Drought and Middle Rio Grande Water Management Issues

Ben Harding, *Hydrosphere Resource Consultants*

New Mexicans are a drought-tolerant species. This should come as no surprise. Earlier inhabitants of this land, the Ancestral Puebloans, survived using miniscule amounts of water, much of it carried by hand and stored in pots! Perhaps they even thrived; evidence indicates that the population of the Four Corners area was greater in the year 1000 than it was in the year 2000.

Modern New Mexico probably has no more water than it did one thousand years ago, but in those thousand years, technology and economy have allowed water to be stored in great volumes and moved great distances. Thus the modern resident of the Middle Rio Grande valley lives life with an abundance of water unimaginable to the Ancestral Puebloans. Even so, the state remains vulnerable to the adverse effects of drought. If New Mexico does not prepare for periods of drought, and then act properly, physical water shortages will be compounded by constraints on water storage arising from the Rio Grande Compact and the Endangered Species Act.

New Mexico has the cultural and historical perspective to embrace the reality of drought. I believe that the state also has the necessary will to take the difficult steps needed to prepare for drought. And New Mexico has many tools at its disposal with which to cope with drought.

THE NATURE OF DROUGHT

Probably the sparest meaningful definition of drought is a temporary period of water scarcity. Although the shortfall of snowfall or rainfall that brings about a water shortage is almost entirely outside our control, how we manage our water and natural systems over the long term can either mitigate or prolong and accentuate the effects of drought.

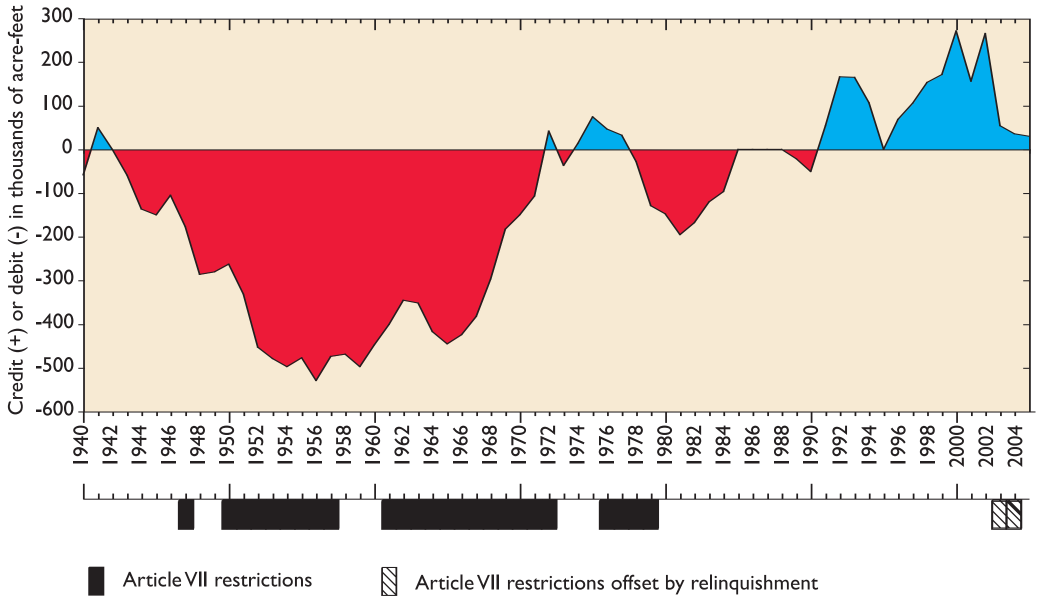
What are the adverse consequences of drought in the Rio Grande? The obvious consequence is a reduction in physical supply. Physical scarcity can imperil water supplies for irrigation or municipal uses, and water for natural systems and even aesthetics. As if that's not enough, a period of low stream flows can trigger parts of the Rio Grande Compact that place legal restrictions on the storage and release of water for use in the Middle Rio Grande valley, restrictions that can persist even after the drought has broken.

PHYSICAL SCARCITY

Physical scarcity is usually mitigated by storing water in plentiful years and applying it in water-short years. Both surface water and ground water storage are used to maintain physical supplies during times of drought. Increasing efficiency can help sustain supplies of stored water, but once stored supplies are depleted, continuing drought will inevitably result in a reduction in beneficial use and impacts on natural systems.

LEGAL SCARCITY—THE RIO GRANDE COMPACT

Legal scarcity can be painful. Even in times of abundant supplies, legal constraints such as those that might be imposed by the Rio Grande Compact on operation of reservoirs upstream of Elephant Butte Reservoir can restrict storage and later use of water. What is important to recognize about the compact is that even though it places strict constraints on how much Rio Grande water New Mexico is entitled to use over the long term, it provides substantial flexibility to the state in how it copes with drought over the short term. The compact sets out how much water New Mexico is entitled to consume in the middle valley in any given year. Article VI of the compact provides for a system of annual credits and debits, reflecting over- and under-delivery of water, respectively, in any one year, and it requires that a running sum of the annual debits and credits be maintained. So long as the running total accrues to an overall credit, there is no consequence, but once New Mexico accrues a debit then she must keep a reserve in New Mexico reservoirs in an amount equal to the accrued debit (Article VI restrictions). Article VI also sets an upper limit of 200,000 acre-feet on New Mexico's accrued debit. The Rio Grande Compact defines "Usable Water in Project Storage" as the amount of water that is legally available for release from Elephant Butte and Caballo Reservoirs. Article VII of the Rio Grande Compact restricts storage in some New Mexico reservoirs when



New Mexico's history of credits, debits, and Article VII restrictions. The red-colored areas in the upper chart represent debits resulting from New Mexico's under-deliveries under the Rio Grande Compact. Blue areas show credits resulting from accumulated over-deliveries. The lower chart shows periods when Article VII restrictions were in place. The hatched bars show that in 2004 and 2005 restrictions would have been imposed but were offset by relinquishment of credits.

Usable Water in Project Storage falls below 400,000 acre-feet (Article VII restrictions). Under these circumstances, if New Mexico has accrued credits, it may relinquish some credits and store an equal amount of water. Enforcement of the Rio Grande Compact would be by a federal water master, by order of the U.S. Supreme Court.

CONSEQUENCES OF LEGAL SCARCITY

Compact restrictions on water storage reduce the effectiveness of upstream reservoirs and consequently reduce the physical supply of surface water available in the Middle Rio Grande valley. Once one fully understands the compact restrictions, one key fact becomes apparent: It is only when compact delivery credits are exhausted (either by overuse or by relinquishment) that any adverse legal consequences arise from the compact. A comparison of the situation during the current drought with the situation during the drought of the 1950s and 1960s illustrates this point.

THE CURRENT DROUGHT

Elephant Butte Reservoir spilled in 1995, and Usable Water in Project Storage stayed between 1.5 and 2 million acre-feet until 2000, at which point it began a steady decline. The cause of this decline is straightforward: Rio Grande Project users, in accordance with project rules, continued to get a full delivery from Elephant Butte Reservoir despite declining inflows. Usable storage slipped below the Article VII storage restriction trigger level in August of 2002, and stayed below that limit until the spring of 2005. Since that time it has bounced above and below the limit. At the end of 2002 New Mexico had an accrued credit of 265,000 acre-feet, so the state was able to offset the restrictions by relinquishing 175,000 acre-feet of credits, which allowed Middle Rio Grande water users to store a like amount of water in upstream reservoirs, primarily El Vado Reservoir but also in the city of Santa Fe's reservoir, as seen in the figure on this page. That 175,000 acre-feet of water, along with San Juan–Chama water, is the water that has been used over the past three years to supplement the river when natural supplies were scarce. It provided water to Middle Rio Grande Conservancy District farmers, to the citizens of Santa Fe, and for the Bureau of Reclamation to meet river-flow targets for the silvery minnow. Contrast this outcome with what happened in the 1950s.

THE DROUGHT OF THE 1950s AND 1960s

Compact accounting began in January 1940. The following five years were relatively wet; Elephant Butte

Reservoir stayed above one million acre-feet from 1941 through 1945 (it spilled in 1942), but, during this time New Mexico steadily accrued a debit, which, by the end of 1945, had reached 150,000 acre-feet. The debit continued to increase, exceeding the 200,000 acre-foot limit set in Article VI during 1948 and reaching a maximum of 529,000 acre-feet in 1956. New Mexico entered the severe drought of 1950–1956 with a deficit that already exceeded the limit set in Article VI. Not surprisingly, Texas sued New Mexico before the U.S. Supreme Court in the fall term of 1951, but this suit was thrown out on a technicality in February 1957. During the period from 1948 through 1968 New Mexico was continuously in violation of Article VI requirements and was under Article VII restrictions approximately two-thirds of the time. These restrictions amplified the impact of that already-severe drought.

Obviously nature deals us cards over which we have no control, but New Mexico can decide how to play its hand. Nothing about coping with drought will be easy, but careful preparation will help prevent or mitigate the most severe consequences of drought.

STRATEGY FOR THE LONG TERM

A strategy sets out big, long-term goals. I suggest three such goals for New Mexico:

- ***Preserve stored water supplies.*** There is not much more to be said about this strategy—it is the instinct of water managers. Remember that stored water includes ground water. Since San Juan–Chama Project water is accounted outside the Rio Grande Compact, preserving those supplies for times of shortage and compact restriction is vital.

- ***Maintain an accrued compact credit.*** Maintaining a compact credit avoids any legal restrictions on the use of reservoirs or stored water and thus is an adjunct to the first element of the drought-coping strategy. Because relinquishments may be necessary to offset Article VII restrictions, the accrued credit should be large enough to maintain a credit, even if small, after a relinquishment.

- ***Develop contingency plans.*** In the event that catastrophe strikes, have a plan in place, even if it is only a framework for decision making. Contingency plans should be developed for events that are precedented but extremely rare. What constitutes "extremely rare" is a policy decision. Planning for ill-defined, unprecedented, or unforeseeable events should be done but falls outside the domain of drought. One example of an unprecedented event would be extensive wildfires that change the nature of the Rio Grande watershed in New Mexico and Colorado. The effects of climate change are nearly certain to occur, but exactly what those effects will be is ill-defined.

TACTICS FOR THE SHORT TERM

Tactics are the means of achieving strategic goals. In baseball, making outs is a strategy; throwing strikes is a tactic. I suggest three means to meet the strategic goals:

- ***Increase efficiency of use***. Increasing the efficiency of agricultural and municipal use preserves physical supplies, either in reservoirs or aquifers. Although the amount of water consumed by a given agricultural or municipal use (beneficial consumptive use) is a stubborn fact, the amount of water applied to that use can be reduced by increasing efficiency.

- ***Balance consumptive use against credit status.*** The amount of New Mexico's accrued credit reflects the degree to which the state has balanced consumptive use against its entitlement under the Rio Grande Compact. If the state wishes to increase its credit (or reduce its debit), it must reduce consumptive use by reducing beneficial use, by reducing evaporation (primarily from Elephant Butte Reservoir), or by reducing consumptive use from riparian vegetation.

- ***Balance credit status against project storage.*** Article VII restrictions can occur even when New Mexico has properly balanced its water use against its entitlement (the current drought is an example). When project storage is high, it is sufficient to maintain only a positive credit. As Project Storage decreases, the probability of Article VII restrictions increases, and the accrued credits should be increased accordingly.

  The Rio Grande Compact also provides that accrued credits are reduced by the amount of spills. As project storage increases, the probability of a spill increases, and the state may wish to increase the amount of beneficial use, increase the amount of stored water (including recharge of ground water) to the extent possible, or both.

TOOLS

Administration. New Mexico is a prior appropriation state. This principle, which is set out in the New Mexico Constitution, means that a person who first puts water to beneficial use (and does so properly according to New Mexico law) will forever have the right to use water before those who put water to use later. A succinct statement of the prior appropriation principle is “First in time, first in line.” Administration under the prior appropriation system is the big lever that the state possesses to balance beneficial consumptive use against New Mexico’s entitlement. Although water has been put to use in the Middle Rio Grande valley for hundreds of years, water rights in the valley have not yet been adjudicated. Adjudication is a process wherein a court defines, once and for all, the priority and the quantity of each water right in the valley. Until the Middle Rio Grande is adjudicated, an interim approach, such as Active Water Resource Management, will be required for administration. It is worth considering that, as onerous as it may be to have the state engineer administering water rights in the Middle Rio Grande, administration by the state is preferable to administration by a federal water master.

Water bank. Strict priority administration of water rights is not economically efficient. Water markets provide one means of increasing economic efficiency but, because the process of transferring a water right is costly, existing water markets favor permanent transfers. In one sense a water bank is simply a set of rules that facilitates temporary, short-term transfers of water (as opposed to permanent transfers of water rights). A water bank, properly formulated, could reduce transaction costs and thereby facilitate temporary transfers of water. This would improve both market efficiency and the long-term prospects for irrigated agriculture in the Middle Rio Grande valley.

River management. Riparian consumptive use and reservoir evaporation (90 percent of which occurs at Elephant Butte Reservoir) combine to make up more than half of all depletions in the Middle Rio Grande valley. Reducing these depletions will not come easily—some programs to eliminate non-native vegetation have not lived up to their promise, but even modest reductions, accruing over the long term, will substantially improve the state’s ability to maintain a compact credit.

Forecasting, statistics, and research. Good forecasts of water supply can improve water management decisions. Improved stream flow forecasts will become available, and targeted research can further improve forecasting in the Middle Rio Grande. Careful statistical analyses and modeling of historic and prehistoric (tree-ring reconstructions) stream flows can provide insight as to how to respond to a given forecast. Other fruitful areas for research are water markets, water banks, and approaches to reducing depletions from riparian vegetation and reservoir evaporation.

Information and education. Water management policies and practices must be transparent to all interested parties. As water management policies and practices evolve, it will be important to inform and educate all interested citizens to the facts and implications of those policies and practices.

A Killing "Cure"—Agricultural-to-Urban Water Transfers in the Middle Rio Grande Basin

Lisa Robert

In the summer of 2006 delegates from three adjacent water planning regions convened in Albuquerque to talk about the "gap" that exists between water supply and water demand in the central Rio Grande basin, and to address potential conflicts contained in their separate strategies for dealing with that shortfall. It was soon apparent that both the Jemez y Sangre and Middle Rio Grande planning regions had completed their state-mandated water plans in a hopeful vacuum: each assumed that agricultural water (upwards of 12,500 acres worth in the case of the Middle Rio Grande) could be acquired from somewhere downstream to help alleviate their respective insufficiencies.

For the most part, that "somewhere downstream" meant Socorro County, at the tail end of the Middle Rio Grande Conservancy District and just above Elephant Butte Reservoir, where, in terms of the interstate compact that apportions the river's annual flow, New Mexico ends and Texas begins. But planners in that bottommost region had a revelation for their neighbors to the north: "The idea of upstream regions coming to Socorro to transfer water is inconsistent with reality," said a Socorro/Sierra representative. "*We* have a deficit too. *There is no water to transfer*."

Yet the export of historic water rights from rural Socorro to swelling urban centers upriver has been underway for many years. Within the Middle Rio Grande Conservancy District's Socorro Division, water appurtenant to more than 1,800 acres of farmland—nearly 25 percent of the senior rights once in existence between Lemitar and San Marcial—have already been sold, generally to facilitate development in Valencia, Bernalillo, Sandoval, or Santa Fe Counties.

Photo Not Available Online

Current conditions in the Middle Rio Grande basin are testing the old assumption that water can be transferred from agricultural to urban uses without jeopardizing either the relationship between river and ground water, or the one between ecology and economy.

Agricultural water rights have also been transferred out of the valley north of Lemitar, and it is likely that well over 3,500 acres have been retired countywide. The costs of that loss may not be immediately apparent, but they are heavy, and they are certain.

Transfers are the mechanism by which water rights are moved from one category of use to another, and/or from one place of use to another within a stream system, in this case, the Middle Rio Grande basin. In the most common type of transfer, a surface water right is severed from the parcel of land it historically served and exchanged for the right to pump ground water in another part of the basin. This balancing act is necessary because (1) the surface water of the Rio Grande and ground water in adjacent aquifers is fundamentally one-and-the-same, and (2) the Rio Grande is a "fully appropriated" stream system, meaning there is no surplus to allocate to new uses. Retiring and transferring historic agricultural water rights offers the only ready source of supply for new municipal and industrial development. A transfer is therefore a reallocation of water, and by statute the state engineer is responsible for ensuring that a change in a right's point of diversion, or its place or purpose of use, will not impair another's water rights. In addition, the state is also mandated to consider possible impacts of the transfer on water conservation, and on "public welfare," although precisely what the latter means has yet to be determined. Notice of a proposed transfer must be posted in a newspaper of local, general circulation for three consecutive weeks, and the Office of the State Engineer may conduct a hearing on any subsequent protests.

But water transfers have not always been handled according to the foregoing rules. From the early 1970s to 1994, a policy known as dedication enabled an applicant to obtain a permit to appropriate ground water on the condition that senior water rights would eventually be retired to counter the effects of new pumping on the river. Agricultural lands from which the water would be transferred did not necessarily have to be identified; if they were identified, proof of the water right's validity was often nominal or entirely lacking; and no public notification process was required, meaning no protest of the transfer was possible. Worse, the requisite drying up of the transfer-from parcel was frequently deferred: Sellers were often allowed to continue irrigating until some future date, with no clear-cut method for ensuring that once the right was being fully exercised at the new location, water use would be terminated at the old location. In short, dedications evaded almost all of the legal requirements for transferring a water right.

The imprecise trail of middle basin water transfers is etched in pencil on a set of paper maps at the Office of the State Engineer. According to staff, the maps are accurate to within three weeks and thus comprise "the most complete" record available, yet they do not differentiate between dedications and formal transfers, and they do not indicate whether the transfer-from lands have actually been fallowed. Nor have all of these transactions been logged into WATERS, the state's GIS database, and data entry pertaining to the Middle Rio Grande has been temporarily halted. With no comprehensive inventory of water transfers, and no tally of "retired" parcels still being irrigated, it is virtually certain that present estimates of agricultural water rights in the mid-Rio Grande are erroneous. That miscalculation has the potential to affect every water right holder, every urban dweller, every resource agency, and every planning effort in the basin.

UNDERMINING THE FOUNDATIONS

Water law in New Mexico is based on priority. The state constitution and many historic treaties guarantee that the oldest appropriators of surface water—generally agricultural users—have seniority in time of shortage, and that newer uses will not be allowed to impair the exercise of older rights. Furthermore, the Rio Grande Compact unequivocally defines the amount of native water that can be consumed in the middle basin. But explosive population growth and development, environmental mandates, and the vagaries of climate change are stressing that finite supply. We are simply using more wet water than we receive, and we have been making up the difference with imported water (e.g., San Juan–Chama Project water) and ground water. Current calculations show a deficit of 40,000 acre-feet per year. In addition to that annual burden, the delayed consequences of past ground water pumping are just beginning to affect the surface flow of the river. The projected additional deficit due to ground water pumping is currently 71,000 acre-feet. Because the basin has not been adjudicated and the sum of its vested water rights is unknown, each new water use has the potential to intensify the regional deficit, impair senior water rights, and invite litigation. Uncertainty is inherent in every water transfer approved by the state engineer because such rulings may be reversed in a future adjudication. Likewise, a lawsuit prompted by compact debt, as occurred on the Pecos River in the 1980s, could cost New Mexico hundreds of millions and will without a doubt have to be paid in water, not dollars.

NEIGHBORHOOD TRAUMA

Water transfers reverberate throughout the community of origin, and the Socorro area, with its farm-based economy and public mandate to preserve agricultural tradition, is no exception. New Mexico acequias have long resisted water transfers on the basis of "third party effects," and those same arguments can be applied to any locale reliant on a fixed amount of irrigated land. As transfers occur, water conveyance system costs will be borne by fewer and fewer users, eventually threatening the practicality of delivery, and discouraging the cultivation of "marginal" lands. The loss of farm-associated revenue affects all local residents. According to Charles Howe, professor emeritus of economics at the University of Colorado-Boulder, and Christopher Goemans, a Ph.D. candidate in economics at the same institution, as agricultural acreage decreases, "activities linked to agriculture are negatively affected: Suppliers of agricultural inputs lose business, processors of agricultural outputs lose supply sources, financial institutions lose the demand for loans, etc." In human terms, those ripples reach far beyond the farmer who sells his water. Seed suppliers, equipment dealers, mechanics, field hands, 4-H kids, bankers, and bureaucrats will all feel the loss.

Agriculture forms the backbone of Socorro County's economy, but its total value is not reflected in crop census reports or income earned. Many Rio Grande valley farms are family-oriented, meaning those who raise the food also consume it. Given that reality, water transfers and the associated loss of agricultural land most certainly have the power to diminish local security and self-sufficiency. They also undermine the public welfare as defined by Socorro area residents, who have opted for rural living, not urban expansion, and who made the preservation of irrigated land a cornerstone of their regional water plan.

In addition to its agricultural riches, Socorro is home to several wildlife refuges and an increasing number of federal, state, and locally funded projects aimed at environmental restoration. Farmlands are integral to these programs because they provide a haven where diversity—tomorrow's saving grace—can flourish at little or no cost to the public. The attrition of agricultural land, as well as Socorro's position at the bottom of the water delivery system, jeopardizes restoration efforts already underway: The more water that is transferred out of the area and withdrawn upstream, the more difficult it becomes for the river and its proxy, the Middle Rio Grande Conservancy District, to transport sufficient flows to and through the Socorro reach.

Finally, agricultural water transfers facilitate "double and triple dipping," placing increased strain on an already-stretched resource. When a farm is sold with the intent of transferring its water to development outside the floodplain, the fallowed land is generally subdivided. Homes built on these properties are often served by domestic wells, ensuring that more water will now be used, some by new development outside the floodplain on either side of the river, and some by new houses in the valley. And of course those who purchase the former farmlands will want to water their acreage. To do so they might apply for an irrigation well, or they might drive one themselves without obtaining a permit, or they might pump more than they're entitled to from their non-metered domestic well, or they might reactivate an old ditch turnout and get water from the conservancy district. In every instance, the "fully appropriated" river is the source of supply, and is thus taxed with delivering several times the amount of the original surface right.

GROUND TRUTH AND PAPER

Throughout the West, and certainly along the populous Rio Grande, it has long been assumed that water for growth will come from agriculture. Implicit in that assumption is the belief that urban development is the highest and best use of Earth's most necessary resource. But is it?

Water transfers have consequences for the hydrologically dependent ecosystem that underpins agricultural and urban health alike. In recent years the creation of a regional water budget for planning purposes, substantial research into local river system dynamics on behalf of the bosque and the endangered silvery minnow, and an increasing ability to model the management of water in the basin have begun to reveal the crucial role played by irrigated land in the Rio Grande valley. Agricultural lands, in conjunction with the water delivery system of the Middle Rio Grande Conservancy District, function as a surrogate for the extensively altered river, helping to maintain the natural link between stream and ground water, giving surface flow access to its natural floodplain, and offering a form of aquifer recharge that is both practicable and economical. As this ecological role is undermined by the demise of irrigation, the entire system suffers a reduced capacity to deal with wet and dry extremes. What is being sacrificed is flexibility, perhaps *the* major key to surviving the uncertainties of global climate change.

Water reallocation will never produce the desired result of a balanced water budget. In shuffling promises, we hew to the path that created deficit in the first place. Transferring paper rights without understanding the wet-water price of such a philosophy endangers not just the so-called "place of origin," but the integrity and livability of the entire river basin.

Water in this desert place has the greatest value when it remains appurtenant to historic lands. There it retains standing under the law, embodies the very soul of New Mexico's traditional peoples, and performs a critical task in the health of the ecosystem. As diminishing oil reserves elevate the cost of transporting food and generating power, as the threat of terrorism counsels local independence, and as global corporations quietly buy up regional water supplies for commercial gain, we would be wise to safeguard the one irreplaceable asset that anchors us legally, defines us culturally, and sustains us environmentally.

I like to call dedications a "pump now, pay later" policy. Basically, you got to pump water out of storage and only acquire the water right when the flows in the *river began to diminish. To me it's sort of like selling short—eventually you have to pay the bill. My big question is where are you going to get the rights to cover all this pumping? I tried to get a handle on the extent of these dedications and we came up with two or three different values. I can tell you that the number is so large it's probably going to require the majority of agriculture in the middle valley to change its purpose of use.*

—Former State Engineer Tom Turney

A Tool for Floodplain Management along the Rio Grande

Matt Mitchell, *Rio Grande Agricultural Land Trust*
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There are a number of issues in the reach of the Rio Grande from San Acacia to San Marcial that threaten future river health and its human and non-human inhabitants. Non-native plants like salt cedar and Russian olive have choked the river channel, restricting high flows of water and limiting regeneration of native plants. These invasive species also pose an extreme fire threat to residents of the area. There is currently no zoning in the floodplain in this reach, and development in flood-prone areas is a potential threat to river management. Incising of the river has decreased the number of regenerative overbank flood events, and, as a result, the aging cottonwood/willow forest is not being replaced. Finally, the San Marcial railroad bridge, because of silt deposition, now has limited capacity to pass seasonal flows of water. Like development, this issue is a limiting factor for water managers upstream. If these issues are not addressed, the river system will continue to degrade.

This paper is a look back over the last fifteen years at activities dealing with floodplain management (or the lack thereof) in Socorro County below San Acacia Diversion Dam. During most of those years, Dick Kreiner was chief of the Reservoir Control Section of the Albuquerque District, U.S. Army Corps of Engineers, and responsible for overseeing flood-control operations at corps reservoirs. It was the corps' job to determine how much water could be released safely from upstream corps dams, and to develop and implement the appropriate operating criteria for day-to-day operations. If an individual had a problem with our operations, they would contact the Corps of Engineers and their situation would be evaluated.

This was the case in 1992, when the corps was working with the Bureau of Reclamation and other agencies to see if they could put a little water in the overbank areas along the Rio Grande for the benefit of the riparian community we call "the bosque." Around this time everyone was beginning to realize that the bosque within the levees was in need of periodic overbank flows to maintain the health of the riparian vegetation. Cochiti Dam, 50 miles north of Albuquerque, had been in operation since 1975 and had quite effectively controlled the high flood flows coming into the Middle Rio Grande valley. It also had cut off most of the sediment load the river was carrying. With the sediment cut off, the river began to scour a deeper channel, and overbank areas in the northern section of the Middle Rio Grande were becoming isolated. It was taking higher flows to wet overbank areas that used to get flooded before construction of Cochiti Dam. The southern sections of the Middle Rio Grande, from Isleta Pueblo to Elephant Butte Reservoir, have areas that flood and therefore have a healthier bosque.

In 1992, when word was sent out about higher flows coming down the Rio Grande to help the environment, an individual contacted the Bureau of Reclamation and said, "Hey, I'm down here in Bosquecito, and you're going to flood my home if you increase the flow in the Rio Grande." Sure enough, after a quick trip down to Bosquecito, there was this new house right along the bank of the river. There are more than 13,000 square miles of uncontrolled area below Cochiti Dam, most of it in the Rio Puerco and Rio Salado drainages. Who, in their right mind, would build a house next to the river with the potential for flooding being so high? As it turned out, the house was built during a dry year and was later sold to this individual. To make a long story short: A small dike was constructed around the house, and the higher test flows followed with no damage to the home.

These higher test flows were timed to mimic the historic high flows on the Rio Grande and designed to promote native cottonwood and willow establishment. A project on the Bosque del Apache National Wildlife Refuge in 1993 and 1994 showed that if higher flows were timed right, native trees could become established and out-compete salt cedar for space on the floodplain. Fourteen years after the test, the native trees established back then have formed a cottonwood forest that still keeps salt cedar out. These test flows and habitat restoration projects started a long series of activities to figure out how to keep this floodplain open for flood waters, how to promote more native plants (instead of salt cedar), and how to assist landowners with improvements on their land.

Most of the Rio Grande farther north in Valencia and Bernalillo Counties is confined by levees on both sides, and the levees pretty much keep out development. In Socorro County below San Acacia Diversion Dam the levee is only on the west side of the river. The east side of the river has large flood-prone areas of private property north of Bosque del Apache National Wildlife Refuge. Shortly after the higher flows of 1992 Army Corps of Engineers representatives briefed the Socorro County Commission about this situation and offered assistance to them if they wanted to pursue participation in the National Flood Insurance Program. The county commission was also advised that for the safety of their residents they might want to consider zoning the river corridor to prevent further development in the Rio Grande floodplain. They thanked the corps for their time and went on to the next item on the agenda. It was very obvious to the corps that there was no political will to zone private property along the river.

What followed was a very interesting series of discussions on how to preserve these flood-prone areas. Advisors from Bosque del Apache National Wildlife Refuge, the Corps of Engineers, and other agencies helped concerned local citizens come up with a potential solution, one that would keep the flood-prone portions of private lands on the east side free from development; would remove the salt cedar and replace it with native grasses, shrubs, and trees; and (most important) would keep it in private ownership. The first meeting of this informal group, which came to be known as the Floodplain Management Group, occurred on the first day of spring in 1999. At that meeting in Bosquecito, the agencies present and the Save our Bosque Task Force got the thumbs up to pursue a floodplain management and habitat restoration program based on the ideas listed above.

The reason there had not been a big problem with development along the east side of the river wasn't because people were afraid of being flooded; they were afraid of getting burned out. Most of this reach was infested with salt cedar, and fires periodically raced through the bosque and adjoining lands with a terrorizing affect on the residents. What if we found a way to remove and control the salt cedar for the landowner in exchange for a conservation easement that prohibits development on the portion of their land in the floodplain? To sweeten the deal, restoration of native plant species could be included to provide wildlife habitat and increase the monetary value of their open lands.

The Save Our Bosque Task Force, the Bosque Improvement Group, several land trust organizations, and the local private landowners worked together to get a working program started. The Rio Grande Agricultural Land Trust received funding from the Bosque Improvement Group to do outreach work with the goal of educating and informing landowners about conservation easements. The Save Our Bosque Task Force received funding from a number of federal, local, and non-profit organizations to complete a feasibility study and conceptual habitat restoration plan for the valley. Both of these documents were done by 2004. One strategy is that the value derived from the retiring of development rights through a conservation easement can be used by the landowners for the required match to obtain state and federal dollars for habitat restoration work in the floodplain. The land remains in private hands, and the landowner gets a long-term partner in the habitat restoration on their lands. After contacting most of the landowners in the area, eight families expressed an interest right away in enrolling in such a program. Many others took a positive but "wait and see" position. Fundraising by the Rio Grande Agricultural Land Trust and the Save Our Bosque Task Force continues, and some dollars have been received to pay for these preliminary projects. A North American Wetlands Conservation Act grant was obtained to fund the establishment of six easements, and habitat restoration dollars have been received through the U.S. Fish and Wildlife Service, with other potential sources contacted. Two of the landowners will be ready to finalize their conservation easements in early 2007, with the others to follow when funding for habitat restoration is made available.

It is important to point out that the priority of those working on this effort was to solve floodplain development problems at the local level. The adage "think globally, act locally" comes to mind. One ill-advised home built on the bank of the Rio Grande has the potential to alter flood-control operations at federal dams that protect nearly a half million people. It also has the potential to jeopardize operations that are striving to sustain and enhance thousands of acres of riparian wetlands, forests, and grasslands, and their associated wildlife communities. These periodic flood waters keep the river channel open and more able to handle flood water that might otherwise threaten the levee protecting farms and communities on the west side of the river.

In the context of the short history provided above, it can be said that there is really no comprehensive program for addressing floodplain management in the reach. Because of the extensive private land in and around the floodplain, workable solutions must begin at the local level to be successful. Unregulated runoff from the Rio Puerco and Rio Salado into the Rio Grande above San Acacia continues to be a major flooding threat to downstream residents.

The Save Our Bosque Task Force, the Rio Grande Agricultural Land Trust, and concerned citizens will continue to work toward solving these important problems for area residents and all New Mexicans, with the voluntary help of the landowners on the east side of the Rio Grande. These landowners have shown their respect and love for their lands and for the Rio Grande, and they will be the best stewards for the future.

Salt Cedar Control: Exotic Species in the San Acacia Reach

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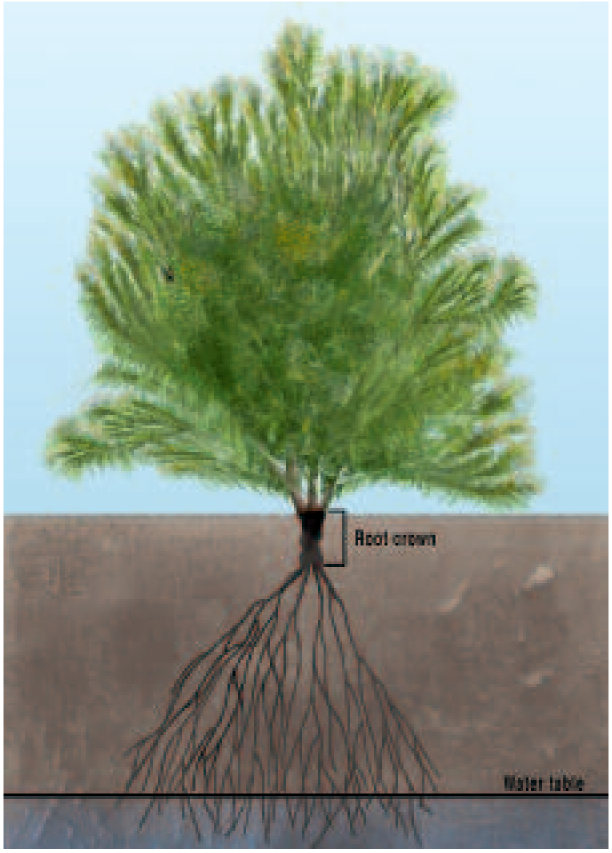
Although there are a number of exotic or invasive plants in the Middle Rio Grande, salt cedar is considered a risk to overall ecosystem health because it forms dense monotypic stands, poses a fire danger to adjacent plants, and has limited benefit to wildlife species. Salt cedar has infested widespread areas of the southwestern United States. In locations where salt cedar has proliferated, accounts of dried-up wetlands and saline soils are told. These plants are native primarily in Asia and the Middle East, so salt cedar is well adapted to our deserts' hot and dry climate. Even so, salt cedar responds to excess moisture with enhanced growth and water use. Due to alleged extravagant water use and observed extreme fire hazard of salt cedar thickets, restoration of the Rio Grande bosque through removal of salt cedar and other invasive vegetation is being relentlessly pursued.

Salt cedar, including several species of the genus *Tamarix*, is one of the most prolific plant species found in the San Acacia reach of the Middle Rio Grande. Infestations can be especially dense in this reach, where impenetrable monospecific stands are common. Downstream from the outflow of the Rios Puerco and Salado, summer flooding provides ideal conditions for germination of salt cedar's many seeds at a time when none of the native cottonwood and willow trees produces seeds. Once established, salt cedar has a further advantage in the San Acacia reach, where the areas of deep water table make it difficult to maintain vigorous native forests. Extraordinary variations in ground water levels are normal in the San Acacia reach, permitting salt cedar thickets to consume excessive amounts of water under some conditions. At the high density that some salt cedar stands reach—more than 6,000 plants per acre—water loss has been estimated in the range of 200 gallons per plant per year—or about three and a half acre-feet of water per acre of vegetation. Research has demonstrated that the water lost from salt cedar leaves can be one and a half acre-feet greater than water lost from an acre of water-conserving native vegetation. However, salt cedar infestations are notoriously difficult to remove effectively, and new growth from buried root crowns can actually consume more water than the salt cedars that were removed in the first place.

IN MONOTYPIC STANDS

Many salt cedar control techniques have been developed and applied in the Middle Rio Grande. Over the past twenty years, mechanical control on the Bosque del Apache National Wildlife Refuge and other locations has been done using bulldozers equipped with root plows or root rakes. This technique is used in areas of dense monotypic stands where other native vegetation will not be impacted. On the wildlife refuge, effective control is achieved when salt cedars are reduced by 99 percent. The last raking should occur in the hottest part of the summer to assure drying of the remaining exposed roots. This technique is not applicable in areas with a high ground water table or in other areas where heavy machinery can't operate.



Schematic of above-ground and below-ground structure of *Tamarix* species, commonly known as salt cedar.

Root plow attached to a D7 dozer, sheering root crowns of salt cedar at the Bosque del Apache NWR, after the above-ground part of plant has been removed.

In those areas, aerial herbicide application has been used for initial control, followed by a controlled burn or mulching of the standing dead tree limbs. Follow-up spraying, grazing, or mulching is always necessary to get close to 99 percent control.

IN MIXED STANDS

In areas with both salt cedar and native plants a gentler approach is necessary. Efforts underway to remove salt cedar from cottonwood forests focus on reducing the fire danger to the native trees and surrounding communities. The Save Our Bosque Task Force is a 501(c)3 non-profit organization formed to 1993 to work toward sustainable riparian areas in the San Acacia reach. The task force has taken the lead in establishing fuel breaks near communities and native forests. The work continues with larger projects planned for the east side of the river near the communities of Bosquecito, Pueblito, and San Pedro. Masticators, excavators, chain saws, mowers, herbicide, and goats have all been used in these mixed stands. And experimentation continues on salt cedar control techniques for unique situations. Whether in solid or mixed stands of salt cedar, there is a necessary follow-up treatment on the remaining live shoots. Current techniques include excavator root extraction, herbicide spot spraying, mowing, or grazing. These follow-up techniques have been tried in various places with differing success. Whether in dense or mixed stands of salt cedar, initial control is only the first step to long-term maintenance of these areas.

Other Prevalent Invasive Species in the San Acacia Reach

Field Bindweed
A creeping perennial that forms dense mats, has a deep root system, and produces seeds with a long viability (up to 50 years). It occurs in most every yard and field in the floodplain in Socorro County. Control can be through herbicide treatment or continual disking.

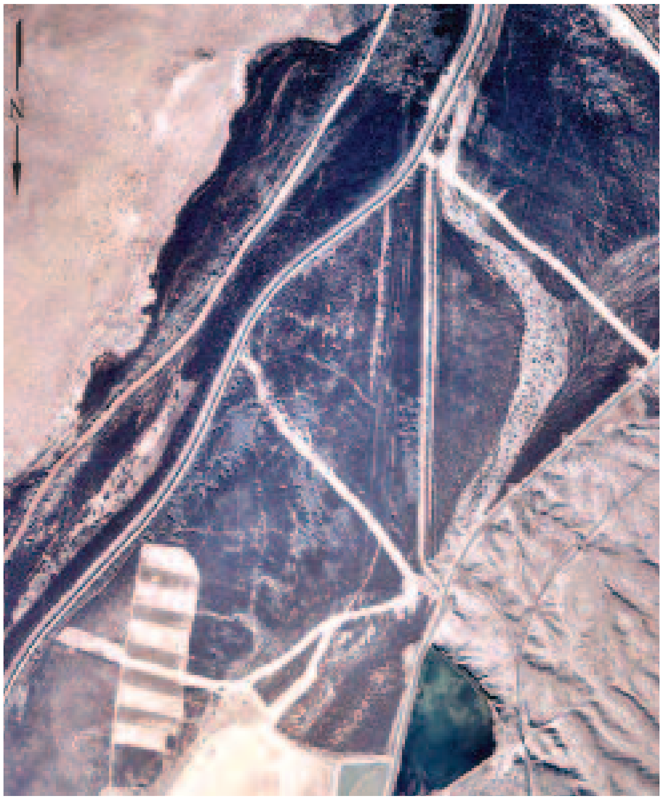
Camelthorn
A spiny, creeping perennial with greenish stems and slender yellow tipped spines. It has a spreading root system, and is found on ditchbanks, roads, and pastures. It is just coming into Socorro County and has been found in the historic floodplain in San Antonio. Control can be through hand digging and herbicide treatment.

Russian Knapweed
A creeping perennial that forms large colonies, spreading from root buds. It is 3 to 4 feet tall, has deep roots (up to 25 feet), and lavender flowers. It occurs in both the historic and active floodplain of the Rio Grande in Socorro County. Control is usually through herbicide treatment.

Perennial Pepperweed
A creeping perennial that forms large colonies and can reach 6 feet tall. The largest concentration in New Mexico occurs on the Rio Grande. It spreads easily and now occurs on ditch banks, in fields, and along the river. It can grow under native and invasive trees and is hard to control, requiring multiple treatments with herbicide.

Russian Olive
An ornamental tree that grows to 30 feet; has red berries in fall, and large spines. This tree was brought into the area as a fast-growing windbreak and bank stabilizer. It has become established on the river mainly through seed dispersal by birds. It forms dense stands along the river, armoring the banks and limiting other native plant growth.

Other invasive or non-native trees found on the Middle Rio Grande include Siberian elm, tree of heaven, and mulberry. All of these invasive plants compete with native plants for room to grow. They can be effectively controlled if follow-up rehabilitation includes establishment of competitive native plants and continual monitoring for re-infestation. Important long-term controls for invasive plants should include addressing seed sources from adjacent areas or upstream on the main stem and on tributaries that feed into the river. Care must be taken when using seed or mulch mixes so that invasive seeds are not included in the mix.



This 1999 aerial photo shows the dense salt cedar at the south end of the Bosque del Apache NWR. The south boundary is at the top of the picture. Dark vegetation is monotypic stands of salt cedar, lighter vegetation is cottonwood forest. Panels visible in the lower left of the photo are part of a salt cedar control experiment area, testing mechanical removal and chemical treatments of salt cedar.

FOLLOWING SALT CEDAR CONTROL

Planting or promoting the natural regeneration of native vegetation, including trees, shrubs, and grasses, is critical for long-term management of these floodplain lands. The native plants can compete quite effectively with salt cedar and other undesirable plants once established. Techniques for this part of effective salt cedar management are being developed. Research into appropriate grass species for different soil textures and ground water levels is in progress. Information on native tree and shrub planting requirements and analysis of the resulting quality of planted areas is also being gathered. As an example, when salt cedar, sometimes used by the endangered southwestern willow flycatcher in this and other river systems, is removed, willow plantings can provide new and improved habitat. Experiments to improve cost effectiveness in establishing willows and enhancing flycatcher habitat are underway on three private and public lands habitat restoration projects this year.

There is an expanding body of knowledge of how to effectively control salt cedar and a growing interest in doing so. But achieving the goal of removing salt cedar and other invasive species such as Russian olive for the purpose of reduced fire hazard, improved biological diversity, or water salvage remains a challenge. Monitoring a site both before and following restoration provides independent evaluation of the pitfalls and successes of a restoration project. For example, the University of New Mexico has conducted continuous monitoring of an understory restoration project in Albuquerque's South Valley, where salt cedar and Russian olive shoots were mechanically removed, and the remaining stumps were treated with herbicide. At this site plant water use was reduced by 21 percent, or 0.85 acre-feet per acre restored, during the first year following restoration. Even though the Russian olive at the site re-sprouted immediately following herbicide application, growth was insufficient to affect the water budget. However, salt cedar re-sprouted from the remaining stumps at the outset of the second year, negating further water savings and illustrating the importance of return visits in removing salt cedar in a manner that succeeds in restoration goals. Without monitoring this site, we are destined to continue spending money on insufficient and ineffective restoration attempts.

This is a 2003 photo of the same area after aerial spraying; lines have been cut for a topographic survey of the area. The view is to the east toward areas that have had the dead (chemically treated) salt cedar burned off.

This photo of the same area was taken in December 2006 after the Marcial Fire (June 2006) and following root plowing and root raking. The focus area is in the center left of the photo. Note the cleared areas to the south and the changes visible since the 1999 photo.

LESSONS LEARNED

Some things that salt cedar control and/or habitat restoration practitioners have learned are that each site is unique in terms of the suite of control and restoration techniques that will work. This is because sites have unique ground water/surface water connection, ground water levels, soil chemistry, soil texture, and flooding potential. Each site is also unique in terms of the existing water use by vegetation and the potential water savings or cost with restoration. Many research projects have measured site specific water use in both native and invasive forests, and the accuracy of those measurements is improving. We generalize the water use by different plant communities at this point, make assumptions, and at some point will have to decide, when we have reached the accuracy we need, just what we can expect to achieve in such a diverse system. The Save Our Bosque Task Force looked at the potential for water savings in the San Acacia reach from the perspective of change in plant density, assuming there would be a change in “leaf area index,” one measure that has been correlated with water use in recent research experiments. Using the change in plant density through habitat restoration, and with the assumption that as you move away from the river channel and gain elevation, you are slowly disconnecting from the river and the shallow ground water of the river basin, a water savings by the natural system was achieved. Improved biological diversity and decreased fire danger from dense vegetation were also achieved. What is most important to remember is that these improvements to the system happen over a long period of time. Diverse native riparian wildlife habitat is only sustainable if the river is allowed to exist as a dynamic part of the system.

Private landowners from the San Acacia reach villages are very interested in salt cedar control and habitat restoration projects that result in fire protection for their homes and improved wildlife habitat on their lands. They also are aware of the need to control salt cedar over the long term so their lands don’t become salt cedar thickets once again.

There are four requirements for success in long-term effective salt cedar control and habitat restoration:

- Select replacement native vegetation appropriate to the site’s flooding potential, ground water level, and soil conditions
- Understand that healthy river functions—sediment movement, occasional flooding to increase decomposition of plants, maintaining an open channel, and ground water recharge—are necessary for cottonwoods and willows to survive and thrive next to the river
- Support landowners for occasional follow-up salt cedar control treatments
- Prioritize, coordinate, and collaborate with other agencies and entities on large-scale, long-term projects to assure funding and information sharing

In this way we work together toward the goals of reduced fire danger, improved biological diversity, and efficient water use by an improved natural system.

To meet these four requirements for success, good working relationships have been developed among private landowners, land managers, federal and state government agencies, non-government agencies, and the Save Our Bosque Task Force in the San Acacia reach. Over the past 13 years, the task force has completed a feasibility study and a conceptual habitat restoration plan for the valley. This plan provides important information on flooding potential, existing vegetation, and possible restoration techniques. From this planning effort the Save Our Bosque Task Force and other interested stakeholders have developed the “Floodplain Management Program” for land protection and habitat restoration. This program seeks long-term solutions to issues of floodplain encroachment, protecting and enhancing private property values, and improving water management flexibility through the San Acacia reach. The Floodplain Management Program is underway and has attracted the interest of a number of landowners.

The Endangered Species Act and the San Acacia Reach

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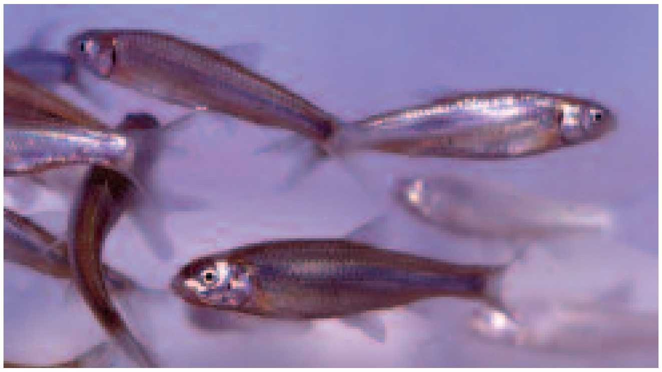
New Mexico's longest river, the Rio Grande, supports three of the state's "listed" species: the endangered Rio Grande silvery minnow, the Southwestern willow flycatcher, and the threatened bald eagle. Each of these species has unique habitat requirements found within the Rio Grande ecosystem. The silvery minnow and flycatcher, in particular, have been affected by past large-scale water operations and management. Both have benefited from recent collaborative efforts to protect existing populations, restore habitat, and manage river flows throughout the system. The San Acacia reach holds special challenges and opportunities for these species and over the long term may be the key to their recovery.

RIO GRANDE SILVERY MINNOW

The Rio Grande silvery minnow historically occupied close to 2,400 river miles in New Mexico and Texas. It was found in the Rio Grande from Española down through Texas to the Gulf of Mexico. It also occupied the Pecos River, from Santa Rosa downstream to its confluence with the Rio Grande in Texas.



The Rio Grande silvery minnow.

Currently the silvery minnow is found only in what is known as the Middle Rio Grande of New Mexico, a 174-mile stretch of river that runs from Cochiti Dam to the headwaters of Elephant Butte Reservoir, about 7 percent of its former range. The silvery minnow was listed as endangered in 1994.

High-quality habitat for the silvery minnow includes stream margins, side channels, and off-channel pools where water velocities are low. Stream reaches dominated by straight, narrow, incised channels with rapid flows typically are not occupied by silvery minnow. The species is a pelagic (open water) spawner that produces 3,000 to 6,000 eggs during a single spawning event. Adults spawn in late spring and early summer (May to June) in association with spring runoff. Eggs and larvae remain in the drift for three to five days.

Approximately three days after hatching, the larvae move to low-velocity habitats where food (mainly phytoplankton and zooplankton—microscopic plants and animals) is abundant and predators are scarce. Higher flows that move water out of the channel and into the floodplain help transport eggs and larvae to nursery habitat. In the winter, silvery minnows congregate in deep, slower waters near debris piles and submerged vegetation.

SOUTHWESTERN WILLOW FLYCATCHER

The southwestern willow flycatcher is a small songbird that winters in the neotropics (southern Mexico to South America) and breeds in the southwestern United States. It was listed as endangered in 1995, largely due to habitat loss and degradation. The highest concentrations of flycatchers in New Mexico are on the Gila River near the town of Cliff, and on the Rio Grande in Socorro County at the headwaters of Elephant Butte Reservoir.

The flycatcher nests in dense riparian areas along rivers, streams, or other wetlands. Nest sites are dominated by dense growths of willows, seepwillow, or other shrubs and medium-sized trees. There may be an overstory of cottonwood, tamarisk, or other large trees, but this is not always the case. In some areas, the flycatcher will nest in habitats dominated by tamarisk and Russian olive. One of the most important characteristics of the habitat appears to be the presence of dense vegetation, usually throughout all vegetation layers. Almost all flycatcher breeding habitats are within proximity (less than 20 yards) of water or very saturated soil. This water may be in the form of large rivers, smaller streams, springs, or marshes. At some sites, surface water is present early in the nesting

Southwestern willow flycatcher.

season, but the ground gradually dries up as the season progresses. Ultimately, the breeding site must have a water table high enough to support riparian vegetation.

THE RIO GRANDE PAST AND PRESENT

Before widespread human influence the Rio Grande was a wide, shallow, perennially flowing river with a shifting sand bottom. The river freely migrated across a wide floodplain. This floodplain was composed of many secondary channels, backwaters, lakes, and marshes. Floods maintained a high water table that provided some open water during very dry times. Such an environment was ideal for supporting silvery minnows and flycatchers.

The Rio Grande, however, has undergone considerable change in the last 150 years, and it is no longer the highly dynamic system it once was. Dams and irrigation diversions are operated primarily to reduce flooding and to supply water for irrigation. In many areas, channel incision has reduced overbank flow onto the floodplain. In the San Acacia reach drying is common. These factors represent threats to the long-term survival of the silvery minnow and flycatcher on the Rio Grande. But recent efforts to restore the Rio Grande and protect these endangered species are reducing threats and improving the silvery minnow and flycatcher's chances of recovery.

THE ENDANGERED SPECIES ACT COLLABORATIVE PROGRAM AND THE 2003 BIOLOGICAL OPINION

The Middle Rio Grande is being protected and restored through the efforts of many organizations and entities. Of particular prominence, both due to its responsibility and membership, is the Middle Rio Grande Endangered Species Act Collaborative Program. Created in 2000 as the "ESA Workgroup" in response to litigation and conflict over water/endangered species issues, the Collaborative Program now includes more than twenty active signatories including state and federal agencies, local and tribal governments, universities, and farming organizations. The program has three interrelated goals:

- To meet the requirements of the Endangered Species Act
- Provide water to those who hold valid water rights
- Comply with the obligations of the multi-state Rio Grande Compact

One of the main responsibilities of the program is to help implement the U.S. Fish & Wildlife Service's programmatic 2003 Biological Opinion on water operations issued to the Bureau of Reclamation and the Corps of Engineers under Section 7 of the ESA. This opinion evaluates the effects of all contractual water deliveries and other operations of the river including river maintenance and flood control (the proposed action), identifies strategies to alleviate jeopardy to listed species, and provides "incidental take" coverage. All federal and non-federal parties that divert water from Cochiti Dam to Elephant Butte Reservoir are afforded ESA coverage, including incidental take, under the 2003 Biological Opinion. This overarching legal protection provides a strong incentive for all partners to assist in meeting the requirements of the 2003 Biological Opinion, and for participation in the Collaborative Program.

The 2003 Biological Opinion determined that proposed diversions and river management actions were likely to cause jeopardy to the silvery minnow and flycatcher, and provided a reasonable and prudent alternative with multiple elements. The alternative requires:

- Coordinated water operations and minimum river flows
- Habitat restoration
- Population management
- Improvements to water quality

The Collaborative Program receives, on average, $10 million annually, through a congressional earmark, to implement these activities. Cost sharing provided by the State of New Mexico has been critical to demonstrating to Congress the program's multi-agency representation and to ensure a non-federal voice in decision making. Through cooperative management, the Collaborative Program has been successful in meeting flow requirements for the past four years and in restoring several hundred acres of habitat. By augmenting flows and with two years of record-high snowmelt (2004 and 2005), silvery minnow populations are returning to prelisting levels. Flycatcher populations have also been stabilized, and its habitat is being created throughout the Rio Grande.

Constructed embayment in the Albuquerque reach of the Rio Grande, designed to provide slow water, nursery habitat for the Rio Grande silvery minnow.

THE SAN ACACIA REACH

The San Acacia reach presents unique challenges and opportunities for silvery minnow and flycatcher protection. This reach encompasses 56 of the 174 river miles within the Middle Rio Grande. This represents 32 percent of the occupied range of the silvery minnow and some of the highest quality habitat found in the system. The largest concentration of flycatchers is also found in this reach. Of the 174 flycatcher territories found on the Rio Grande in 2005, 110 were located south of San Acacia diversion dam. Currently the best and largest contiguous habitat area for flycatchers along the Rio Grande is south of San Acacia near San Marcial.

Aerial view of the Rio Grande in the Bosque del Apache National Wildlife Refuge, showing mature cottonwood bosque, wetland habitats, and some channel braiding, all indicative of dynamic river processes within a connected floodplain.

Generally, habitat on the Rio Grande for both species tends to increase in quality from north to south. Although poor quality (high velocity, channelized) areas and good quality (sand bars, back channels, slackwater) habitat can be found in all reaches, the San Acacia reach exhibits the greatest degree of river/floodplain connectivity and channel complexity. It also contains the largest number of riverine wetlands. What makes this reach challenging, however, is its tendency to dry due predominantly to diversions, ground water pumping, and river drainage to the Low Flow Conveyance Channel.

The Low Flow Conveyance Channel follows the river for 75 miles. It was designed in part to expedite delivery of water to Elephant Butte Reservoir during low flow conditions, as required by the Rio Grande Compact. Water was diverted to the Low Flow Conveyance Channel from the Rio Grande from 1959 to 1985. Because the Low Flow Conveyance Channel is at a lower elevation than the river bed, there is seepage from the river to the Low Flow Conveyance Channel. This causes a significant loss of surface flows in the river channel.

The San Acacia reach has experienced significant drying almost every summer since the mid-1990s. This strains resident and migrant populations of fish and wildlife and challenges efforts to maintain and restore habitat. Low flows and a lack of consistent overbank flooding can negatively affect riparian vegetation and increase fire danger. Not only does this vegetation rely on a high water table, but flood flows remove flammable understory debris, maintain a safe channel capacity, and create space for young plants to grow.

THE RIO GRANDE OF TOMORROW

To succeed in protecting the endangered species of the Rio Grande, we must begin by returning to the Rio Grande its ability to renew itself and its habitats.

Multiple restoration techniques are available to increase river dynamics and complexity. Most of these encourage lateral river movement within the confines of flood control levees, increase river/floodplain connectivity, and create habitats that may be inundated at lower flood flows. Such techniques include lowering banklines, modifying in-channel islands, reconnecting isolated channels, and building embayments. Broad application of these techniques can increase the amount of habitat available for both the silvery minnow and flycatcher. If strategically located, suitable habitat may be supported even during times of lower flows. Significant potential exists for such habitat improvements in the San Acacia reach. Due to a lack of levees on the east side and an already high degree of floodplain connectivity, many areas within this reach may be easily reconnected to the riverbed.

OPPORTUNITIES TO PARTICIPATE

Multiple opportunities exist for those interested in participating in endangered species habitat restoration, monitoring, and research. The Collaborative Program provides funds each year for projects and activities throughout its program area on the Rio Grande (http://www.fws.gov/mrgesacp/). Funding for projects that benefit listed and non-listed species is available through:

- The Middle Rio Grande Bosque Initiative (http://www.fws.gov/southwest/mrgbi/)

- The Partners for Fish and Wildlife Program (http://www.fws.gov/ifw2es/newmexico/)

- Tribal Wildlife and Tribal Landowner Incentive Programs and other grant opportunities may be found at http://www.fws.gov/grants/

Suggested Reading

Middle Rio Grande Ecosystem Bosque Biological Management Plan; the first decade—a review and update, Robert, L., Aurora Publishing, Albuquerque, New Mexico, 2005.

Habitat restoration plan for the Middle Rio Grande, Tetra Tech EM Inc., 2004.

Biological and conference opinions on the effects of actions associated with the programmatic biological assessment of Bureau of Reclamation's Water and River Maintenance Operations, Army Corps of Engineers' flood control operation, and related non-federal actions on the Middle Rio Grande, New Mexico, March 17, plus amendments, U.S. Fish and Wildlife Service, 2003.

A Few Definitions

Listed Species—Under the Endangered Species Act (ESA), species may be listed as threatened or endangered. Endangered means a species is in danger of extinction throughout all or a significant part of its range—the geographic area a species is known to or believed to occupy. Threatened means a species is likely to become endangered within the foreseeable future throughout all or a significant part of its range. The purpose of the ESA is to protect and recover these imperiled species and the ecosystems upon which they depend. The U.S. Fish and Wildlife Service is the agency principally responsible for administering the ESA.

Section 7 Consultation—Section 7 of the ESA requires federal agencies to use their legal authorities to promote the conservation purposes of the law. This section also requires federal agencies to consult with the U.S. Fish and Wildlife Service to ensure that actions they authorize, fund, or carry out will not jeopardize listed species. The consulting agency then receives a "biological opinion" on the proposed action. In the relatively few cases where the U.S. Fish and Wildlife Service determines that the proposed action will jeopardize the species, they must offer "reasonable and prudent alternatives" about how the proposed action could be modified to avoid jeopardy. It is very rare to withdraw or terminate projects because of jeopardy to a listed species

Take—The ESA makes it unlawful for a person to take a listed animal without a permit. Take is defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or attempt to engage in any such conduct." Through regulations, the term "harm" is defined as "an act which actually kills or injures wildlife. Such an act may include significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering." River drying that strands fish or kills trees that ESA-listed birds use, could be considered take under the ESA.

Incidental Take Statement—Through Section 7 consultation, the U.S. Fish and Wildlife Service provides federal agencies with an incidental take statement that identifies the amount of take reasonably expected to occur due to the proposed action. This amount of take is considered lawful provided agencies comply with reasonable and prudent measures (determined by the service and issued in the biological opinion) to minimize take.

Opportunities for Long-Term Bosque Preservation in the San Acacia Reach

Gina Dello Russo, *Bosque del Apache National Wildlife Refuge*

The Rio Grande through New Mexico has been an oasis to settlers for many centuries. It has also drawn wildlife to its abundance of food and shelter within a harsh desert environment. We hope it will survive to do both long into the future. The river is now at a cross roads. Will it survive continuing urban growth along its banks? Will it survive changes in climate? Will the humans presently living along its course recognize the importance of the river in replenishing ground water supplies, assuring wildlife abundance through bosque preservation, and contributing to human health and recreation?

The term bosque as used here includes not only the wooded areas adjacent to the river but all of the plants and animals that live along and in the river, and the dynamics of the river itself. One doesn't exist without the other. Bosque preservation ultimately will include changing the current dense strip of trees, both native and invasive, to a patchwork or mosaic of grasslands, wetlands, shrublands, and forests that we see only in glimpses nowadays. Preservation will require maintaining some of the river processes that will help us design and maintain this mosaic. And finally, preservation will require coordination to ensure that our work is both economically and ecologically efficient.

WHAT ARE THE BENEFITS OF LONG-TERM BOSQUE PRESERVATION?

The benefits of bosque preservation include the creation and maintenance of a habitat mosaic with periodic floodplain flooding. They include reduced fire danger in wildlife habitat and adjacent to private residences. This is accomplished through increased decomposition following flooding, by the active removal of dense invasive forests, and with the maintenance of strategic fire breaks.

It has been shown that the removal of dense stands of salt cedar, followed by the establishment and maintenance of the native grasslands and open forests, results in a reduction of water use by the natural system. The bosque's more efficient use of water makes it easier to maintain the connectivity between open water and shallow ground water, and thus to maintain important habitat areas for endangered species and to reduce losses through evapotranspiration.

Removal of dense salt cedar as part of bosque preservation also assists with water and sediment management. High flows that can spread across a wide floodplain are less likely to endanger the flood-control levee on the west side of the river. Sediment deposition across this wider floodplain during flooding also slows down channel aggradation. Sediment deposition and movement is very important to the plants and animals along this sand-bed river system. These sediments carry nutrients and lay down the seed bed for the establishment of native plants on the floodplain. River flows that are high enough to scour vegetation off sand bars keep the river channel open, increasing the safe channel capacity through the San Acacia reach.

Land values increase when dense stands of invasive trees are removed from private property. A feasibility study completed in 2001 showed that lands with native forests and grasslands were three times as valuable as those with dense salt cedar. Many landowners have voiced their preference for improved native wildlife habitat on their properties.

BOSQUE PRESERVATION IN THE SAN ACACIA REACH TODAY

The communities in the San Acacia reach are making progress toward long-term bosque preservation. The Save Our Bosque Task Force, a diverse group of federal, state, and local government agencies, private landowners, and concerned citizens, has been working together since the early 1990s on issues of public use and recreation, floodplain encroachment, improved biological diversity, endangered species habitat improvement, water use by the natural system, wildfire danger, and invasive species control. Most important, they've done this with the involvement of private landowners and entities from the local area. They have evaluated the potential for bosque preservation in this reach through a feasibility study, planning efforts, and work on a reach-wide monitoring and adaptive management program. These programs provide important information about changes to the river and floodplain. Partnerships with local and regional universities are strong, with much of the research occurring on the Bosque del Apache and Sevilleta National Wildlife Refuges. This research is improving our understanding of bosque water use, fuels reduction, salt cedar control, and habitat restoration techniques.

Adaptive Management

Farmers, developers, industries, other states, salt cedar thickets, the silvery minnow, and even the relentless New Mexico sun all demand their share of Rio Grande water. How should we "manage" these demands so that each gets the appropriate amount? Who decides this, and on what basis? What happens when things change? To date, Rio Grande management has been criticized for not learning from mistakes, for not recognizing research results and new technologies, and for its inflexibility toward new approaches. It has been criticized for not adapting to changing environmental conditions and social needs. Adaptive management can address these issues and provide a structured process that integrates science and allows the flexibility to explore new options, avoid gridlock, and collectively move forward to solutions.

Adaptive management can be defined as an integrated, multidisciplinary approach for confronting uncertainty. It is a philosophy that is used when developing a plan to address environmental and ecological issues. It states that a roadmap should be developed for how to manage, for example, all uses of water in the Rio Grande. All stakeholders should be involved, actions should be taken based on the best science and information currently available, research should be conducted to evaluate success and explore new options, changes should be made to the plan that accommodate the new research, and implementation should continue. Then the cycle is repeated as an open-ended process. It is adaptive because it acknowledges that managed resources will always change as a result of human intervention, surprises are inevitable, and new uncertainties will emerge. It requires that we look at problems in holistic ways and work toward long-term solutions. Adaptive management states that decisions and policies are not merely ends, but means to probe alternatives and understanding in anticipation of future changes and unexpected outcomes. Middle Rio Grande stakeholders are beginning to explore, contemplate, and develop adaptive management strategies on this river system to the benefit of the environment, water managers, and communities.

For more information, visit the Collaborative Adaptive Management Network at www.adaptivemanagement.net.

The wildlife habitats of the bosque in the San Acacia reach are more diverse than in other reaches of the Rio Grande, and they remain relatively healthy, even in these times of limited water supply and changes in water management. Why? Because this reach retains critical physical processes, including occasional floodplain flooding, sediment movement and deposition, and ground water connectivity. The connectivity between the river and floodplain is greatest in this reach of the Middle Rio Grande in terms of continuous river miles. Moderate discharges on the river (3,000 to 7,000 cfs) simulate the flood pulses that scour sand bars, keeping the river channel open, establishing new vegetation on the floodplain, and

The Rio Grande in flood in 1979, looking east across the floodplain at the Bosque del Apache National Wildlife Refuge. Occasional flooding on the river maintains healthy cottonwoods and willows, recharges the shallow ground water aquifer in the valley, and removes vegetation from the river channel so that high water passes safely.

providing diverse aquatic habitat. Efforts are underway to quantify the ecological benefits of flood pulses in terms of flood control, water delivery, and habitat diversity, based on the high spring flows of 2005. However, if flooding occurs at the wrong time of year, it supports the spread of invasive species and promotes increased water use. Summer floods are inevitable, for they come from monsoonal rains on large tributary watersheds or from localized heavy rains. If a reach of river is dominated by flashy summer floods, it will favor salt cedar; if it has both occasional spring floods that establish native plants and flashy summer floods, the native plants will have the edge.

Programs such as the Save Our Bosque Task Force Habitat Restoration Program, the Socorro Soil and Water Conservation District's Invasive Species Control Program, and the Socorro County Wildfire Protection

Program are well established and provide habitat enhancement assistance. These programs also offer technical resources to landowners and managers for continued maintenance of enhanced bosque areas. Since 1999 the Save Our Bosque Task Force has hosted a number of informal meetings for private landowners, government agency staff, and interested citizens, providing opportunities to understand and discuss important bosque issues.

HOW CAN WE CONTINUE TO WORK TOWARD BOSQUE PRESERVATION?

If we are to achieve balance among water users and retain the natural beauty, diversity, and benefits of the river, we need to devote our attention to three broad areas:

Improved Information

- We need to develop models that look at the ecological costs and benefits to changes on the river, including water availability and management, infrastructure, changes in ground water levels, and sediment movement. Modeling efforts from the water management agencies have improved our ability to predict water delivery and movement under different river flow and diversion scenarios. A ground water model is being developed for the San Acacia reach and other reaches of the Middle Rio Grande. But no modeling currently exists to determine the changes to plants along the river as a result of changes in water management or availability. Changes to plants in turn affect the wildlife populations that depend on those plants. Ecological models of the Middle Rio Grande including the San Acacia reach are being developed to improve what we know about the flexibility of the plants and animals along this river. They are needed to answer questions such as: How much drying can occur before stresses result in a die back of existing cottonwoods, willows, and wetlands? What ground water connections are required to sustain a healthy, diverse bosque? What magnitude and frequency of flows are required to maintain the bosque we have today, and to enhance and sustain the bosque into the future? These models will help us understand how much bosque preservation is provided by river flows and how much we, the stakeholders, will need to manage.
- We need to implement monitoring programs that track improvements, and we need to focus on research that will address improved techniques, knowledge, and cost-efficiency of efforts on the ground.
- We need to identify opportunities that will support and increase the river's connection to its floodplain.
- We need to identify opportunities that will provide occasional flood pulses onto that floodplain. Our decision-making ability is limited without tools to predict the plant and animal responses to changing river flow patterns. And long-term sustainability of the bosque ecosystem will require a thorough evaluation of how improved river function and bosque preservation can benefit water management in the future.

Screwbean mesquite grassland at the Bosque del Apache National Wildlife Refuge. These open areas benefit wildlife such as deer and turkey and have high soil salinity levels and dense clay lenses. Such areas would have been found all along the river in the past. If restored, these areas will serve as natural fire breaks on the floodplain.

ACTIVE RESOURCE MANAGEMENT

Active resource management on the Middle Rio Grande would couple water management programs to the other resource programs along the Middle Rio Grande more closely so that, where possible, water management is benefiting other resources. These other resources include healthy riparian areas on the active floodplain, an open floodplain to safely carry high flows without endangering structures, balanced availability of water for recreation on all reaches of the Middle Rio Grande, and infrastructure that provides protection to the valley but allows for long-term sustainability of these other resources. Active resource management requires that water management agencies communicate more effectively with other resource managers and land owners. Specifically:

- We need to support programs that offer landowners alternatives to building houses in flood-prone areas of valley, especially east of the river where no flood control levee exists.
- Where possible, we need to allow the river to occupy more of its floodplain. The current infrastructure of the San Acacia reach was completed in the 1950s. The flood control levees in the San Acacia reach are constructed of unconsolidated spoil material. In many parts of the reach, it is difficult to keep the river flowing because of the ground water gradient to lower-lying lands, the Low Flow Conveyance Channel, and riverside drains. Invasive species are choking the river channel and making it difficult for the river to carry moderate to high flows. Now would be a good time to look at infrastructure changes and improvements that would benefit both economic and ecological aspects of the system for the long term. The federal government is looking at opportunities to widen the floodplain to allow the river more room to work and to provide levee protection. Two areas being considered for improved river/floodplain connectivity are in the Bosque del Apache National Wildlife Refuge and the Tiffany basin.
- We need to support programs that provide landowners with incentives to maintain habitat areas free of fuel buildup and invasive species. The Save Our Bosque Task Force and other interested parties have been developing a program of voluntary conservation easements that, coupled with habitat enhancement on private lands, provide protection from floodplain encroachment, improve biological diversity, and increase land values. This allows periodic high flows for the benefit of water delivery and the bosque.
- We need to provide venues where landowners and land managers can communicate their concerns and ideas for protecting their lands.

Restored wetland feature at the Bosque del Apache National Wildlife Refuge. Constructed ditches, drains, and sleughs deliver water to managed wetlands but also benefit waterfowl and other wading birds. Dense willow stands adjacent to these areas add to wildlife habitat diversity.

IMPROVED COORDINATION

Many different agencies and organizations are involved in efforts toward long-term bosque preservation in the San Acacia reach. And we are making progress here. We need to coordinate those efforts more closely to maximize their effectiveness. Although the specific goals of these different efforts vary, there are common threads: controlling invasive plants; improving forest, scrubland, and grassland health; providing for wildlife and human use; and decreasing the local fire danger. We need to work together more closely on our efforts at habitat enhancement, which include monitoring programs, the timing of on-the-ground projects, and sharing the lessons learned.

Many funding sources are available for certain aspects of bosque preservation, but often these funds go unused. There may be restrictions on how those funds can be used, and annual funding cycles are not always productive. But often the lack of coordination between those working toward habitat enhancement is an issue, as well. Effective salt cedar control and native plant establishment can take a number of years. Those working on bosque enhancement have certainly become well-versed in the different requirements for funding sources, matches, schedules, and restrictions. Coordinated funding sources that allow for comprehensive project implementation would really improve our chances at long-term bosque preservation. We need to review the efficacy of projects funded under existing funding sources, and identify what is missing from these funding sources that would allow for successful completion and maintenance of ongoing habitat enhancement projects.

Some other specific areas where we need to improve coordination of our efforts include:

- Developing programs that provide long-term resources for necessary maintenance of improved habitat areas
- Developing agency partnerships to address key issues:

  –Controlling and preventing infestations of invasive weeds

  –Offering incentives for land managers and owners to participate in programs that protect and benefit the bosque

  –Increasing awareness of the value of the bosque

  –Building partnerships that are committed to long-term bosque preservation

  –Monitoring our progress toward greater bio logical diversity, floodplain protection, fire protection, invasive species control, efficient use of water for the natural system, and endangered species habitat improvement

We must balance river water use with the other water uses in the valley along the Middle Rio Grande. Current local and regional planning efforts must look at what potential water use would be needed to sustain a healthy bosque into the future, and at ways to conserve water for other uses. With a better understanding of the river's water needs, people along the river will be able to make informed decisions about preserving this part of the community. Any program for promoting water balance through management will have to provide venues where landowners and land managers can communicate their concerns and ideas and work toward solutions. I am hopeful that we can make informed decisions that will allow our bosque to continue to thrive, nourishing future generations of people and wildlife.

How Science Can Provide Pathways to Solutions—The Technical Toolbox

Susan Kelly, *Utton Transboundary Resources Center, University of New Mexico School of Law*
Geoff Klise, *Water Resource Specialist*

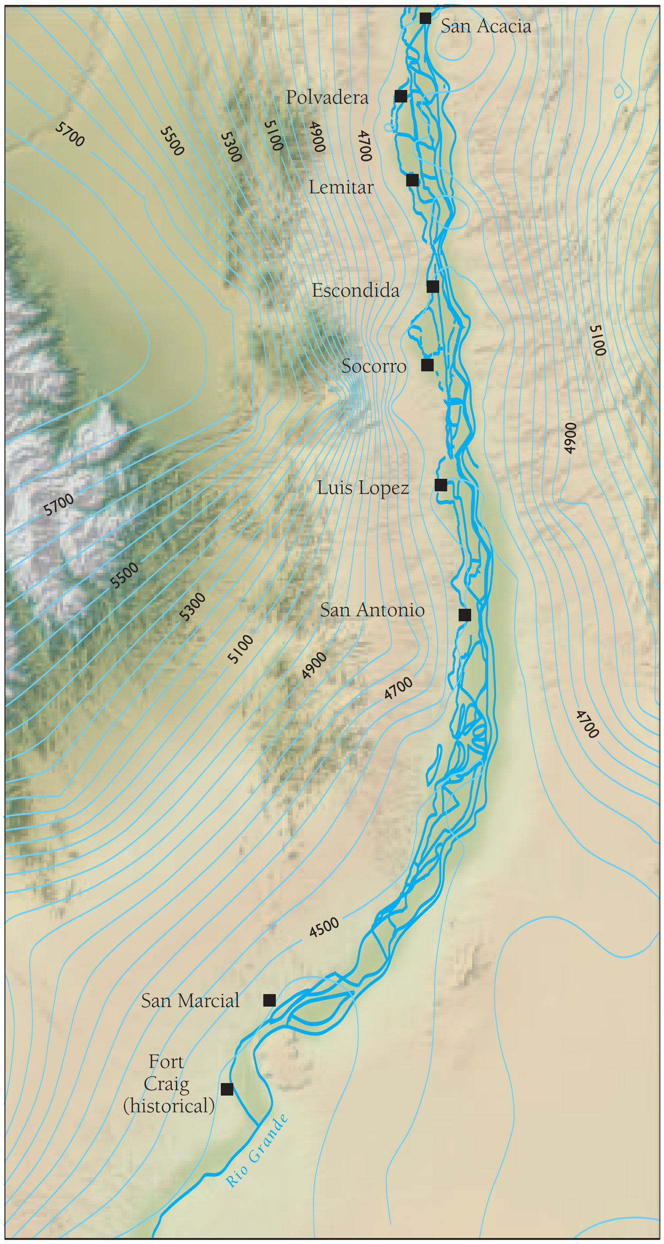
Policy makers and decision makers often rely upon scientists to provide answers to some of the most pressing problems they face. Scientists have a number of tools at their disposal to do this, including the whole array of technical tools we call "models." Models are generally complex computer programs that deal with real data in an effort to simulate the behavior of natural systems, taking into account an array of variables, from basic physical data—the length and shape of a stream bed, for instance—to complex and often unpredictable variables like rainfall, climate, and future water use. All of this is done in an effort to predict and gage the hypothetical effects of various scenarios so we can understand the impacts of the decisions we make, and chart a course for a future we wish to see.

To address water supply issues in the San Acacia reach, hydrologists and water resource planners use regional models that address the broader Upper Rio Grande watershed in combination with models that look specifically at hydrology in the San Acacia reach. These dynamic modeling tools help us understand the workings of the natural hydrologic system, the riparian ecosystem, and the human impacts on water supply in this region. Understanding these complex relationships, and trying to predict how they will interact in the future, is the objective of modeling. This paper offers a look at some of the more significant efforts at developing and using hydrologic models and other technical tools applicable to the San Acacia reach.

HYDROLOGIC MODELING—THE UPPER RIO GRANDE WATER OPERATIONS MODEL

The basic tool for water supply planning in the Middle Rio Grande is the Upper Rio Grande Water Operations Model, or URGWOM. This is a multi-agency water operations model designed to help manage the accounting and operational decision making of many agencies. It is currently used on the Rio Grande throughout New Mexico to simulate water storage and delivery operations, to model flood control operations, and to provide a basis for long-range planning from thousands of pieces of information on water use, climate, evaporative losses at reservoirs, seepage to

Map of the Upper Rio Grande Basin, the area where water operations can be simulated in the Upper Rio Grande Water Operations Model (URGWOM).



Map of simulated water table, using linked surface water and ground water model for Socorro and San Marcial Basins between San Acacia and Elephant Butte Reservoir. To understand the general water movement in the shallow aquifer, monitoring wells in the study area were used to develop a water table map. In general, ground water moves from east to west to the center of the basin, where it discharges to the surface water. The water table map also indicates a strong north-south hydraulic gradient.

ground water, snowmelt runoff, and other hydrologic variables. It provided forty years of flow and storage projections for the Upper Rio Grande Water Operations Review and Draft Environmental Impact Statement, which evaluated alternatives for future water management.

URGWOM was developed by the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation, with significant participation by the U.S. Geological Survey and the state of New Mexico. It continues to be refined and improved, and our ability to use it for planning purposes in conjunction with other modeling tools is expanding. To model actions involving changes in how federal agencies operate the reservoirs on the Rio Grande and requiring changes in legislative authority, we would have to revise our current model. The Interstate Stream Commission is leading work by the URGWOM tech team that will allow the model to simulate the interaction between the shallow and the deep water aquifers. This revision will allow the model to depict more accurately how water is routed between Cochiti and Elephant Butte.

THE MIDDLE RIO GRAND WATER SUPPLY STUDY

The Middle Rio Grande Water Supply Study, Phase 3, conducted by S.S. Papadopulos & Associates in 2004, evaluated the regional water supply. The conjunctive ground water–surface water supply available to the Middle Rio Grande region, under the constraints of the Rio Grande Compact, is characterized under a range of conditions. The study evaluates the probability of compliance with the Rio Grande Compact, assuming projected demand through year 2040. The study relied on demand projections as developed in the Jemez y Sangre, Middle Rio Grande, and Socorro–Sierra regional water plans, and assumes implementation of management actions suggested by the plans. The study concluded that the Middle Rio Grande region would likely have a severe water deficit in 2040 without implementing the water plans, and that even with full implementation (a highly optimistic future scenario) there would remain a projected deficit.

SAN ACACIA SURFACE WATER/GROUND WATER MODEL

The San Acacia Surface Water/Ground Water Model was created to improve our understanding of the complex interactions between the surface and subsurface hydrologic systems in the Socorro and San Marcial basins. Developed by the Interstate Stream Commission, the model simulates the Rio Grande channel, the Low Flow Conveyance Channel (LFCC), the main irrigation canals and drains, and the alluvial and Santa Fe Group aquifers in the reach from San

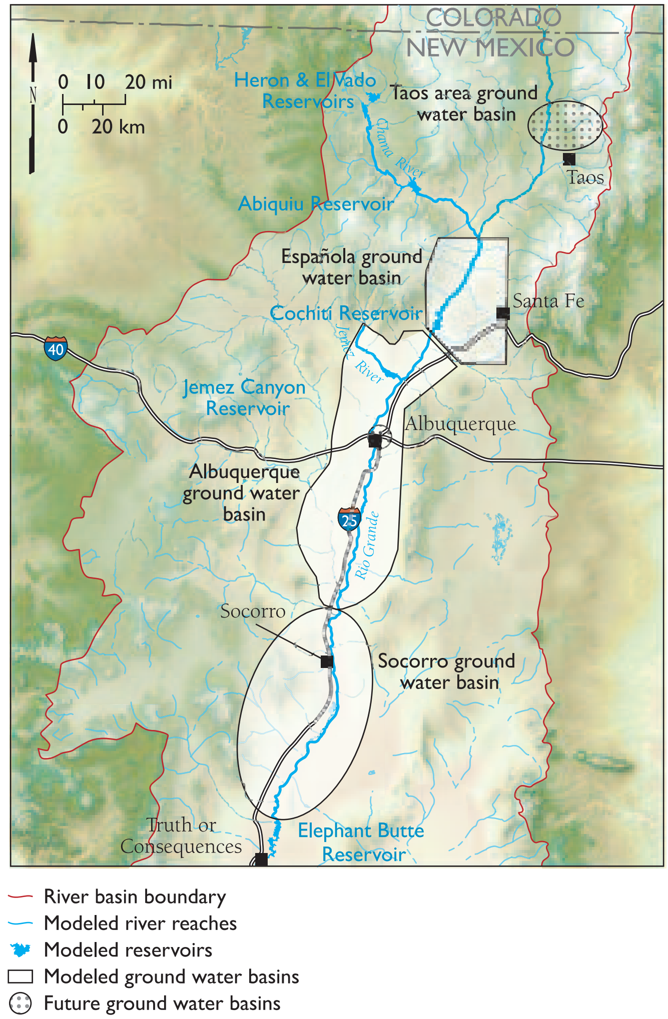
Acacia to Elephant Butte. The purpose of the model is to evaluate potential system-wide depletions that may result from various actions, including operation of the LFCC, implementation of habitat restoration projects, and modifications (both natural and man-made) of the river channel. A recent update uses a high-resolution telescopic model that focuses on the riparian area from the river west to the LFCC to predict the effects of habitat restoration between Highway 380 and San Acacia on water supply.

COOPERATIVE MODELING IN THE MIDDLE RIO GRANDE

In the late 1990s regional water-planning efforts in the Middle Rio Grande were initiated by the Middle Rio Grande Water Assembly and the Mid Region Council of Governments. Sandia National Laboratories was contracted to develop a decision support tool to conceptualize how water is used in the region, to understand the complexities of the system, and to recognize tradeoffs and consequences with different conservation approaches. Although the planning was done above the San Acacia reach, the model looks at flows into Elephant Butte for the purposes of meeting the obligations of the Rio Grande Compact with Texas. The model represents complex interactions and feedback between physical and social systems. Sandia National Lab included components such as surface water, ground water, population, and demands from urban use, agriculture, evaporation, and environmental uses.

The model was created in a collaborative fashion, with members of the planning groups giving input to the modeling team. The Utton Center at the University of New Mexico provided facilitation to the model development team, acting as an impartial party to manage the meetings and foster communication. Because of the number and variety of participants, facilitation was needed to organize input and bring closure to the discussion of issues. The simulation results gave the planning group a preferred scenario that was used as the platform for finishing the regional water plan. Local governments in the region, including the cities of Albuquerque, Rio Rancho, and other municipalities, adopted the plan as the "guidance document" for their own planning efforts. Implementation of the plan, as with the Socorro–Sierra and the other regional plans mandated by the state of New Mexico, will require significant action on the part of many entities in the region.

Building on the success of the Middle Rio Grande



Integrated Hydrologic Modeling, an interactive planning tool for the Upper Rio Grande.

Water Assembly collaboration, Sandia National Laboratory is currently working with the URGWOM team to develop a complementary system dynamics model, based on the original Middle Rio Grande planning model. Integration of both models will improve management of water resources in the Rio Grande basin because of the ability to model the interaction between surface and ground water. Decision makers can use the model to understand the impacts of reservoir operations on the river and ground water systems.

In the San Acacia reach, there are many different modeling efforts underway that ultimately will be included in a unified water operations model for the Rio Grande. Watershed models are being developed by New Mexico Tech; the Rio Salado will be the first. A mortality model for the Rio Grande silvery minnow was built to try and understand how water quality affects

What Is Modeling?

In general terms, a model is a simplified representation of a complex real system. Because it is very expensive and time consuming to test the effects of management changes on a real hydrologic system, we take a shortcut and develop a model of each aspect of the system that we need to understand. Each model must be complex enough to include all the phenomena and structures that are important to us, but not so complex as to be mathematically insolvable.

The structure of a model is developed using basic information about the system we are simulating—for example, the length and width of the streambed for surface water models, and the nature of the rocks that make up the aquifer system for ground water models. The system is divided up into grid cells or nodes, each of which represents a small chunk of the system.

Input to a ground water or surface water model includes the inflow of water (aquifer recharge in the case of a ground water model, and flow from upstream and from tributaries to a surface water model), as well as diversion of water from the system. A model uses basic equations that govern the flow and conservation of water (like Darcy's Law) to keep track of this water and move it along at the proper velocity, from cell to cell or node to node, and determine its fate.

A ground water model calculates what the water levels in the aquifers will be, and how much ground water will discharge into adjacent streams A surface water model calculates how much river water makes it downstream, how fast it gets there, and in the case of complex, rule-based models, how much is diverted from reservoirs for irrigation, how much is released from the reservoir into the stream bed, and how much remains in reservoir storage.

—Excerpted from an article by Peggy Barroll et al. on hydraulic modeling, which appeared in our 2003 Decision-Makers Field Guide, *Water Resources of the Lower Pecos Region, New Mexico*.

silvery minnow populations. In addition, data from the Interstate Stream Commission's San Acacia Surface Water/Ground Water Model will also be included. Because actions taken upstream affect water flows in the San Acacia reach, integrating water operations with Sandia's model will provide decision makers with a comprehensive set of tools that can help decipher the relationships between physical and social systems on the river between San Acacia and Caballo Reservoir.

SOCORRO–SIERRA REGIONAL WATER PLAN

The Socorro Soil and Water Conservation District (SWCD) is a government subdivision of the State of New Mexico very active at helping to direct funding and education from a variety of sources to those at the local level within the San Acacia reach. The SWCD was designated as the fiscal agent for writing the Socorro–Sierra Regional Water Plan. (The San Acacia reach lies within this planning region.) The Interstate Stream Commission accepted the regional plan in 2004 as the guiding document for planning efforts in Socorro and Sierra Counties. Prepared by Daniel B. Stephens & Associates, in cooperation with a wide variety of professionals and interested citizens, the plan contains a wealth of information on the region's projected demand for water, assesses ground water and surface water supplies, and evaluates alternative future scenarios for balancing supply and demand. There is still much work to be done to implement the three regional plans between Otowi and Elephant Butte and to reconcile their recommendations. There are conflicts among them, particularly concerning the transfer of water rights from agriculture to urban uses.

EVAPOTRANSPIRATION MODELING

Evapotranspiration is one of the most significant depletions on the river; therefore, tools to model evapotranspiration are critical. The ET Toolbox, a modeling tool developed by the U.S. Bureau of Reclamation, is the evapotranspiration model for the Middle Rio Grande. The primary purpose of the ET Toolbox is to estimate daily rainfall and water depletions (both agricultural and riparian) and open water evaporation within specific reaches. For operational and management purposes, the ET Toolbox provides products by river reach and by Middle Rio Grande Conservancy District (MRGCD) division to show various consumptive use requirements. These daily values can be used by URGWOM.

A high density evapotranspiration network, with real-time state-of-the-art instrumentation and modeling integrated with real-time remote imagery, is being developed as a collaborative project between the University of New Mexico, New Mexico State University, and New Mexico Tech in a project known as EPSCoR. The hydrology component of EPSCoR will result in coupling and extending models for climate and hydrologic predictions and increasing the connectivity between ground-based and satellite-based data. The main objective is to extend and integrate a network of telemetered instruments that provide ground-based measurements of evapotranspiration in different ecosystems (riparian, upland, and agricultural). The primary product will be high frequency, high resolution evapotranspiration maps for the Rio Grande watershed between Cochiti Reservoir and the Mesilla Valley. Data products will be prepared and distributed via the Internet in a form accessible to researchers, managers, and water users.

DECISION SUPPORT SYSTEM FOR THE SOCORRO DIVISION

The Middle Rio Grande Endangered Species Act Collaborative Program is a multi-agency group of stakeholders trying to address in a cooperative manner science, habitat, and water supply issues for endangered species. Together with the Interstate Stream Commission they funded development of an effective rotational water delivery system for the Belen Division of the MRGCD in FY 2003. In FY 2004 the decision support tool was extended to the Socorro Division. Through work accomplished by Colorado State University and S. S. Papadopulos & Associates, a scheduled, rotational water delivery system for irrigators was designed. This replaced the continuous, on-demand delivery of the past. The rotational delivery system has resulted in significant reductions in water diversion in the Belen and Socorro Divisions of the MRGCD. There is a need to improve the model and its data sets, including validation of assumed values of irrigation efficiency, soil moisture depletion, and the extent of conveyance losses in delivery channels. The assumptions need to be compared to field conditions, and the return flow functions need improvement.

The MRGCD has actively embraced the rotational delivery system. The new operational system, combined with other improvements such as new flow meters on all diversions and delivery canals, automated water control gates on diversion dams and canals, limited lining of canals, and other improvements to the water conveyance system, has allowed the MRGCD to reduce depletions by 47 percent since 1996. In spite of severe drought conditions that have drastically reduced upstream storage of water during this time period, MRGCD has been able to provide an adequate supply of water to farmers throughout the district. This has also helped the MRGCD and other water managers keep enough water in the Rio Grande to protect the endangered silvery minnow and southwestern willow flycatcher and thus avoid threatened legal impediments.

GEOGRAPHIC INFORMATION SYSTEM AND REMOTE SENSING DATA

Operating on the University of New Mexico campus in Albuquerque, the Earth Data Analysis Center (EDAC) houses an extensive repository of Geographic Information System (GIS) data for New Mexico. The data can be downloaded by anyone and viewed with either standard commercial software or open source software. The clearinghouse includes data on general boundaries, roads, cities, topography, climate, geology, soils, elevation, water resources, aerial photographs, remote sensing, and population.

Because these data cover the entire state of New Mexico, specific information regarding the San Acacia reach can be extracted. Besides the statewide coverage, there are some datasets that are specific to the San Acacia reach, such as detailed land use inventories, trends, and vegetation maps. These data are constantly updated and represent the best collection of publicly available GIS data that can be used by decision makers in the San Acacia reach.

In 2003 NASA funded a center at the University of New Mexico devoted to acquiring real-time remote sensing data. The Center for Rapid Environmental Assessment and Terrain Evaluation (CREATE) uses existing satellites and a new ground station to acquire and process data in a very short amount of time. In addition, the data are available at much higher resolution than other remote sensing products. These data can be used in decision support systems to help understand evapotranspiration rates, for snowpack analysis, fire condition, vegetation growth, and landscape changes. In the San Acacia reach, the CREATE group has been supporting the evapotranspiration work being conducted as part of the EPSCoR program.

ECOSYSTEM RESEARCH

Located in the San Acacia reach, the Sevilleta National Wildlife Refuge's Long Term Ecological Research Center (LTER) has been conducting research on how climate change can impact ecosystems. Sevilleta is unique in that many biotic zones intersect within the refuge; the area can thus provide sensitive indicators for environmental response to climate change. Recent research projects have looked at the impact of climate change on vegetation, the response of vegetation to prescribed burns and cattle grazing, and evaporation and transpiration in uplands and riparian areas near the Rio Grande.

Sevilleta houses a large "spatial database" for both

GIS and remote sensing data that have been collected as part of the research conducted at the LTER. Some of the data are from publicly available sites and clipped into the LTER boundaries. All of the research conducted at Sevilleta is within the San Acacia reach, although some projects have locations both inside and outside Sevilleta, such as the evapotranspiration research conducted by EPSCoR.

The San Acacia reach has many sophisticated tools and models available to provide guidance on our water future: water for future human use, water for agriculture, water to meet the terms of the Rio Grande Compact and a treaty with Mexico, and water for the ecosystem. Models and studies are continually being refined, updated, and improved as better data are obtained—but the basic tools are in place. The extreme variability of water supply on a year-to-year basis, and the inherent difficulty in predicting variability in the future, make "certainty" a challenging target.

Models and planning tools can provide information to help policy makers make the most informed decisions. The hardest work remains in the arena of public policy. Obtaining the legal mechanisms to administer water rights above San Acacia is essential to achieving long-term sustainability in the San Acacia reach. It is critical that the three regional plans in the areas that affect the water supply in the San Acacia reach be consistent in both recommendations and implementation. Allowing scientists to use the models and propose options to managers and policy makers without being unduly constrained by political issues is the best hope for arriving at sustainable solutions.

Suggested Reading

For a hands-on look at one hydrologic model, the Sandia National Laboratories Middle Rio Grande Cooperative Model (2005), go to http://nmh2o.sandia.gov/ExTrainSD/SDWelcome.asp

The Socorro Soil and Water Conservation District Regional Water Plan is available at http://www.socorroswcd.com Click on the link that says Regional Water Plan for information on projected water supply and demand in the region.

For more information about the basin and the San Acacia reach hydrology, visit the U.S. Army Corps of Engineers at http://www.spa.usace.army.mil/urgwom

For detailed information about the Middle Rio Grande water supply and demand issues, have a look at the S. S. Papadopulos & Associates' Middle Rio Grande Water Supply Study, Phase 3, available at http://www.ose.state.nm.us/isc_planning_mrgwss.html