Infrastructure and Management of the Middle Rio Grande

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Many entities are involved in water management in the Middle Rio Grande valley from Cochiti to Elephant Butte Reservoir. These entities own and operate various infrastructure in the Middle Rio Grande valley that are highly interconnected and ultimately affect water management of the Rio Grande. This paper describes major hydrologic aspects of the Middle Rio Grande valley, including water management activities of the U.S. Bureau of Reclamation, major infrastructure of the Middle Rio Grande Project (including the Low Flow Conveyance Channel), and focusing on issues downstream of San Acacia Diversion Dam. Although other entities such as municipalities have significant water management responsibilities in the Middle Rio Grande valley, they will not be addressed in this paper.

The Middle Rio Grande Conservancy District, a political subdivision of the state of New Mexico, was formed in the 1920s as a conglomeration of a number of acequias (community irrigation ditches) and the six pueblos of the Middle Rio Grande valley. In 1950 Congress authorized the Middle Rio Grande Project to stabilize and improve the economy of the Middle Rio Grande valley by rehabilitation of the Middle Rio Grande District facilities and by controlling sedimentation and flooding on the Rio Grande. The U.S. Bureau of Reclamation and the Corps of Engineers jointly planned the development of the project. In the Middle Rio Grande valley, the Bureau of Reclamation undertook rehabilitation of project irrigation and drainage works and channel realignment, and the Corps of Engineers was responsible for flood protection.

MIDDLE RIO GRANDE VALLEY INFRASTRUCTURE

The Middle Rio Grande Project irrigation distribution and drainage system begins just below Cochiti Dam and extends to Elephant Butte Reservoir, 174 miles when the reservoir is at maximum capacity. The project is capable of supplying irrigation water for as many as 90,000 acres within the Middle Rio Grande valley including water for the Pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta.

The Middle Rio Grande Conservancy District (MRGCD) consists of four divisions: Cochiti, Albuquerque, Belen, and Socorro, serving irrigated lands within the Middle Rio Grande valley from Cochiti Dam to the Bosque del Apache National Wildlife Refuge. The four divisions are served by Middle Rio Grande Project facilities, which consist of the floodway and three diversion dams, more than 780 miles of canals and laterals, and almost 400 miles of drains. Users are served by direct diversions from the Rio Grande and from internal project flows such as drain returns. These irrigation facilities are operated and maintained by MRGCD.

COCHITI DIVISION

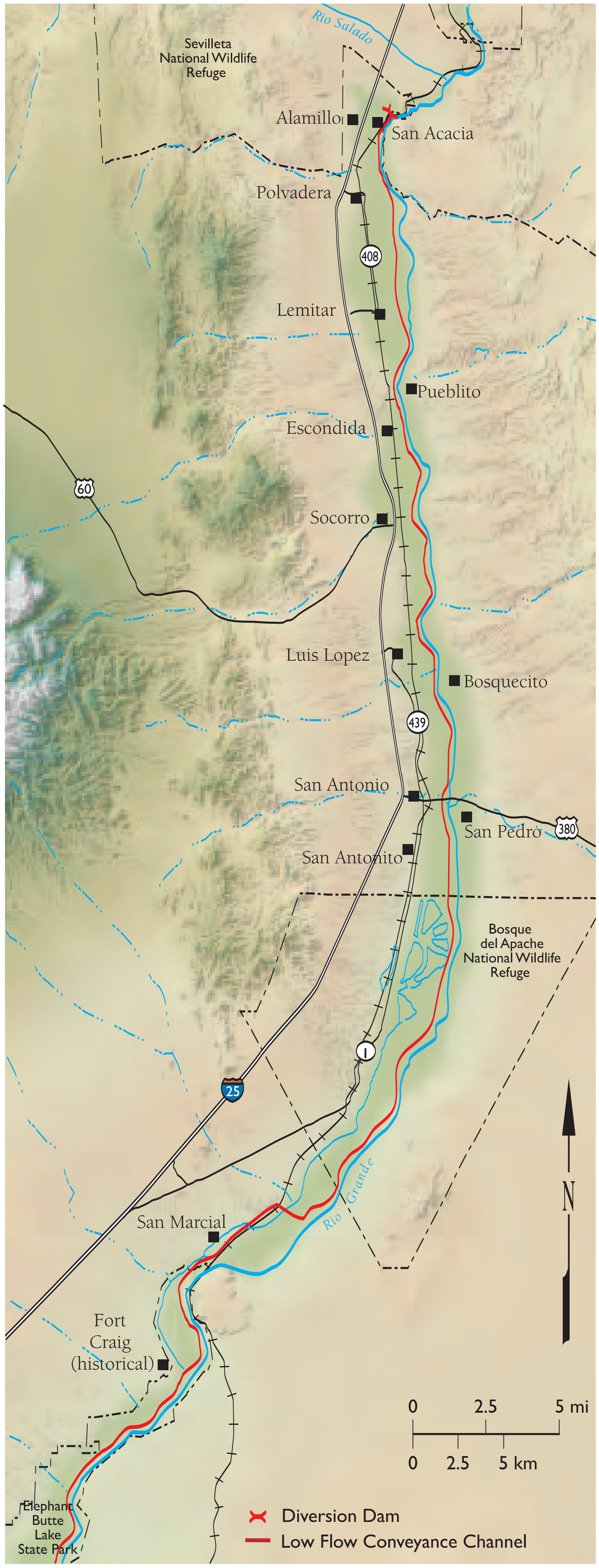
Project diversions from the Rio Grande begin at Cochiti Dam, through two canal headings that serve the Cochiti Division. The Cochiti East Side Main and Sile Main canals deliver water to irrigators on both sides of the Rio Grande. Galisteo Creek and Tonque Arroyo, both east side tributaries, join the Rio Grande between Cochiti Dam and Angostura Diversion Dam. Diversions within the Cochiti Division primarily serve the Pueblos of Cochiti, Santo Domingo, San Felipe, and Santa Ana and the communities of Pena Blanca and Sile.

ALBUQUERQUE DIVISION

Angostura Diversion Dam, a concrete diversion dam, takes water from the Rio Grande to serve the Albuquerque Division of MRGCD. The Rio Grande from Angostura Diversion Dam to Isleta Pueblo is influenced by many factors including contributions from the Jemez River, which flows into the Rio Grande just downstream of Angostura Diversion Dam, municipalities adjacent to the river, and MRGCD operations. The city of Albuquerque waste water return flows and soon-to-be-completed drinking water diversion from the Rio Grande are within this reach. The Albuquerque Division of MRGCD serves the Pueblos of Sandia, Santa Ana, and Isleta, as well as non-Indian users in Bernalillo, Corrales, and Albuquerque.

BELEN DIVISION

The Belen Division of MRGCD diverts water from the Rio Grande at Isleta Diversion Dam, a concrete diver-



sion dam on Isleta Pueblo. The Rio Puerco and the Rio Salado enter the Rio Grande from the west side 42 and 51 miles respectively below Isleta Diversion Dam. These tributaries are a significant source of heavy sediment-laden flows to the Rio Grande, particularly from summer monsoon events and can be a major source of irrigation water to Socorro Division farmers when upstream supplies are limited. Delivery and drainage for the east side of the river ends in this reach where the Lower San Juan Riverside Drain outfalls to the river about three miles upstream of the confluence with the Rio Salado. The Belen Division serves Isleta Pueblo, several New Mexico Department of Game and Fish refuges, the Sevilleta National Wildlife Refuge, and irrigators in several communities including Bosque Farms, Los Lunas, Los Chaves, and Belen.

SOCORRO DIVISION

About 55 miles downstream of Isleta Diversion Dam, the final Rio Grande diversion for MRGCD is the San Acacia Diversion Dam, a concrete diversion dam that serves the Socorro Division. The Socorro Division also relies on flows from several sources within the project systems, including the Unit 7 Drain, supplied by surface water and ground water return flows from the Belen Division, and direct diversions from the Low Flow Conveyance Channel. The Socorro Division serves users in the Socorro area, and the U.S. Fish and Wildlife Service Bosque del Apache National Wildlife Refuge.

SAN ACACIA DIVERSION DAM TO ELEPHANT BUTTE RESERVOIR

As of October 2006 it was approximately 78 river miles from the San Acacia Diversion Dam to the Elephant Butte Reservoir pool. This distance varies depending on the elevation of Elephant Butte Reservoir. When Elephant Butte Reservoir is at maximum capacity, it is about 54 river miles from San Acacia Diversion Dam to the reservoir pool. There are no major tributaries to the Rio Grande below San Acacia Diversion Dam. However, several arroyos and two flood control channels enter the Rio Grande from both sides of the river. The east side of the river is constrained not by a levee or drain, but rather by the east mesa valley wall. The mainstream Rio Grande channel in this section of the river is roughly 200 to

Middle Rio Grande Project features.

600 feet wide and is meandering near San Acacia, becoming more braided downstream.

This stretch of river contains two parallel channels: the mainstem Rio Grande and the Low Flow Conveyance Channel. The Low Flow Conveyance Channel is located on the western side of the Rio Grande, runs parallel to it at a lower elevation, acting as a drain, and is protected from the river by a continuous spoil dike. As previously mentioned, there are diversions from the Low Flow Conveyance Channel for the MRGCD and the Bosque del Apache National Wildlife Refuge. There is a flow constriction approximately 45 miles downstream of San Acacia Diversion Dam near the San Marcial Railroad Bridge. This constriction is due to the river bed rising (aggradation) at the bridge. The Corps of Engineers is currently evaluating options for replacing the spoil dike protecting the Low Flow Conveyance Channel (LFCC) and relocation of the San Marcial Railroad Bridge.

Sediment deposition has a significant impact on this stretch of the river. High sediment loads in the Rio Grande have led to significant aggradation of the river from the Bosque del Apache National Wildlife Refuge to Elephant Butte Reservoir. Due to this aggradation, the river bed is generally above the level of the surrounding valley floor downstream of the refuge. This aggradation and other factors such as vegetation growth have made maintaining a connected river to the Elephant Butte Reservoir pool an issue since the early 1950s. River channelization projects have historically been needed to ensure delivery of water to Elephant Butte Reservoir. These projects are cooperatively funded and constructed between the Bureau of Reclamation and the state of New Mexico. At present more than 20 miles of temporary channel have been excavated since 2000. This temporary channel work has been crucial in maximizing delivery of water to Elephant Butte Reservoir. It is estimated that about 15,000 acre-feet of water per year has been saved because of the temporary channel work.

There is a complex hydrologic connection between the Rio Grande, the LFCC, and drainage from irrigation on the west side of the Middle Rio Grande valley. Middle Rio Grande Project facilities and drainage converge in this area west of the LFCC and eventually end up in the channel with one minor exception: irrigation drainage directly to the river. In addition, due to aggradation of the river, significant seepage takes place from the Rio Grande to the LFCC, which acts as a drain for the valley. Such a multifaceted hydrologic system leads to challenging operations that are described later.

LOW FLOW CONVEYANCE CHANNEL

The Middle Rio Grande Project's LFCC parallels the Rio Grande on the west side and originally extended from San Acacia Diversion Dam to the narrows of Elephant Butte Reservoir. The LFCC is owned, operated, and maintained by the Bureau of Reclamation. Construction began in 1951 and was completed in 1959. The LFCC was constructed to aid delivery of Rio Grande compact waters and sediment to Elephant Butte Reservoir. It also served to improve drainage and provide additional water for irrigation. It is a riprap-lined channel that parallels a 54-mile reach of the Rio Grande from San Acacia to San Marcial. The LFCC collects river seepage and irrigation surface and subsurface return flows, thus reducing evaporation. The usefulness of the LFCC is dependent upon the water level of Elephant Butte Reservoir. Depending upon the condition of the outfall, a maximum of 2,000 cfs can be diverted into the LFCC at San Acacia.

Diversions from the river into the LFCC began in 1953, and diversions at San Acacia began in 1960. With above average water years the reservoir was relatively full through the 1980s. During this time the lowest reaches of the LFCC, which were inundated by the reservoir, became filled with sediment. This made the outfall of the LFCC difficult to maintain, and therefore diversions ceased in 1985. Since that time the LFCC has carried only drainage and irrigation return flows, with minor exceptions.

Currently the spoil dike that protects the LFCC (and surrounding lands such as the Bosque del Apache National Wildlife Refuge) from Rio Grande flooding is threatened by overtopping downstream of the Bosque del Apache Wildlife Refuge because of sediment deposition in the river channel. Environmental groups have also raised concerns about the impacts of future LFCC operations on the bosque, wildlife resources, and endangered species in the river below San Acacia Diversion Dam. The states of Colorado, New Mexico, and Texas, and farmers in the lower Rio Grande have raised concerns that compact deliveries will be impaired if the LFCC is not operated. Due to these factors and the condition of the channel outlet, operations of the LFCC as originally intended are not currently possible.

In order to meet needs of the endangered Rio Grande silvery minnow, the Bureau of Reclamation began pumping from the LFCC into the Rio Grande at four locations in 2000. These pump sites begin approximately 20 miles downstream of San Acacia Diversion Dam at the Neil Cupp pump site. Two sites

A Few Definitions

Canal—a waterway channel designed for draining or irrigating land.
Diversion—a structure constructed to divert water from one course or body of water to another.
Drain—a canal designed for draining irrigated land.
Floodway—an area which serves as a course of conveyance for the river.
Lateral—a side canal designed for irrigating land.
Levee—an embankment designed to prevent flooding.
Outfalls—the outlet of a canal or drain to the river.
River recessions—the upstream receding of water within the river.
Spoil dike—an embankment constructed, but not designed, to control and confine water.

are located at the northern and southern boundaries of the Bosque del Apache National Wildlife Refuge, approximately 6 and 16 miles downstream respectively from the Neil Cupp location. Finally pumping occurs at the Fort Craig site approximately 10 miles downstream from the southern boundary of the Bosque del Apache National Wildlife Refuge. Fifteen pumps are currently available to supplement Rio Grande flows and manage river recessions consistent with the current Biological Opinion.

ENDANGERED SPECIES OPERATIONS

The U.S. Fish and Wildlife Service issued a Biological Opinion on March 17, 2003, which affects water operations along the Rio Grande. The Biological Opinion contains flow targets for dry, average, and wet hydrologic years and when certain Rio Grande Compact restrictions affecting upstream storage are in place. The Biological Opinion focuses on keeping the Rio Grande continuously wet when possible between Cochiti Dam and Elephant Butte Reservoir to meet the needs of the Rio Grande silvery minnow. In average and dry years, and when certain Rio Grande Compact restrictions are in affect, the focus shifts to maintaining continuous flow to Elephant Butte Reservoir through the spawning period (June 15), with some flexibility to allow drying post-spawn.

The Bureau of Reclamation's Supplemental Water Program began in 1996 when supplemental water was first acquired and managed to augment river flows. Since then the program has been significantly expanded to assist in maintaining flows to meet Biological Opinion flow requirements. Two major components of the bureau's Supplemental Water Program include securing water from willing buyers/leasers to be released to the Rio Grande from upper-basin reservoirs, and pumping from the LFCC into the Rio Grande below San Acacia. The Supplemental Water Program supplies generally are released from storage in Heron, El Vado, or Abiquiu Reservoirs. It takes a minimum of seven days for water released from Heron and El Vado Reservoirs to get to San Acacia Diversion Dam and a minimum of five days for water released from Abiquiu Diversion Dam to reach San Acacia Diversion Dam.

Water management for endangered species from San Acacia to Elephant Butte Reservoir involves a multifaceted operation because of the complexity of the hydrology, the many entities involved, and ever-changing conditions. A key component impacting the hydrology and conditions in the area is losses in the system. Losses are defined as the reduction in quantity of water in transit not attributable to intended removal such as diversion. Losses in the Rio Grande are in large part a result of evaporation and consumption by riparian vegetation (evapotranspiration). These losses approach 50 percent of total depletions in the San Acacia reach and can vary greatly depending on weather conditions. The need for releases of supplemental water and pumping from the LFCC varies on a daily basis depending on many hydrologic conditions including losses in the system, diversions and return flows from water users, snowmelt runoff, and summer thunderstorm contributions to flow. With supplemental water supplies a minimum of five days travel time to San Acacia Diversion Dam, it can be difficult to maintain necessary endangered species flows. The LFCC is used to assist in maintaining those flows and to help manage river recession in times when continuous flows are not required under the Biological Opinion.

There will always be a need to manage the river above Elephant Butte Reservoir. The high sediment loads coupled with the relatively flat valley slope require regular channel maintenance to keep water flowing to the reservoir. With continuously changing river conditions, management of the river in this area will take careful evaluation and analysis.

The future of water management below San Acacia will likely evolve as decisions are made on water management needs, including endangered species needs, operations of the LFCC, and potential modifications of infrastructure such as the LFCC, associated levees, and the San Marcial Railroad Bridge. Such decisions will affect the hydrologic and environmental conditions through this reach; therefore, they will take careful consideration and evaluation and will require input from many entities.

Impacts of Middle Rio Grande Project Construction on the Middle Rio Grande Floodway—Rolf Schmidt-Petersen, *New Mexico Interstate Stream Commission*

The Middle Rio Grande Project was constructed and is operated to provide flood protection, control sediment movement, and improve valley drainage and downstream water deliveries within the valley from Velarde to Elephant Butte Reservoir. While the goals of the project were accomplished in part, the Rio Grande in the middle valley became less like a natural river system. The project also served to create and maintain the full canopy cottonwood bosque seen in parts of the valley today. Unfortunately and fortunately, it has had other effects, outlined below:

Cochiti Reach—Here the floodway is variable in width (up to 2,000 feet), bounded by discontinuous spoil bank levees and many small, relatively short riverside drains, which return water to the river at many points within the reach. The river flows in a narrow, deep channel up to several hundred feet wide, with few islands. Project infrastructure is used to deliver water to the pueblos of Cochiti, Santo Domingo, and San Felipe, and to farmers in Pena Blanca and Algodones. It protects agricultural lands, portions of the Cochiti, Santo Domingo and San Felipe Pueblos, and houses in the lower portions of the valley. Due partly to construction of project facilities, the river has incised within the originally constructed channel, reducing the potential for flooding. Due to the incision and downstream constraints on releases from Cochiti and Jemez Canyon Reservoirs, bosque flooding does not normally occur. Silvery minnow are present in small numbers.

Albuquerque Reach—The floodway here is more constrained (less than 1,500 feet wide) but the channel is somewhat wider (~600 feet), and many islands have formed over the past ten years of drought-induced lower flow. The floodway is bounded by spoil bank levees, a couple of engineered levees, and nearly continuous riverside drains. Project infrastructure is used to deliver water to the pueblos of Santa Ana, Sandia, and Isleta, and to farmers in Corrales and Albuquerque. River incision has reduced flooding potential by levee sloughing or overtopping, but the potential for flooding due to a bank erosion-caused levee breach remains. Because the bottom of the river is generally perched above lands outside the levees, a levee breach could have significant impacts. Flood protection issues have increased from the protection of agricultural lands and infrastructure and parts of downtown Albuquerque, to protecting people and their homes in much of the valley. Bosque flooding does not normally occur in this reach. This has prevented new cottonwood trees from germinating and reduced habitat for the silvery minnow. Balancing flood protection with ecosystem and endangered species preservation is an obvious challenge.

Isleta Reach—South of Albuquerque the floodway and river channel are approximately the same width as in the Albuquerque Division and are bounded by spoil bank levees and nearly continuous riverside drains. Project infrastructure is used to deliver water to the pueblo of Isleta, to farmers in the valley from Bosque Farms to Bernardo, and to the wildlife refuges at Bernardo and La Joya. Levee sloughing, overtopping and bank erosion of the levee are potential flood threats. Many islands have formed in the river over the past decade. Due to the shift from rural to suburban conditions in the valley, flood protection priorities in this reach are similar to those in the Albuquerque reach. Because the river channel has not incised significantly in this reach, significant areas of bosque can and are flooded under the maximum upstream flow releases. Thus, the potential for cottonwood reproduction is high, as is the potential for spawning and recruitment of the silvery minnow. In 2005 this reach of the river had some of the highest number of collected silvery minnow. However, flood control issues in the San Acacia reach constrain upstream flood control reservoir releases, which in turn limit the potential for additional flooding of the bosque in this reach and upstream.

San Acacia Reach—The San Acacia Division has a markedly different floodway configuration than the two reaches directly to the north. The river here is unconstrained by a levee on its east side. The floodway can be over 2,000 feet wide in places and the river channel quite variable in width (from 100 to over 1,000 feet). Several small discontinuous drains on the east side of the river serve to drain water from relatively small farmed areas back to the river. The LFCC currently serves as the riverside drain on the west side of the floodway. The LFCC is larger and deeper than most other riverside drains in the middle valley. South of Escondida, the LFCC does not return water to the river. Because of aggradation of the river bed, water in the LFCC is conveyed directly to Elephant Butte Reservoir. Significant bosque flooding can and does occur south of Escondida. Most irrigation, including that on the Bosque del Apache, occurs west of the floodway and is served by the Socorro Main Canal and the LFCC.

In sharp contrast to the reaches to the north, sediment is being deposited by the river, and the river bed has aggraded in the reach from just north of NM–380 south. In some places near San Marcial the bed of the river is 5–10 feet higher than the valley floor to the west and 2–3 feet higher than the valley floor to the west, creating a significant flood risk. Levee sloughing, overtopping, and bank erosion of the levee are potential flood threats. Significant amounts of money are spent each year by the Bureau of Reclamation and the ISC to keep the river channel open and reduce the risk of a levee failure. However, the existing flood risks significantly constrain upstream releases from the Corps of Engineers flood control reservoirs, which limits the potential for flooding of the bosque in upstream reaches.

The Middle Rio Grande Water Budget: A Debt Deferred

Deborah L. Hathaway and Karen MacClune, *S. S. Papadopulos & Associates*

Ground water has enabled increased water use over the past several decades without significant impact to the stream system; however, this practice is not without cost. As lagged impacts of past pumping reach the river, ever increasing offsets will be required. For a time, these offsets can be met with stored surface water, for example, Albuquerque's stored San Juan–Chama Project water in Abiquiu Reservoir. However, so long as water use exceeds water supply, balancing the water budget, again, is deferred to the future. Ultimately, a reduction in water use will be required to equal supply, or, alternatively, new supplies, not connected to the Rio Grande, must be acquired.

The Middle Rio Grande region (using a definition consistent with the Rio Grande Compact) extends along the Rio Grande from Cochiti Reservoir to Elephant Butte Reservoir, a distance of approximately 175 miles. Within this reach of the Rio Grande are many tributary streams and ground water basins. A water budget analysis for the region, including both surface water and ground water, indicates that, on average over the long term, the combination of regional water use and downstream compact obligation exceeds water inflow. At present, the difference is supplied by ground water stored in basin aquifers, as is reflected by declining ground water levels most notably in the Albuquerque reach. Regional water planners are projecting increased population, with commensurate increase in urban water use.

New Mexico pioneered the recognition of ground water-surface water interrelationships in water rights administration almost 50 years ago, when New Mexico State Engineer Steve Reynolds imposed controversial and unpopular requirements necessitating the offset of surface water impacts resulting from ground water pumping. This approach, in theory, would allow the utilization of what was then believed to be vast ground water resources, while keeping the river "whole." While painful to those who would prefer to pump ground water without considering surface water impacts, the system was clever. With this approach, significant additional development along the Rio Grande could and did occur, and compliance with the Rio Grande Compact, governing downstream delivery obligations, was manageable. State Engineer Reynolds understood that the plan would require ever-increasing offsets as stream depletion grew, and that, ultimately, the plan was not sustainable. However, his statutory charge obligated him to make water available to the public for beneficial use, so long as existing water rights were protected. Problems associated with growing stream depletions from ground water pumping were not imminent, and would not be problematic during planning periods (typically, 20 or 40 years) being addressed with water management actions at that time.

Today many stakeholders in the Middle Rio Grande understand that the existing pattern of water supply and water use is not sustainable. The lagged impact of ground water pumping on the stream system continues to grow. For various practical and political reasons, offsets don't always match the lagged impacts to the streams. And, it is recognized that the ground water resource itself has limits. At state, regional, and local levels, questions are asked: What is the water supply? What is the water demand? What are the consequences of making up deficits with ground water? And, what is the cost, economically, environmentally, socially, and culturally? Addressing these questions has been the focus of regional and state water planning over recent years. Support for this planning process has been the goal of the recent quantification of the Middle Rio Grande water budget by S.S. Papadopulos & Associates, Inc. in 2004.

THE WATER BUDGET: INFLOWS, OUTFLOWS, AND DEFICITS

The term "water budget" is commonly applied by hydrologists to mean an accounting of the inflow to, outflow from, and storage in a hydrologic unit such as a drainage basin or aquifer. In this fashion, the Middle Rio Grande water budget is characterized through examination of water supply from streams and ground water, and water use from both resources.

Surface water supply to the Middle Rio Grande region comes from several sources:

- Inflow from the Rio Grande main stem and native inflow from the Rio Chama, reflected in the gage at Otowi;

- Imported San Juan–Chama water, originating from the San Juan River basin in Colorado, also reflected at the Otowi gage; and,
- Inflow from tributaries to the Rio Grande between Otowi and Elephant Butte, most notably the Rio Jemez, Rio Puerco, and many monsoon-driven arroyos and rivers, including the Rio Salado.

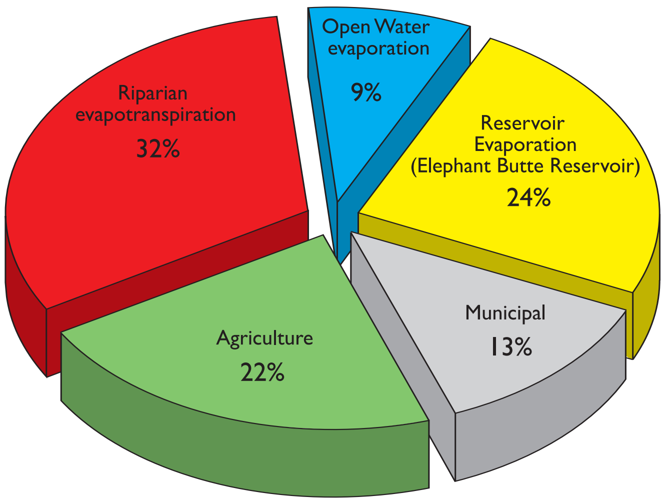
The surface water supply varies dramatically from year to year. For example, between 1950 and 2002, the annual Rio Grande inflow at Otowi (excluding imported water from the San Juan basin, termed, San Juan–Chama inflow) ranged from 255,000 to 2,170,000 acre feet, with a mean value of 940,000 acre feet. Similarly, the tributary inflow is highly variable. The San Juan–Chama inflow, on the other hand, is relatively stable with about 81,000 acre-feet per year available to the Middle Rio Grande region, with Heron Reservoir used to store and regulate this supply

The ground water supply in the Middle Rio Grande is stored in basin aquifers through which the Rio Grande passes. Although the aquifers receive recharge along the mountains that bound the basins, the recharge is significantly smaller than the amount of ground water pumped. The aquifers function as underground storage reservoirs. As water is withdrawn, ground water levels drop, reflecting the removal of stored water; i.e., "mining" of ground water. Also occurring is some replacement of ground water from the surface water supply via stream depletion.

Water use in the Middle Rio Grande can be broken down into four main categories:

- Agricultural water use
- Municipal (including industrial and domestic use)
- Riparian water use (water use by non-cultivated vegetation along the river or other channels, in the bosque, and in receding reservoir pools)
- Open-water evaporative losses from rivers, ponds, and reservoirs

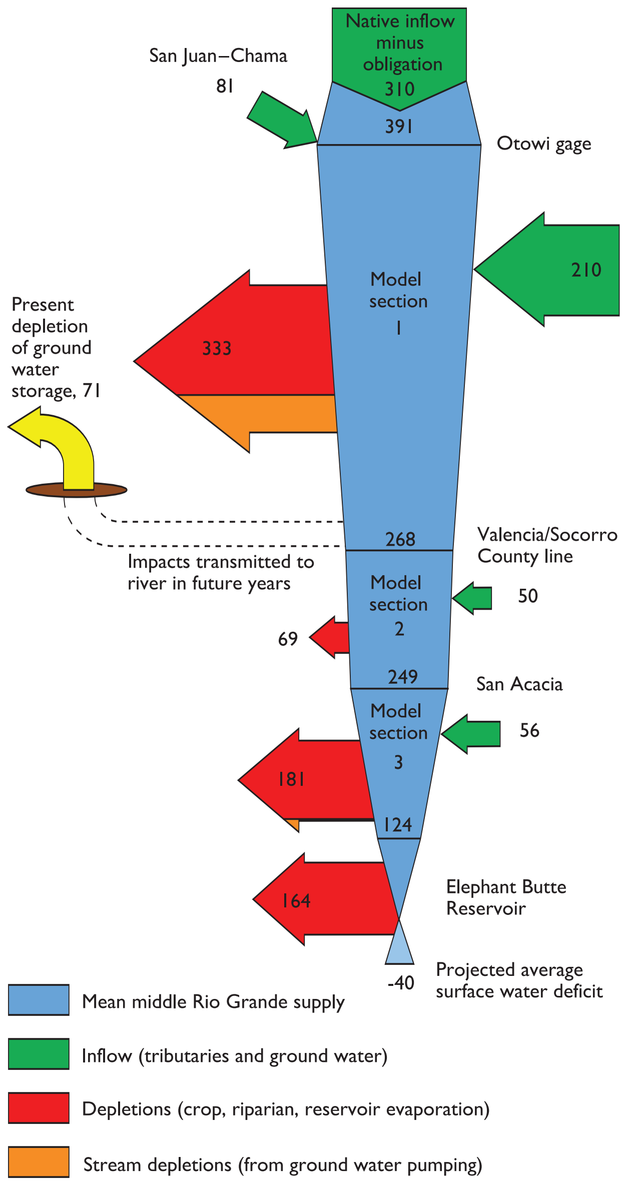
The pie chart of consumptive use in the Middle Rio Grande on this page shows the relative percentages of water use in these categories, including water use that is derived from both surface water and ground water. Of the total consumptive water use of about 700,000 acre-feet per year, the largest single use is riparian



Consumptive water use on the Middle Rio Grande.

evapotranspiration (water used by plants in the riparian zone adjacent to the river) at 32 percent. Reservoir evaporation and agricultural consumptive use are estimated at 24 percent and 22 percent of the total, respectively. Consumptive urban use, including both surface water and ground water (minus wastewater returns to the river) represents 13 percent of water use. The category with greatest variability is the reservoir evaporation, which is dependent on the surface area of the reservoirs. Evaporation from Elephant Butte (including evapotranspiration from plants in drained areas when the reservoir level is low) has ranged from about 80,000 to 260,000 acre-feet per year over the 1950–2002 period.

A large percentage of inflow to the Middle Rio Grande is obligated to users below Elephant Butte Reservoir under terms of the Rio Grande Compact. The downstream obligation under this agreement is based on native inflow at the Otowi gage. For example, in rough terms, the delivery obligation is 57 percent of inflow at lower flows, i.e., below about 600,000 acre-feet per year; is about 60 to 62 percent of inflow at average inflows, i.e., in the range of 900,000 to 1,000,000 acre-feet per year; and is 80 percent when inflow is as high as 2,000,000 acre-feet per year. Using the schedule provided in the compact, one can calculate the average delivery obligation over a period of years, corresponding to any given set of inflows. For inflows such as those occurring between 1950 and 2002, an average of corresponding compact obligations is 645,000 acre-feet per year. Of course, this value varies dramatically from year to year.



Water budget for the Middle Rio Grande, showing inflow and consumptive use along the stretch of river between Otowi gage and Elephant Butte Reservoir. Numbers are thousands of acre-feet.

A useful way to view the Middle Rio Grande water budget is to examine the portion of the supply that is available for consumptive use in the Middle Rio Grande region, apart from the compact delivery obligation. The water budget schematic on this page illustrates average inflow available to the region and consumptive uses along various reaches between Otowi and Elephant Butte, based on present levels of population and water use under a wide range of climate conditions, as developed from a modeling analysis conducted for the Middle Rio Grande Water Supply Study. In this schematic the compact obligation is subtracted from the upstream inflow at Otowi, to highlight the amount of flow available to New Mexico for consumptive use above the Elephant Butte Dam, including evaporation from the Elephant Butte Reservoir. Inflows and outflows are depicted, along with the "bottom line," a value representing surplus or deficit water at the downstream end of the region, or a likelihood of credit or debit under the compact. Using assumptions developed with the best available data and a wide range of potential climate conditions, on average, this region is projected to experience a shortfall of approximately 40,000 acre-feet per year in terms of surface water supply, and an additional deficit of 71,000 acre-feet per year occurs as a result of ground water pumping. This result does not represent specific conditions in any given year, nor does it necessarily translate to a compact violation. In reality, water management agencies work together with water users to avoid such a condition. With such efforts and other favorable conditions, despite the drought in recent years, New Mexico continues to maintain compact compliance. Nevertheless, and despite uncertainty in the water budget terms, the water budget modeling exercise underscores what has been the assumption by water management for decades: *The basin is fully appropriated*. New water uses impacting stream flows can only be supported by the cessation of old uses such that the overall consumptive use of stream flow does not increase.

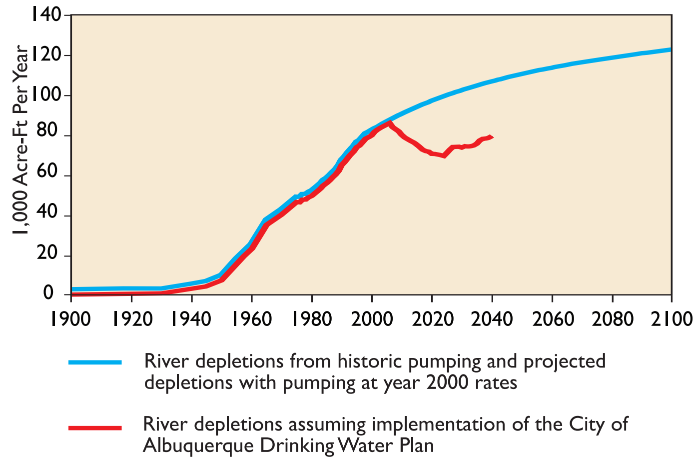
BORROWING TO MAKE ENDS MEET: GROUND WATER

Presently, ground water in the amount of about 156,000 acre-feet per year is pumped throughout the Middle Rio Grande region, largely, for urban uses. Up to the present, to large degree, the stream impacts have been offset by wastewater inflows, thus, significant net depletion to surface flows has not occurred. However, the stream impact is lagged in time; the impact will grow over time, even if current pumping rates are held constant. The graph on the next page shows river depletions from historic pumping in the Middle Rio Grande valley, projected river depletions assuming current pumping rates are held constant into the future, and projected river depletions assuming implementation of the City of Albuquerque (Water Authority) Drinking Water Plan, whereby the Water Authority will reduce ground water pumping and supplement their supply with their San Juan–Chama water delivered via the Rio Grande. Under implementation of the Drinking Water Plan, which among other measures includes reduced usage per person, stream depletion from ground water pumping is reduced over about a twenty-year period, but then returns to an increasing trend. By the year 2040 stream depletions will have risen back to 2000 levels and will continue to increase.

Ground water has enabled increased water use over the past several decades without significant impact to the stream system; however, this practice is not without cost. As lagged impacts of past pumping reach the river, ever increasing offsets will be required. For a time, these offsets can be met with stored surface water, for example, Albuquerque's stored San Juan–Chama Project water in Abiquiu Reservoir. However, so long as water use exceeds water supply, balancing the water budget, again, is deferred to the future. Ultimately, a reduction in water use will be required to equal supply, or, alternatively, new supplies, not connected to the Rio Grande, must be acquired.

Alternatives

Exacerbating the balancing of the water budget is the fact that urban use is projected to increase due to population growth. Furthermore, some agricultural proponents are working toward reclaiming and irrigating additional lands. Many alternatives are being considered by the three planning regions within the Middle Rio Grande to address the anticipated growth. Some planning regions expect to retire agricultural land and transfer the water rights to urban use (and some planning regions are strongly opposed to this alternative). The reduction of riparian water uses within the bosque and reservoir delta is also proposed. In fact, the control of water depletion from riparian vegetation such as salt cedar has been an essential feature of water management for decades. For example, the construction and maintenance of agricultural drains, the Low Flow Conveyance Channel, and the Elephant Butte Pilot Channel have served to control water depletion from riparian vegetation. However, additional long-term depletions associated with Endangered Species Act requirements could make the riparian depletion control efforts more difficult and costly to perform. The ability to institute new riparian depletion control projects is likely limited. Several alternative water sources have been explored by Middle Rio Grande water stakeholders, including the use of desalinated water and cloud seeding. These options, presently in developmental stages, promise to be expensive.



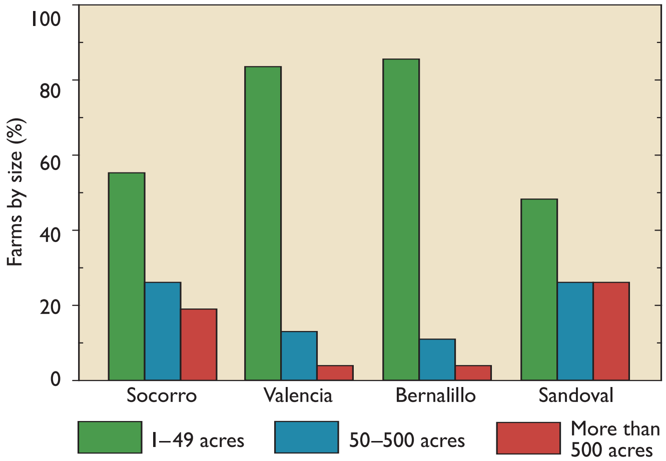
Given that the amount of water consumptively used within the Middle Rio Grande is limited by the Rio Grande Compact, the surface water supply must be recognized as a singular and limited water supply. Significant work remains for planning regions to get onto "the same page" with respect to hydrologic, environmental, and cultural realities of alternatives for balancing the water budget. Implementation will be costly and will take time. However, many stakeholders and planners now recognize that the time has come to reconcile the water budget and effectively plan for the future. Forty-year planning horizons that were envisioned decades ago have come and gone.

Agriculture in the Middle Rio Grande Valley

Cecilia Rosacker-McCord, *Rio Grande Agricultural Land Trust*
James McCord, *Hydrosphere Resource Consultants*

The Rio Grande corridor in Socorro County contains the largest contiguous undeveloped tracts of farmland in the Middle Rio Grande valley. The river and adjacent farmland function as a linked hydrologic and ecologic system, providing habitat to the endangered silvery minnow and southwestern willow flycatcher and some of the most significant remaining cottonwood–willow forest or "bosque" in the Rio Grande basin (in fact in the entire southwestern U.S.). The farmland in this reach, together with the managed field crops and wetland habitat at Bosque del Apache National Wildlife Refuge, provides winter habitat to more than 100,000 migratory waterfowl of the Rio Grande flyway.

Farmland in the Middle Rio Grande valley is managed as small (less than 50 acres), medium (50 to 500 acres), and large (500 to 1,000 or more acres) farms. Socorro County operates more medium and large farms than the more populated counties of Valencia, Bernalillo, and Sandoval and cultivates more than 20,000 irrigated acres. The productive bottom lands of the Rio Grande produce some of New Mexico's most delicious green chile and melons, and most nutritious alfalfa hay.



Farms (by size) in counties of the Middle Rio Grande valley. Socorro County is home to the greatest number of medium and large farms (more than 50 acres). Data from the U.S.D.A. 2002 Census of Agriculture.

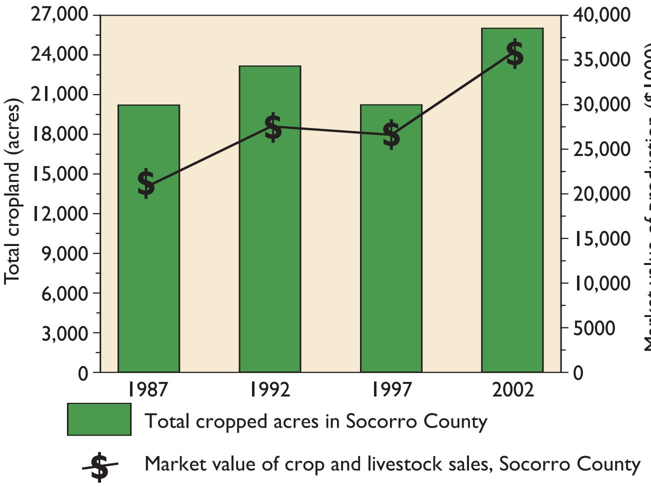
Row crops provide an increasing percentage of cash crops in the Middle Rio Grande valley. Vegetables, melons, potatoes, and sweet potatoes account for $212,000 in sales in Socorro County alone.

The San Acacia reach stretches from the San Acacia Diversion Dam near the village of San Acacia southward to the Bosque del Apache National Wildlife Refuge and is contiguous with the Socorro Division of the Middle Rio Grande Conservancy District. In addition to describing the current status of agriculture in Socorro County, this article highlights ongoing trends and implications of those trends on the future of agriculture and local communities. The topics we focus on include acreage of farmland, loss of farmland to development, water rights and trends in water rights transfers, value of agricultural products grown in the area, and economic benefits of agriculture to communities of Socorro County. In addition, we identify some of the intangible benefits that agriculture provides to the area and the state and the potential public policies that may help preserve agriculture in the region.

IRRIGATED FARMLAND AND FARM ECONOMY IN SOCORRO COUNTY

The U.S. Department of Agriculture's 2002 Census of Agriculture, conducted by the National Agricultural Statistics Service, provides estimates of, among other things, the amount of irrigated farmland and farm income on a state and county basis. According to these data, Socorro County had an estimated 12,373 acres of irrigated land in 2002. In addition to this cropland, approximately 5,000 acres are irrigated at Bosque del Apache National Wildlife Refuge to grow feed crops and create moist-soil wetlands that benefit migratory waterfowl. The figure on this page summarizes irrigated acreage and market value of crops and livestock, both indicators of the health of irrigated farmland agriculture, and shows that irrigated farmland has been decreasing in Socorro County since 1992, but production value is steady or rising. In 2002 the total market value of crops and livestock in Socorro County, much of which is connected to farming in the valley of the Rio Grande, was $35,776,000, significantly more than any other county in the Middle Rio Grande valley.

Forage crops, primarily alfalfa, remain the number one cash crop in the Middle Rio Grande valley.

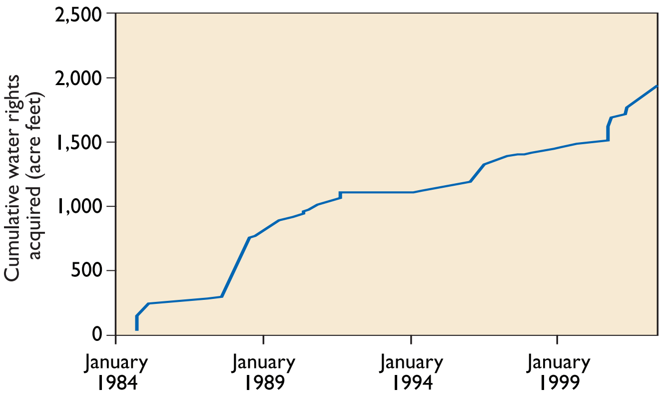


Historical trends in total irrigated crop acreage and farm production value in Socorro County. Data from the U.S.D.A. 2002 Census of Agriculture.

Socorro County produces a mix of crops. Of the 10,381 acres harvested in 2002, more than 9,000 acres (or about 90 percent) was cultivated in hay, grain, and grass forage, primarily alfalfa, which support the beef and dairy industry. Significant crops grown on the remaining acreage include feed corn, permanent pasture, and chile. In addition to livestock (cattle and horses) that graze on the permanent pasture, during the winter months many of the alfalfa fields are stocked with cattle trucked from nearby ranchlands. Since 2004 a significant increase in cattle prices has provided a healthy increase in the income for livestock and hay producers. Mixed vegetables grown for direct marketing (farmers' markets, farm stands, and local restaurants) typically occupy less than one percent of the total acreage, but they include an impressive and growing array of produce, including dry beans, snap beans, beets, carrots, eggplant, herbs, brassicas, potatoes, lettuce, melons, spinach, onions, peas, peppers, squash, sweet corn, tomatoes, and fruit. Chile and mixed vegetables have the potential to yield far greater net income ($2,000 to $10,000 per acre) than hay ($200 to $600 per acre), but require significantly more difficult-to-find farm labor. With the right equipment, one or two individuals can successfully operate literally hundreds of acres of hay land, whereas a vegetable grower requires a dozen or more laborers for 100 acres of chile.

HISTORICAL TRENDS IN WATER RIGHTS IN SOCORRO COUNTY

Surface water rights are generally associated with irrigated farmland, and that certainly holds for Socorro County. Other papers in this volume present information on water diversions, depletions, and water rights associated with irrigated lands. In this paper we highlight trends related to the transfer of water rights off of these lands and the impact that process has on the agricultural economy for the area. Because the waters of the Rio Grande are fully appropriated, increased demand by the growing population centers to the north of Socorro County, particularly the Albuquerque and Santa Fe metropolitan area, as well as the dramatic increase in the value of water rights (from $1,000/acre-foot in 1990 to more than $10,000/acre-foot today), a thriving market for transfer of water rights from the region has developed.



Time series graph of Socorro County irrigation water rights acquired by the city of Albuquerque (Office of the State Engineer file number RG-960).

Many such transfers have already occurred, and many applications are presently pending. For example, in the portion of the Socorro valley between San Acacia and Lemitar, we estimate that approximately 400 acres had their pre-1907 water rights sold and transferred before 2003, and more transfers certainly have occurred since then. Considering that this 7-mile reach of the valley has roughly 4,000 acres of farmland, approximately 10 percent of the farmland in Socorro's north valley has been sacrificed for the sake of growth in the Middle Rio Grande valley's metropolitan areas. One example of transfer of agricultural surface water rights to non-agricultural uses was obtained by reviewing the city of Albuquerque's water rights file with the Office of the State Engineer (file number RG-960). This file indicates that nearly 2,000 acre-feet of Socorro County irrigation water rights had been sold and transferred to the city of Albuquerque through the end of 2003. This represents more than 5 percent of the private irrigation rights in the county transferred to the city of Albuquerque alone through 2003.

Given that the Socorro–Sierra Regional Water Plan identified preservation of water for agriculture as one of its top three priorities, this trend should be worrisome to residents of the area. Evaluation of ways to minimize these transfers is an important component of the Socorro–Sierra Regional Water Plan, and local governments in the planning region are investigating their options for mitigating the adverse impacts of water rights exports. Obvious adverse impacts include the loss of irrigated farms and the many benefits they provide (see below), and the forsaking of all economic enterprises that depend on water (essentially everything), leaving the Socorro valley a dry and dusty, economically depressed area. This is similar to the situation faced by the communities in the Owens valley of California after the city of Los Angeles acquired their water.

AGRICULTURE PROVIDES INTANGIBLE BENEFITS TO LOCAL COMMUNITIES AND THE STATE

Visiting the farmland of Socorro County underlines the fact that this very narrow ribbon of arable land running alongside the Rio Grande (less than one mile wide in many places) is a limited and endangered resource for New Mexico. Historically we are an agrarian society, so New Mexico's original settlements lie along the river. As some of these original villages have grown into towns and cities, we now find that our agricultural lands are threatened due to their development potential and/or valuable appurtenant water rights. The families that have farmed these lands, their culture, and way of life are thus threatened and may be lost forever. These lands offer the promise of a local, sustainable food supply in the future and are an incubator for a rich, uniquely New Mexican rural culture. The deterioration or collapse of rural communities results in negative social and cultural impacts not accounted for in traditional economic value analyses.

Agricultural lands provide critical wildlife habitat and open space in the Middle Rio Grande valley.

Apart from the fact that we grow the most delicious chile in the world, our farmlands produce a number of other products, including alfalfa, cotton, pecans, onions, lettuce, melons, apples, and just about any other fruit or vegetable you might find at the grocery stand. You need only visit our farmers' markets to experience the incredible variety of products grown here. Beyond their capacity for food production, these agricultural lands provide critical wildlife habitat and corridors, not to mention beautiful, scenic open space for all to enjoy. Vital rural communities rich in culture and traditions are essential ingredients for another of New Mexico's largest industries, as well: tourism. Tourism to the Bosque del Apache National Wildlife Refuge provides Socorro County one of its greatest sources of outside income.

Finally, consider that in this time of concern for homeland security it is now more critical than ever to keep our agricultural lands and food-producing capacity alive in all parts of the country, including New Mexico. While many Americans are rightly concerned about our energy security, most forget that as we lose our agricultural lands and the ability to feed ourselves, we become dependent on other countries for our food supply, at our own peril.

FUTURE TRENDS AND A POTENTIAL AGRICULTURAL PRESERVATION TOOL

Growing populations and dramatically increasing land and water rights values have created significant pressure to convert our productive lands out of agriculture. Many (if not most) of the agricultural landowners who have made a living off the land are approaching retirement age, and appreciated land and water values offer those landowners the promise of a comfortable retirement. As they approach their golden years, only two options currently exist for cash-strapped landowners: sell the land, or sell the water rights, to developers. Ultimately this means the loss of most of our irrigated farmland and the associated direct and intangible benefits described above.

Organizations such as Rio Grande Agricultural Land Trust are working with state and federal policy makers to develop a third option for landowners to realize the financial benefit of appreciated resource values, while at the same time preserving in perpetuity the agricultural, wildlife-habitat, and open-space values provided by the land. One of Rio Grande Agricultural Land Trust's efforts with policy makers is the development of a farmland preservation program for the state of New Mexico through what's known as a conservation easement. This is a non-development deed restriction that a landowner can elect to place on their land should they desire that it be maintained solely for agricultural production in the future. A landowner can donate a conservation easement on their land, and they will receive significant federal and state tax benefits. Alternatively they can sell the "development rights" to a qualified non-profit organization such as Rio Grande Agricultural Land Trust, and that organization would be obligated to monitor annually the easement and, if necessary, enforce it through the courts if a subsequent landowner attempted to violate the easement. Given that the value of development rights is typically appraised at about 70 percent of the full market value, purchasing them would take a fair amount of cash.

The U.S. Department of Agriculture's Farm and Ranchland Protection Program is a federal program that offers great promise for the farmers and ranchers of New Mexico. The Farm and Ranchland Protection Program provides compensation to landowners for their development rights and requires a minimum 50 percent cash match to the federal contribution. This type of "purchase of development rights" program for agricultural lands can be referred to as a Purchase of Agricultural Conservation Easement (or PACE) program. Rio Grande Agricultural Land Trust receives calls on a weekly basis from farmers, ranchers, and community leaders wanting to protect thousands of acres of agricultural land valued in the millions of dollars. Unfortunately, due to the lack of a state program in New Mexico that provides the requisite non-federal cash match, the federal program is almost non-existent here. Meanwhile the neighboring state of Colorado has received between $4 and $7 million of Farm and Ranchland Protection Program funds for each of the last several years, largely because of the state money dedicated for purchase of conservation easements that can be used for the required Farm and Ranchland Protection Program match. Rio Grande Agricultural Land Trust has thus been proactively engaging the governor's office and selected state legislators to develop a PACE program for New Mexico.

The Middle Rio Grande Ecosystem through the San Acacia Reach

Lisa M. Ellis, *Department of Biology, University of New Mexico*

In an arid region where water is limited, the Rio Grande once created a patchwork of floodplain plant communities that provided habitats for a rich diversity of animals. Essential to sustaining the diversity was the dynamic ebb and flow of the river, characterized by high spring floods alternating with periods of low discharge. Historically, such seasonal changes in river discharge orchestrated key ecological processes within the Middle Rio Grande ecosystem's floodplain and river. However, floodplain habitats along the Middle Rio Grande have decreased in recent years, largely because the hydrologic connection between the river and its floodplain has been disrupted by various forms of human activity. Despite the great decrease in habitat diversity, the San Acacia reach (between the San Acacia Diversion Dam and Elephant Butte Reservoir) retains a high potential for restoration.

RIVER CONNECTIVITY AND THE FLOOD PULSE

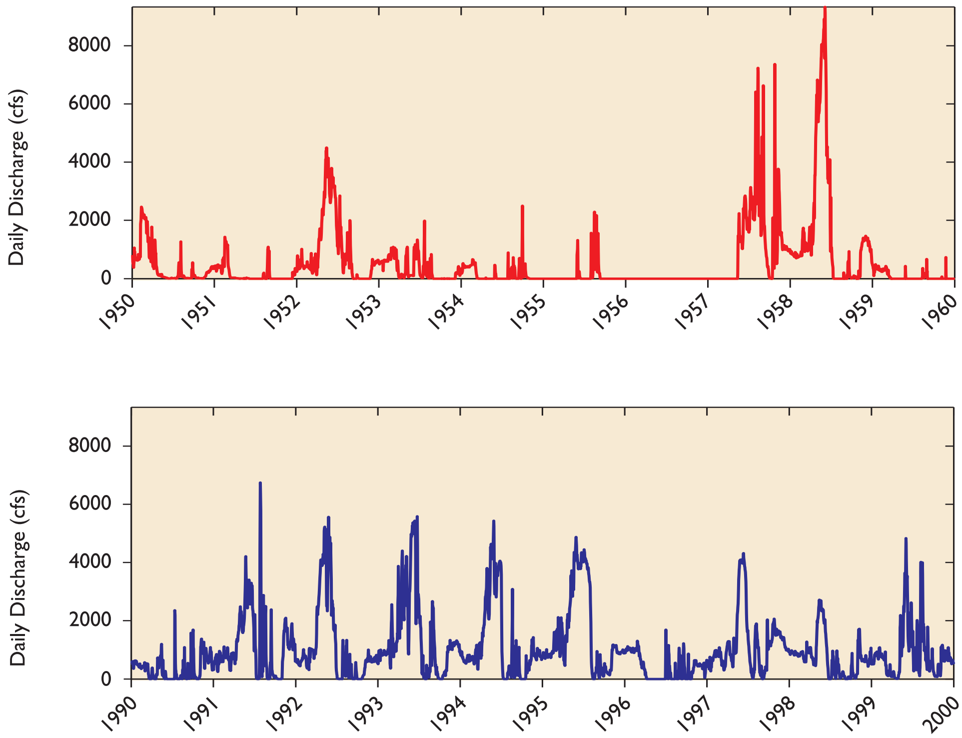
After more than a century of trying to modify and control the flow of large floodplain rivers, we now understand the importance of seasonal changes in water levels and how these help to maintain a river ecosystem's biological function and diversity. Along large rivers such as the Middle Rio Grande, periodic soil saturation by overbank or seep flooding—the "flood pulse"—regulates such functions as riparian (riverside) production, decomposition, consumption, and succession, all processes central to the ecosystem's integrity. In the Middle Rio Grande valley, as in other parts of the world, there is now an effort being made to restore the connectivity between rivers and their floodplains, with a particular emphasis on reestablishing natural flow regimes that drive the functioning of the rivers' riparian communities.

Thus along the Middle Rio Grande, including the San Acacia reach, reestablishing the natural pulse of the river is essential to restoring ecosystem processes. Before extensive river alteration, this reach was characterized by a broad floodplain supporting an ever-changing mosaic of habitats including patches of cottonwoods and willows of varying ages, open grassy meadows, marshes, ponds, sparsely vegetated akali flats, and open sandbars. This habitat mosaic was maintained by the considerable variation in river flow. The essential feature of the natural hydrograph for the Middle Rio Grande was a spring flush of water, which typically occurred in late May as a result of spring snowmelt from surrounding mountains. In some years this would have been a gentle rising of water to inundate forests, meadows, and other low-lying areas, but in other years high discharge meant scouring floods that cleared vegetation off sandbars and created optimal sites for cottonwood and willow regeneration. These scouring floods also transported sediment and reworked the channel, thus changing the appearance and position of the river bars. Open, moist sandbars are required for cottonwood and willow regeneration, because young seedlings cannot grow under the shade of a mature forest. Considerable sediment enters the Rio Grande via the Rio Puerco and Rio Salado. The San Acacia reach, lying below these confluences, benefits from this sediment.

The low-gradient, broad floodplain once favored a meandering channel, which helped to create the patchwork of habitat types. For example, old loops of the river were cut off to form oxbow ponds and eventually marshes and wet meadows. The connection between the river and ground water was and still is important for maintaining these habitats, because it wets the otherwise unsaturated soil above the water table.

Within the forest, the inundation of the rising river promotes a variety of ecosystem functions that are essential to maintaining the various floodplain habitats. For example, flooding increases rates of wood and leaf decomposition. In sites that are flooded regularly, increased rates of decomposition and subsequent mineralization (brought about by promoting fungal and bacterial activity) mean that nutrients are cycled back into the system more quickly, promoting new plant growth. As floodwaters percolate through the forest, impurities are filtered out and water quality increased. The deposition of sediments within the forest also provides an influx of beneficial nutrients.

Periods of low flow are also important to the system. Low water levels help to maintain suitable water temperatures, dissolved oxygen, and other water chemistry levels. Drawdown rates following flooding determine the fate of young plants beginning to germinate on the still-moist but exposed soils. Low flows also enable fish to move between feeding and spawning grounds and allow fish and amphibian eggs to remain suspended in the slow-flowing water column.



Daily discharge for the Rio Grande Floodway at San Marcial from 1950–59 (top) and from 1990–99 (bottom). Although fairly extensive regulation was already in place during the first decade, the upper graph still illustrates greater variability in flow, with higher highs and lower lows compared to the second decade, which was recorded after Cochiti Dam was built.

AN ECOSYSTEM DISRUPTED—LOSS OF THE FLOOD PULSE

We now know that high demands on river flow for irrigation withdrawals, along with efforts to constrain and straighten the river channel, impoundment of water, and even overgrazing in the upper watershed, have contributed to ecosystem degradation along the Middle Rio Grande valley. Along the San Acacia reach this degradation has resulted in significant loss of floodplain habitats. Reduction in peak discharge, along with early direct efforts to straighten the river, has greatly changed channel morphology. Over time, the channel has become narrower, more incised, and less active. New sandbar creation has decreased, and older bars are no longer scoured by high spring floods. This means that germination sites for cottonwoods and willows have greatly decreased, and remaining sites are commonly within the active channel, where young trees are killed by rising water. Without adequate germination sites, the forest cannot regenerate sufficiently to maintain itself, and as old trees senesce, they will not be replaced. Eventually, the cottonwood bosque will be lost.

The absence of flooding is also noticeable within the forest. Lack of seasonal inundation has greatly slowed leaf and wood decomposition, leaving increasing piles of organic debris and removing valuable nutrients from the system for long periods of time. Meanwhile, fungal and microbial activity slows down under dry conditions. The absence of floodwaters means that nutrient-laden sediments are not brought into the forest. Mature cottonwoods and willows are very sensitive to drops in the water table. Because they are phreatophytic, meaning their roots reach down into ground water, these trees are particularly affected by desiccating conditions resulting from water regulation. Cottonwoods are known to have reduced growth or increased mortality below dams or diversions, and to be especially susceptible to branch die-back induced by drought. Thus in addition to the decrease in regeneration seen with changes in sandbar morphology, increased mortality of adult cottonwoods has greatly diminished the quality of riparian habitats.

Further, the buildup of woody debris, which results from the increased branch death of cottonwoods during drought combined with decreased decomposition rates, promotes the spread of wildfires. Fire severity can be quite high in cottonwood forests with large amounts of dead and downed woody debris, and cottonwood survival in such fires is quite low. The loss of wetlands and wet meadows, together with their replacement by mainly exotic (non-native) trees and a more continuous forest constrained within levees and bluffs, means that natural fire breaks once inherent in the system are no longer in place. Fires also are fueled by the abundance of these exotics, particularly salt cedar.

Salt cedar (or tamarisk) is a particular problem along the San Acacia reach. Large sections of the floodplain here are covered only in salt cedar, to the

Aerial view of the Rio Grande in the Bosque del Apache National Wildlife Refuge, showing mature cottonwood bosque, wetland habitats, and some channel braiding. Note the old channel in the bottom of the picture. Sites like this have high restoration potential through restored flooding.

exclusion of other plants. Salt cedar can easily colonize areas disrupted by fire or other means, and in doing so, out-compete native cottonwoods and willows. Salt cedar is generally considered to be low-quality habitat for birds, and where it forms extensive monotypic stands (having only one type of plant), bird diversity is reduced. Much of the reduced quality of terrestrial habitats along the San Acacia reach is due to the presence of salt cedar. It affects aquatic habitats by stabilizing the riverbank and trapping sediments, which raises the level of the bank and reduces the potential for overbank flooding.

HABITAT DIVERSITY SUPPORTS WILDLIFE DIVERSITY

Riparian and floodplain habitats in arid regions are particularly valuable to wildlife. These habitats provide scarce resources not available in surrounding uplands, such as water, soils that allow digging, unique plant community types (e.g., large trees), other animals for prey, and more favorable ambient temperatures. They support a particularly high diversity of animal species, and often high population sizes. For example, at least 14 amphibian species, 29 reptile species, more than 200 bird species, and more than 50 mammal species have been observed within the Rio Grande floodplain of Socorro County. Invertebrate life is particularly well represented. At the Bosque del Apache National Wildlife Refuge at least 187 taxa of surface-active arthropods (insects, spiders, and their relatives) were identified in cottonwood sites alone.

The bird diversity of the San Acacia reach is quite rich, partly because the mosaic of plant communities provides opportunities for a variety of types of birds. For example, mature cottonwoods support species such as timber gleaning nuthatches and cavity-nesting woodpeckers and chickadees. Open sites with sunflowers or other non-woody plants are favored by seed-eating finches and sparrows, whereas sandbars and mud flats support large numbers of shorebirds. Marshes contain a number of wetland specialists, including blackbirds, herons, and rails. Ponds are filled with a variety of ducks, and cultivated fields are favored by flocks of geese and cranes. The importance of each habitat varies somewhat seasonally, depending upon breeding, migration, and over-wintering behavior. Neotropical migrant land birds breed here during the spring and summer, migrating shorebirds stop in large numbers during the spring and fall, and waterfowl are abundant during the winter. Taken together, the regional diversity of birds is extremely high due to the presence of all of these floodplain habitats, but this is threatened by the loss of habitat diversity. For example, the spread of salt cedar across the floodplain, to form monotypic stands that replace native habitats, decreases the options available to birds and other animals.

The San Acacia reach of the Rio Grande provides warm-water fish habitat, but channel narrowing and vegetation encroachment have decreased its favorable habitat characteristics. The reach supports at least 16 fish species, including natives and non-natives, but overall diversity has decreased due to extinctions and extirpations. A few species that do well during low-flow conditions, or recolonize rapidly after river drying, now dominate.

The loss of floodplain habitats has impacts on all wildlife in the San Acacia reach, but implications for threatened and endangered species are particularly great. Two federally listed endangered species have received much attention in recent years, the southwestern willow flycatcher and the Rio Grande silvery minnow. Both species have suffered greatly due to habitat loss, and both would benefit by restoration of the flood pulse. These two cases are prime examples of species needing ecosystem protection and illustrate the problems faced by all species. The southwestern willow flycatcher breeds in habitats with dense riparian vegetation, typically willows, seepwillows, or other shrubs or medium-sized trees, and very near to standing water or saturated soils. Overbank flooding is especially important in maintaining this vegetation and is one of the main factors determining habitat suitability. Restoring the flood pulse will increase habitat for this species.

The Rio Grande silvery minnow was once widespread along the Rio Grande south of Española, but now is restricted to the Angostura (Albuquerque), Isleta, and San Acacia reaches of the Middle Rio Grande. Until recent channel drying, the San Acacia reach supported the largest population and has been included in designated critical habitat. During much of the year, silvery minnows prefer pools, backwater, and secondary channels, habitats that are now limited in abundance. There appears to be a strong, positive correlation between silvery minnow abundance and river discharge. Silvery minnows spawn in response to the spring/early summer spike of water discharge—another direct link to the flood pulse. During years of low river flow, the river channel along the San Acacia reach often dries up completely, thus eliminating aquatic habitats. Extensive salvage and captive breeding efforts have saved the silvery minnow to date; however, the reconnection of the river to the floodplain is needed for its ongoing survival.

The San Acacia reach retains a significant amount of biological diversity and has definite potential for restoration. Although vulnerable to channel drying during years of low river discharge, it also experiences flooding at moderate flows. The northern end of the reach is incised and requires approximately 10,000 cfs discharge to initiate significant flooding, but the middle and lower portions of the San Acacia reach experience flooding at 3,000 cfs and 2,700 cfs, respectfully. The area of Bosque del Apache National Wildlife Refuge is particularly favorable to flooding and retains some floodplain connectivity. In some areas, a wide channel remains. The reach benefits from limited human development within the floodplain. Removing salt cedar, enhancing channel dynamics, and restoring flooding are all feasible and will contribute greatly to maintaining the high biological diversity of the region.

The dry river bed in the Bosque del Apache National Wildlife Refuge during the summer of 2005. Extensive channel drying in the San Acacia reach puts the endangered Rio Grande silvery minnow, as well as other aquatic species, in great peril.

The author wishes to thank Dr. Cliff Crawford and Gina Dello Russo for comments on this manuscript, Dr. Tom Turner for an update on the Rio Grande silvery minnow, and Dr. Chris Young for making the hydrograph.

The Middle Rio Grande—Short on Water, Long on Legal Uncertainties

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If you go out and look at the Middle Rio Grande these days, you'll see one stream of water flowing down the river. However, this river basin is one of the longest-settled, deeply hydraulic areas in the world. The river that runs through it reflects the many layers of governance that have overlaid the river in the more than 500 years that the river has maintained itself and supported human settlements dependent on it. In its long history of human use, the river has supported and been governed by the laws of Native American sovereigns, the Spanish Crown, the Mexican Republic, the territory of New Mexico, the state of New Mexico, and the United States. The laws of these different sovereigns have been laid down one on top of another and are often poorly integrated, if integrated at all.

These days we are accustomed to viewing the Middle Rio Grande surface flows as being made up of several different kinds of water: native flow, flood flow, stored flow, imported flow, and even flow contributed by interconnected ground water flows. These different flows reflect different sources for the single body of water we see when we stand on the Central Avenue bridge and watch the water come down. Imagine how much more complex the layered situation is when we consider that these different flows are themselves subject to different legal claims: Pueblo claims under Native American law, ancient acequia claims under Spanish and Mexican law, Middle Rio Grande Conservancy District claims under state law, Endangered Species Act claims under federal law.

If we're New Mexicans, bred to the basic law of the state, we tend to think that the law of prior appropriation governs these different sources of water established at different times. That law of prior appropriation said that rights to water were established by capturing water and applying it to beneficial use. The earlier you captured the water, the better your right to the common source shared with many others. Over the years we've tried to shoehorn all manner of different claims into the prior appropriation slipper. These days we talk about "non-consumptive beneficial uses," even though twenty years ago that term would have struck some listeners as an oxymoron. These days we acknowledge that restoration of rivers like the Rio Grande to more natural conditions is important, but we struggle to make sure a more natural flow does not increase depletions in the stream system, as the prior appropriation system says it should not.

Despite these and other Herculean efforts to cabin and contain ancient claims and new claims within the doctrine of prior appropriation, the boundaries are breaking down everywhere: Base flow may be subject to priority administration, but stored federal water is not; Pueblo water rights may be subject to federal control, but certainly are not governed by state law. Imported San Juan–Chama water may lie outside both state and Pueblo law. We don't know the answers to these puzzles.

In the end it's what we don't know about the simple and scant waters of the Rio Grande that may be the most important thing. How many basic facts about legal claims to the Middle Rio Grande don't we know at a time when the river is becoming more and more crucial to life here? Let me count a few.

PUEBLO WATER RIGHTS ON THE RIO GRANDE

Start with the six Middle Rio Grande pueblos. This is as good a place as any to begin, because the Pueblo claims to the river are so basic, so unknown, so unquantified, and so potentially large. We are accustomed to say that the 1938 Rio Grande Compact limits New Mexico's access to surface and ground water in the Rio Grande generally and in the Middle Rio Grande in particular. I'll come to the compact next, but the Pueblo claims come before the compact, which exempts them from its terms.

No one has ever formally and finally determined the nature and extent of Pueblo water rights outside the Middle Rio Grande although the numbers are everywhere. The Abeyta and Aamodt proposed settlements from Taos and Nambe don't tell us much, although, like most settlements, they vary from the formal law a lot. For example, under the proposed Aamodt settlement, the San Ildefonso Pueblo would agree to a senior surface water priority of a little less than 80 acres. Judge Mechem's 1985–1987 district court rulings said that the pueblos of Nambe, Pojoaque, and Tesuque had a prior and paramount right to their historically irrigated acres as of June 6, 1924, and quantified those. The San Ildefonso Pueblo would have received 365 acres of prior and paramount rights to the surface flows of the stream system and the interrelated ground water. This unique decision, establishing what the lawyers call the Mechem Doctrine, was never appealed and never confirmed by any higher court. Mechem based the general Pueblo doctrine he invented on the 1928 act by which Congress authorized inclusion of the six Middle Rio Grande pueblos in the Middle Rio Grande Conservancy District (MRGCD). That act confirmed the prior and paramount rights of those pueblos to some 8,800 acres (and a right equal with other district lands to an additional 12,000 acres), and Mechem found that the 8,800 acres represented the best evidence of the 1924 historically irrigated acreage of those pueblos.

The pueblos have always maintained that this congressional limitation on their prior and paramount rights applies only to water delivered through the MRGCD works. Other water, including ground water and water diverted from works other than the MRGCD's, was not limited by the 1928 act. At least three Tenth Circuit Court of Appeals judges who considered the nature and extent of the Pueblo water rights in 1976 thought that they probably had Winter's Rights, an expansive federal right based on practicably irrigable acreage, not actual irrigation.

Who is right in this tangled 75-year complication of half steps and missteps and stumbles and paralysis? No one yet knows. The range of possibilities still runs from the minimal rights accorded under state law to the maximum allowed under the Homeland and Practicably Irrigable Acreage standards of the full-scale Winter's Doctrine. If state law is the rule (and it seems highly unlikely), then the rights of the Pueblos would be minimal and manageable. If Winter's doctrine is applied, the Isleta Pueblo alone would command the whole flow of the Middle Rio Grande and its related ground water. If the Pueblos exercised their maximum rights to deplete the river, those new depletions would probably be charged to New Mexico under the 1938 Rio Grande Compact. New Mexico could not possibly meet its compact delivery obligations without catastrophically reducing other net depletions. That's a wide range of unknowns, and it's entirely outside what we call the primary limits on ground water imposed by the 1938 compact.

THE 1938 RIO GRANDE COMPACT

For the last decade we've paid lip service to the fact that the 1938 Rio Grande Compact obligations fundamentally limit New Mexico's net depletion of Rio Grande waters. The 1938 Hinderlider case teaches us that compact obligations come before any state law rights come into play. The 1938 compact shows us that New Mexico's obligations are measured by an index inflow at Otowi and a computed outflow below Elephant Butte. The gage relationships are based on 1929 conditions on the river. New Mexico is responsible for everything that happens between Otowi and Elephant Butte—everything being direct agricultural depletions, indirect municipal depletions, natural depletions, riparian depletions, and Pueblo Indian depletions. We used to think that winter snowpack above Otowi or summer torrential rains below Elephant Butte controlled New Mexico's widely varying deliveries and are allowable under the compact. But in the last 40 years, claims on the river have changed: Agriculture is down, municipal obligations to the river are up, and environmental attention to the river is producing its own set of new claims. The compact is blind to the causes of those increases and decreases. Based on flows as it is, the compact only sees allowable net depletions and sets absolute limits on the balance of those that control river flows. The sum of net depletions can't change, but the balance of them certainly can and has. As I noted before, New Mexico is responsible for all net depletions and is especially responsible for shifts and increases in net depletions created by rules of law. And these rules we don't know much about.

MUNICIPAL WATER

New Mexico fed the astronomical growth of its principal cities from 1950 to today primarily on stored ground water. New Mexico led the rest of the western states in its recognition that ground water is related to and responsible for interrelated surface water flows. The basic rule was this: Because depletions of surface water flows were limited to those allowed by the compact, New Mexico could switch uses from agriculture to municipal use, for example, but net depletions couldn't increase for any reason between Otowi and Elephant Butte. For a while existing agricultural uses, increasing municipal demand, and even growing riparian consumption could coexist, but eventually they would have to be re-ordered.

That eventuality has arrived. New Mexico knows that it has to react but hasn't decided how. Two recent examples from our biggest municipalities show the quandary we are now in. The 2000 Rio Rancho permit, which allowed the city to increase its ground water diversions to 25,000 acre-feet a year, put the city in hock to the Rio Grande for that full amount.

Initially the Office of the State Engineer tried to call the whole loan at present and at once, telling Rio Rancho that it couldn't pump any of the increase it had won until it offset all the future effects on the river. Eventually the state and the city agreed on a less draconian, staged series of offsets. The fact remains that Rio Rancho must reduce depletions on the Rio Grande by 25,000 acre-feet in order to leave the river in its compact-defined whole. That equals 12,000 acres of irrigated land, whole reaches of bosque riparian vegetation, or some other source. But it's got to be wet water. Nothing else will satisfy those compact gages.

We don't now know where the water will come from. I chatted once with an old time, retired, astute northern New Mexican who went door to door in Tesuque looking to buy a mere 5 acre-feet of wet water rights there at any price. He personally knew most of the residents. No one offered to sell. Some old time friends shut the door in his face, so offended were they at even the request that they sell their water rights.

There doesn't seem to be a much bigger voluntary market for old, secure water rights in the Rio Grande valley. You've heard the debates and proposed legislative limitations from the New Mexico governor and legislators on municipal power of eminent domain over land. Imagine the hell there would be to pay if Rio Rancho went into Socorro County to force by condemnation the transfer to the city of ancient surface water rights of farmers there. I once asked the Rio Rancho water attorney what she thought would give. "Something will change," she said. But she didn't know what, and neither do I.

In some ways the city of Albuquerque's recent fundamental switch from stored ground water to surface water represents the opposite side of the municipal coin. Deciding that its reliance on mining stored ground water was not sustainable, the city will switch to pumping a cocktail of imported San Juan–Chama stored water and ground water to satisfy a growing urban demand. San Juan–Chama water doesn't count in fixing New Mexico's delivery obligations at Otowi under the compact, but that water does show up at Elephant Butte and can help in meeting the state's obligation there. Switching to San Juan–Chama surface water will reduce that compact gift. At the same time, the switch will reduce another incidental contribution to New Mexico's compact obligation, the stored ground water that the city has pumped for 50 years, run through its municipal system, and discharged to the Rio Grande as a gift to the state's compact flows. Sandia National Laboratory computer models suggest that the combined loss of San Juan–Chama water and stored ground water may throw New Mexico off as much as 50,000 acre-feet per year in compact deliveries. But you don't need to go that far to recognize that municipal demand is already altering the balance of inputs and outputs in the middle reach of the river in fundamental ways and making deep commitments to the future of the river. We just don't know how much, and we don't know where the new balances leave us with respect to our fundamental compact obligations. In considering the city's newest application, the Office of the State Engineer's hearing examiner didn't say much about this rebalancing and said nothing real about the effect of the change on New Mexico's fundamental compact obligations.

THE MIDDLE RIO GRANDE CONSERVANCY DISTRICT

In the streets you often hear suggestions that it will require regional governance to solve the Middle Rio Grande problems, governance to match the width and depth of the resource problem. But for 75 years we've had a regional water government, the MRGCD. Thus far the MRGCD has contributed more to the problem of unknown claims to the river than it has contributed to a regional solution to the shifting demands, although the MRGCD has moved positively in this direction in the last decade. In recent public pronouncements the MRGCD has claimed a right to the water needed to irrigate 123,000 acres in the Middle Rio Grande. The authority for that number used by the district is thin indeed. It's not clear whether the claimed right is for diversion alone or for the full beneficial use of the water needed to irrigate the 123,000 acres. The fact that the MRGCD's recent statistics show that only about half of those acres, 61,000, are currently irrigated through district works would give anyone pause. Does the MRGCD "own" the water rights needed to irrigate the present acreage? Does the MRGCD "own" the water needed to irrigate the other dry 62,000 acres? Can the MRGCD and its water bank control that much water?

Two basic problems make it hard to see the MRGCD clearly. The first is the basic historical situation on which the MRGCD was overlaid in 1924. The best historical estimates suggest that irrigation in the Middle Rio Grande reached its peak in 1880 when approximately 120,000 acres were irrigated. A familiar set of hydrologic problems—poor drainage, an aggraded river bed, a diminished supply—contributed to a sharp drop in irrigation between 1880 and 1928 when the new district issued its plan for improvements. The MRGCD's vast and effective system of diversions and drains did bring back a lot of these acres, but to whom? The district, or the land owners of appurtenant water rights, or some hybrid of the two?

The statutory charter of the MRGCD compounded the basic confusion. The 1914 Ohio statute on which New Mexico's 1923 and 1927 statutes were based said that any improvements made by the new Ohio conservancy districts belonged to the districts. The statutory corollary in the Ohio statute said that landowners within the new districts could only claim ownership of uses that they could have made without the benefit of the conservancy district statute. These Ohio provisions made their way awkwardly into the 1923 and 1927 New Mexico statutes. They were subject to supplemental amendments that are too complicated to detail here. Suffice it to say that the MRGCD Magna Carta is hardly clear about the nature and extent of MRGCD ownership of and control over Rio Grande water.

FEDERAL CLAIMS TO RIO GRANDE WATER

Everybody knows about the tizzy into which the silvery minnow and the Endangered Species Act have thrown Rio Grande water managers. Thus far, a series of lawsuits, congressional acts, state law permits, and federal dam operations have been cobbled together to yield a tenuous compromise. The minnow may just be the beginning of federal alterations to inputs and outputs, to incidental contributions, and to unintended depletions to Middle Rio Grande surface flows. What remains unclear is how new federal operations will impact the 405,000 acre-foot maximum depletion that is allowed the Middle Rio Grande under the 1938 compact. Existing old compacts like the 1938 Rio Grande Compact don't even mention new federal claims. Suggestions for new compacts, none of which have yet been adopted, universally recommend making the federal government a more formal party to the agreements than it has been in the past, defining the federal rights and apportioning the effects of them among compacting states. Without such formal recognition, the federal government remains free under the supremacy clause and its own federal mandates to rework river flows. Which state pays for the federal changes if they effect state compact obligations, as they surely will?

We're accustomed in these post-silvery minnow days to look upstream on the Rio Grande, to look to the San Juan–Chama Project imported waters, or to look to federal dams at El Vado, Heron, and Abiquiu as the source of boons or bains to Rio Grande flows, depending on your perspective. The upstream problem is so potentially significant that we even have academic conferences on dam operations on the Rio Grande and its tributaries. But let me end by looking downstream at the effect of federal operations not so much on upstream inflows as on downstream deliveries.

Of course, I'm referring to the controversial Low Flow Conveyance Channel just above Elephant Butte. Put in almost 60 years ago by the Bureau of Reclamation as a way of increasing New Mexico's compact deliveries at a time when the state was falling farther and farther behind, the Low Flow Conveyance Channel seemed to work. New Mexico made up for its compact under-deliveries with the help of the channel. However, one of the unintended consequences of the Low Flow Conveyance Channel was a drying of the river itself in the reach below the Low Flow Conveyance Channel's intake. Long a legitimate target of environmental complaints about the harm done to the river itself by man-made alterations like the channel, the Bureau of Reclamation, especially since the turn of this century, has used the channel less and less. And one of the unintended consequences of that return to natural flows may well turn out to be compact under-deliveries for which the state of New Mexico will be responsible.

A SHORT END TO A LONG AND NEVER-ENDING STORY

The sum of all of these uncertainties—the nature and extent of pueblo and MRGCD rights, the source of rights for increasing municipal demand, the unintended consequences of changes to policies—is even greater uncertainty. On the wall of the office of the deputy chief counsel of the Office of the State Engineer is a map showing the surface water districts in New Mexico. It looks like a donut. Districts to the south, west, north, and east of the Rio Grande surround a hole in the center: the Middle Rio Grande from Otowi to Elephant Butte. From this perspective, the Middle Rio Grande looks like a black hole in the middle of a state where the water resource is more or less regulated. This fate is especially ironic when you consider that the Middle Rio Grande is both the longest-settled area of a deeply hydrologic state and the engine of future economic growth in the state.

Surface Water Management: Working within the Legal Framework

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There are six major reservoirs in New Mexico upstream of the Middle Rio Grande. This paper provides some background on how those reservoirs are operated within the current legal framework and how those operations meet various purposes and needs within the Middle Rio Grande.

Between the Colorado–New Mexico state line on the north and Elephant Butte Reservoir on the south, four major tributaries join the Rio Grande, including the Rio Chama, the Jemez River, the Rio Salado, and the Rio Puerco. The Rio Chama is the primary tributary, heading in the San Juan Mountains of southwest Colorado and joining the Rio Grande just north of Española. Other significant tributaries include the Red River, Rio Pueblo de Taos, Embudo Creek, and Galisteo Creek flowing out of the Sangre de Cristo Mountains; the Jemez River flowing out of the Jemez Mountains;and the Rio Salado and Rio Puerco, which join the Rio Grande just above San Acacia. With the exception of the Rio Chama and the larger streams originating in the Sangre de Cristos, these tributaries are ephemeral, flowing only during snowmelt runoff or in response to heavy precipitation events.

The six major reservoirs described here are Heron, El Vado, and Abiquiu on the Rio Chama; Cochiti on the Rio Grande; Galisteo on Galisteo Creek; and Jemez Canyon on the Jemez River. Reservoir storage is usually discussed in units of acre-feet, which is the amount of water that it takes to cover one acre to a depth of one foot, or approximately 326,000 gallons.

RIO GRANDE RESERVOIRS

Heron Reservoir

Heron Reservoir is located on Willow Creek just above its confluence with the Rio Chama in northern Rio Arriba County. It was constructed in 1971 with a storage capacity of 401,000 acre-feet and is owned and operated by the U.S. Bureau of Reclamation. Heron is the storage reservoir for the San Juan–Chama Project, a federally authorized diversion project that brings roughly 100,000 acre-feet per year of water across the continental divide from the San Juan River basin and into the Rio Grande basin. That water flows through a series of tunnels into Willow Creek, then into Heron Reservoir. Heron is allowed to store only San Juan–Chama water; it is not authorized to store native Rio Grande water (water that originates as runoff within the Rio Grande basin). San Juan–Chama water is contracted to several different water users throughout the Upper and Middle Rio Grande including multiple municipalities, the Jicarilla Apache Nation, the Pueblo of Ohkay Owingeh (formerly San Juan), and two irrigation districts. The city of Albuquerque and the Middle Rio Grande Conservancy District are the two largest project contractors. San Juan–Chama Project water is managed and accounted separate from native Rio Grande water.

El Vado Dam and Reservoir

El Vado Reservoir

El Vado Reservoir is located on the Rio Chama just a few miles below Heron Reservoir. It was constructed in 1935 by the Middle Rio Grande Conservancy District (MRGCD) and has a storage capacity of 180,000 acre-feet. Both San Juan–Chama and native Rio Grande water are stored in El Vado. The U.S. Bureau of Reclamation currently operates El Vado primarily to provide supplemental irrigation supplies to the MRGCD by agreement with the district. Native water is stored pursuant to New Mexico Office of the State Engineer permit number 1690, issued in 1930 (at press time, ownership of El Vado Dam and Reservoir and state engineer permit number 1690 was the subject of a legal dispute between the MRGCD and the U.S. Bureau of Reclamation). The federal government also stores and releases water from El Vado Reservoir to the prior and paramount lands of the six middle Rio Grande pueblos during times of low flow on the Rio Grande. Those lands have senior water rights to any other MRGCD lands.

Abiquiu Reservoir

Abiquiu Reservoir is located on the Rio Chama approximately 30 miles downstream of El Vado, and about 30 miles upstream of the confluence of the Rio Chama with the Rio Grande. Abiquiu Reservoir was built in 1963, is owned and operated by the U.S. Army Corps of Engineers, and has a maximum capacity of 1,200,000 acre-feet at the top of the spillway crest. The reservoir was initially authorized as a flood and sediment control reservoir, but in 1981 Congress authorized the reservoir to store up to 200,000 acre-feet of San Juan–Chama water. In 1988 Congress authorized Abiquiu to store up to 200,000 acre-feet of native Rio Grande water, provided that the storage space is not needed for San Juan–Chama water.

Abiquiu Dam and Reservoir

Cochiti Reservoir

Cochiti Reservoir was built in 1975, is owned and operated by the U.S. Army Corps of Engineers, and has a maximum capacity of 590,000 acre-feet at the top of the spillway crest. Cochiti is located approximately 50 miles upstream of Albuquerque and is the major flood control reservoir for the Middle Rio Grande valley. It is also the only reservoir on the mainstem of the Rio Grande above Elephant Butte Reservoir in New Mexico. Cochiti was initially authorized as a flood and sediment control reservoir. In 1964 Congress authorized the formation of a permanent recreation pool for Cochiti Reservoir of roughly 50,000 acre-feet, which is maintained with San Juan–Chama water.

Cochiti Dam and Reservoir

Galisteo Reservoir

Galisteo Reservoir is located on Galisteo Creek approximately ten miles above its confluence with the Rio Grande near Santo Domingo Pueblo. Owned and operated by the U.S. Army Corps of Engineers, it was constructed in 1970 for flood and sediment control and has a maximum capacity of about 90,000 acre-feet at the top of the spillway crest. Galisteo is different from the other reservoirs in that its releases are uncontrolled below 5,000 cubic feet per second. There are no outlet control works, so what comes in essentially equals what goes out. Water becomes temporarily stored if inflow exceeds 5,000 cubic feet per second, so most of the time the reservoir is completely dry.

Jemez Canyon Reservoir

Jemez Canyon Reservoir is located on the Jemez River a few miles above its confluence with the Rio Grande. Owned and operated by the U.S. Corps of Engineers as a flood and sediment control reservoir, it was constructed in 1953 and has a maximum capacity

Galisteo Dam (at far left). This earth-filled structure is 2,820 feet long with a maximum height of 158 feet. There are no outlet control works, so water becomes temporarily stored only if inflow exceeds 5,000 cubic feet per second, and most of the time the reservoir is completely dry.

of about 100,000 acre-feet at the top of the spillway crest. Jemez Canyon is similar to Galisteo Reservoir in that it is also operated as a dry reservoir. However, flow out of the reservoir is controlled by outlet works that allow release of flood waters at a desirable rate.

All of the major reservoirs in the basin are operated in accordance with various federal and state laws that constrain or limit those operations to specific purposes or functions. The most important of these is the Rio Grande Compact.

THE RIO GRANDE COMPACT

The Rio Grande Compact, an interstate agreement that apportions the waters of the Rio Grande between the states of Colorado, New Mexico, and Texas was executed in 1938 and became effective in 1939. Under the compact New Mexico is allowed to consume on average roughly twice as much water as Colorado and three times as much as Texas. New Mexico's share includes the amount of water it is entitled to consume between the Colorado–New Mexico state line and the Otowi gage, the amount in the Middle Rio Grande valley between Otowi gage and Elephant Butte Reservoir (including all tributary inflow and San Juan–Chama Project water), and the amount in the Elephant Butte Irrigation District below Elephant Butte in the Lower Rio Grande.

There are a number of compact restrictions that have an impact on reservoir operations and surface water management in the Middle Rio Grande valley. The most important is Article VII, which prohibits increasing storage of native Rio Grande water in any upstream reservoir constructed after 1929 when the combined storage in Elephant Butte and Caballo Reservoirs, not including credit and San Juan-Chama Project water, is below 400,000 acre-feet. All of the major reservoirs are subject to this restriction except Heron, because it does not store native Rio Grande water.

The Article VII storage prohibition can have a major impact on water management in the middle valley, particularly on El Vado Reservoir, which primarily stores irrigation water for MRGCD. Article VII was invoked in 2002 for the first time since 1979 and was in effect until May of 2005. Since that time it has gone into and out of effect as water storage has fluctuated at Elephant Butte and Caballo Reservoirs. Article VII storage restrictions also impact McClure and Nichols Reservoirs on the Santa Fe River, two relatively small reservoirs with a combined capacity of slightly less than 4,000 acre-feet that provide a significant portion of the city of Santa Fe's water supply.

WATER OPERATIONS AND MANAGEMENT

The term "reservoir operations" refers to the rate and timing at which storage or inflow into a reservoir is released or detained. The term "water operations" includes downstream monitoring to ensure that desired flows are achieved from changes in reservoir operations, and management of downstream diversions of flows released from storage. There are essentially three main types of water operations that impact the Middle Rio Grande:

- Irrigation operations
- Flood control operations
- Environmental operations

The tools that are used by water managers to conduct these operations include near real-time flow and storage data provided by stream gages via satellite uplink, automatically controlled reservoir and diversion gates that can be supervised from the office, and sophisticated computer models to track water accounting and help plan operations.

One important thing to keep in mind while reading the following descriptions of specific reservoir operations is that very little of the native Rio Grande water originating within the basin is actually captured and stored in the major reservoirs. On average, roughly 100,000 acre-feet of native Rio Grande water, less than 10 percent of the annual average flow at Otowi gage, has been historically held in storage (at least temporarily) upstream of Elephant Butte. The vast majority of the combined storage of Heron, El Vado, Abiquiu, Cochiti, and Jemez Canyon Reservoirs has historically been San Juan–Chama Project water.

STORAGE AND FLOW

Reservoir storage and stream flow are intimately related. Flow can become storage by capturing it in some type of container, such as a reservoir. Storage can become flow by releasing it from that container. (A continuous flow of one cubic feet per second for 24 hours is equal to roughly two acre-feet of storage.)

Water is stored in reservoirs for several different purposes. Water stored for later release to meet a downstream demand, such as irrigation demand when stream flows naturally become low, is termed conservation storage because it is water conserved to meet a future use. The primary purpose of El Vado Reservoir is to provide conservation storage for irrigation use. Flood control storage is water temporarily stored to prevent or alleviate downstream flooding. Permanent storage, such as the Cochiti recreational pool, is maintained indefinitely to provide recreational, fish, and wildlife benefits.

WATER ACCOUNTING

All the water flowing through the basin is accounted in one fashion or another to ensure that its management and use is in compliance with all applicable law. All reservoir storage and flows at particular gages are accounted to ensure that Colorado is meeting its Rio Grande Compact obligation to New Mexico and that New Mexico is meeting its obligation to Texas. Water is also accounted on the level of individual ownership of various parties who have a right to its use such as the irrigation storage water released by the MRGCD, San Juan–Chama water moved from one reservoir to another by various parties, or supplemental water leased by the federal government for the endangered silvery minnow.

IRRIGATION OPERATIONS

Irrigation operations primarily consist of changing the rate and timing of storage releases from El Vado Reservoir to ensure there is sufficient flow in the Middle Rio Grande to meet the irrigation diversion needs of the MRGCD. To determine the rate of release, the MRGCD evaluates the amount of native flow moving downstream in the Rio Grande at Embudo and the amount of native flow contributed by the Rio Chama and other tributaries and compares that amount with their estimated future diversion demand. Diversion needs must be estimated two or three days into the future in order to determine how much storage to release from El Vado Reservoir to supplement the natural flow, as it takes that much time for those releases to reach the middle valley. Diversion needs fluctuate with weather conditions and the day of the week. Irrigation demand is generally higher on weekends, except holiday weekends. Irrigation storage is released only when the natural flow is insufficient to meet the MRGCD's irrigation needs. Natural flow is generally only sufficient to meet that need early and late in the irrigation season, during the snowmelt runoff and during periods of heavy monsoon activity.

FLOOD CONTROL OPERATIONS

Flood control operations adjust the rate and timing of releases or detention of inflow at the Corps of Engineers' flood control reservoirs: Abiquiu, Cochiti and Jemez Canyon Reservoirs. Releases at the fourth flood control reservoir—Galisteo—are uncontrolled. The four reservoirs are operated as a system to ensure that flow levels at critical downstream points are not exceeded. Flood control operations usually occur during snowmelt runoff when the mountain snowpack is heavier than normal and during heavy summer monsoon seasons. The snowmelt runoff of 2005 was the most recent major period of flood control operations, when approximately 75,000 acre-feet of flood control storage was detained in Abiquiu and 45,000 acre-feet in Cochiti. That water was released once runoff flows receded and it was safe to do so.

Article VII storage restrictions do not impact flood control operations at Abiquiu, Cochiti, or Jemez Canyon. In addition, in accordance with federal law, when the natural flow during the tail end of the snowmelt runoff drops to a level that is insufficient to meet MRGCD's diversion needs, any floodwater in storage is retained until after the irrigation season ends to ensure that the Rio Grande Project receives the water it would have if the flood control reservoirs did not exist.

ENVIRONMENTAL OPERATIONS

Environmental operations for the endangered silvery minnow have had the most impact on the Middle Rio Grande in recent years. Since 1996 the U.S. Bureau of Reclamation has been leasing water from willing parties to provide supplemental flows for the minnow in the middle valley. Since 2001 that supplemental water has been used to meet legally established levels of flow for the minnow as required by the Endangered Species Act. This water is leased and stored in Heron, El Vado, or Abiquiu Reservoirs and released during times when the natural flow of the river becomes too low to maintain certain levels in specific reaches of the Middle Rio Grande. A significant amount of management and coordination between the federal, state, and local water management agencies is necessary to successfully accomplish these operations. It is particularly difficult to efficiently provide relatively small flows to the lower end of the system at San Marcial by release of supplemental water stored in reservoirs on the Rio Chama when it takes five plus days for those releases to travel that distance.