

Long River, Short Water: The Rio Grande Water Development Story

Steve Harris, *Rio Grande Restoration*

The rich alluvial valleys of the Rio Grande have supported agriculture for nearly a millennium. In a semiarid land, through capricious swings of drought and flood, the soils and water of the river have nurtured substantial civilizations and inspired cultural traditions that continue to enrich modern New Mexico.

The river's first farmers were Pueblo people. One scholar estimates sixteenth century Pueblo populations as great as 80,000 persons, in 100 villages, making the Rio Grande Pueblo civilization the greatest concentration of settled farming villages in the American Southwest. The first farmers were irrigators, though they appear to have relied more upon such elegant moisture-conserving techniques as water-retaining terraces, cobble mulches, and self-contained "waffle gardens" than on intensive dam and canal systems. Because labor requirements were high, Puebloan agriculture was a necessarily cooperative venture. Their use of resources was likely governed less by political control than by traditional sacred relationships to land, sky, and river.

Though at times as many as 30,000 acres may have been cultivated, Pueblo impacts to the stream would seem modest to modern-day farmers. European explorers marveled at the quality and abundant yields of Pueblo plantings. Indeed, the earliest Spanish colonists might have perished without the surpluses of corn and beans laid up by the first farmers.

THE SPANISH ENTRADA

In 1591 the frontier of European expansion reached the Rio Grande. Driven hither by the quest for wealth and Christian evangelism, Spanish conquistadors found both minerals and souls were hard to come by. Still, compared with the expanse of desert to the south, the *Rio Bravo del Norte* offered rich soils and abundant water. Encouraged by grants of land from the royal government, a stream of Spanish immigrants, mainly impoverished exiles, flowed into the region over a 250-year period and conquered the north.

An advanced irrigation technology came with them, in the form of acequia agriculture. Headings of rock and brush and hand dug canals served to turn water onto pastures and cultivated fields. In the few large towns royal governments, *alcaldes* and *ayuntamientos*,

governed colonial affairs, including the division of water, whereas in the many small villages an indigenous water democracy maintained a cooperative governance by acequia *majordomos* and *comisionados*.

Spanish traditions, grafted onto new world realities, suggest that water users shared the benefits and losses of the variable supply. Priority of first use was respected, though not with such exclusivity as in the modern appropriation doctrine. When water was scarce, demonstrated needs (especially for drinking water and stock watering) and concepts of fairness were often the basis for an allocation decision. These traditions continue to carry legal weight, as formalized in the 1907 Territorial Water Code.

By 1821 acequia agriculture, both Pueblo and Hispanic, had grown until it involved no more than 150,000 scattered acres between Taos and Tome. Possessed of pragmatic technologies for water control, acequia irrigators relied on cooperation, hard labor, and the will of God to bestow the blessings of the river to their land.

ANGLO-AMERICAN CONQUEST

The United States' conquest of Mexico's northern territories in 1848 signaled a profound transformation of the localized, cooperative traditions of water development and governance on the Rio Grande. In their place, industrial technologies and the U.S. doctrine of "Manifest Destiny" established a model for national possession of western lands. Henceforth, a restless hoard of speculators swept over North America's vast western empire to turn minerals, timber, grass, and water into dollars.

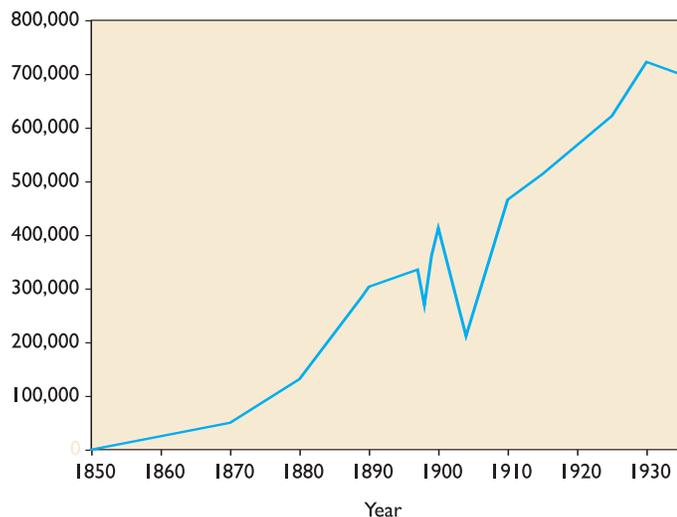
Agriculture was a key part of the U.S. national policy of rapid immigration and development of the West's natural resources. However, to farm successfully beyond the one hundredth meridian required irrigation. From a few successful experiments with large-scale irrigated farming, ambitious water diversion projects spread like prairie fire to every river valley in the West. Quickly, possession of western rivers was granted not to the owners of the land or the communities through which they flowed, but to the persons who built the works that diverted them.

The growth of irrigation from the Rio Grande typifies

the explosiveness of this process. In 1850 Rio Grande farms from San Luis Valley of Colorado to El Paso Valley, Texas, totaled less than 200,000 acres. By the time the temporary Rio Grande Compact was signed in 1929, irrigation in the basin encompassed more than 1,000,000 acres.

COLORADO DEVELOPMENT

The vast, fertile, high-elevation San Luis Valley was not settled until 1851, when Hispano settlers spilled northward from the Taos region and were soon joined in 1878 by westering Mormon farmers. The opening of the Denver and Rio Grande Railroad to Alamosa in 1878 ignited the biggest of the Rio Grande's "big barbecues." Between 1880 and 1890 British speculators financed five large canals dug by mule-drawn scrapers. Cumulatively these canals could divert almost 5,000 cubic feet per second, virtually the entire spring runoff of the main river. Colorado attempted to secure legally the natural advantage of its location at the top of the hydraulic system, claiming an unimpeded right



Irrigated acreage in San Luis Valley, Colorado, illustrating the growth in upstream water diversions, which has dramatically impacted New Mexico water supplies from the Rio Grande.

to the waters that arose within the state. Though disabused of their "doctrine of sovereignty" by the Supreme Court in 1917, the great deeds of irrigation development were largely already done. A general stream adjudication completed in 1891 showed that more than 300,000 acres had been placed under ditch. The impact of this rapid and extensive development would be immediately felt by downstream water

users and would impact the course of Rio Grande history for more than a century to come.

NEW MEXICO

Meanwhile and farther south, expansion of irrigation was also occurring, though at a more restrained pace. In the Rio Arriba (that stretch of the river north of La

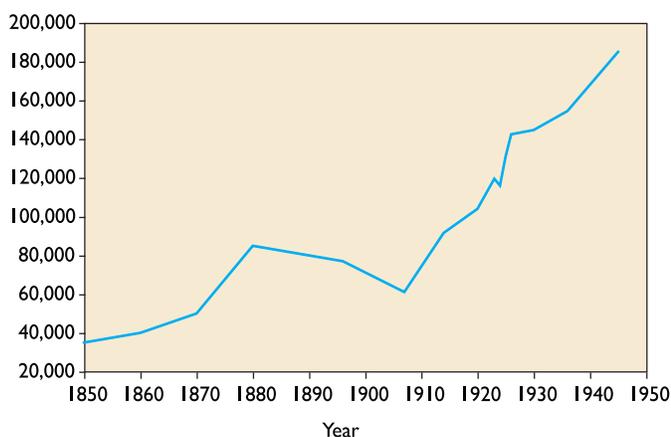


"The Big Barbecue"—a term applied by historian Charles Wilkinson to the rapid conversion of Western resources into wealth in the late nineteenth century. This log jam is on Embudo Creek, circa 1915. The timber was headed to the Rio Grande, through White Rock Canyon, and ultimately by rail to Albuquerque.

Bajada), irrigation had long since reached its full development, with perhaps 100,000 acres applying water from the several hundred acequias originating in tributary streams. In the Rio Abajo (middle Rio Grande), after the settling of Tome in 1739, Spanish–Mexican farming grew continuously until 1880, when it comprised about 124,000 acres, irrigated by more than 70 traditional acequias.

When the Atchison, Topeka, and Santa Fe Railroad reached Santa Fe in 1880, New Mexico also connected to commerce with the wider nation. Industrial-scale grazing began to make economic sense, and the north experienced a sheep-grazing boom. Likewise, thousands of acres of Sangre de Cristo forests were harvested and boomed down the Rio Grande to Embudo Station for use as railroad ties. A result of this large-scale timber development, abetted by a national policy of fire suppression, was that the Rio Grande's high-elevation watersheds, upon which the region's acequias depended, were rapidly transformed. Snowmelt in the Rio Grande's tributaries began to come more

quickly and in reduced volume, its hydrographs less attenuated into the summer season. Sediments released by logged-off forests and grazed-off grasslands aggraded river channels, which, with reduced peak flows from Colorado diversion, were less able to maintain themselves.



Irrigated acreage in Mesilla, Rincon, El Paso, and Juarez valleys, New Mexico, Texas, and Mexico, illustrating the sharp growth in irrigated acreage after construction of Rio Grande Project canals below Elephant Butte.

THE RIO GRANDE PROJECT

Water development in the Mesilla and El Paso/Juarez Valleys followed the pattern of the Middle valley, up to a point. An 1858 survey portrayed acequia farming in the region utilizing about 10,000 acres. By 1880 as many as 25,000 acres may have been irrigated, and speculators had their eyes on more.

But in 1890 what would become a nine-year drought descended on the Rio Grande. The years of low snowpack dampened the onrush of development and led to substantial, if temporary, declines in irrigated acreage. The San Luis Valley took whatever water it could, and the middle valley often diverted what remained of the river. In the El Paso/Juarez Valley, these upstream diversions compounded the drought and caused the region's famous vineyards to wither and die. About the same time, and far downstream, steamboat navigation of the Rio Grande below Laredo ceased forever.

In 1889 the Rio Grande Dam and Irrigation Company of Mesilla, New Mexico, was incorporated and proposed the construction of a reservoir and canal system to irrigate 530,000 acres in Mesilla Valley. By 1895 the company had received approval for a reservoir

right of way from the Secretary of Interior. El Paso/Juarez farmers responded to the impending, profound water shortage with outrage, leading Mexico to file damage claims for \$35,000,000 against the United States. Here was a serious diplomatic breach, and the International Boundary Commission was assigned to study the problem. The problem, their report concluded, was that the border area "suffered from the increased use of water in Colorado."

After a decade of diplomatic wrangling border officials in the two countries determined that the solution was to build a storage dam at the El Paso Narrows. Suddenly there were two conflicting reservoir proposals on the table. El Paso/Juarez interests were utterly opposed to the Elephant Butte Project; it was too far away, and the speculators were geographically too well-positioned to intercept and control the water. New Mexico strenuously opposed the El Paso dam, which provided no water storage for proposed developments around Mesilla.

By 1906 an unlikely, but momentous, series of events had occurred, resulting in resolution of the 18-year-old problem:

- First, a territorial court rejected U.S./Mexico arguments that the private dam would illegally interfere with navigation of the river. Resolving the litigation in the case's third review, the U.S. Supreme Court ruled that the Rio Grande Dam and Irrigation Company had waited too long to begin construction on the Elephant Butte Project. Its patent was thereby repealed, clearing the way for a single federal project.
- The International Treaty of 1906 "to equitably distribute the waters of the Rio Grande" was signed by both nations, who assented to a three-way split of the lower Rio Grande. In the 1906 treaty, Mexico settled for a 60,000 acre-feet guarantee, delivered from the reservoir each year "except in times of extraordinary drought."
- After more than twenty years of stormy debate on how best to advance western irrigation, Congress passed the landmark Reclamation Act of 1902, creating a firm policy of federal financing (and control) of irrigation development. In exchange for the territorial engineer's granting 730,000 acre-feet of water rights to the federal Rio Grande Project, New Mexico induced its border neighbors to accept the Elephant Butte Reservoir site.
- In 1908 "all the unappropriated waters of the Rio

Grande and its tributaries” were decreed to the Reclamation Service. In 1911 construction began on the project; by 1916 a completed Elephant Butte Reservoir, one of the Reclamation Service’s first projects, began to store the 2.6 million acre-foot for which it was designed.

RIO GRANDE COMPACTS

A federal embargo, declared by the Secretary of Interior in 1896, prevented Colorado from constructing the dam it desired at Wagon Wheel Gap but otherwise did little to reduce the development of new irrigation. While Supreme Court cases, international treaties, and major reservoirs were being negotiated, the sovereign state of Colorado continued expanding its exploitation of the Rio Grande. In 1924 San Luis Valley water commissioners reported a total of 621,826 acres under irrigation, up from 213,210 in 1896.

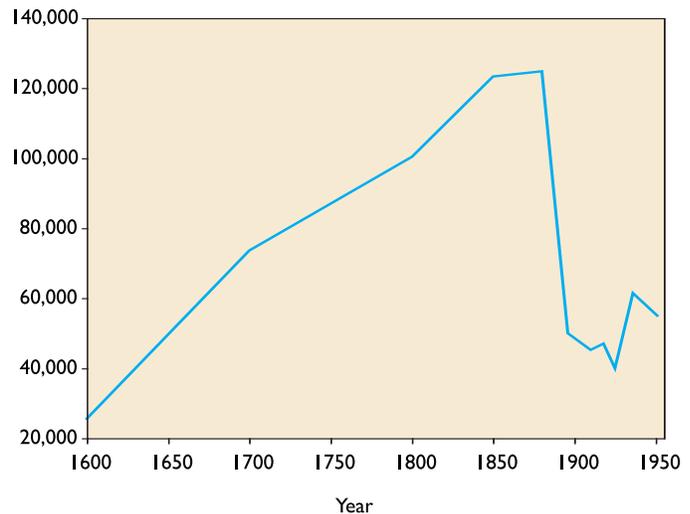
Fervid ambition was the only factor governing either the Rio Grande Project or San Luis Valley development, as by 1929 irrigation had increased dramatically, both downstream of Elephant Butte and in Colorado. Even with a period of abundant snows in the 1920s, the Rio Grande regularly disappeared at late season in the middle valley. It was becoming clear that only an interstate agreement could bank the fires of the Rio Grande’s big barbecue.

In 1925 the embargo was lifted, as Colorado, New Mexico, and Texas agreed to seek an interstate compact equitably dividing the Rio Grande among them. A temporary compact was put into effect in 1929 to freeze the apportionment at then-current levels. To effect a permanent agreement, and to determine the nature of the water supply and the relationship of each segment’s demands, required the collection and analysis of water-use data. Under auspices of the National Resources Committee, national and state scientists conducted an exhaustive joint investigation to determine the facts needed to equitably balance each section’s inflow, outflow, and demand.

Completed in 1935, the National Resources Committee’s regional planning report provided the foundation for a definitive negotiation among the states. The report acknowledged that the Rio Grande was at or beyond the limits of the water it could be expected to provide: “...with the available water resources of the Rio Grande apparently fully appropriated, the approval of any new projects involving additional drafts upon those resources seem to point inevitably to further conflict...”

The three sections’ bottom line for negotiations to

resolve the conflict was clear. Colorado would consolidate the dramatic gains it had made and perhaps be allowed to build a storage reservoir. The middle valley, too, would need its own reservoir to regulate late season supplies. Rio Grande Project users wanted assurance that the others would leave enough water to supply their needs and aspirations. Thus informed, the compact commissioners and their legal and technical advisers negotiated, over three years, a set of delivery schedules and various caveats to fix their irrigation demands to the fluctuating supply, resulting in the present Rio Grande Compact.



Irrigated acreage in Middle Rio Grande, Cochiti to San Marcial, New Mexico, illustrating precipitous declines in irrigation when sediment burdens and aggrading channels combined to waterlog more than half of the historically irrigated lands. Note also the partial reclamation resulting from MRGCD and federal projects.

MIDDLE RIO GRANDE PROJECTS

With or without interstate accords, the Middle Rio Grande valley increasingly found itself in a desperate position: bracketed by two thirsty, fast-moving competitors, one of which had recently vouchsafed a claim to virtually the entire flow of the river. Its organizing principle, the acequia system, isolated it from the power politics of large-scale irrigation. It had no reservoir to regulate a diminishing river. Its economy was also declining in lockstep with intensifying competition from the other two regions and the deteriorating condition of its lands.

Not only were its supplies of river water diminishing, but in the mid-river, the Rio Grande was leaking into the fields. By 1896 irrigated agriculture had declined from a high of 125,000 acres to 50,000

acres. The deadly combination of silt from deteriorating watersheds being deposited in the channel, reduced channel-forming flows from water intercepted by upstream irrigators, and its own flood irrigation practices clogging the Rio Grande, raised its channel above the elevation of the surrounding floodplain and seeped into much previously productive land. A 1918 state engineer inventory of middle valley conditions revealed nearly 60,000 acres of waterlogged and alkali-salted former farmland. In addition, the aggrading river flooded with increasing frequency, playing havoc with earthen irrigation works and cutting sandy channels across the beleaguered farms.

Following several abortive local efforts to finance a drainage system, a joint Bureau of Reclamation–state engineer commission proposed a solution: a comprehensive plan for drainage, flood control, and channel



The same bend in the Rio Grande near San Acacia in 1905 (left), showing a broad channel, flood-swept sandbar, and large wetland in distance, and again in 1989 (right). By 1989 the river flowed only partly in its native channel, with a levee, riverside drain,

rectification, complete with a (180,000 acre-foot) storage dam, and a consolidated series of diversion dams and main canals to replace the primitive diversions and ditches. Because such a project promised to be extremely costly, farmers hoped that it might be financed through the federal Reclamation Fund. However, because New Mexico had already received a substantial share of such funds in the lower river, another mechanism would have to be found.

An intensive lobbying effort by Albuquerque and rural leaders convinced the state legislature to approve the Conservancy District Act of 1923. Districts created pursuant to this act were to be organized and administered by a state district court, upon petition by 100 landowners. After two petitions to the district court, the Middle Rio Grande Conservancy District was suc-

cessfully organized in 1925. The Middle Rio Grande Conservancy District was to serve all lands in the floodplain of the Rio Grande between Cochiti and San Marcial and thus could add its assessments for flood protection to the property taxes collected from residents of Sandoval, Bernalillo, Valencia, and Socorro Counties. The 130,000-plus acres projected to receive irrigation water from the district would be levied additional assessments to construct and maintain those works. Included in the conservancy district were 28,500-plus acres of Pueblo Indian lands, for which Congress appropriated more than \$1.5 million to cover construction costs on Indian lands.

At the outset, some of the district's intended beneficiaries opposed creation of the district, and many remained suspicious of its subsequent arrangements. The Middle Rio Grande Conservancy District was a



and main canal joining the Santa Fe railroad along its neatly engineered course. A thicket of invasive salt cedar now covers the floodplain and confines the river channel, which has narrowed by 200 feet and aggraded 15 feet in the 84-year interval.

new and powerful political subdivision of the state, with extensive powers to make regulations, levy taxes, condemn and own lands and water rights, salvage water, remove or relocate structures, fill lands, retard silt, re-engineer stream channels, construct drains, dams, levees, canals, roads, bridges, stream gages, and electric power plants. Its water rights were to be exempt from forfeiture under state law or taking by other political subdivisions. As it condemned existing acequias, the conservancy was required to supply its parciantes (shareholders) with the water entitlements to which they had become accustomed.

In 1928 the Middle Rio Grande Conservancy District submitted its "Official Plan for Flood Control, Drainage and Irrigation" to the district court. Construction soon began on four diversion dams,

their connecting main canals, a valley-wide system of riverside and interior drains, and El Vado Reservoir. Initial tax assessments appeared to be substantial enough to satisfy court-appointed appraisers that the district could service the bonds it let to finance the estimated \$12 million cost of construction.

Unintended consequences from the conservancy district's project were substantial. Water supply to some ditches was interrupted during construction, reducing their *parciantes'* ability to farm for one or two years. Several thousand acres of farmland were condemned for rights of way to the drains and canals. A number of irrigators failed to make their annual assessment payments, resulting in foreclosure of some 34,000 acres by the state. Other ratepayers felt that the original glowing promises of project benefits had been overstated. Certainly, the flood control works did not prevent the devastation of the Socorro division by the 1937 and 1941 floods. Siltation and aggradation of the channel continued to plague the river. Additionally, there were, and continue to be, assertions that the broad powers of the Middle Rio Grande Conservancy District inhibited the state engineer's authority to administer individual water rights priorities.

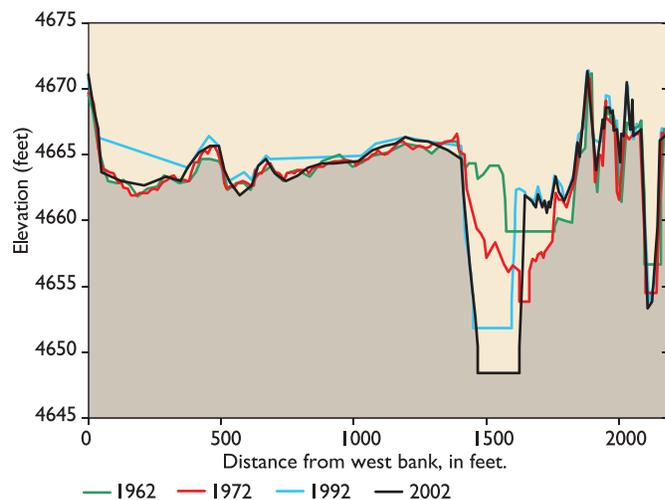
At least some of the project's benefits were realized: as many as 20,000 acres were drained and (at least temporarily) reclaimed for farming. The construction of El Vado Reservoir succeeded in extending late-season water supply to the district's four irrigation sections.

Further bedeviling the Middle Rio Grande valley, an interregional conflict erupted when the district began to fill El Vado Reservoir for the first time in 1935. Texas sued New Mexico and the Middle Rio Grande Conservancy District in the U.S. Supreme Court, claiming that the defendants were impairing the water supply in Elephant Butte, in violation of the 1929 compact. This litigation was dismissed after the 1938 compact was signed by the three states. By 1941 Congress was authorizing the Corps of Engineers to study the still-unmet drainage and flood control needs of the region.

Nor did the district quite succeed in rescuing its farmers from financial woes. In danger of defaulting on the bonds that financed the project, the district appealed to Congress in 1948 for relief of its debts and the rehabilitation and further improvement of its dam, diversions, and levees. The Flood Control Act of 1948 authorized a Middle Rio Grande Project through the U.S. Army Corps of Engineers and appropriated \$15 million through the Bureau of Reclamation to provide the district with debt relief and another round of middle valley "improvements." These improvements included 300,000 jetty jacks to straighten and confine

the river channel. Reclamation was to hold the titles to the water rights and capital works as security for repayment of this crucial federal investment.

The focus of the Middle Rio Grande Project was primarily on the worsening siltation problems. It gave the Bureau of Reclamation the authority to maintain an open river and funds to channelize 127 miles of river from Velarde to Elephant Butte, resulting in the placement of over 300,000 jetty jacks to confine the river channel over the next 20 years. The Flood Control Act of 1950 authorized more than \$50 million to the Corps of Engineers to construct flood and sediment control reservoirs, the crux of a strategy to radically reduce sediment inputs to the valley. Abiquiu Reservoir on the Rio Chama and Jemez Canyon Dam were completed for this purpose in 1954. Construction of the additionally contemplated sediment and flood control reservoirs was deferred until a Rio Grande Reservoir Regulation Plan was negotiated to the satisfaction of Colorado and Texas. In 1965 the corps began work on its own Middle Rio Grande Project, completing Galisteo Dam in 1970 and Cochiti Dam in 1975.



Time series of Rio Grande channel forms near San Acacia, showing a dramatic narrowing and incising of the river channel.

Cochiti has been a particularly significant development in the history of the Rio Grande. Its location on Cochiti Pueblo lands displaced much of the floodplain farming that was culturally and economically critical to the tribe. During its construction, a sacred site important to Cochiti and its neighboring Pueblos was carelessly destroyed. Then, when the reservoir filled, seepage below the dam waterlogged what remained of the Pueblo's farmlands. One intended benefit, sediment abatement in the middle valley, resolved itself

poorly as sediment-starved waters began to progressively scour the river channel downstream. Cochiti Reservoir's position athwart the mouth of White Rock Canyon isolated the river below from a natural refugium for aquatic species, contributing to the decline and endangered status of the Rio Grande silvery minnow. It has, however, kept its flood control promise, intercepting potentially damaging floods in 1979, 1985, and 1995.

RECENT TIMES

The Rio Grande Compact, with its cornerstones of sound science and frank if difficult negotiations, has served to moderate the consequences of the Rio Grande's century-and-a-half-long development orgy. The compact, first administered in 1940, is the foundation of today's "law of the river," which also includes a welter of contracts between special water districts and the Bureau of Reclamation, water rights administration in three states, and the decisions made by thousands of individual water users and their districts.

Unfortunately, both Colorado and New Mexico have found that they cannot always reliably comply with the compact's downstream delivery requirements. And so, when threats of harm cannot otherwise be reconciled, the courts are standing by.

During the severe drought of the 1950s the New Mexico State Engineer and the Middle Rio Grande Conservancy District again found themselves before the U.S. Supreme Court to answer for a water debit that had exceeded its 200,000 acre-foot limit allowed by the compact. The proximate cause of this action was a renewed assertion that New Mexico was storing water in El Vado Reservoir in violation of the Rio Grande Compact. The U.S. Supreme Court dismissed this litigation, ruling that Texas had failed to name an indispensable party, the United States in its capacity as trustee for the six Middle Rio Grande Pueblos and their water rights.

By 1956 New Mexico's debit had grown to more than 500,000 acre-feet, before rehabilitation of waterlogged lands undertaken by the Middle Rio Grande Project could produce additional water flows. The Low Flow Conveyance Channel, which began operating in 1953 in an attempt to make New Mexico's compact deliveries more reliable, provided a bit of the long sought drainage objective. The channel did, in fact, produce water and reduced the state's compact debit, but today it serves mainly to drain a Rio Grande channel perched dozens of feet above the surrounding floodplain.

The San Juan–Chama Project also helped New

Mexico to become compact compliant. The project began diverting water from the San Juan River basin into Heron Reservoir in 1972, and started releases in 1974. One of its original stated purposes was to provide 42,500 acre-feet per year to "replace previous and anticipated [Rio Grande] basin depletions caused by miscellaneous uses." San Juan–Chama Project water has helped ease the state's chronic non-compliance, sending an average of 30,000 annual acre-feet downstream, effectively offsetting water sucked from the river by ground water pumping.

During the same period, Colorado's accrued debit swelled to almost 1,000,000 acre-feet. In 1966 New Mexico joined Texas in a Supreme Court suit that resulted in an agreement by Colorado to begin to reduce its huge deficit. Across-the-board curtailment of San Luis Valley irrigation forced farmers to conserve and reduce their water applications.

The federal Closed Basin Project, which began salvaging shallow ground water in 1984, was designed to reduce the state's accrued debit. Nevertheless, it was not until Elephant Butte Reservoir spilled in a very wet 1985 that Colorado's 30-year-old water debt was forgiven.

Over the past 20 years, with a blessing of abundant snowpacks, both Colorado and New Mexico have maintained compliance with the water delivery requirements of the Rio Grande Compact.

FINALE

Stretched thin by the dizzying pace and magnitude of water development, the Rio Grande/Rio Bravo basin remains enmeshed in a perpetual conundrum: there are simply more claims to Rio Grande water than the river can reasonably be expected to provide. Its core ecology, the very structure, and function of the river have been profoundly altered, with unfortunate outcomes: It ceases to flow at the behest of unrestrained economics; its leveed banks armor continuously narrowing and aggrading channels, disrupting the conveyance of water; biodiversity continues to decline. Successive engineering projects have disrupted the productivity of its adjoining lands, now beset by invading plants and, consequently, fire.

Another chapter of the saga will be written by the present generation. Access to the river by growing, thirsty urban populations and the emergence of concern for the fate of Rio Grande ecosystems have joined the perennial contenders for the limited supply. The planned use of San Juan–Chama Project water by Albuquerque, Santa Fe, and other communities suggests that a challenging new version of the intricate old balancing act lies just ahead.

An Introduction to Rivers of the Arid Southwest

Robert A. Mussetter, *Mussetter Engineering, Inc.*

One of the most startling paradoxes of the world's drylands is that, although they are lands of little rain, the details of their surfaces are mostly the products of the action of rivers. To understand the natural environments of drylands, deserts, arid, and semiarid regions of the earth is to understand the processes and forms of their rivers.

—William L. Graf, *Fluvial Processes in Dryland Rivers*

Rivers are the primary conduits by which water and the products of continental weathering are delivered to the oceans. Flowing water provides the energy that moves the weathered soil and rock material, along with organic matter that is important to the ecosystem, downstream through the river system. The water is derived from precipitation that falls on the earth's surface and continues through the hydrologic cycle in a variety of forms, including surface runoff, infiltration into the ground water system, and evaporation and transpiration back into the atmosphere where it contributes to later precipitation. At many locations, much of the water that appears as river flow is derived from the ground water system, which provides storage that sustains stream flow during dry periods. In rivers with mountainous headwaters, winter precipitation is temporarily stored as snow until the seasonal temperatures rise above the melting point, releasing it into the local stream system.

The relative contribution of each of the above factors to the flow at any particular location and time varies considerably. Intense local storms can cause extreme changes in stream flow over very short time periods on the order of minutes to hours, whereas seasonal changes in temperature and precipitation result in predictable patterns in stream flow over the course of the year. Longer-term climate variability causes both cyclical variability and random fluctuations in the amount of stream flow over a few to many years. Global warming may also affect long-term stream flow patterns.

In addition to stream flow that is mostly climate driven, the physical characteristics of rivers are strongly influenced by the basin geology that controls the character of the sediment in the river bed and banks, and provides structural controls on the alignment,

slope, shape, and dynamic behavior of the river. From the human perspective, these characteristics are critical because they affect the capacity of the river to safely carry flood flows and its ability to continue carrying lower flows when the water is essential to ecosystem health and water supply needs. The dynamic (erosional and depositional) behavior of the river is also important because it affects the safety of infrastructure, particularly during high-flow periods.

Because water is key to nearly all physical and biological processes, river corridors are a critical component of the natural ecosystem. This is nowhere more true than in arid regions, where the health of the riparian corridor is tied directly to the amount and timing of flow that mostly originates from outside the local area. Natural stream flow patterns in arid rivers tend to be more variable than in temperate- or humid-zone rivers, and the species that are found in arid rivers generally have adapted to this high variability. Human use of the water often alters the flow patterns and thus the health of the ecosystem. Understanding these effects and managing water use to support human needs and protect public safety during flooding, while minimizing ecosystem impacts, are key challenges for river managers.

HYDROLOGY OF THE RIO GRANDE

All of the above factors that affect stream flow are important in the Rio Grande basin. The Rio Grande, originating in the mountains of southern Colorado, is the fifth longest river in North America, with a total contributing drainage area of about 176,000 square miles, including the arid lands of New Mexico, Texas, and northern Mexico. Annual precipitation in part of the upper basin averages nearly 40 inches per year, whereas much of the middle and lower basin receives less than 10 inches per year. Typical of arid rivers, the Rio Grande tends to lose flow in the downstream direction, and did so even under native (pre-European settlement) conditions, due to infiltration and evapotranspiration. Upstream water use and to a lesser degree increased evapotranspiration losses caused by the proliferation of salt cedar and other non-native vegetation now cause river flows to decrease in the downstream direction even more so than under native



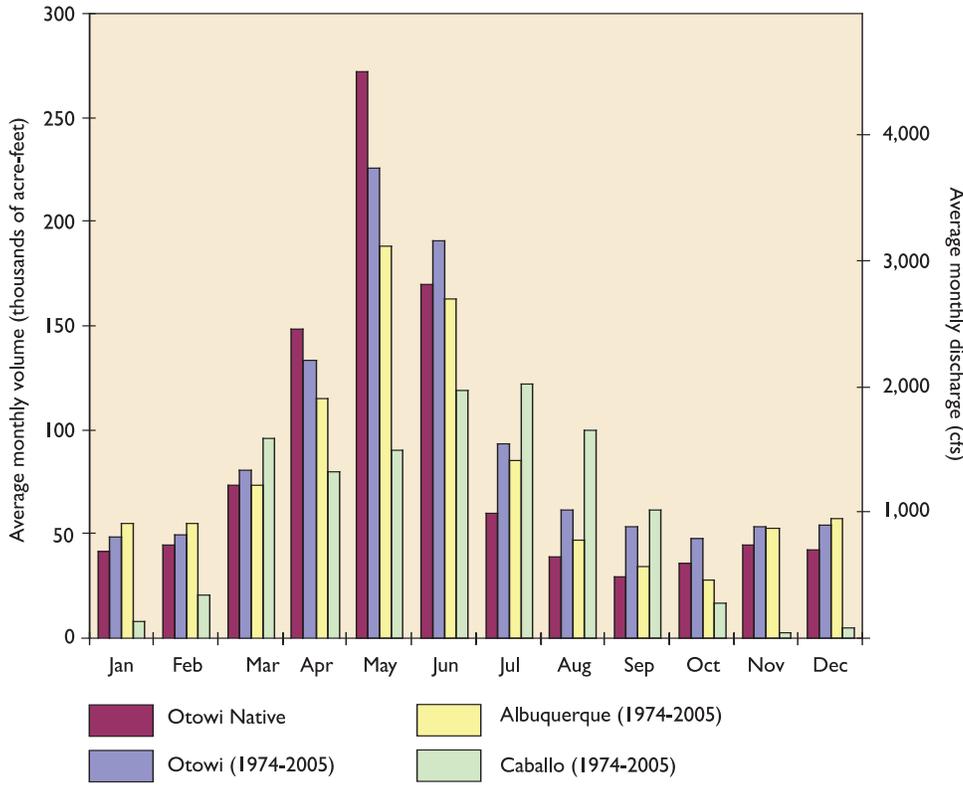
The Rio Grande watershed. The Rio Grande drains areas of three states and parts of northern Mexico.

Below El Paso the river forms the international boundary between the U.S. and Mexico.

conditions.

The annual water volume of the Rio Grande that flows past the Otowi stream gage above Cochiti Reservoir averaged about 1.1 million acre-feet under native conditions, and the current long-term average is about the same. The volume varies significantly

from year to year. The lowest recorded volume at Otowi since 1895 was about 360,000 acre-feet (1904), about one-third of average, and the highest recorded volume was about 2.4 million acre-feet (1940), about 220 percent of average. Over the more recent six-year period (water years 2000 through 2005), the average



Average monthly flows on the Rio Grande, at four locations, as noted.

less than the long-term average.

Native flow volume estimates unfortunately are not available for the middle and lower reaches. Since 1973 when Cochiti Dam was completed, the amount of water passing Albuquerque averaged slightly less than 1 million acre-feet per year, and this decreases to about 0.73 million acre-feet below Caballo Dam. The post-Cochiti average at Albuquerque was about 40 percent greater than the 30-year average from the early 1940s to early 1970s. The difference between the two periods is due to both direct human influence (e.g., imported flows from the San Juan–Chama Project, completed in 1971), and natural causes (i.e., extended periods of below average precipitation in the 1940s through mid-1970s and above average precipitation in the 1980s through mid-1990s.)

Under both native and current conditions, the bulk of the annual flow volume is derived from snowmelt from the upper basin; thus, the highest sustained flows typically occur during late spring and early summer. Prior to significant water development, about 60 percent of the annual native volume in the upper reaches occurred during April through June, and less than 15 percent occurred during July through September. Seasonal patterns in the downstream

reaches were probably similar to the upstream reaches. Human-induced factors, including the water storage system, imported flows, urbanization and channelization, and increased evapotranspiration as a result of non-native vegetation, now affect the seasonal flow patterns, with the magnitude of the effects increasing in the downstream direction. In the upper and middle reaches, about half of the annual flow volume now occurs during April through June, and the July through September percentages have increased to 15–20 percent. In contrast, only about 40 percent of the annual flow below Caballo Dam now occurs during May through June, but the amount during July through September represents about 40 percent of the annual volume.

The reasons for this difference are complex, but they are mostly driven by upstream, man-induced changes. Late summer, monsoon season runoff from the middle and lower basin is also a factor.

GEOMORPHOLOGY OF THE RIO GRANDE

The geomorphic characteristics of rivers represent the integrated effects of the physical factors in the basin and drainage network that include the quantity and timing of flow (i.e., the hydrology), drainage basin geology, riparian vegetation, and human modifications. Rivers tend to adjust their gradient, plan form (their down-valley and cross-valley alignment), cross sectional shape, and the sediment size toward a state of dynamic equilibrium (or long-term balance) with the upstream water and sediment supply. In this regard, it is a common premise that alluvial rivers tend to adjust their cross sectional size so that the capacity at which water will spill onto the floodplain (often referred to as the bankfull capacity) corresponds to the maximum discharge that occurs for a few to several days each year. Because of the highly sporadic nature of the runoff, however, arid rivers such as the Rio Grande may be close to equilibrium

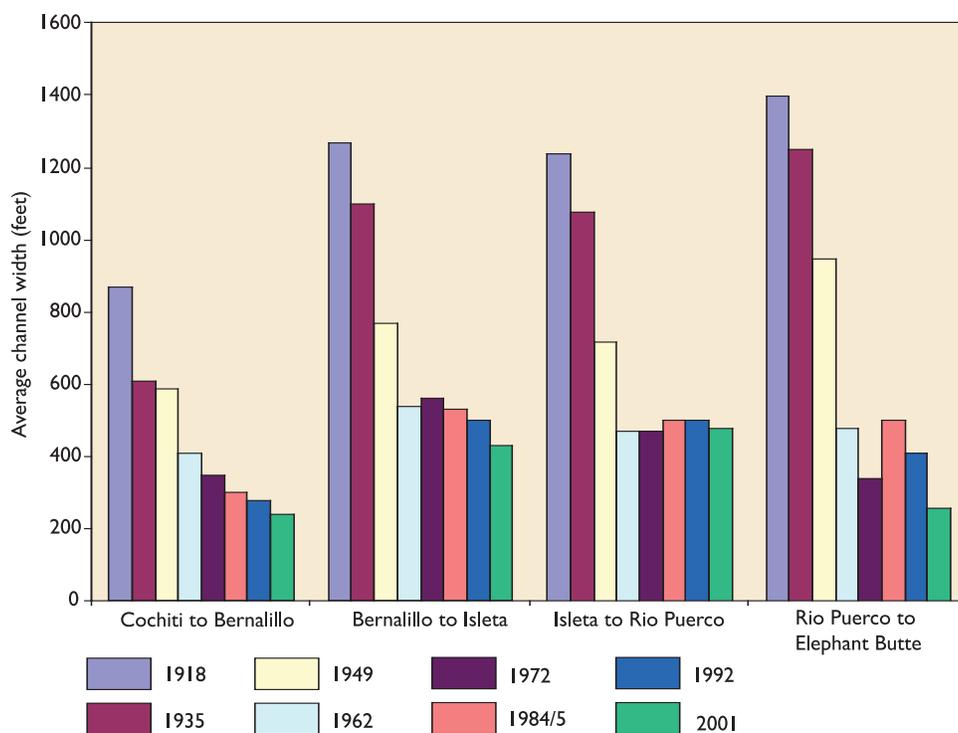
for only a very small percentage of the time; thus, the in-channel capacity can vary considerably from the annual peak flows.

High flows that occur on an annual or less frequent basis are the most important in forming and maintaining the river channel. Erosion, transport, and deposition of sediment during these high flows are, in turn, key to maintaining certain aspects of the ecosystem. In river systems like the Rio Grande, high flows result from both snowmelt runoff and runoff from intense rainstorms in the lower basin. Although the storm-driven flows can be as high, or higher than, the snowmelt-driven flows, the latter tend to occur for much longer durations; thus, they do more work in shaping and modifying the channel. Before construction of Cochiti Dam, the annual maximum snowmelt-driven discharge near Albuquerque exceeded 7,000 cubic feet per second (cfs) in about one of every two years, on average. With the upstream flood-control system, this maximum discharge is now only about 5,400 cfs. During the pre-dam period, peak discharges as high as 42,000 cfs occurred in the Albuquerque reach and 100,000 cfs near San Marcial, causing widespread flooding. The highest peak flow in the Albuquerque reach since completion of Cochiti Dam was 9,500 cfs in 1984, and the maximum flows rarely exceed 8,000 cfs.

In the Albuquerque reach, flow begins to spill into the bosque at 5,000 to 6,000 cfs, which is consistent with the current typical annual peak flow. Under native conditions, the in-channel capacity was much more variable both spatially and temporally than today due to channel enlargement during infrequent high flows and re-adjustment during longer duration low- to-moderate flow periods. The active channel now is more consistent in size along the reach and varies less in size over time than under native (pre-European settlement) conditions due to dampening of the extreme flows by the flood-control system and lateral controls on channel widen-

ing by the jetty jacks and infrastructure.

Both the gradient and sediment size tend to decrease in the downstream direction in most rivers, and the Rio Grande is no exception. The Rio Grande falls about 12 feet per mile between Velarde and the mouth of the Rio Chama, decreasing to about 4 feet per mile through the Albuquerque reach and to around 3 feet per mile between El Paso and Fort Quitman in the lower reach. Similarly, the typical bed material upstream from Cochiti Reservoir is mostly gravel and cobbles, changing to mostly sand at and downstream from Albuquerque. Even the sand decreases in size moving downstream from Albuquerque toward



Average width of the active channel of the Rio Grande at different periods, from 1918 to 2001 (Data from the Bureau of Reclamation).

Elephant Butte. The interaction of these particles with the flow significantly affects the dynamic behavior of the river. In gravel and cobble bed reaches, relatively high flows are required to move the material and adjust the shape and elevation of the channel bed; thus, the bed is static most of the time. In contrast, flows of nearly all magnitudes can move sand-sized particles; thus, the channel bed is under a state of constant adjustment in these reaches.

Historically, the middle and lower reaches of the Rio Grande carried one of the highest sediment loads of any river in the world, and much of this sediment



Oblique aerial view of the Rio Grande in the early 1960s, soon after completion of a jetty jack field and dredging of a pilot channel.

consisted of very fine silt- and clay-sized particles. Trapping of sediment by Cochiti and other upstream dams has significantly reduced the concentrations. Upstream from Albuquerque, concentrations are now only 2.5 to 3 percent of their historic values. Inflows from local tributaries with fine soils in their watersheds cause the concentrations to increase as one moves downstream from Cochiti toward Elephant Butte.

The fine material had a profound effect on the dynamic behavior of the river under historic conditions, and this effect continues today. During flooding, the silts and clays were carried into the overbanks where they settled out onto the valley floor, building up the floodplain and river banks with cohesive, difficult-to-erode sediment. As a result, the river banks are relatively erosion resistant, limiting the ability of the river to erode laterally. Because the fine sediment tends to have high water-holding capacity and is rich in nutrients, the overbanks provided excellent habitat for riparian vegetation that, historically, consisted of a variety of species including cottonwood. These characteristics are also very suitable for the more recently introduced non-native species such as salt cedar; thus, they are both a blessing and a curse with respect to the health of the riparian zone.

Under native conditions, the Rio Grande through the middle valley was relatively wide and braided with multiple smaller channels separated by active sandbars. In the early 1900s the active channel averaged more than 1,200 feet wide between Bernalillo and the mouth of the Rio Puerco. The river subsequently narrowed to only about one-third of its historic width due to the combined effects of the jetty-jack fields, other human encroachments, and reductions in the peak flows. The river has continued to narrow in some locations since the 1960s, but at a much slower rate, and it is likely approaching equilibrium with the regulated flow regime.

The river has undergone other important changes due to human activities that include changes in size of the bed material and changes in the elevation of the channel bed relative to the floodplain. The reach downstream from Cochiti Dam, for example, has exhibited the classic response to sediment trapping in a reservoir by coarsening the bed material and downcutting as the river made up for the deficit in sediment supply by mining material from the bed. Before construction of the dam, the bed material between Cochiti and Angostura was mostly sand, with 20 to 30 percent medium-sized gravel. The sand has now been largely depleted, and the bed material is primarily gravel. The bed has also downcut by an average of 2 to 4 feet. The gradient restoration facilities that were constructed over the past several years on and near the Santa Ana Pueblo below Angostura are an attempt to mitigate the effects of this downcutting. The opposite effect has occurred at the head of Elephant Butte Reservoir, where the flatter river gradient due to the reservoir has caused sediment deposition, raising the river bed by several tens of feet. The limited hydraulic capacity of the San Marcial Railroad Bridge is an obvious manifestation of this process.

The water development system in the Rio Grande basin is critically important in sustaining water supply and protecting public safety, but this system has changed the physical characteristics and dynamic behavior of the river. Although many of these changes provide positive benefits to our ability to use the river as a resource, they have also had unintended and undesirable consequences to both the health of the ecosystem and our ability to protect critical infrastructure. River managers face a difficult challenge in balancing the costs and benefits of maintaining the system, while finding ways to mitigate the unintended and undesirable effects.

The Surface Water/Ground Water Connection

Robert S. Bowman, *New Mexico Institute of Mining and Technology*

The surface water that we see flowing in the Rio Grande, in irrigation canals, and in drains is intimately linked to the underlying ground water. The surface water and the ground water in fact form one integrated system.

The ground water is not some mysterious lake or stream that's flowing below us out of sight; instead, ground water is simply water held in the spaces between grains of sand, clay, or gravel. In the soil, some of the empty spaces are also filled with air; deeper, the air is displaced, and the pores are totally water-filled. This is the ground water zone. If you dig a hole along the banks of the Rio Grande the hole will remain open and air-filled until a certain depth. Then, as you dig the hole deeper, it will fill with water to some level below the ground surface. This water surface is the level of the ground water table. Below this, you're in the ground water aquifer.

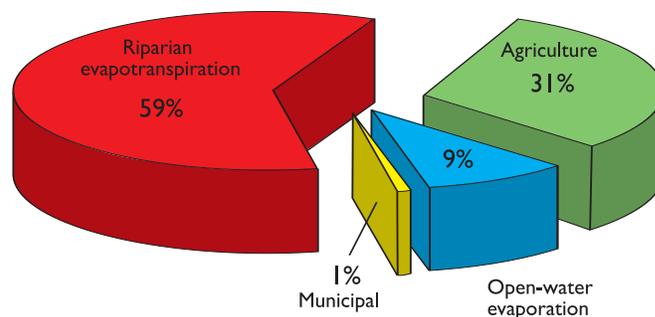
The Rio Grande valley between San Acacia and Elephant Butte Reservoir can be envisioned as a sand- and gravel-filled bathtub with a shallow trench running down the middle. The sides of the bathtub are the uplands and mountains rising to the east and west of the river; the bottom of the bathtub is formed by deep, compacted sediments. At the north end of the tub water flows into the trench (the Rio Grande) through the diversion dam at San Acacia. At the south end the Rio Grande flows into Elephant Butte Reservoir and eventually "drains" from the tub through Elephant Butte Dam into the Mesilla Valley.

As water flows down the Rio Grande some of it seeps through the river bed and spreads out underground. But it can only seep so far before it hits the relatively impermeable sides and bottom of the tub. So the bathtub gradually fills with water, the sand and gravel become saturated from the bottom up, and the water table rises. Once the water table reaches the base of the trench the seepage is reduced, and more of the water entering the valley at San Acacia stays in the river bed all the way to Elephant Butte.

Of course, the bathtub model is an oversimplification of the actual system; some river water can leak out the sides and bottom of the tub, and some water enters the tub from sources (such as rising geothermal waters) other than the river. But in general the water

that enters the valley stays in the valley until it reaches Elephant Butte. One exception, however, is the water consumed by evapotranspiration.

Evapotranspiration is the water lost to the atmosphere by evaporation from the soil and open water, and by transpiration of water through the leaves of plants. Another term for evapotranspiration is "consumptive use"—the water that is "consumed" and no longer available in the surface water/ground water system. To a first approximation, the only water that leaves the valley between San Acacia and Elephant Butte is that which is evapotranspired.



Estimated average annual consumptive use of water between San Acacia and San Marcial. Data provided by Nabil Shafike of the New Mexico Interstate Stream Commission.

The pie chart on this page shows the average annual consumptive use of water between San Acacia and San Marcial, upstream from where the Rio Grande enters Elephant Butte Reservoir. More than half of the consumptive use in this reach is evapotranspiration by riparian vegetation along the river, and almost a third is evapotranspiration from agricultural crops. In total, about 10 percent of the water flowing into the valley at San Acacia is lost to evapotranspiration by the time the river reaches San Marcial. Since most of the dissolved salts remain in the water during evapotranspiration, the salt concentration in the river and in the ground water generally increases as you move downstream. Small inputs of high-salinity water from natural sources other than the Rio Grande also make significant additions to the salt load of the system.

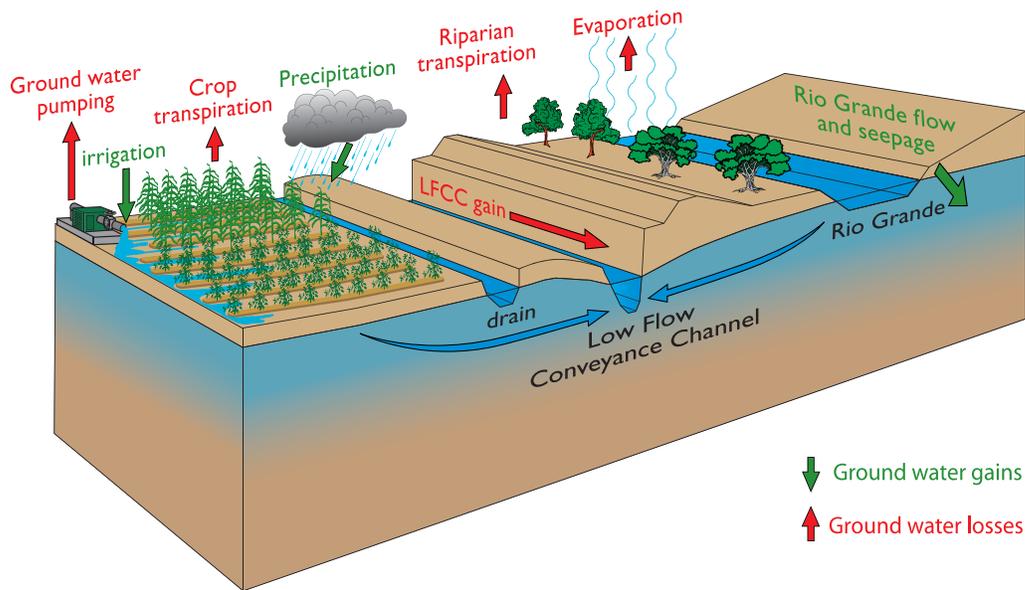
Until recent times the Rio Grande was the only

trench running the length of the valley. However, in response to the drought of the early 1950s and the precipitous drop in Elephant Butte Reservoir, the Low Flow Conveyance Channel (LFCC) was constructed to reduce seepage losses as water moved down the valley. After 1959 some or all of the water from the Rio Grande was diverted to the LFCC at San Acacia Dam and traveled approximately 75 miles to the head of the reservoir.

During the wet period of the mid-1980s Elephant Butte Reservoir filled to capacity; by 1987 there was no need to divert water from the Rio Grande into the

flow underground toward it from the east and the west. The LFCC thus currently acts as a surface drain.

The approximately 90 percent of the water remaining in the valley after evapotranspiration losses can move interchangeably between the surface and ground water systems. As mentioned above, water generally seeps from the Rio Grande to the shallow aquifer as it traverses the valley from north to south. But this ground water can appear once again as surface water in the LFCC. This surface water-to-ground water-to-surface water interchange is shown schematically in



Schematic cross section of the Rio Grande valley showing the linked surface water/shallow ground water system,

emphasizing gains and losses to the ground water. The LFCC gain is, in fact, a loss to the ground water.

LFCC. Elephant Butte receded during the 1990s, but sedimentation during the wet years plugged the channel and left the LFCC disconnected from the reservoir. Today the LFCC no longer flows into Elephant Butte but instead discharges into a large “delta” area at the north end of the reservoir, where it supports a dense population of salt cedar and other phreatophytes. Budgetary constraints along with the need to maintain minimum flows in the river (e.g., to support the silvery minnow population) have slowed progress in re-engineering the connection between the LFCC and Elephant Butte Reservoir.

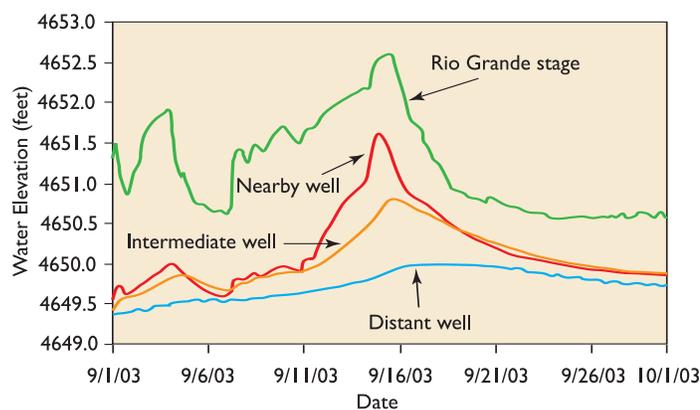
The average bed elevation of the LFCC is below that of the bed of the Rio Grande, and generally lies below the level of the ground water table—it represents a new, deeper trench in the bathtub. Since the LFCC is the topographic low point in the valley, water tends to

the illustration on this page. Just as water spilled on a sloping desk runs toward the bottom of the desk, water flows underground from a high point on the water table to points where the water table is lower. Ground water tends to flow from below the Rio Grande west into the LFCC, and from below agricultural fields east into the LFCC. Thus, even though the Rio Grande is no longer directly diverted into the LFCC, much of the river’s flow still ends up as surface water flowing toward Elephant Butte via this large drain.

The illustration above also points out many of the other important interactions between surface water and ground water, with an emphasis on gains and losses to the ground water. Water seeps from the Rio Grande as it flows southward, recharging the shallow ground water aquifer. Some of this water reemerges as surface water in the LFCC. Water is diverted from the

river at San Acacia Dam to supply the valley's farm irrigation system. A portion of the irrigation water applied to the fields percolates through the soil to recharge the ground water, and can move underground to the LFCC to reappear as surface water. Some of the rain and snow that fall on the watershed can percolate through the soil and reach the water table. And some ground water flows into the valley from the Albuquerque Basin to the north.

Simultaneously water is being lost from the system, and hence from the ground water, due to evapotranspiration. There is direct evaporation from the open water surfaces of the Rio Grande, the LFCC, and agricultural canals and drains. Close to the river, riparian vegetation transpires water to the atmosphere; farther from the river, in the irrigated portion of the valley, crops also transpire water. Water pumped by wells for irrigation and for domestic purposes removes water from the aquifer; much of this water is subsequently lost from the system as evapotranspiration.



Changing water table levels over a one-month period in wells in response to increasing flows in the Rio Grande below San Acacia Dam. The nearby well is 102 feet from the river, the intermediate well is 388 feet from the river, and the distant well is 1,224 feet from the river.

Compared to the hundreds of thousands of acre-feet that flow down the Rio Grande between San Acacia and Elephant Butte in an average year, relatively little ground water is pumped from the aquifer. During the wet period from the early 1970s to the late 1990s, when surface water was plentiful, almost no water was pumped for irrigation. Even during the dry years of the late 1990s and early 2000s, most of the water for irrigation was provided by surface water diversions from the river. Domestic well pumping in the region amounts to only a few hundred acre-feet of water per year.

The ground water pumping situation in the San

Acacia reach is in sharp contrast to that of Albuquerque and Bernalillo County. In 2005 about 100,000 acre-feet of water were pumped by Albuquerque city wells, and thousands more were pumped by domestic wells.

The ground water table responds very rapidly to changes in river flow, and flow in the river likewise responds quickly to changes in the elevation of the water table. The strong connection between surface and ground water levels is shown in the graph on this page, which illustrates the water table response to increasing river flows below San Acacia Dam following a series of heavy rainfalls in the fall of 2003. The changing river flow is shown by the stage (or height) of water in the river relative to sea level. The water table elevations in wells at different distances away from the river are also shown relative to sea level.

The ground water response to fluctuating river flows is dramatic. Within a few hours after an increase in river stage, increased seepage from the river causes the water table at a well very near the river to rise. An intermediate well responds later, and the well most distant from the river takes several days to fully respond. As the flow in the river decreases and the river stage drops, the water table drops correspondingly. In a sense the aquifer “breathes in” water in response to increased flow in the river. When the river flow decreases, the aquifer “breathes out” and returns some of the water back to the river.

A related but contrasting situation occurs when ground water is pumped from the aquifer by irrigation or domestic wells. Pumping of wells, particularly when they are close to the river, causes a drop in the water table elevation and an increase in the gradient between the river and the water table. Analogous to the gradient between the Rio Grande and the LFCC, this increased gradient causes more water to seep out of the river bed, reducing the flow in the river. The effect of a single pumping well on river flow may be difficult to detect, but the combined pumping of many wells can have a measurable effect. The large-scale pumping of the aquifer in the Albuquerque area since the 1950s has caused the water table to drop hundreds of feet in some areas, with a resultant increase in seepage from the river. This extraction of ground water has far exceeded the ability of river seepage to replenish it.

As shown by the above examples, the strong interconnections between surface water and ground water mean any perturbation in one part of the system affects the other. Ground water pumping lowers the water table and increases river seepage, ultimately

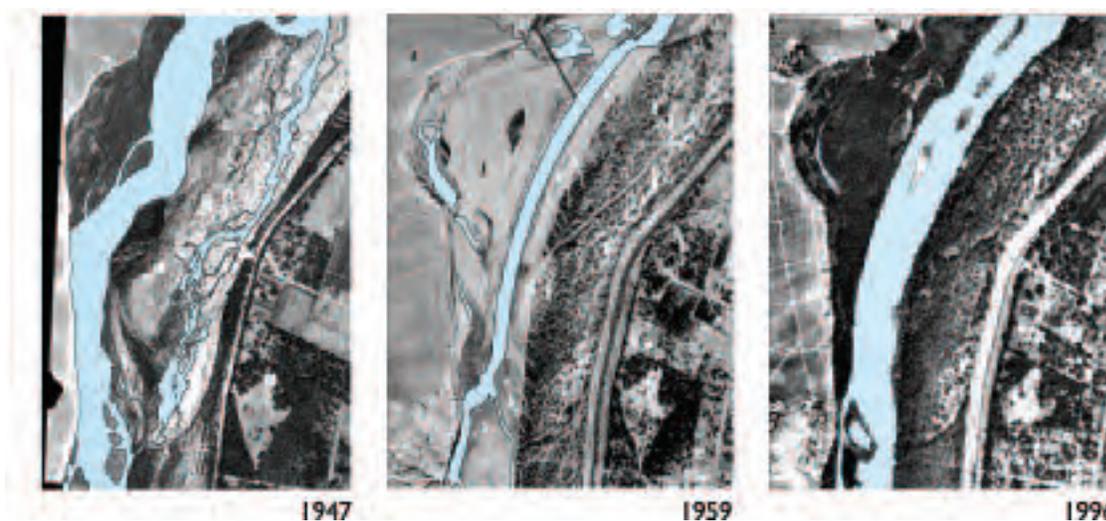
reducing flow in the river. Reducing seepage (e.g., by concrete-lining of irrigation canals or of the river bed itself) reduces recharge to the aquifer and allows the water table to drop, potentially reducing riparian evapotranspiration to the point that undesirable species such as salt cedar as well as desirable species such as cottonwood may be unable to survive. Thus, any alteration in river management will affect ground water dynamics, just as increased ground water pumping, particularly if water is exported out of the immediate vicinity, will cause changes in the Rio Grande and the riparian community it supports.

Ecology of the Middle Rio Grande of New Mexico

Mary J. Harner and Clifford N. Dahm, *University of New Mexico*

The Middle Rio Grande is located in central New Mexico between Cochiti Dam and Elephant Butte Dam. People have used the Middle Rio Grande and its surrounding land for centuries for agriculture, grazing, and timber. However, widespread physical alterations to the river did not occur until recent times. Major changes took place during the twentieth century as people became concerned about floods, accumulation of salt in agricultural soils, and delivery of water downstream to Texas and Mexico. Flood-control dams, levees, and diversion structures were built,

included patches of forests of various ages (ranging from recently established to mature), shrubs, herbaceous plants, and grasslands. Islands in the river channel contained a mix of semi-aquatic habitats and early successional vegetation. This diversity of habitats over small areas provided a mix of resources for plants, animals, and microbial communities. In addition, the river flooded predominantly in spring, as snow melted from mountains in northern New Mexico and southern Colorado, and in late summer during monsoon-season storms. These floods increased soil moisture, cleared



Aerial photos highlighting the channels of the Rio Grande in Albuquerque near the Rio Grande Nature Center. Photos depict the river in 1947, prior to regulation, with overbank flooding (note colonization of young cottonwoods in vicinity of side channel); in 1959, following the 1950s drought

and immediately after the construction of levees (which parallel the channel) and jetty jacks (perpendicular to the channel); and in 1996, with a simplified river channel and a contiguous, mixed forest of cottonwood and non-native species. Photos depict a 2-km stretch of river.

including Elephant Butte Dam (1916), drainage ditches parallel to the river channel (1920s), levees (1950s), and Cochiti Dam (early 1970s). In addition, urban development extended closer to the river.

Before regulation the Middle Rio Grande flowed through a network of channels separated by islands. Channels changed position frequently over the river's sandy foundation, and this movement maintained a diversity of habitats. Aquatic habitats included the main channel, side channels of shallow, slowly moving water, as well as ponds and marshes. Terrestrial habitats

vegetation from river banks, deposited sediment from upstream, altered channel structure, decomposed organic matter, and distributed aquatic organisms and seeds.

Regulation disconnected the river from its floodplain. Installation of levees constrained the river to a single floodway, and side-channels, wetlands, and ponds nearly disappeared. Dams eliminated large floods, increased flows in the river during summer, trapped sediment, and produced barriers to movement of aquatic organisms. Without floods, dense forests developed along the river because scouring flows were

unavailable to remove vegetation. The dominance of non-native plants increased throughout the riparian areas. Wood and leaves accumulated on the forest floor because water was unavailable to decompose and transport it from the forest. The combination of dense vegetation, large accumulations of wood and decaying leaves, and lack of wet soil increased the size and frequency of wildfires. Continued growth of the human population led to more agricultural and urban floodplain development, increased inputs of treated waste water to the river, and increased use of river and ground water.

VEGETATION

Riparian forests in low-lying regions along the Middle Rio Grande are locally known as “bosque,” the Spanish word for woodland. The native bosque contains forests of Rio Grande cottonwoods, with shrubs and herbaceous plants growing beneath the cottonwoods. Native woody shrubs along the Middle Rio Grande include Goodding and coyote willows, New Mexico olive, baccharis, and false indigo bush. Sedges, rushes, cattails, and yerba mansa grow in moist soils. Plants more tolerant of drier and saltier soils, such as mesquite and salt grass, live on higher or disconnected surfaces.

Cottonwood trees require floods to establish. They release windblown seeds in spring at the time when the river naturally flooded. Cottonwood seedlings need direct sunlight, and their roots must touch wet soil. Floods create sites for recruitment of cottonwoods by scouring away plants that would otherwise shade young seedlings and by elevating soil moisture. Ideal conditions for cottonwood establishment occurred historically once every 5 to 10 years. These optimal conditions no longer exist. Rio Grande cottonwoods have not reestablished themselves over large areas since the early 1940s, following the last large floods. Therefore, most Rio Grande cottonwoods are 60 years old or older. Young trees are not replacing mature cottonwoods because large floods have been eliminated.

Non-native plants that do not require such precise conditions for recruitment are replacing cottonwoods along the Middle Rio Grande. Salt cedar and Russian olive are common non-native trees in the bosque. They release seeds throughout the summer and can grow under the shade of other vegetation. Whether salt cedar uses more water than native plants or increases salt in soil is a focal area of study. Measurements of water loss along the Middle Rio Grande show that forests containing a mixture of cottonwoods

and non-native plants use the most water. Forests of only cottonwood, only dense salt cedar, or only Russian olive use slightly less water than cottonwood forests with a non-native understory. People are removing non-native plants over large areas to possibly conserve water, reduce the risk of wildfires, and encourage growth of native plants.

MICROBIAL COMMUNITIES

Microorganisms, such as bacteria and fungi, play critical roles in ecosystems. They decompose organic matter, such as leaves and wood, and transform nutrients into forms that are available for uptake by algae and plants. Flooding stimulates microbial activity, and abundances of bacteria and fungi are higher at sites that regularly flood. Some fungi, known as mycorrhizal fungi, live on or within the roots of plants. These fungi provide nutrients to plants in exchange for energy (carbon) from plants. Roles of soil fungi in riparian ecosystems are a current area of research along the Middle Rio Grande. Some researchers seek to understand whether fungi and other microorganisms should be added to soil to promote plant growth during restoration projects aimed at reestablishing native vegetation following disturbances, such as fire.

INVERTEBRATES

Hundreds of species of invertebrates inhabit the Middle Rio Grande. Aquatic invertebrates include various species of mayflies, stoneflies, caddisflies, midges, and true flies. Aquatic invertebrates use leaf and woody debris for habitat, and they commonly live in shallow, low-velocity channel edges and backwaters. Today, lack of habitat limits the abundance of some aquatic invertebrates in the Middle Rio Grande. In addition, degradation of water quality negatively affects some species. For example, several species of mollusks inhabit isolated springs along the Middle Rio Grande. They are sensitive to changes in their environment, and several species are now listed as endangered. In contrast, the introduced Asiatic clam, which can tolerate degraded conditions in the river, is now found throughout the Middle Rio Grande.

Terrestrial invertebrates also have important roles in the bosque ecosystem. Some terrestrial invertebrates break down organic matter by chewing it into pieces. Two non-native terrestrial isopods (pill bugs) are dominant decomposers of organic matter in these forests. Other terrestrial invertebrates feed upon leaves in the canopy of trees, and some prefer stressed cotton-

woods. Flooding has been shown to affect the composition of invertebrates. Crickets, a native decomposer, tend to increase in abundance when soil moisture rises. Abundance of carabid beetles increases at sites that continue to flood, and their densities might serve as indicators of hydrologic connectivity between the river and the forest.

FISH

Historically the Rio Grande in New Mexico contained 17 to 27 species of fish, including big river fishes such as longnose gar, shovelnose sturgeon, and American eel. Reduced river flows and increased sedimentation led to the extirpation of many fish. Elephant Butte Dam stopped upstream migration of large species. Operation of Cochiti Dam reduced water temperatures, sediment loads, and habitat complexity throughout the Middle Rio Grande. During recent years, drying of the main river channel killed fish and reduced their migrations. Many native fish have been lost from Rio Grande, and 13 to 19 non-native species of fish have been introduced, including the common carp and white sucker. Only one native minnow species remains, the Rio Grande silvery minnow. It once lived throughout the Upper and Lower Rio Grande, as well as the Pecos River basin. Today the silvery minnow lives only between Cochiti Dam and Elephant Butte Reservoir.

AMPHIBIANS & REPTILES

Amphibians, which live part of their life cycle in water, once thrived in wet meadows, marshes, and floodplain ponds along the Rio Grande. Amphibians living along the Middle Rio Grande include: Couch's spadefoot toad, Woodhouse's toad, great plains toad, and northern leopard frog. Some native amphibians, especially the northern leopard frog, have been negatively affected by reductions in availability of floodplain pools, as well as by predation by introduced bullfrogs. Common reptiles that live along the Middle Rio Grande include the eastern fence lizard, New Mexico whiptail lizard, spiny softshell turtle, and common garter snake.

MAMMALS

Several species of large mammals, including grizzly bears, jaguars, and gray wolves once inhabited the Rio Grande valley but are no longer present. People also depleted populations of beavers during the nineteenth

century. Beavers were restocked from 1947 to 1958 and now maintain healthy populations in riverbanks. Rock squirrels and valley pocket gophers also live along the Middle Rio Grande. Pocket gophers burrow in floodplain soils, and their activities move deep soil to the surface, thus increasing the cycling of nutrients and movement of soil microbes. Small mammals along the Middle Rio Grande include the white-footed mouse, house mouse, tawny-bellied cotton rat, western harvest mouse, hispid cotton rat, white-throated woodrat, Ord's kangaroo rat, and piñon mouse. Many small mammals prefer grassy areas of the floodplain. The white-footed mouse, which often nests in cavities of trees, avoids drowning during floods by climbing trees. Three species of bats commonly roost under old wooden bridges along the Middle Rio Grande. These bats are primary consumers of night-flying insects.

BIRDS

Riparian forests in the desert Southwest provide nesting and foraging habitats for resident and migratory birds. Riparian areas often have high numbers of avian species, and this has been documented in woodlands and marshes along several rivers. More than 270 species of birds use habitats along the Rio Grande, and many breed along the river. Birds of the Middle Rio Grande include Bewick's wren, great blue heron, black-chinned hummingbird, white-crowned sparrow, downy woodpecker, and great horned owl. Tens of thousands of waterfowl, such as snow geese and sandhill cranes, spend the winter along the Middle Rio Grande, especially in the areas between Bernardo and the Bosque del Apache National Wildlife Refuge. Many of these birds feed on alfalfa and corn throughout the river valley. Birds bring nutrients from adjacent terrestrial areas to wetlands at night while they roost in the safety of shallow water or islands. Chemical signals of corn and alfalfa, which can be identified by stable isotopes, appear throughout the food web, especially in fish and crayfish.

Habitat loss via reduction of wetlands and decreases in forests with multiple layers of vegetation has contributed to declines in some species of birds along the Rio Grande. Birds use a variety of riparian habitats for nests. Some build nests on the ground or in shrubs, others use the canopy of trees, and some nest within cavities of trees. The endangered southwestern willow flycatcher relies upon dense shrubs along waterways for nests. Introduced European starlings, which nest in tree cavities throughout the bosque, compete with native cavity nesting birds. Bird use of native versus

non-native plants along the Middle Rio Grande is an area of current research. Some research suggests that riparian forests with a mix of native trees and shrubs of different sizes have the greatest diversity of birds.

PEOPLE

The Rio Grande and its bosque have provided resources for humans for thousands of years. Native Americans living in pueblos used water from the Middle Rio Grande for irrigation. During the seventeenth century, Spanish settlers developed a permanent system of diversions known as acequias. European settlers used riparian areas for cattle grazing and timber harvesting. Today more than half of New Mexico's population resides in the Rio Grande basin. Managers seek to balance human demands on the river with needs of other organisms that rely upon the Middle Rio Grande. Efforts are underway to restore parts of the bosque to native vegetation and to reduce risks of catastrophic fires. Managed floods that match the timing, but only a fraction of the size, of historic floods have been used in the Middle Rio Grande to demonstrate the importance of floods to the ecosystem. General knowledge of bosque ecology is reaching the public through programs like the Bosque Ecosystem Monitoring Program, a program that brings hundreds of school children to the river each year to learn about and measure components of the ecosystem.

Suggested Reading

Middle Rio Grande ecosystem: Bosque Management Plan, Crawford, C. S., Cully, A. C., Leutheuser, R., Sifuentes, M. S., White, L. H., and Wilber, M. P., U.S. Fish and Wildlife Service, District 2, Albuquerque, NM, 1993.

Middle Rio Grande biological survey, Hink, V. C. and Ohmart, R. D., Report submitted to U.S. Army Corps of Engineers, Albuquerque, NM, 1984.

Managing Surface Waters on the Upper Rio Grande

Rolf Schmidt-Petersen, *Rio Grande Bureau, New Mexico Interstate Stream Commission*

The Upper Rio Grande basin stretches from the headwaters of the Rio Grande in Colorado to Fort Quitman, Texas, 70 miles southeast of El Paso. Surface water flow in the basin is highly variable and can easily vary 50 percent above or below the long-term mean flow. Surface water management in the Upper Rio Grande basin has evolved to address this variability so that water users can be protected in times of both drought and flooding. People sought to fund and build water projects that would store floodwater, thus reducing flooding risk and allowing the stored floodwater to be used later in the year, when natural flows were low, to irrigate crops. One significant example, the construction and subsequent operation of the Rio Grande Project, resulted from controversy associated with a multi-year drought in the 1890s.

Several years of low snowmelt, in combination with increased irrigation diversion, mostly in the San Luis Valley of Colorado, resulted in water shortages throughout the basin with the most pronounced effects experienced in the lower parts of the basin. Texan, New Mexican, and Mexican farmers along the international border suffered significant shortages in supply. Although individual farmers complained for years, it was not until Mexico formally complained that the U.S. government became actively involved. In 1896, in an attempt to “freeze” development upstream of the border, the Secretary of the Interior declared an embargo prohibiting use of federal funds or grants of easements across federal land for water development projects. That action effectively stopped additional large-scale water development upstream of what is now Elephant Butte Reservoir until the 1920s.

In 1906 the United States and Republic of Mexico resolved their differences when they entered into the International Treaty of 1906. Except in times of extraordinary drought, the treaty guarantees Mexico 60,000 acre-feet of water each year at El Paso. The U.S. Congress authorized construction of the Rio Grande Project in part to assure the guarantee could be fulfilled.

THE RIO GRANDE PROJECT

The Rio Grande Project, located in southern New Mexico and northwest Texas, consists of two reservoirs

(Elephant Butte being one) and four river diversion dams. It extends 130 miles south from Elephant Butte Reservoir past Las Cruces, New Mexico, and El Paso, Texas, to the Hudspeth County line in Texas. It was constructed by the U.S. Bureau of Reclamation in the early twentieth century, in part to comply with terms of the 1906 treaty. Its primary purpose is to deliver water to 160,000 acres of land in New Mexico and Texas for irrigation, and to provide 60,000 acre-feet of water annually to Mexico.

Construction and operation of the Rio Grande Project resolved issues between the U.S. and Mexico about surface water delivery north of Fort Quitman, Texas, and south of Elephant Butte Reservoir. It established the infrastructure and operations necessary for the U.S. to store Rio Grande waters in Elephant Butte Reservoir and to deliver the stored water for irrigation use in New Mexico, Texas, and Mexico. The project also significantly reduced flooding risk and improved surface water security for people living south of Elephant Butte Reservoir. Although the amount of water available from the Rio Grande Project has varied through time, the project clearly has brought much more certainty to landowners downstream.

Elephant Butte Reservoir was the first large storage reservoir on the Rio Grande and is the primary storage reservoir for the Rio Grande Project. It is the largest reservoir in the Upper Rio Grande basin. Its primary authorized purpose is to provide water for irrigation. Although Congress authorized a “recreation pool” for the reservoir in 1974, no permanent source of water was reserved for the pool. (A recreation pool is storage space within the reservoir for water that would never be released; it would be lost only through evaporation. The idea is to hold some water in the reservoir even during the driest times.) The reservoir therefore has no defined minimum pool, and recreational water users do not have a water right.

The Bureau of Reclamation and two U.S. irrigation districts (the Elephant Butte Irrigation District in New Mexico and the El Paso Water Improvement District No. 1 in Texas) run the Rio Grande Project. The Bureau of Reclamation makes allocations of project water to the two U.S. districts and Mexico during each irrigation season (March through October) through the U.S. International Boundary and Water Commission.



The Rio Grande basin in New Mexico north of Elephant Butte Reservoir.

Each district’s board of directors uses the Bureau of Reclamation’s allocations to develop general plans for storage releases (of their respective allocations) during the irrigation season. Individual farmers are allocated a set amount of surface water by their district for use during the irrigation season, based upon the irrigable acreage held by the farmer. An individual farmer orders surface water from the district as needed until his/her allotment is fully delivered. Each district and

Mexico (through the U.S. Section of the International Boundary and Water Commission) make regular requests of the Bureau of Reclamation for delivery of water at specific diversion dams to meet their farmers’ orders. The Bureau of Reclamation then releases from storage the amount of water needed to provide the requested river diversions.

Rio Grande Project water is also used for municipal and industrial purposes. The City of El Paso is a

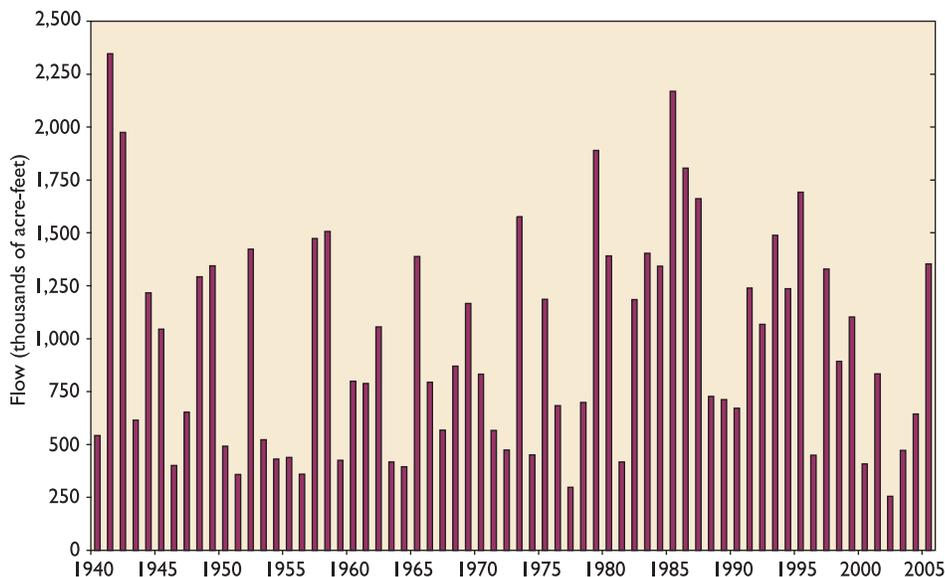
landowner in El Paso Water Improvement District No. 1, has followed the land it owns or leases, requests surface water from the district as any district farmer would, and then uses the delivered surface water for municipal and industrial purposes.

The Rio Grande Project set the stage for battles between direct flow users north of Elephant Butte Reservoir and water users south of the reservoir. Water use north of the reservoir continued to be constrained by the ability of individuals to divert water from the river, the variability in supply, sedimentation, the ability of people upstream to take and consume water, and the inability of most people to receive federal funds and permissions to cross federal land to improve access to surface water. In both Colorado and New Mexico above Elephant Butte Reservoir, water users were experiencing shortages especially toward the end of the irrigation season.

CONFLICT AMONG COLORADO, NEW MEXICO, AND TEXAS

By 1925 the Secretary of the Interior had lifted the federal water development embargo of 1896 when he authorized rights of way for construction of a reservoir in Colorado. The embargo had remained in place long after Elephant Butte Reservoir became operational. People downstream of the reservoir were adamant about the need for the embargo to remain in order to protect Elephant Butte Reservoir storage. They had the federal government as an ally, because neither they nor the federal government wanted to allow reservoirs to be built upstream, given that such reservoirs would reduce the amount of water making it to Elephant Butte Reservoir. People upstream were adamant that damage from floods and drought made it difficult for them to take water from the river and use it as they had before the embargo.

Upon partial lifting of the embargo, Coloradans built several small reservoirs without federal funding. After lifting of the embargo, New Mexicans in the



Unregulated native Rio Grande flow at the Otowi gage near Los Alamos. The Otowi gage provides an estimate of annual water supply conditions both upstream and downstream. If upstream water users are experiencing flooding or drought, such events are observed in the gage record. Because 80–85 percent of the water that flows in the Upper Rio Grande basin in most years flows past this point, the gage provides an estimate of how much surface water was available downstream.

middle valley sought to reclaim lands damaged during the preceding 30 years, reduce flood risk, and improve their irrigation infrastructure. The Middle Rio Grande Conservancy District was organized in 1925 to do just that. It drained waterlogged lands and removed some seventy different river diversion points, consolidating them to the four that exist today (Cochiti, Angostura, Isleta, and San Acacia) for delivery of water to district farmers. Some seventy different acequias operating in the middle valley in the early 1920s were subsumed by the conservancy district. It centralized the irrigation delivery system and constructed El Vado Dam and Reservoir.

The efforts of the Middle Rio Grande Conservancy District resulted in reclamation of previously waterlogged lands within the district, significantly improved water delivery to farmers, and somewhat reduced flood threat. Those efforts—and funding—were largely non-federal in origin, with the exception of funds associated with a 1928 act of Congress that provided funding for work associated with water delivery to Pueblo lands within the district. The 1928 act also established broad categories of water rights and priorities within the district. Most explicitly, it designated specific amounts of lands within the six Middle Rio Grande pueblos as having a senior water right to any other Middle Rio Grande Conservancy District lands

How Surface Water Management Decisions are Made

The Colorado Division of Water Resources oversees surface water diversions north of the state line with New Mexico to deliver water to its farmers and to the State of New Mexico under the 1938 compact. The Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Bureau of Indian Affairs, New Mexico Office of the State Engineer/Interstate Stream Commission, and Middle Rio Grande Conservancy District collaborate on irrigation deliveries, maintaining U.S. Fish and Wildlife Service Biological Opinion river flow targets in the middle valley, and compact management between the state line with Colorado and Elephant Butte Dam. The Bureau of Reclamation, U.S. International Boundary and Water Commission, Elephant Butte Irrigation District, and El Paso Water Improvement District No. 1 collaborate on surface water management for the Rio Grande Project.

The Colorado Division of Water Resources tracks Rio Grande surface water flows at the state line with New Mexico relative to its upstream 1938 compact index flows and associated delivery requirements. Based upon their projections of needed deliveries, the district engineer coordinates with water users to decide when the irrigation season will begin and end and curtails surface water diversions during the irrigation season (sometimes for water users with rights that significantly pre-date the signing of the compact) in order to meet its required annual deliveries to New Mexico. The Corps of Engineers coordinates with the Division of Water Resources and the Bureau of Reclamation to oversee flood operations at Platoro Reservoir on the Conejos River, when downstream river flow conditions warrant such operations.

In the Upper and Middle Rio Grande valleys of New Mexico, surface water management can be separated into three main categories, the winter, the irrigation season, and flood control operations. During the winter (November through February), the Bureau of Reclamation, the Army Corps of Engineers, and the Interstate Stream Commission coordinate to manage the system's reservoirs in compliance with the 1938 compact to route 1938 compact deliveries to Elephant Butte Reservoir and to maintain river flow on the Rio Chama by moving San Juan–Chama Project water to various delivery points. Generally, management for endangered species flow targets is not necessary during the winter.

During the irrigation season (March through October), the Bureau of Reclamation, the Corps of Engineers, the Bureau of Indian Affairs, the Fish and Wildlife Service, the Middle Rio Grande Conservancy District, the Interstate Stream Commission, and the Albuquerque Bernalillo County Water Authority confer daily, as necessary, on river flow conditions throughout the Upper and Middle Rio Grande valleys. Based upon the amount of surface water flowing naturally into the middle valley, weather condi-

tions in both the upper and middle valleys, irrigation demand, and the needed Biological Opinion flows, decisions are made on whose water and how much water to release from upstream reservoirs. The agencies coordinate to deliver water to the Middle Rio Grande Conservancy District diversion dams and maintain compliance with the Fish and Wildlife Service Biological Opinion. During the snowmelt runoff they work, as needed, to provide flows for spawning and recruitment of silvery minnow. During low flow periods they coordinate to observe and manage river drying throughout the Middle Rio Grande valley, salvage silvery minnow, and thus reduce take of silvery minnow.

As warranted by snowpack, reservoir, and river conditions, the corps manages its reservoirs (Abiquiu, Cochiti, Jemez Canyon, and Galisteo) to store floodwater and provide flood damage protection to lands and people living in the upper and middle valleys from Abiquiu to Elephant Butte Reservoir. The water management agencies coordinate with the State Emergency Management Office and individual county emergency managers, as necessary, to provide flood warnings. The Bureau of Reclamation conducts emergency operations as necessary to limit the potential for flooding within the Middle Rio Grande Project. Additionally, the Middle Rio Grande Conservancy District may increase its diversions from the river in order to reduce pressure on the downstream levee system.

In the Lower Rio Grande, the Bureau of Reclamation, the Elephant Butte Irrigation District in New Mexico, and the El Paso Water Improvement District No. 1 in Texas run the Rio Grande Project. The Bureau of Reclamation makes allocations of project water to the two U.S. districts and Mexico during each irrigation season (March through October) through the U.S. Section of the International Boundary and Water Commission. Each district develops general plans for storage releases (of their respective allocations) during the irrigation season and allocates water to individual farmers. An individual farmer orders surface water from his/her district as needed until his/her allotment is fully delivered. The City of El Paso is a landowner within the El Paso Water Improvement District No. 1, receives annual allocations of water from the district, and uses its allotted surface water to provide drinking water to its citizens. Each district and Mexico (through the U.S. Section of the International Boundary and Water Commission) make regular requests of the Bureau of Reclamation for delivery of water at specific diversion dams to meet their farmers' orders. The Bureau of Reclamation then releases from storage the amount of water needed to provide the requested river diversions. The U.S. Section of the International Boundary and Water Commission oversees flood control operations.

and indicated that lands not previously irrigated (newly reclaimed lands) had the most junior priority.

As part of an effort to have the 1896 embargo lifted, the state legislatures of New Mexico and Colorado each passed statutes in 1923 authorizing designation of commissioners to pursue formulation of an interstate compact for the Rio Grande. In 1926 Texas joined the Compact Commission to protect its water user interests.

THE 1929 RIO GRANDE COMPACT—THE “STANDSTILL COMPACT”

The temporary Rio Grande Compact, signed in February 1929, was designed to maintain the status quo in the basin. Major parts of the agreement included:

- A condition that neither New Mexico nor Colorado could increase diversions or storage of water on the Rio Grande until such time as the resulting depletions were offset by drainage projects. The primary assumption is that the drainage projects would return an equal amount of water to the river as that consumed by the reservoir storage and associated release operations. This facilitated efforts in Colorado to construct a drainage project to drain water from the “closed basin” in the San Luis Valley of Colorado to the Rio Grande and build a mainstem reservoir. In New Mexico it facilitated efforts to improve drainage in the middle valley and to construct El Vado Reservoir.
- A provision for creation of a Compact Commission to permanently and equitably apportion the river in the Upper Rio Grande basin.
- A provision that each state will maintain stream flow gaging stations and exchange records of measurements.

The 1929 compact created a path for the three states to agree upon water use limits and delivery requirements. It also set the stage for Coloradans and New Mexicans north of Elephant Butte Reservoir to push aggressively for funds, both private and federal, to improve their ability to control and use water. The period between 1929 and 1938 was one of cooperation and conflict: the Rio Grande Joint Investigation of water uses in the Upper Rio Grande basin was being conducted collaboratively in the midst of a U.S. Supreme Court lawsuit filed by Texas against New Mexico and the Middle Rio Grande Conservancy

District, in part over the construction of El Vado Dam and Reservoir. Not many people realize that the Rio Grande Compact of 1938 settled a U.S. Supreme Court lawsuit in addition to resolving water uses from the headwaters of the river in Colorado to Fort Quitman, Texas; the lawsuit was dismissed upon signing of the 1938 compact. And the 1938 compact was signed shortly after agreements between the U.S. government and water users in Elephant Butte Irrigation District and El Paso Water Improvement District No. 1 were signed, dividing the irrigable lands of the Rio Grande Project, with 57 percent going to Elephant Butte Irrigation District and 43 percent to El Paso Water Improvement District No. 1.

THE 1938 RIO GRANDE COMPACT

The 1938 compact was designed to stabilize water depletions in the Upper Rio Grande basin as they existed in 1929. It reflects the efforts of the negotiators to ensure that the same general quantity of flow that made it to Elephant Butte Reservoir before 1929 continued to do so. The 1938 Rio Grande Compact established surface water delivery obligations for Colorado to New Mexico near the state line and New Mexico to Texas at San Marcial near the headwaters of Elephant Butte Reservoir. The compact sets annual delivery obligations of Colorado to New Mexico and a nine-month delivery obligation of New Mexico to Texas. As a result, it also established depletion amounts for both Colorado and New Mexico of the natural flow of the river at certain points.

The 1938 compact provides for both drought and high-flow conditions. It does not require Colorado or New Mexico to deliver the exact amount of water scheduled annually each and every year. The compact allows for the accumulation of over deliveries (credit) and under deliveries (debit). It allows for significant debits in deliveries to accrue before either Colorado or New Mexico are in violation of the compact. Additionally, if Elephant Butte Reservoir is full and spills, the compact provides that all credits or debits are wiped out.

What does the 1938 Rio Grande Compact mean in practice for people living in New Mexico or Colorado north of Elephant Butte Reservoir? The Rio Grande Compact establishes depletion amounts for Colorado and New Mexico of the natural flow of the river at certain points. Although it is up to each state to decide how its water is used, any new use has to be balanced by reduction of an existing use. Alternately, new uses can be supported using imported water supplies such

as San Juan–Chama Project water. Ground water can be used as long as the impact of that use on the Rio Grande is offset. Typically, ground water withdrawn will eventually deplete the river in the same amount as that pumped. Furthermore, the compact places restrictions on the operation of reservoirs in New Mexico and Colorado constructed after 1929 if the storage supply of the Rio Grande Project drops below a specified level, or if either state has an accrued compact debit.

THE 1948 RIO GRANDE COMPACT RESOLUTION

In 1948 the Rio Grande Compact Commission approved a resolution moving the New Mexico delivery point from the headwaters of Elephant Butte Reservoir to Elephant Butte Dam. The move was made

because of difficulty measuring the flow of the Rio Grande at the old delivery point and to develop an annual delivery obligation of New Mexico to Texas. The commission did so in part by estimating long-term evaporation rates from Elephant Butte Reservoir, based upon historic Rio Grande Project operations.

With the above changes, the negotiators also removed a clause from Article IV of the 1938 compact concerning application of New Mexico's delivery schedule. The clause had required changes to the delivery schedule should New Mexico deplete the runoff of tributaries to the Rio Grande between Otowi Bridge and San Marcial during the summer months by works constructed after 1937. The resolution removed one impediment to the federal government's construction of Middle Rio Grande Project facilities. Finally, because many of the depletions in the middle valley

A Few Definitions

Direct Flow Right—A water right, with a priority date, to divert a certain amount of water from a stream and put it to beneficial use.

Storage Right—A water right to store surface water at times when downstream senior direct flow and storage rights are satisfied. The stored water is released upon the call of the storage right holder for downstream beneficial use. Once released, the storage water suffers natural losses between the point of release and point of diversion.

Rio Grande Project—A U.S. Bureau of Reclamation water project in southern New Mexico and northwest Texas consisting of two reservoirs and four river diversion dams. The project extends 130 miles south from Elephant Butte Reservoir past Las Cruces, New Mexico, and El Paso, Texas, to the Hudspeth County line in Texas. The project was constructed to deliver water to 160,000 acres of land in New Mexico and Texas for irrigation purposes and to provide 60,000 acre-feet of water to Mexico annually.

Middle Rio Grande Conservancy District—An entity organized under the New Mexico Conservancy Act of 1923, as amended to plan for reclamation, flood protection and irrigation in the Middle Rio Grande. The district is located in the middle of the state, extending south from Cochiti Reservoir 150 miles past Albuquerque and Socorro to the northern boundary of the Bosque del Apache National Wildlife Refuge. The district oversees operation of a reservoir on the Rio Chama and four river diversion structures within the Middle Rio Grande valley.

Elephant Butte Irrigation District—An entity governed by an elected board and organized in New Mexico in 1918 to contract with the Bureau of Reclamation for irrigation works ultimately servicing some 90,000 acres of irrigable land within the New Mexico portion of the Rio Grande Project. The district requests reservoir releases from the Bureau of Reclamation for New Mexico farmers, diverts that water at one of three diversion dams, and then delivers the water to its constituent farmers.

Middle Rio Grande Project—A U.S. Army Corps of Engineers and Bureau of Reclamation project authorized in 1948 and 1950 to provide additional flood control, storage, channel rectification, restoration of irrigation works, and other efforts on the Rio Grande between Velarde, New Mexico and Elephant Butte Reservoir.

San Juan–Chama Project—A U.S. Bureau of Reclamation project consisting of three diversion dams, three tunnels, and one reservoir. The project is used to deliver a portion of New Mexico's Upper Colorado River Compact water apportionment from the San Juan Basin to the Rio Grande Basin. The Bureau of Reclamation diverts water from three tributaries of the San Juan River in southwest Colorado and transports it under the continental divide via a series of tunnels to Heron Reservoir on Willow Creek just above its confluence with the Rio Chama. The bureau contracts with various entities in the Rio Grande basin north of Elephant Butte Reservoir for annual deliveries of San Juan–Chama Project water from Heron Reservoir.

are natural, the resolution established a need for New Mexico to maintain the river through the middle valley to both control natural depletions and efficiently deliver water to Elephant Butte Reservoir. To put it another way: In order for New Mexico to increase its human water use in the middle valley it must reduce and control existing natural uses (evapotranspiration from the bosque or evaporation from open water).

THE MIDDLE RIO GRANDE PROJECT (1948 AND 1950 FLOOD CONTROL ACTS)

Large floods in the early 1940s resulted in significant short-term and long-term harm for people living in the middle valley. The Middle Rio Grande Conservancy District's irrigation infrastructure suffered significant damage; the district was nearly bankrupt, lands in the valley became salinated or waterlogged, and the river channel ceased to exist south of the Bosque del Apache National Wildlife Refuge. Given the hardship, residents once again sought to reduce flood risk and improve conveyance of water. Additionally, New Mexico began to accrue significant compact under deliveries.

The Middle Rio Grande Project, a joint U.S. Army Corps of Engineers and U.S. Bureau of Reclamation project, was therefore advocated and supported by many parties as a way of addressing the myriad of middle valley water problems. The project included construction of four large flood control reservoirs, removal of multiple miles of river channel from the valley, construction of the Rio Grande "floodway" and the Low Flow Conveyance Channel, and reconstruction of parts of the Middle Rio Grande Conservancy District.

The operations of all the Corps of Engineers flood control reservoirs must comply with the 1938 compact. The corps cannot store native Rio Grande water except for floodwater, cannot deviate from defined operations without approval of the Compact Commission, and must pass floodwater through the system at the highest "safe" rate possible. Under certain circumstances, the corps cannot release stored floodwater after July 1 of any year until the end of the Middle Rio Grande Conservancy District's irrigation season.

The river realignment and water conveyance facilities of the Middle Rio Grande Project reduced water consumption and aided New Mexico in meeting its delivery obligations. The Middle Rio Grande Project was and remains a key element in New Mexico's ability to maintain compact compliance. Consequently, maintenance of the Middle Rio Grande Project is vital for the state.

THE SAN JUAN-CHAMA PROJECT

This project, constructed by the U.S. Bureau of Reclamation in the 1960s and early 1970s, imports water to the Rio Grande basin from the San Juan Basin for use in New Mexico. It is accounted separately from native Rio Grande water and provides water to help alleviate shortages in available native Rio Grande water. In the future San Juan-Chama water will be a primary source of drinking water to the citizens of Española, Los Alamos, Santa Fe, and Albuquerque.

The Bureau of Reclamation operates the project, diverting a portion of New Mexico's Upper Colorado River Compact apportionment from the San Juan Basin to the Rio Grande basin. The project provides additional surface water for New Mexico water users with San Juan-Chama contracts. The operation of the project requires complex accounting procedures. In order for the system to function properly, a partial adjudication of water rights was conducted on the Rio Chama by the Office of the State Engineer to protect San Juan-Chama Project water from being consumed by the acequias once it is released from upstream reservoirs. Additionally, the state engineer established bypass flow requirements through El Vado and Abiquiu Reservoirs to provide Rio Chama acequias their senior water rights downstream of Abiquiu Dam.

The San Juan-Chama Project brings added flexibility in managing water in the Upper Rio Grande basin above Elephant Butte Reservoir. It has been used to maintain the pool of water in Cochiti Reservoir, the recreation pool in Elephant Butte Reservoir, for irrigation, and to offset the effects on the river of pumping for municipal and industrial uses. The water has also been used to provide secondary benefits such as winter flows on the Rio Chama and to aid in meeting flow targets of the Endangered Species Act between its point of release and point of use.

THE 1950s DROUGHT AND U.S. SUPREME COURT LITIGATION

During the 1950s drought Texas sued New Mexico and New Mexico and Texas sued Colorado in the U.S. Supreme Court. The suits were filed to force New Mexico and Colorado to comply with the 1938 compact and make up under deliveries (then more than 300,000 acre-feet for New Mexico and 900,000 acre-feet for Colorado). The Texas case against New Mexico was dismissed on a technicality. Nonetheless, with one caveat, El Vado Reservoir has since been operated in compliance with the 1938 compact. The federal gov-

ernment, as part of its tribal trust responsibility to the six Middle Rio Grande pueblos, stores water in El Vado Reservoir as insurance for delivery of direct flow to the Prior and Paramount Lands (lands identified as having a senior water right to other Middle Rio Grande Conservancy District lands in the 1928 act of Congress) of the six Middle Rio Grande pueblos. The stored water is released for delivery when the direct flow of the river drops below levels the federal government has estimated to be needed to adequately deliver water to the Prior and Paramount Lands.

In 1968 the U.S. Supreme Court granted a stipulation for continuance of the *New Mexico v. Colorado* case as long as Colorado met its annual compact obligation until it was once again in compliance. Colorado met or exceeded its obligation each year from 1968 through 1984 and has remained in compliance since then. Its remaining under-delivery to New Mexico was cancelled in 1985 when Elephant Butte Reservoir spilled. The case was subsequently dismissed. To meet its annual obligation, Colorado restricts the diversion of surface water users with rights that pre-date the 1938 compact.

Suggested Reading

Upper Rio Grande Water Operations Review and Environmental Impact Statement. U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and New Mexico Interstate Stream Commission, 2005.

The Upper Rio Grande: A Guide to Decision-Making, Steven J. Shupe and John Folk-Williams, Western Network, Santa Fe, New Mexico, 1988.

The Administration of the Rio Grande Compact in Colorado, Steven E. Vandiver. CLE on the Law of the Rio Grande, 2003.