating, swimming, fishing and picnicking opportunities for our people. Plants and animals that have been gone for many years may return home once again. Wetlands will be restored, providing us with an environment most of us have never known. S

David DeJong

David DeJong

Top from left to right: The Gila River flowing above the Ashurst-Hayden Diversion Dam; An irrigation diversion dam on the Gila River, near Safford, Arizona; With the restoration of water, the River people are rebuilding their agrarian heritage. The furture holds great promise for their children.



The Santa Cruz River on April 16, 1903, looking upstream from just north of the current 22nd Street Bridge in Tucson. (D. Griffiths, Courtesy of the National Archives.)

Requiem for the Santa Cruz River and Other Reflections

Julio Betancourt, Ph.D.
National Research Program,
Water Mission Area,
U.S. Geological Survey

Some thirty years ago, my toddler son and I would escape the hustle-and-bustle of Tucson and drive south past Martinez Hill to Pima Mine Road, where the Santa Cruz River enters the San Xavier District of the Tohono O'odham Nation. Here the river has incised a convenient gully, some 20 feet deep and 50 feet wide, into Pleistocene clay. Mark could run loose in the confined channel,and I kept one eye on him, the other one on the lookout for Pleistocene fossils —white pieces of tortoise, camel, and horse jutting out from the riverbank. A mile or so downstream, the channel widened a few hundred feet, where loose silts and sands had long accumulated and then got reamed, most recently during the 1983 and 1993 floods. This transition from Pleistocene to Holocene, and from narrow gully to broad channel, marks the spot where Mark would tucker out and we could head back. Our monthly pilgrimage to Pima Mine Road bonded father and son, but also provided a chance for reflection about the intertwining between climate, arroyo formation, and water development, the topic of my then ongoing dissertation research at the University of Arizona.

Left: Floods in August 1890 cut deep arroyos upstream of St. Mary's Road. Two years earlier, the heading of Sam Hughes' shallow 'intercept' ditch would have been in the foreground of this image. (George Roskruge, 45852, courtesy of the Arizona Historical Society.) Right: This 1907 photograph shows cottonwood trees along the narrow channel north of the Congress Street Bridge. (W. T. Hornaday, 11669, courtesy of the Arizona Historical Society.)

When the fossils were deposited in the Pleistocene, pinyon, juniper, and oaks covered the alluvial fan and groundwater recharged readily, enough to emerge as springs in the valley. As it warmed and dried in the Holocene, groundwater levels remained high but the vegetation shifted to saguaros and palo verdes, a brighter hue of green. Valley-wide floods along the Santa Cruz, then a braided stream, were slowed by marshlands near Tucson and San Xavier and spread tons of sediment across the floodplain. This valley filling was interrupted by extensive episodes of channel downcutting around 9000 to 6400, 4500, 3000, 1000, and 500 years ago. For reference, at the time of Columbus the river channel south of San Xavier was about 500 feet wide and 18 feet deep. The shallow groundwater allowed the regrowth of dense vegetation, and the large channel refilled with sediment in just a few centuries. Prior to the twentieth century, arroyo cutting and filling had been the normal state of affairs.

At the time of Columbus, the Santa Cruz River channel south of the San Xavier Mission was about 500 feet wide and 18 feet deep.

Short and discontinuous arroyos existed along the middle Santa Cruz as early as 1849, but elsewhere the river flowed at the surface of the valley and had not cut a deep channel in the floodplain. Near San Xavier del 'Bac' (a Spanglization of wa:c, or vaak, which probably refers to the place where the perennial surface flow sank back into the valley fill), perched groundwater along what was then called the Spring Branch, or Agua de La Misión, supported extensive marshlands, a thick forest of unusually tall mesquites, and a maze of irrigated fields that provisioned the Tohono O'odham and the mission. Further downstream at Tucson (Spanglization of chuk-son, the Piman word for "spring at the base of the black mountain," in reference to Sentinel Peak), the perennial flow was impounded at Silver Lake, sustaining both irrigation and recreation, and turning the water wheels at a succession of flour mills.

As Tucson prospered, development of additional water for irrigation and domestic use became paramount, and trouble brewed for the river. In 1882, then mayor of Tucson,


Left: An earthen dam constructed in the 1850s created Silver Lake at the base of Sentinel Peak (A Mountain) in Tucson, shown here in winter sometime during the 1880s. A resort hotel can be seen across the water on the right. (Photo 18335, courtesy of the Arizona Historical Society.) Right: Silver Lake 1981. In the 1890s, floods damaged the dam that created Silver Lake, and both the dam and its resultant lake were gone by the 1900s. (R. M. Turner, Stake 1060.)

Downcutting refers to the vertical erosion that, during floods, can incise floodplains by dislodging cohesive sediment and transporting it further downstream in the deepened channel. In the case of the Santa Cruz and other valleys in the Southwest, downcutting or arroyo cutting, was accomplished by the formation of "knickpoints" or abrupt vertical drops in the stream gradient and their migration upstream as floodwaters cascade over the resulting bluff or "headcut."

Robert N. Leatherwood, devised a scheme by which gravity flow from the base of a discontinuous arroyo near what is now Valencia Road was piped six miles to the Old Pueblo. A year later, Solomon Warner complained that Leatherwood's scheme had reduced inflows into Silver Lake, making it impossible to run his flour mill at the base of Sentinel Peak. This spurred Warner to dam the West Branch of the Santa Cruz and create a separate reservoir (Warner's Lake) to turn his water wheel. In 1884, Warner received legal notice from Hereford Lovell, an attorney for the landowners immediately downstream, that he was obstructing streamflow into the public acequia (the main irrigation canal), depriving the oldest fields of irrigation water without consent. The trouble was translated downstream when the owners of the oldest irrigated fields cut off the water north of the hospital lane (St. Mary's Road). Those owning land to the north relied on irrigation to grow a second wheat and barley crop during the hot summer. They partly blamed the summer water shortage on Chinese vegetable gardens that required more irrigation and had sprouted in the oldest fields since the coming of the railroad. The landowners to the north lost the lawsuit, and Mother Nature complicated matters further in the year that followed. In 1886, a dry summer ended with flooding that swept away the dams at Silver Lake and Warner's Lake. And then on May 3, 1887, the largest earthquake in Arizona history shook up buildings in Tucson and shifted the source of the Spring Branch a couple of miles upstream.

As has always been the case with water development on the Santa Cruz, somebody concocted a partial answer. The O'odham rushed to build a dam at the new source of the Spring Branch, only to be washed out by another round of floods a few months later. Immediately after the 1887 floods, Sam Hughes and his son-in-law Robert Treat excavated a ditch where the hospital lane forded the river to tap into the shallow groundwater and chan-

Left: This photograph of the West Branch (the channel in the foreground) and the Santa Cruz proper (channel not visible in the photo), taken from A Mountain in 1904, near the current intersection of Mission Road and 22nd Street, shows the headcut resulting from Sam Hughes' ditch. The remnant of an old dam can be seen left of center, just upstream from what was then the confluence of the mainstem and West Branch. (Walter Hadsell, 24868, courtesy of the Arizona Historical Society.) Right: By 2000, the West Branch was engineered to join the Santa Cruz channel further upstream, and the river channel was locked in place with soil cement. (D. P. Oldershaw, Stake 1026.)

Arroyo cutting may rate as Tucson's worst environmental disaster, and it happened not just along the Santa Cruz, but also along the San Pedro and other rivers throughout the Southwest.

nel it several miles downstream. But they were short on capital and failed to protect the heading. In summer 1890, four major floods spaced three to ten days apart, widened the heading a couple of hundred yards and extended it two miles upstream (see photo pg. 14). George Roskruge, then serving as City Engineer, photographed the gaping channel at the hospital lane and described it as, "Sam Hughes' ditch taking a walk to Maish's lake [Silver Lake] after water." Sustained flooding in winter and spring of 1904–1905 and 1914–1915 eroded the arroyo another fifteen miles upstream, and put to ruin many farmlands and water works along the Santa Cruz, from below Tucson to above San Xavier. From my vantage point, arroyo cutting rated as Tucson's worst environmental disaster, and it happened, not just along the Santa Cruz River, but also along the San Pedro and other rivers throughout the Southwest. It was a regional disaster and led to the abandonment of many riverine settlements in the area.

My dissertation focused on carefully documenting the history of nineteeth-century arroyo cutting and evaluating the possible causes. Unfortunately, it was a story without a punchline, and I failed to publish it as a book in the late 1980s. A few years ago my colleague Bob Webb pushed to resurrect the manuscript, this time focusing not so much on the causes of arroyo cutting but on the aftermath. Bob Webb is a Tucson-based geomorphologist and has long been studying modern channel changes along the Santa Cruz. He and Ray Turner, a renowned ecologist who had helped me match historical photographs of the floodplain in the 1980s, began repeating them again from 2000 to 2010 as part of a regional effort that led to publication of two University of Arizona Press books, the *Changing Mile Revisited* (2003) and *Ribbon of Green* (2007). Bob convinced me that the punchline to the Santa Cruz manuscript was not what caused arroyo cutting, but how the ensuing groundwater overdraft needed to grow a million people in the Tucson Basin had inflicted even more irreversible damage.

Left: The 1914 flood on the Santa Cruz at Congress Street. A deep arroyo eroded the channel near downtown Tucson in 1890 and 1891, making river crossings more difficult. By the early twentieth century, bridges were replacing fords where the channel had once been broad and shallow. This bridge of steel and wood was built near downtown Tucson after the floods of 1904 and 1905. (Photo by Godfrey Sykes, Sykes Family Collection. Courtesy of the Arizona Historical Society.) Right: The Santa Cruz during the 1983 flood. This image was taken near its peak discharge (52,700 cubic feet per second) at the St. Mary's Road Bridge. (J. L. Betancourt, Stake 1320.)

To help document the ecological impact of groundwater withdrawal on the San Xavier District of the Tohono O'odham Nation, Bob recruited Roy Johnson, an ornithologist who in the 1950s had assisted the Smithsonian's Joe Marshall counting birds and studying habitat loss in what was once the Great Mesquite Forest, that grove of mighty mesquites south of San Xavier del Bac. This forest, and the marshlands fed by the Spring Branch, had long been a mecca for ornithologists, a veritable hotspot for regional biodiversity. Roy inventoried countless observations of birds and other vertebrates made by biologists since the 1850s. The result of our collaboration is *Requiem for the Santa Cruz: An Environmental History of an Arizona River* (University of Arizona Press, 2014), a memorial to a river and a habitat that, because of groundwater overdraft, can no longer be revived or restored.

The Great Mesquite Forest, that grove of mighty mesquites south of San Xavier del Bac, and the marshlands fed by the Spring Branch, had long been a mecca for ornithologists, a veritable hotspot for regional biodiversity.

A lot of water has passed under the bridge since my son Mark was a toddler and we whittled the day away walking the river channel. He is a capable outdoorsman, so occasionally I recruit him to help out in the field. The tables have turned, and it is now my son that keeps an eye out for his dad. When the book was recently published, I gave Mark a copy and reminded him of the good times we had spent on the Santa Cruz. We discussed what is happening now on the San Pedro River, where current groundwater withdrawals threaten migratory stopovers for nearly half of all North American bird species. And yes, we also commiserated about how human history invariably repeats itself. ■

More information on the history of the Santa Cruz River and repeated photography through time can be found in:

Webb, R. H., Betancourt, J. L., Turner, R. M., and Johnson, *R. R. Requiem for the Santa Cruz: An Environmental History of an Arizona River.* Tucson: University of Arizona Press, 2014.


EDI

Aquatic Architects at Work:

THE RETURN OF Beaver TO THE SAN PEDRO RIPARIAN NATIONAL CONSERVATION AREA

Marcia Radke - *Wildlife Biologist, Bureau of Land Management, San Pedro Project Office*

In 1826, trapper James Ohio Pattie dubbed the lower San Pedro River "Beaver River." He and his party had been trapping beaver along the Gila River and its tributaries, but found that northern stretch of the San Pedro "very remarkable for the number of its beaver... At this place we collected 200 skins." In 1846 the San Pedro River was described by the Johnston expedition as "covered with a dense growth of mesquite, cottonwood, and willow, through which it is hard to move without being unhorsed."

At that time, the riverbanks were lushly vegetated, providing cover and resources to countless animals. Beaver bones excavated at a cultural site near Redington (northeast of Tucson) probably dating from before the Spaniards arrived, suggest perennial flow where now the river flows intermittently at best. It is not hard to imagine the expansive cienega floodplain with grasslands, marshlands, and mesquite bosques along its course. There are many historic references to how a man on horseback was barely visible in the sacaton grasslands that once flourished here.

Pattie was one of hundreds making a living trapping beaver for a highly lucrative international industry in which the underhairs of beaver fur were felted for the popular, sturdy and waterproof "beaver hats." By Pattie's time, European beavers had been virtually extirpated, and North American trappers had been filling the bill for more than a century, devastating beaver populations across this continent. By the late 1880s, beaver in the San Pedro were gone, and with them, their beneficial services in the landscape. The eradication of beaver and, subsequently, beaver dams, along with land management actions at the time, likely contributed to a channel varying in depth from 3 to 20 feet almost the whole length of the San Pedro River.

Even at that time, some naturalists had a pretty good idea of the connection between beaverless waters and bank cutting; beaver dams checked the forceful flow of floodwater and slowed channel cutting. In the 1930s, the U.S. government put beaver to work restoring streams in the Pacific Northwest, Wyoming, and Utah. In the 1950s, reintroduced beaver helped restore stream habitats on the Mogollon Rim in Arizona. By the late twentieth century more ecologists and wildlife agencies were considering the restoration of rivers by beaver reintroduction.

Traci Swift

William R. Radke

© Harold E. Malde/courtesy The Nature Conservancy

Upper left: Since the introduction of beaver into SPRNCA, this beaver has been spoted on the south side of the Huachuca Mountains. Upper right: A cottonwood tree felled by beaver along the San Pedro River. Bottom: A stretch of the lower San Pedro River near Dudleyville.

Beaver in the Ecosytem

Beavers *(Castor canadensis)* are the largest rodents in North America, with adults usually weighing between 25 and 70 pounds. These hefty, semi-aquatic animals have long been attributed with industrious character in folklore and popular culture. In fact, the association is apt, and their diligent dam-building not only serves their families, it positively impacts the hydrology and ecology of rivers. They are, in fact, a keystone species—"a species on which other species in an ecosystem largely depend, such that if it were removed, the ecosystem would change drastically."

William R. Radke

Larry Hinchliffe

JoAnn Hinchliffe

Above: Water pools behind a beaver dam on the San Pedro River, facilitating recharge into the aquifer. Above right: Raccoons (Procyon lotor) *are found in the desert wherever there is water. Right: Flame skimmer dragonfly* (Libellula saturata).

Beaver influence community diversity and ecosystem structure through tree felling and dam building. Beaver herbivory tends to result in large woody material in the floodplain, which enhances the amount of water that may be captured and stored. Water impounded behind beaver dams increases the area of riparian habitat, and, through groundwater recharge, leads to elevated water tables. In addition, the beavers' removal of trees allows the river to cut into banks where woody vegetation is removed, creating increased sinuosity and slowing water movement out of the area, widening the floodplain, and creating areas for future establishment of riparian vegetation that prevents erosion.

Typically nocturnal or crepuscular, beavers live and work in groups called "colonies." The colony generally consists of up to a half dozen or so individuals in a family, and together the colony occupies a pond or stretch of stream, uses a common food supply, and maintains a common dam or dams. Recent genetic research suggests that although colonies are composed primarily of first and second-order relatives, they may also include unrelated individuals and that mating can occur between members of neighboring colonies. Piling logs, branches, rocks, and mud, they build dams behind which stream waters pool. They may den in burrows in stream banks or in lodges that they construct. Beavers also build mud mounds in and around their lodges, dams, and trails and mark them with castoreum, a urine-based secretion. This castoreum has a distinct scent that allows them to distinguish among family, neighbor, and non-neighbors, and both sexes apparently use this to mark territory.

Prescription for the San Pedro

In 1998, the Bureau of Land Management (BLM), with public input, approved a plan to improve the hydrological health and riparian community of the San Pedro Riparian National Conservation Area (SPRNCA) through the reintroduction of beaver. After the initial release of eight beaver in 1999 by BLM in cooperation with Arizona Game and Fish Department, another five beaver were introduced in 2000, and another two beaver in 2002. Since 2000, the BLM and other participating groups such as the Friends of the San Pedro River, The Nature Conservancy, and many volunteers have closely monitored the beaver and possible effects of their populations on the San Pedro River. We have mapped and documented the expansion of active beaver dams each year and determined site fidelity, i.e. the number of years a dam is located in the same or nearby location. Results of the beaver reintroduction have had the effects that we expected on near-stream water levels, or the hyporheic water in the stream bed and banks. And the beavers have given us a couple of pleasant surprises.

The total number of beaver on SPRNCA is now estimated at 40, and the total number of dams has increased from five in 2000 to a high of 39 in 2010, with an average

EDI

Tana Kappel/courtesy The Nature Conservancy

Left: Young beaver eating riparian vegetation. Right: A lush stretch of the upper San Pedro River, near Fairbanks.

of about 20 dams per year from 2000 to 2013. There have been more than 300 dams documented in about 170 locations. Of the 300 dams, most were used for one year, and about one-third are used for more than one year, with some dam sites used as many as eight years.

In studies elsewhere, researchers found that beaver selected first those areas that created the largest ponds with the greatest potential for expansion (a choice we might have expected, given that larger ponds provide beavers with greater protection from predators and a greater area in which to forage for vegetation for food and dam building). However, as more of these favored sites were occupied, new ponds were limited to less desirable sites. This was also evident on SPRNCA, where the beaver appeared to prefer dam sites where side washes enter the San Pedro River and to reuse these sites more consistently than sites without tributary washes. Tributary washes provide large amounts of sand, gravel, and rock at the confluence with the river. Beaver appear to prefer these confluences, where these sediments allow lower and shorter dams. Because of the sediment build up, deep ponds are created, which cause a backlog of water over long distances, allowing beaver to expend less energy in dam building while still ponding significant amounts of water.

Beaver dam site fidelity on SPRNCA appears to be mainly affected by rain events that trigger high flood flows in the river. Small or isolated flood events may not wash out beaver dams, but larger flood events wash out many, if not all, individual dams. This is probably because large segments of the San Pedro River within the SPRNCA are still entrenched (i.e. the original base level has been downcut from erosion, forming a confined area with little or no floodplain). In addition, the growth of Fremont cottonwood, Goodding's willow, seep willow, and other vegetation along the river banks catches sediments and holds soil in place along the river channel. This "armoring" of the banks, in conjunction with historic entrenchment, results in large amounts of water funneling through with high velocity during significant flood events, which can wash away beaver dams. Although beaver have been back on the San Pedro River for fifteen years, the entrenchment that happened to the river beginning in the late 1800s will take many decades to repair, and dams will continue to wash out until sinuosity and aggradation returns to the river. Eventually, beaver dams may be able to better enhance this needed sinuosity and aggradation.

Monsoonal flooding may also factor into beaver dispersal. Young beaver leave their parent colony at approximately two years of age in search of their own mates and territories. On SPRNCA, beaver may use monsoonal floods to find new areas to colonize and establish their own territories. Beavers were reported on the south side of the Huachuca Mountains during the summers of 2012 and 2014. These individuals probably emigrated from SPRNCA upstream

Mike Lunn

Mike Lunn

Above: A BLM Fisheries Biologist points to a new occurrence of Huachuca water umbel (Lilaeopsis schaffneriana) *that appeared along the river just downstream from a beaver dam where it had not been previously documented, April 2012. Right: Close up of the patch of the endangered Huachuca water umbel.*

into Mexico and then upstream again into the Huachucas. A beaver was also reported in Mexico during 2012 in the headwaters of the Santa Cruz watershed, and this, too, may be a beaver from SPRNCA.

One of the beneficial ecological services performed by beaver has already been seen following the SPRNCA reintroduction. Studies of beaver previously documented that beaver dams increase hyporheic flows—the water flow beneath the streambed, where groundwater and surface water meet. This effect has been observed on SPRNCA at sites with tributary washes, where even a small beaver dam built on top of sand, gravel, and rock bars caused the river to pond substantially. Hyporheic flows at these locations contribute to water storage capacity and enhance bank storage for later release during dry periods. Anecdotal evidence for this later release of water over a longer time period appeared on SPRNCA in 2012 with the presence of a patch of the Huachuca water umbel *(Lilaeopsis schaffneriana* var. *recurva)* about 4 meters downstream of a beaver dam. The dam created permanent water in an area where this federally endangered aquatic-obligate plant could grow, where it had not been found before. Hyporheic flow enhanced by beaver dams, in conjunction with increased organic material in the floodplain from beaver herbivory, may eventually result in a significant increase in the water-holding ability of the San Pedro River system. Unusual water levels observed from monitoring by US Geological Survey indicates that beaver dams on SPRNCA are raising near-stream water levels as predicted, which means there should be a little more water available in the alluvial aquifer for low flow discharge during the drier times of the year.

> ***Beaver dams increase hyporheic flows—the water flow beneath the streambed, where groundwater and surface water meet—enhancing bank storage for release during dry periods.***

Although the effects of beaver reintroduction on the San Pedro River have been positive in elevating near-stream water levels around beaver dams, prognosis for the river is guarded because of groundwater extraction. Recent modeling by US Geological Survey indicates streamflow depletion could occur within ten years as a function of 1,500 hypothetical well locations in the aquifer underlying the upper San Pedro River Basin. Hopefully, beaver impacts will be able to modulate the effects of groundwater pumping, and the riparian vegetation, wildlife, endangered species, and beaver on SPRNCA won't be left high and dry in the future. S

Conserving the San Pedro River

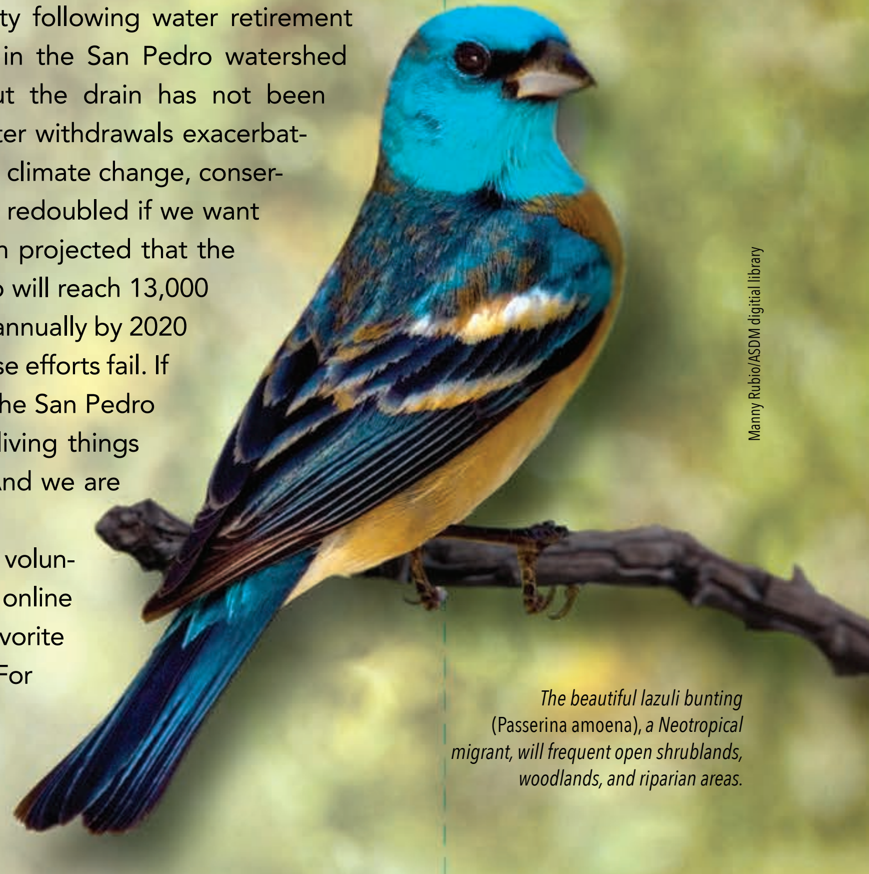
The San Pedro River is the last remaining major free-flowing river in the Southwest. It is also the last remaining significant north-south riparian corridor in the Southwest, critical to hundreds of species of migratory birds, as well as hundreds of resident animals. However, this life-giving ribbon has been in decline for decades. Since the 1940s, base flow in the river has decreased more than 60 percent, and, in most stretches, the riparian community is losing ground.

Recognizing its value to both humans and wildlife, in 1988 the U.S. Congress established the San Pedro Riparian National Conservation Area (SPRNCA), which protects a segment of the upper (southern) reach of the river, and spurred broad-based efforts to conserve its natural resources. In 1996, the Upper San Pedro Partnership (USPP) was formed. The partnership includes local government entities, as well as local and private nonprofits, including The Nature Conservancy (TNC), Friends of the San Pedro, BLM, Fort Huachuca, and the obvious state and federal agencies concerned with water and wildlife. (Look online for a full list of participants). A binational initiative with Mexican agencies was also formed to address conditions of the San Pedro's headwaters in Sonora. Long focused on life-giving rivers, The Nature Conservancy has also focused conservation efforts in several stretches of the lower (northern) San Pedro (as well as tributaries and other riparian areas such as Aravaipa Creek, Sonoita Creek, and Canelo Hills).

In SPRNCA, partners have worked to minimize groundwater withdrawal, recharge aquifers, restore perennial surface flow, and maintain water quality, taking various approaches—from purchasing agricultural property along the river and retiring water withdrawal, to introducing beaver, to building watershed improvements, to wastewater recharge projects, to water conservation campaigns. Every year since 1999, hundreds of volunteers have walked the river prior to the summer monsoon to measure perennial stretches and identify areas where restoration might best be focused. Overall, thousands of man-hours and significant funds have been and continue to be invested in hopes of restoring surface water and recovering or maintaining a rich riparian community.

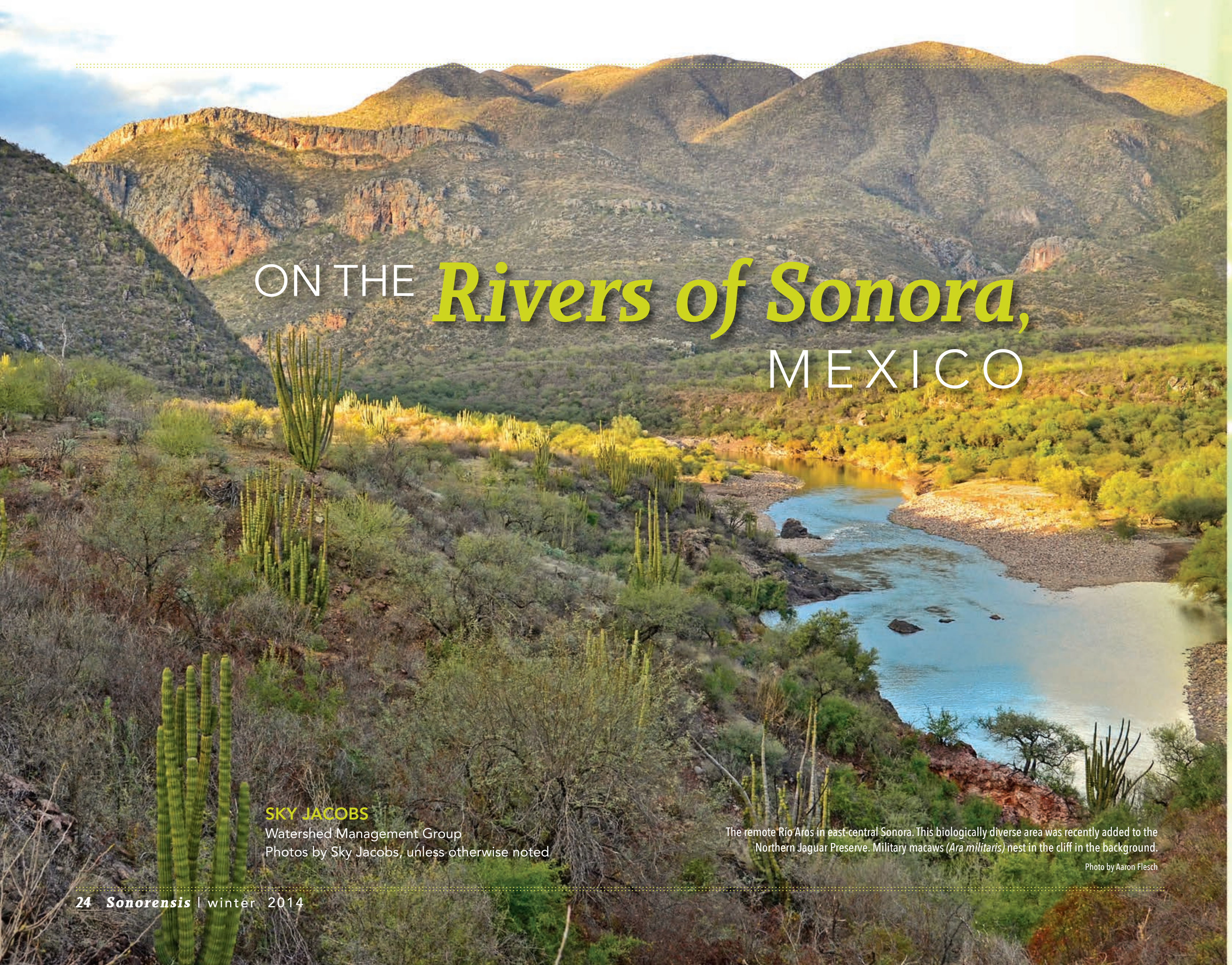
Some progress has been made. Flows near the southern end of SPRNCA have actually expanded, and recovery of flows and riparian biodiversity following water retirement near TNC land investments in the San Pedro watershed have been documented. But the drain has not been plugged, and with active water withdrawals exacerbated by long-term drought and climate change, conservation efforts will need to be redoubled if we want to save the river. It has been projected that the water deficit in the San Pedro will reach 13,000 acre-feet (4.2 billion gallons) annually by 2020 if water-conservation and reuse efforts fail. If that happens, the ribbon of the San Pedro will cease to be green, and living things dependent on it will suffer. And we are all connected.

If you are interested in volunteering for our rivers, check online for opportunities with your favorite conservation organization. For a bio-rich note on the San Pedro volunteer monitoring effort look for http://blog.nature.org/conservancy/2014/08/11/searching-for-water-on-the-san-pedro/.



Manny Rubio/ASDM digitial library

The beautiful lazuli bunting (Passerina amoena), *a Neotropical migrant, will frequent open shrublands, woodlands, and riparian areas.*



ON THE *Rivers of Sonora,* MEXICO

SKY JACOBS
Watershed Management Group
Photos by Sky Jacobs, unless otherwise noted

The remote Río Aros in east-central Sonora. This biologically diverse area was recently added to the Northern Jaguar Preserve. Military macaws *(Ara militaris)* nest in the cliff in the background.
Photo by Aaron Flesch

Until the late 1990s I had made only a few forays into the wilds of Sonora, but the hook had already begun to dig its way in. Around that time I began fieldwork with my friend Aaron Flesch for his master's thesis, which required us to traverse much of the *bronco* state of Sonora. Sonora's unexplored canyons, where the Neotropics draw their last northward breath, began to draw us in.

At some point in the early 2000s we realized that remote, tropical canyons in eastern Sonora could be accessed via its rivers. What better way to explore and enjoy the terrain than by floating through it? When ideas turned to action, we were surprised how little guidance we could find. Rivers in the western United States are overrun with boaters, yet 125 miles (200 km) south of the border there remained little-known stretches of waterway. Plenty of people told us we were crazy to boat unknown Mexican rivers, especially with the undercurrent of fear surrounding drug cartel operations. By our first trip on the upper Río Yaqui in 2003, we still knew very little about this large, muddy watercourse that would be taking us in her arms.

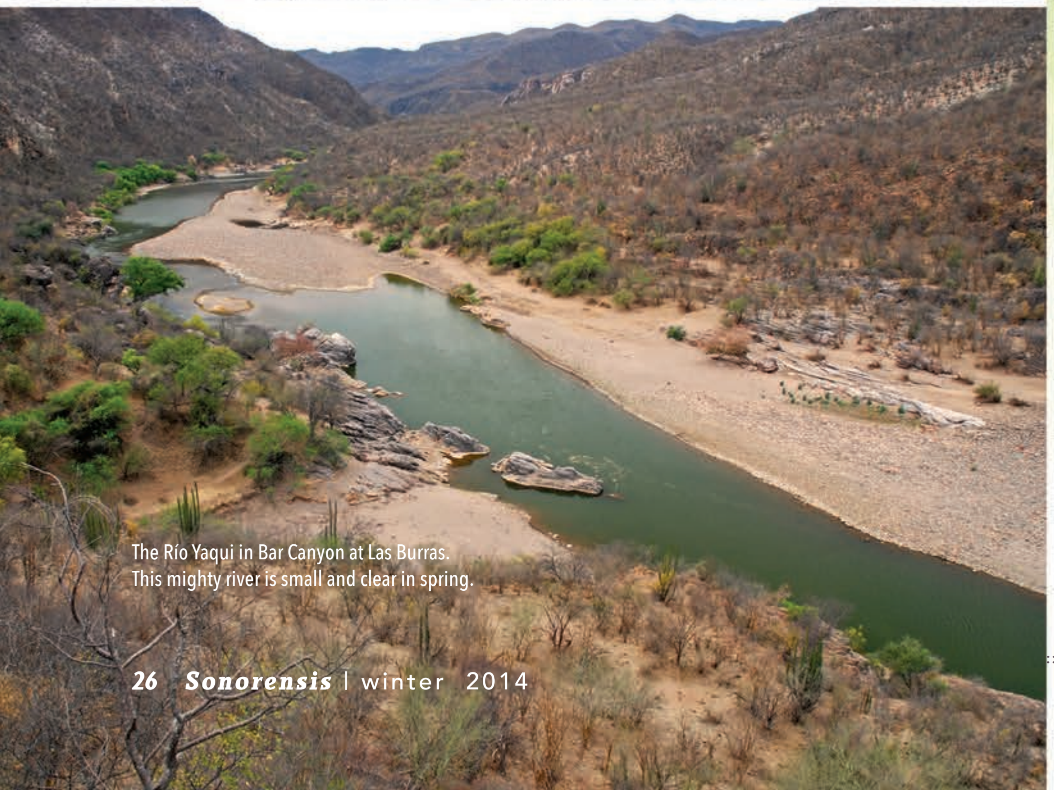
The Río Yaqui and its tributaries drain the largest watershed in northwestern Mexico. It covers about 30 percent of Sonora and drains portions of Chihuahua as well, encompassing nearly 80,000 square kilometers. The Yaqui, also the longest river in northwestern Mexico, remains one of the least manipulated large rivers in the greater Southwest and Mexico. There are only two reservoirs on the main reach, Presa el Novillo and Presa el Oviáchic, and only one on its main northern tributary, Presa la Angostura on the Río Bavispe, about 62 miles (100 km) north of its confluence with the Yaqui. This leaves most of the Yaqui watershed undammed, with a natural hydrological cycle.

Looking back at that initial excursion, it was like a gringo's first visit across the border in Nogales. We only got our feet wet. The short stretch of the Río Yaqui we explored, while remote and beautiful, was relatively tame. The next year, in the 2004 monsoon season, we floated a two-person inflatable kayak down Río Bavispe from Granados south to its confluence with Río Yaqui, and then to Sahuaripa. This trip was an eye opener, with unexpected challenges, including a massive flood and an unnavigable rapid. After leaving our put-in area, we saw no other humans for over 70 miles (113 km) of river. We discovered side canyons with giant tropical figs, very fresh adult and cub jaguar *(Panthera onca)* tracks in the mud, Neotropical river otters *(Lontra longicaudis),* and many species of plants and animals near the northern limits of their range. Keep in mind this is only about 200 miles (322 km) from Tucson, Arizona! The rivers of Sonora beckoned us to explore further.

A native spider lily *(Hymenocallis sonorensis)* grows along the banks of the Río Aros in sediment deposited by receding floodwaters.

Massive flood debris on the Río Aros. Because the Aros watershed is large and free from dams, annual monsoons can generate very large floods, important in maintaining this ecosystem.

Photo by Aaron Flesch



The Río Yaqui in Bar Canyon at Las Burras. This mighty river is small and clear in spring.

OVERVIEW OF THE RIVERS OF SONORA

Northern Sonora has a climate of high evaporation and low rainfall, which does not lend itself to perennial rivers. In fact, most are intermittent and/or ephemeral. Even the mighty Río Yaqui isn't much more than a "creek" during the dry season, with flows of 100–200 cubic feet per second.

Surprisingly, no Sonoran river currently discharges into the ocean, except during flood events. Western Sonora's extensive plain of sandy soil "eats" rivers, absorbing them into large underground aquifers before they can reach the sea. Historically, even prior to dams and diversions, only the Río Yaqui regularly flowed its full length to the Gulf, and even it failed on occasion.

With limited surface water in this arid region, riparian areas take on increased importance for people, plants, and wildlife. Indeed, these oases are essential to many species. Throughout human history in the region, human settlements have been located along valley-bottom channels. Here, deep bottomland soil—sediment deposited by eons of flooding—grows food necessary to sustain human populations in the region. The floodplain of the Río Yaqui is one of Mexico's largest and most productive agricultural areas, built by millennia of sediment washed down from its vast watershed.

> The river-naming convention in Mexico is different from in the United States. Generally, when two important tributaries converge, the resulting river has a new name not associated with either contributor.

In southern Arizona we receive just over half our precipitation in the monsoon season, with the rest delivered by Pacific Jetstream storms from late fall to spring. But as one travels south and east, winter rain becomes less abundant, while monsoonal rainfall increases. In Sonora, annual rainfall varies drastically, from 2–3 inches (5–8 cm) in the northwestern tip to about 40 inches (100 cm) near Yécora in the Sierra Madre Occidental.

Eastern Sonora's low and middle elevations are dominated by Sinaloan thornscrub, which relies primarily on monsoon rain. This vegetation community remains dull and gray much of the year, but mere days after the first monsoon rains quench the parched landscape, green begins to overtake gray, revealing a different world where a cacophony of biodiversity flourishes. Waterways are transformed from sandy washes, stagnant pools, or small trickles into forceful, sediment-laden torrents. The change is incredible. Monsoon rains cause river levels to rise and fall continuously and without warning. Drastic fluctuation in flows is part of the character of Sonoran rivers.

MAJOR WATERSHEDS OF NORTHERN SONORA

Northeastern Sonora holds the headwaters for many of the rivers of the greater Sonoran Desert Region. The San Pedro and Santa Cruz Rivers drain through the high grassland valleys south and west of the Huachuca Mountains, and flow north through southern Arizona. The headwaters of the Ríos Sonora and Asunción, as well as the northern headwaters of the Río Bavispe, also get their start in close vicinity.

The Río Asunción is a key watershed for communities in northwestern Sonora. Two primary reaches, the Bambuto and Cocospera, merge to form Río Magdalena, which feeds several important Sonoran towns before becoming the Río Asunción. The Asunción does not have perennial flow, but its remaining groundwater continues to feed substantial agriculture. Historically much of this true desert river was waterless, except where geology forced its reemergence at the hot and dusty towns of Pitiquito and Caborca.

The Río Altar is a significant tributary to the Asunción and harbors true desert oases. It's the only Sonoran river with long above-ground flows that runs squarely through true Sonoran Desert. Although its headwaters seep out of the Atascosa Mountains just southwest of Tucson, most people in southern Arizona are not familiar with the Río Altar. Cottonwood and willow gallery forests line stretches of this river, and some important remaining mesquite bosques feed off of its groundwater. I have spent much time in this valley over the last 15 years and despite its dangerous reputation, have grown fond of its natural character and great people.

WATERSHED DECLINE

Sadly, most of Sonora's rivers are in decline. Just as in the southwestern United States, increasing demand by our human population has put pressure on Sonora's rivers and aquifers. In my adult life I have seen several stretches run dry and gallery forests disappear. The upper Ríos Altar, Santa Cruz, and Magdalena have seen major cottonwood diebacks in the past decade, and these changes are hard on wildlife and humans alike.

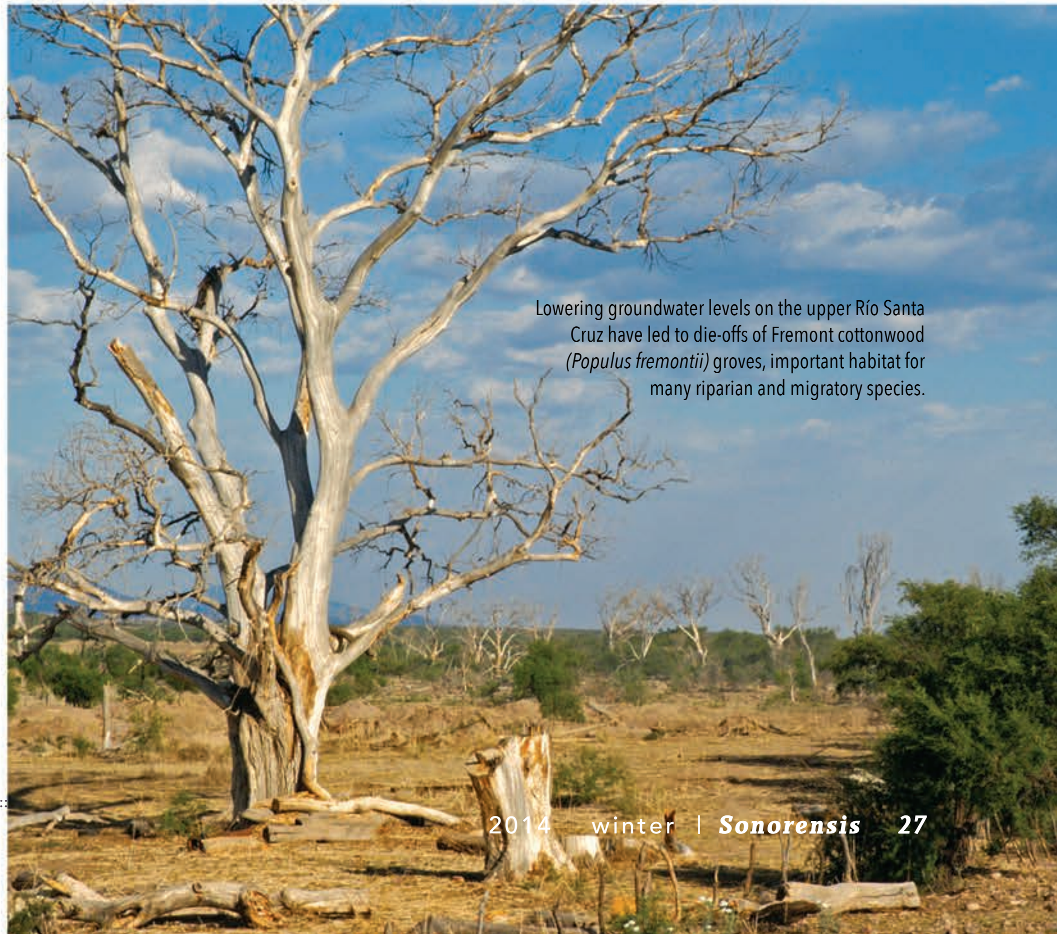
Since anyone can remember, the town of Magdalena has enjoyed the beautiful and shady Río Magdalena. It has sustained this community since the late 1600s, and its banks have long been a gathering place for picnics and parties. But within just the last several years, this stretch has completely transformed; the cottonwood gallery forest has died and the creek no longer flows. The reach of the Magdalena supporting cottonwoods has been creeping north, upstream. Though no one knows with certainty what degree of which factors are responsible, Nogales, Sonora, has increased pumping in the upper watershed.

I have walked a transect on the upper Río Altar at least once a year since the early 2000s. This stretch had substantial flow until recent years, and is now almost dry. To put the change in perspective, this now dry reach hosted breeding green kingfishers *(Chloroceryle americana),* which I observed mating here around 2005.

The Río Sonoyta, discounting Río Colorado, is Sonora's northwestern-most river. It traverses the driest part of the Sonoran Desert, a vast area devoid of rivers and, indeed, much water of any kind. Historically, the Sonoyta had several kilometers of perennial flow, yet in the last few years it has teetered on the edge of disappearing altogether. The Sonoyta pupfish *(Cyprinodon eremus,* aka Quitobaquito pupfish) has survived here for millennia, but is in danger of being extirpated from the river. Its only other natural population is in the nearby Quitobaquito Springs, which has seen recent instability in water levels.

Groundwater pumping has played a large part in riparian decline in many watersheds. Much of Sonora's landscape has lost the "sponge" of healthy topsoil and vegetation from overgrazing, causing long-term reduced infiltration of rainwater. In the last 15 years, northern and western Sonora has also suffered from drought conditions exacerbating these issues.

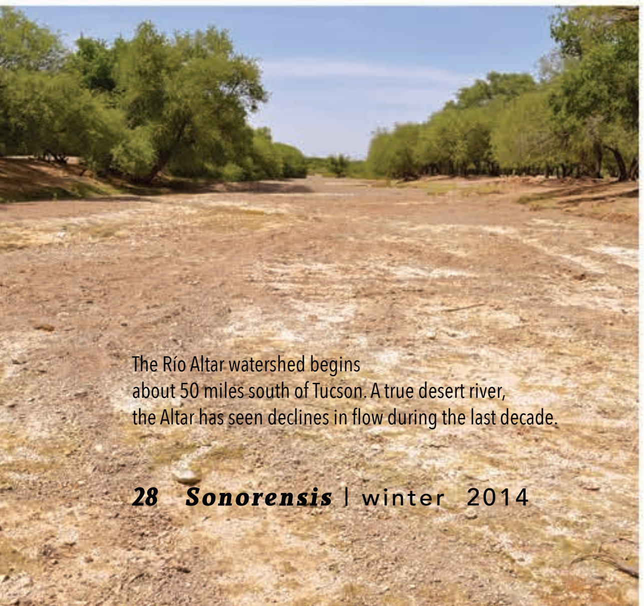
The Río Bavispe, where it emerges from its mountainous headwaters into the flat U-shaped valley around the Sierra El Tigre.



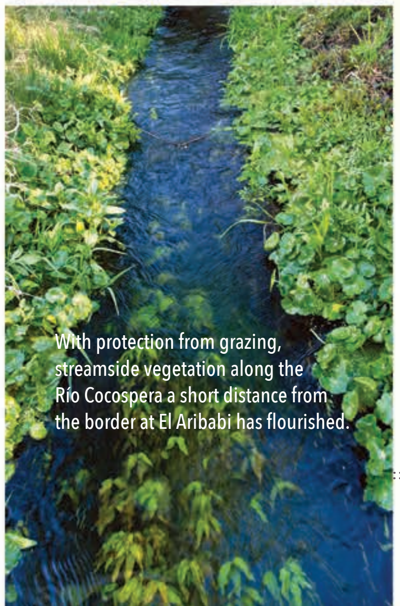
Lowering groundwater levels on the upper Río Santa Cruz have led to die-offs of Fremont cottonwood *(Populus fremontii)* groves, important habitat for many riparian and migratory species.

RIVERS OF NORTHERN SONORA

Map by Sky Jacobs



The Río Altar watershed begins about 50 miles south of Tucson. A true desert river, the Altar has seen declines in flow during the last decade.



With protection from grazing, streamside vegetation along the Río Cocospera a short distance from the border at El Aribabi has flourished.

RESEARCH TOWARD CONSERVATION

Back in 2004, boating the smaller Bavispe, we had a bit of a shock when we hit its junction forming the Río Yaqui. The other fork, the Río Aros, was huge—much bigger than we anticipated, making the Bavispe look like a small backwater. We knew that the area was devoid of sizable human settlements clear to the other side of the Sierra Madre spine in Chihuahua. That moment inspired four additional boating expeditions to thoroughly investigate the Río Aros and its tributaries, as well as many overland surveys and explorations. In 2005 we organized a cadre of biologists for an excursion to help secure recognition for the important biological diversity of this region. Our team produced an extensive report that was cited by Mexican biologists and resource managers working to stop construction of a proposed dam on the Río Aros.

The importance of the area for wildlife had caught the attention of other biologists and conservationists as well. In 2003 the nonprofit Northern Jaguar Project purchased a 10,000-acre ranch adjacent to the Aros/Bavispe/Yaqui confluence in an effort to protect breeding jaguars and their habitat. The reserve has grown to over 50,000 acres and is protecting a multitude of flora and fauna. It has also extended its reach by working with nearby landowners, practicing restoration techniques, as well as assisting and funding important research, including some of our later expeditions.

Sonora's waterways and canyons host amazing biological diversity and abundance. They are also key to the persistence of human communities in this dry, unforgiving landscape. The importance of these life-giving places for all creatures cannot be overstated. S

BEYOND DIVERSION AND WITHDRAWAL

In August 2014, the Río Sonora ran orange. This alarming and unnatural occurrence was caused by millions of gallons of sulfuric acid leach solution containing heavy metals that escaped from holding facilities at Grupo Mexico's Cananea Buena Vista Mine. More than 10 million gallons poured into the Río Bacanuchi, a tributary of the Río Sonora. The orange plume contaminated drinking water for towns all the way from Cananea to Ures, whose municipal water supplies had to be shut down, and eventually reached Hermosillo, where it has contaminated the state capital's former municipal water supply reservoir. The contamination caused significant fish die-off in the rivers, and undoubtedly killed numerous other aquatic animals and plants. Lime was added to the river to offset the sulfuric acid, but an effective cleanup is unfeasible. Water trucks have been delivering drinking water to towns and villages along 160 km of the Río Sonora, and will have to do so for the foreseeable future.

PIPING THE *Río Yaqui*

Hermosillo was founded in another, less populated century on the banks of the Río Sonora in the hot dry coastal plain. Until recently, the city's water had come primarily from a reservoir on the outskirts of town and the large aquifer fed by Río Sonora. But in recent years the reservoir has been mostly dry, and groundwater reserves have been heavily tapped.

In 2010, as part of *Sonora Si*, the state of Sonora initiated the $286-million USD Independencia Pipeline project. Recently completed, the pipeline has begun carrying water and is expected to move around 500,000 gallons per day, pumping water from Presa Novillo on the Río Yaqui about 85 miles (135 kilometers) to Hermosillo. It is expected to provide roughly 80% of Hermosillo's municipal water use.

The Yaqui (Yoeme) people actively opposed the project, raising serious concerns, including issues surrounding agricultural water rights of people in the Yaqui delta region, where they have used Río Yaqui water to irrigate crops for thousands of years. Litigation is ongoing, but a recent agreement stipulates that water from the pipeline be used only for human consumption, and not for mining and a list of other industrial uses.

The Independencia Pipeline project, like the CAP in the United States, highlights both the limited supply and importance of water resources in the Sonoran Desert Region, as well as the need for communities to work towards more sustainable livelihoods.

Suggested Readings FOR Desert Rivers

The following short list provides recommended readings for a deeper understanding of rivers, water, landscapes, and people in the Sonoran Desert Region and the greater Southwest. This list includes both classics and more recent releases that are destined for that category. They vary from technical scientific publications, to on-the-ground guides, to inspired natural history essays.

A River No More: The Colorado River and the West. Phillip Fradkin. New York: Knopf, 1981.

Aridland Springs in North America: Ecology and Conservation. Lawrence E. Stevens and Vicky J. Meretsky, eds. Tucson: Arizona-Sonora Desert Museum/University of Arizona Press, 1999.

Cadillac Desert: The American West and Its Disappearing Water. Mark Reisner. New York: Penguin Books, revised edition. 1993.

Dry Borders: Great Natural Reserves of the Sonoran Desert. Richard S. Felger and Bill Broyles. Salt Lake City: University of Utah Press, 2006.

Ecology and Conservation of the San Pedro River. Juliet C. Stromberg and Barbara Tellman, eds. Tucson: University of Arizona Press, 2009.

Killing the Hidden Waters. Charles Bowden. Austin: University of Texas, 1977.

Once a River: Birdlife and Habitat Changes on the Middle Gila. Amadeo Rea. Tucson: University of Arizona Press, 1983.

Red Delta. Fighting for Life at the End of the Colorado River. Charles Bergman. Golden, CO: Defenders of Wildlife and Fulcrum Press, 2002.

Requiem for the Santa Cruz: An Environmental History of an Arizona River. Robert H. Webb, Julio L. Betancourt, R. Roy Johnson, Raymond M. Turner; Foreword by Bernard L. Fontana. Tucson: University of Arizona Press, 2014.

Run, River, Run: A Naturalist's Journey Down One of the Great Rivers of the West. Ann Zwinger. Tucson: University of Arizona Press, 1984.

Santa Cruz River Initiative, Living River Report, Sonoran Institute. http://www.sonoraninstitute.org/where-we-work/southwest/santa-cruz-river.html

Sonora: An Intimate Geography (University of Arizona Southwest Center). David Yetman. Albuquerque: University of New Mexico Press, 1999.

The San Pedro River: A Discovery Guide. Roseann Beggy Hanson. Tucson: University of Arizona Press, 2001.

Two more comprehensive but important books with conservation messages about the equations of water, natural resources, and people.

Countdown: Our Last Best Hope for a Future on Earth. Alan Weisman. New York: Little, Brown and Company, 2013.

Unquenchable: America's Water Crisis and What to Do about It. Robert Glennon. Washington, DC: Island Press, 2010.

ARIZONA SONORA DESERT MUSEUM
2021 N. Kinney Rd.
Tucson, AZ 85743-8918