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Water, Watersheds, and Land Use in New Mexico

Impacts of Population Growth on Natural Resources

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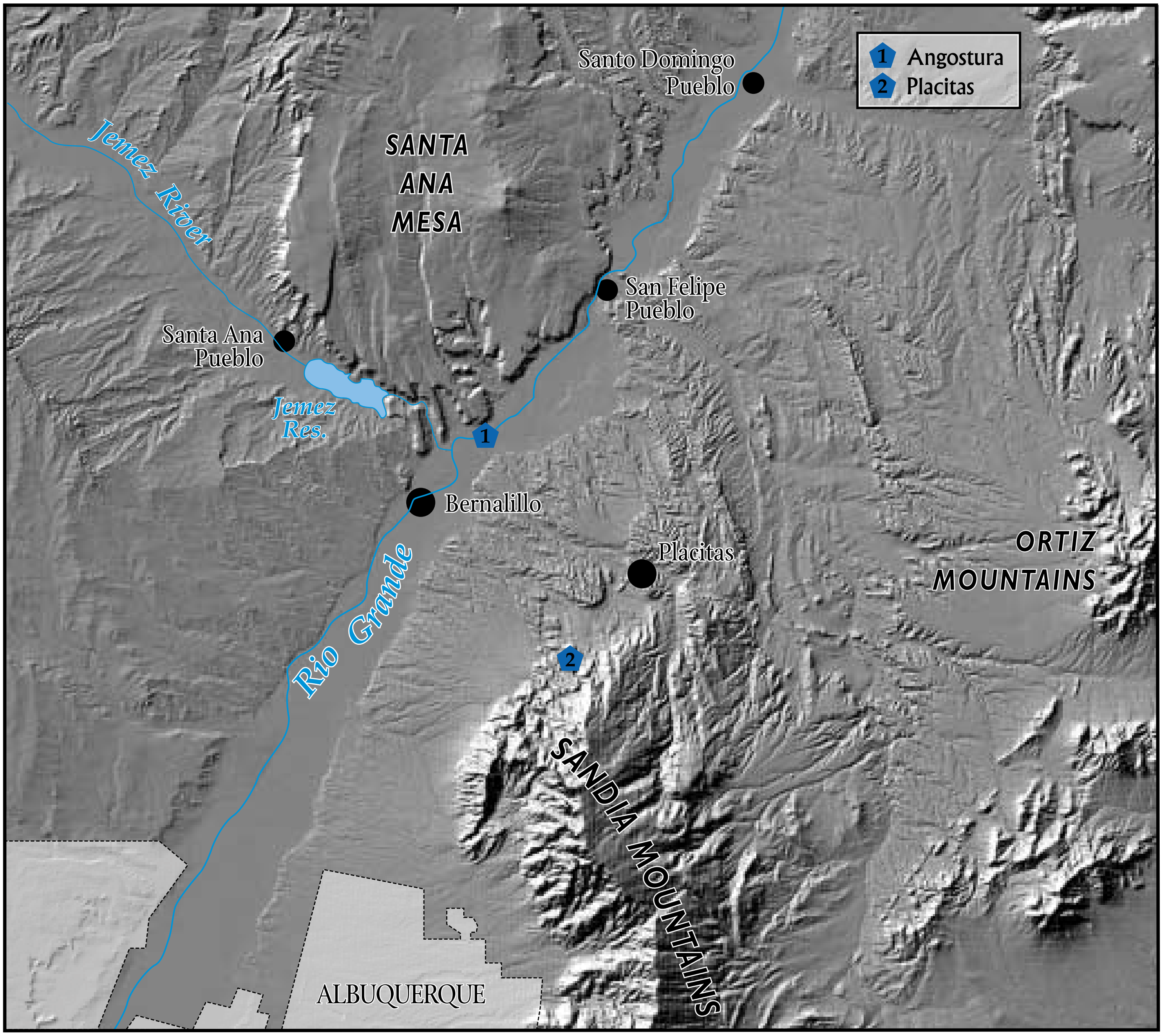
The Middle Rio Grande—
Impacts of Growth on Water Resources



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The Middle Rio Grande Conservancy District

by *Subhas K. Shah*, Chief Engineer, and *Sterling Grogan*, Biologist/Planner, Middle Rio Grande Conservancy District

This paper summarizes the history of 20th century water problems in the middle Rio Grande valley and describes how the Middle Rio Grande Conservancy District, which was created to respond to those difficulties, has evolved to support endangered species and help sustain agriculture in central New Mexico.

In the 1920s much of the once-irrigable land within the middle Rio Grande valley was saturated and unusable due to aggradation of the river and a corresponding rise in the water table. Irrigation works were in disrepair and needed much work and the valley was subjected to periodic flooding, often with devastating effects.

Efforts to solve these and other problems led to the creation of the Middle Rio Grande Conservancy District in 1925 to provide flood control, drainage, and irrigation for the middle Rio Grande valley. The conservancy brought 70 acequias into one unified entity designed to make all suitable lands in the middle valley irrigable.

During the 1940s the conservancy was financially unstable, and the canals, drains, levees, and other works were deteriorating. Consequently, the conservancy asked the U.S. Department of the Interior Bureau of Reclamation to take over the operation of the district temporarily and retire its outstanding bonds. In 1951 the conservancy entered into a 50-year, interest-free repayment contract in the amount of $15,708,567 with the Bureau of Reclamation for the benefit of the district. In 1975 the Bureau returned operation of the system to the conservancy, and in late 1999 the conservancy paid off the debt. Because of the successful efforts of the conservancy, the middle Rio Grande valley and its citizens are now protected from flooding; the once-saturated soils have been drained and restored to a condition suitable for farming, development, and other uses; and the old irrigation works have been rehabilitated or replaced.

The Middle Rio Grande Conservancy District today extends from Cochiti Dam south for approximately 150 mi to the Bosque del Apache National Wildlife Refuge (Fig. 1). The conservancy encompasses approximately 278,000 acres in four counties, of which 128,787 acres are irrigable lands. At present, approximately 70,000 acres are using irrigation water. Within the district's boundaries are thousands of property owners and many towns and villages, six Indian pueblos, and much of the city of Albuquerque. Over one-quarter of the population of New Mexico resides within the conservancy, much of it in some of the most rapidly urbanizing areas in the state. The conservancy maintains and manages four diversion dams, 834 mi of canals and ditches, and 404 mi of riverside drains that are capable of delivering water for irrigation and a variety of other purposes.

As guardian and advocate of the waters of the middle Rio Grande for its constituency, the conservancy is adapting its water policies and methodologies to meet changing needs. The conservancy meets those needs through its water bank, through planning efforts for protecting endangered species, and through an ongoing program to upgrade the technology and management of the water conveyance system.

Because of the varied history and make up of the conservancy, seven categories of legally recognized water rights are found within the district boundaries. In total, the amount of consumptive use allowed by state Engineer permits within the boundaries of the conservancy from surface flows of the Rio Grande is approximately 298,339.4 acre-ft. Total net diversions from the Rio Grande average 350,000 acre-ft annually, of which about 238,000 acre-ft are consumptively used. The acreage under permits held by the conservancy may be greater than land actually irrigated today because the permits have not been fully developed. Determining the total perfected amount of the conservancy right is a complex process that is currently under way.

To meet the changing needs of its constituents, the conservancy's board of directors established a water bank in 1995. The water bank is essentially a water management system and a method by which the district manages the distribution of water within the conservancy by moving water from areas where it is not being used to areas of need. In this way, the district can maximize the beneficial use of water within the conservancy. Holders of current water rights within the conservancy who are not using their rights can place those rights in the water bank. Persons or entities that need water can "borrow" water from the bank. Thus, water use can be maximized by delivering it to where it can continue to be put to beneficial use.

There is some irony in the fact that, as a direct result of the measures taken to solve the problems of the early 20th century, the conservancy district today faces new challenges. Primarily as a result of the dams, levees, and channel-narrowing devices built from the 1930s through the 1960s, much of the habitat for endangered species in the middle Rio Grande has deteriorated. As the human population has grown along with awareness of the environmental consequences of what we consider today essential human infrastructure, the conservancy district finds itself fighting new assaults on the district's attempts to support and sustain that infrastructure for agriculture in the middle Rio Grande valley. Foremost among the new challenges is the Endangered Species Act.

The Rio Grande silvery minnow, a small fish that today appears to survive only in the middle Rio Grande between Cochiti Dam and Elephant Butte Reservoir, was listed as an endangered species in 1994. The conservancy district is working closely with the Bureau of Reclamation and other federal and state agencies to protect the minnow and plan for its recovery in ways that allow legally authorized water use and development to proceed in compliance with state water law and interstate compacts.

There is widespread recognition that the potential for dewatering a segment of silvery minnow habitat in the middle Rio Grande is very high, due to multiple use of the water throughout the river system, conveyance losses that depend largely on weather conditions, and other river conditions outside the control of human water users. These uses and conveyance losses from the Rio Grande occur from its headwaters in Colorado to Elephant Butte Reservoir. Therefore, to maintain the viability of agriculture and to benefit endangered species, the conservancy district operates its water conveyance system in close coordination with state and federal agencies. With financial and logistical support from some of those agencies, the conservancy also continues to improve the efficiency of the water conveyance system through automated metering of river diversions and return flows, and other system improvements.

In conclusion, it is important to note that the increase in the urban population of the middle Rio Grande valley has brought with it new demands on our water resources, and the complexity of water management in the middle Rio Grande valley has increased significantly. To respond to the new physical and regulatory challenges, the conservancy is improving operations and increasing its ability to meet changing demands. As demonstrated by the extensive list of ecosystem rehabilitation projects contemplated for improvement of habitat for endangered species along the middle Rio Grande, the conservancy recognizes the need to find balanced solutions to environmental challenges, so that the centuries-old culture of irrigated agriculture can be sustained for our children, who will inherit this magnificent valley.

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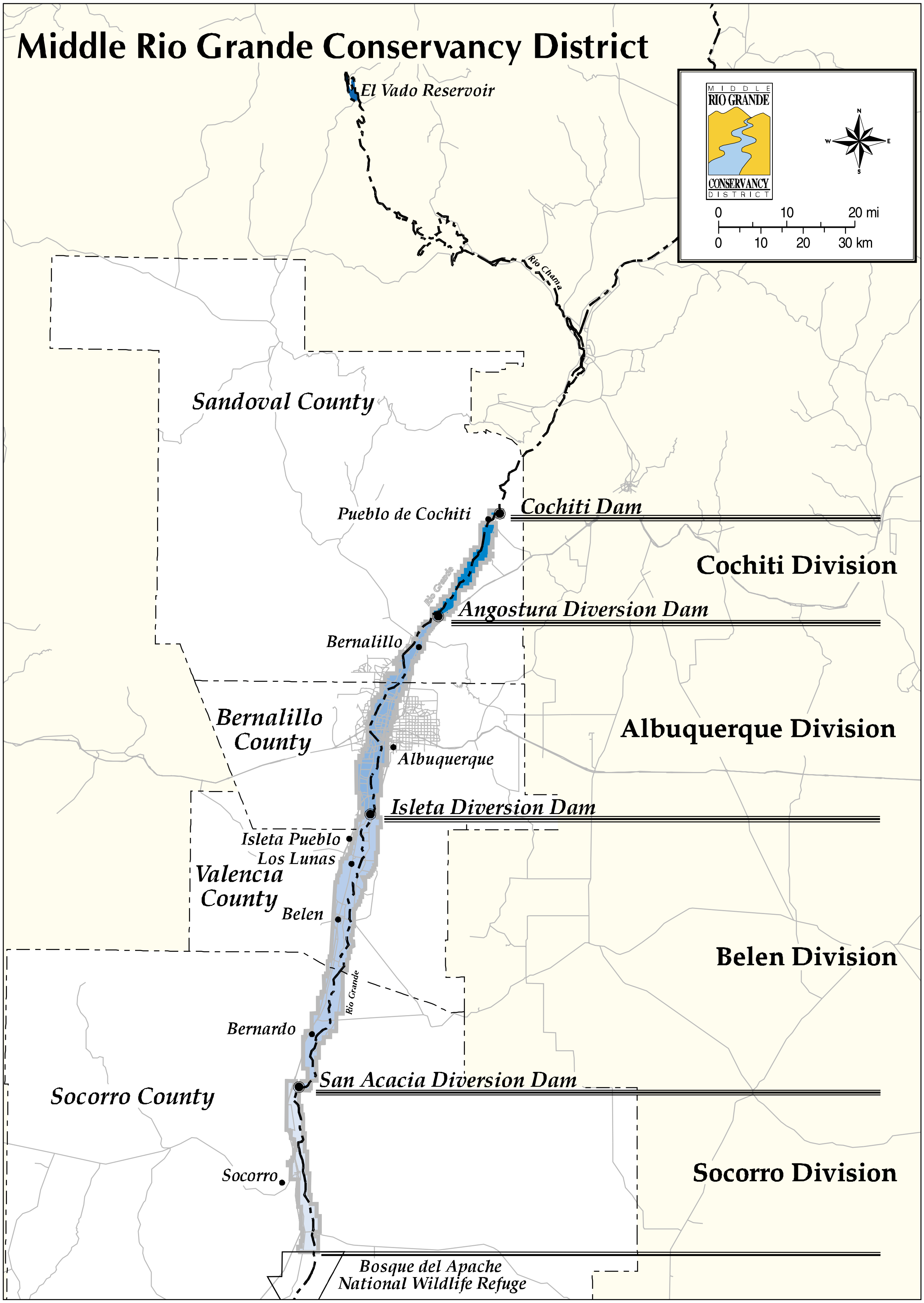

FIGURE 1—Map of the Middle Rio Grande Conservancy District.

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Shah, a native of Gujarat, India, is a Registered Professional Civil Engineer. Before joining the Middle Rio Grand Conservancy District in 1977, Shah gained experience in residential, commercial, and industrial design and construction. As Chief Engineer, Shah serves at the pleasure of the seven-member conservancy district board of directors, and is responsible for all facets of the conservancy district, which spans four middle Rio Grande counties. Shah is widely recognized as an expert in the technical administrative and legal aspects of irrigation, flood control, and drainage operations. He serves on the Water Providers Council of the Middle Rio Grande Water Resources Board, and is active in the Family Farm Alliance and the National Water Resources Association.

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Grogan, the biologist/planner of the Middle Rio Grande Conservancy District, is a landscape ecologist with more than 25 years of experience in land and water management. He is responsible for protection of 150 mi of the middle Rio Grande bosque, management of habitat for endangered species, co-management of Rio Grande Valley State Park, and preservation of agriculture in the middle Rio Grande valley. Sterling is a specialist in the rehabilitation of severely disturbed land. From 1974 to 1997 he managed land rehabilitation and environmental affairs for mining companies in New Mexico and Chile, and consulted on landscape ecology in the Costa Rica, Mexico, Venezuela, and the U.S. He was chair of the Albuquerque/Bernalillo County Air Quality Control Board from 1998 to 1999, and currently serves on the boards of the Cornstalk Institute and the Rio Grande Nature Center. He was a Peace Corps volunteer in Brazil and an Army interpreter in Viet Nam.

The Angostura diversion dam, operated by the Middle Rio Grande Conservancy District, is one of three major diversions of irrigation water along the middle Rio Grande valley. The dam was constructed in 1934 and rehabilitated by the Bureau of Reclamation in 1958. It has the capacity to divert 650 cfs to the Albuquerque Main Canal. It consists of a 800-ft-long concrete weir that has a structural height of 17 ft and a hydraulic height of 4.5 ft. Photo by Paul Bauer, August 2000.

Pueblo Concerns in the Rio Grande Basin

by *Herbert A. Becker*, Water Rights Consultant

Centuries before the coming of the Europeans, the pueblos lived, worked and prospered in the middle Rio Grande basin. Their ancestors used water from the Rio Grande and its tributaries for irrigation, fishing, recreation, commercial, and religious purposes as well as a source of water to meet their domestic needs. Additionally, they used resources from and occupied a much larger land area for hunting and subsistence than they presently own.

These pueblos maintained governmental relations with Spain and then Mexico during the time those countries claimed jurisdiction over the area. Today, the pueblos are federally recognized and maintain government-to-government relations with the United States and the state of New Mexico. They reside on lands that are meant to be a permanent homeland for the pueblos and their members, on which they are to live and practice their culture and maintain their traditions (Fig. 1). The pueblos possess inherent sovereignty, exercise substantial governmental duties and powers, and provide for the health and welfare of the citizens and residents of the pueblos. They also operate commercial, industrial, recreational, and other economic enterprises that provide jobs for their members and non-Indian neighbors.

Historical Action

This century has seen water replace land, as the Indian asset most craved by the state of New Mexico and her non-Indian citizens. Although the pueblos have used water from the Rio Grande since time immemorial, the state of New Mexico, her citizens, and in some cases the federal government have ignored the pueblos' prior rights to the waters of the Rio Grande.

In 1906 Congress entered into a convention with Mexico by which the United States agreed to deliver 60,000 acre-ft of potable water annually from the Rio Grande to Mexico at the Acequia Madre in Juarez, Mexico. Nothing was mentioned in the convention about the pueblos' prior rights to that water. Later, the Elephant Butte Irrigation Project was constructed on the lower section of the Rio Grande in New Mexico in conformance with an application issued by the New Mexico Territorial Engineer; that project relies on water for irrigation that is all junior in priority to the pueblos' rights. Even though the territorial engineer knew that the pueblos had a prior right to the water, the permit issued for that project did not note this when the application to divert water for irrigation purposes was granted. Dams and other diversion structures have been constructed on the main stem of the Rio Grande as well as on its tributaries upstream of the pueblos. These divert water from the river that had previously been available to meet the demands of the pueblos.

Municipalities, commercial and recreational enterprises, industrial concerns, irrigators, and governmental agencies discharge water polluted with chemicals and fertilizers upstream of the pueblos that degrade the quality of the water available to them.

Over the past 50 years, a large number of wells have been drilled in the aquifers that are connected with the Rio Grande and its tributaries, the pumping of which adversely impact the quantity of water available to the pueblos. No pueblo rights were taken into account by the entities drilling the wells or by the Office of the state Engineer in granting permits to drill these wells.

The pueblos realize that if these actions continue unabated, and steps are not taken to address the impacts that added water use will have on the scarce water resources in the middle Rio Grande basin, disaster looms ahead for all.

Actions of the Pueblos

The pueblos have taken the lead in the state to conserve water through holistic agriculture practices, to restore the bosque, and preserve and enhance water quality through the enactment of clean water standards. Isleta was the first pueblo in the United States to obtain certification as a state and have the Environmental Protection Agency (EPA) approve its clean water act standards. Later, Sandia Pueblo achieved the same status. EPA's certification of Isleta as a state for purposes of the Clean Water Act was contested in federal court by the city of Albuquerque, but the federal courts rejected the city's lawsuit and affirmed EPA's certification. Santa Ana Pueblo and Sandia Pueblo have instituted programs to restore the bosque and provide habitat for endangered species.

Several years ago, the pueblos established the Coalition of Six Middle Rio Grande Basin Pueblos. The purpose of the coalition is to permit the pueblos to join together to develop a joint strategy to protect their water resources. As noted above, the state of New Mexico, her political subdivisions, various non-Indian entities, and her non-Indian citizens have made claims to and appropriated the pueblos' water resources, and in an attempt to limit tribal water rights, have sued them in state and federal courts. Those same entities have degraded the quality of the Rio Grande through unregulated discharges and through return flows that contain large concentrations of chemicals and other pollutants. It became clear to the pueblos that none of them had the resources to check these actions and ensure that their concerns about the impacts to their water rights would be heard or addressed unless they joined together. Accordingly, the pueblos created the coalition.

The goal of the coalition is simple—to protect and preserve the pueblos' scarce water resources for use by them now and for generations yet unborn on permanent homelands where their members can practice their traditions, religion, and preserve their culture. The pueblos' water needs, existing and future, include recreation, irrigation, domestic, municipal, religious, industrial, mining, esthetics, minimum-in-stream flows, and other uses.

The coalition's goal can be achieved through cooperative efforts and agreements with their neighbors, through federal legislation, or, if need be, through litigation. It is the pueblos' desire and expectation to work amicably with the state and her citizens to arrive at an agreement that will recognize their right to water of sufficient quantity and quality to meet their present and future uses. The state should become a willing partner in this goal so that all members of the state can benefit in this effort.

This paper discusses the actions taken by the pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta, located in the middle Rio Grande basin, to address their concerns over water issues in the basin. This document does not represent the position of any of the six pueblos. The views expressed here are solely my own. Herbert A. Becker.

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Becker has worked since 1970 in the area of federal Indian law specializing in tribal rights to natural resources, land, jurisdictional, and policy issues concerning the development and quantification of tribal natural resources with emphasis on water rights and water development. He retired from the United States Department of Justice in 1996 as the Director, Office of Tribal Justice and has been running a consultant business since then. In addition to working with tribes from around the United States, he also worked with tribal groups in Canada and represented private mining companies in their relationship with tribes in this country and with indigenous tribal groups around the world.

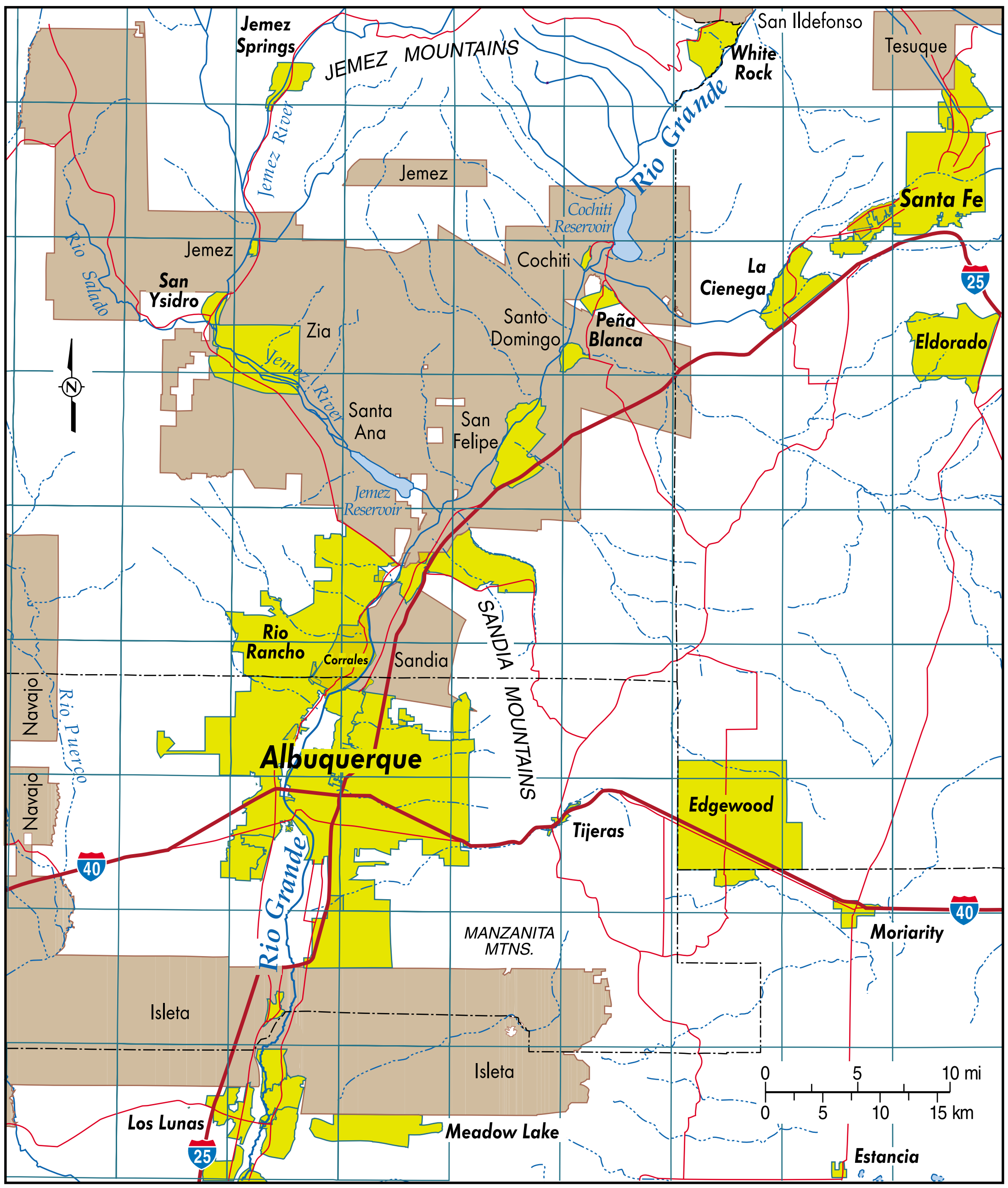

FIGURE 1—Pueblo lands in the middle Rio Grande basin.

Consequences of Endangered Species on Water Management in the Middle Rio Grande: Status, Challenges, Potential Solutions

by *Jim Wilber*, U.S. Bureau of Reclamation

Management of water resources in the middle Rio Grande in New Mexico is a complex undertaking involving considerations ranging from economic factors to hydrologic realities. Water management actions also take place within a complex framework of laws and regulations. Relatively recently, the needs of endangered species have been added to the list of considerations. Within this context, the integration of water resource management and environmental conservation has become a major focus of U.S. Bureau of Reclamation activities.

The Rio Grande silvery minnow is listed as endangered under the Endangered Species Act of 1973, as amended, and currently occurs only in the Rio Grande between Cochiti Dam and the headwaters of Elephant Butte Reservoir, a reduction of over 90% of its historic range. The silvery minnow was historically known to have occurred in the Rio Grande upstream from present-day Cochiti Reservoir, in the downstream portions of the Chama and Jemez Rivers, and throughout the middle and lower Rio Grande to the Gulf of Mexico. Recent monitoring shows that the majority of the silvery minnow are concentrated below San Acacia diversion dam, and populations in the Albuquerque and Isleta reaches are extremely reduced. In general, the native fish community of the middle Rio Grande is in decline in both abundance and diversity of species.

Potential threats to the Rio Grande silvery minnow and the associated native fish community are many. Three significant factors related to water management that affect the silvery minnow today are: (1) reductions in flow and channel dewatering, (2) habitat fragmentation and barriers to movement caused by mainstem dams, and (3) habitat loss due, in part, to channel narrowing and degradation. In light of these factors, the management of water and endangered species becomes inseparable. The challenge is how to meet multiple resource needs with a limited supply of water. The needs of water users, for example, are generally well defined and associated water management practices are already established. On the other hand, while the basic life requirements of the silvery minnow are known, an integrated water management solution to recover the species has not yet been established. Thus, in the short-term, the risk to the silvery minnow remains high, and a potential conflict between water management and endangered species is apparent.

Piecemeal attempts to manage endangered species rarely work. Solutions that may eventually lead to the recovery of the Rio Grande silvery minnow and reduce potential water management conflicts will likely involve a concentrated effort of all federal and non-federal entities with a stake in the Rio Grande. Improvements must be made in all the factors listed above, and more. There are not enough available resources for any one group or resource to hold the key to the recovery of the silvery minnow. A collaborative effort of all stakeholders is required.

The current limited distribution of the Rio Grande silvery minnow has forced water managers to take extreme measures to provide continuous flows in the lower reaches of the middle Rio Grande to protect the remaining populations of the species. A combination of activities including flow management, the removal of barriers to dispersal of the silvery minnow, habitat restoration, and captive rearing of fish may improve the distribution and abundance of the silvery minnow to the extent that the species will be on the road to recovery and increased flexibility in water management will be once again achieved.

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Wilber worked for several years as a fish and wildlife scientist and resource planner for the Delaware Division of Fish and Wildlife. For most of the last 9 years he has worked as a fishery biologist for the Albuquerque Area Office of the Bureau of Reclamation. His primary role has been to coordinate endangered species-related research, monitoring, operations, and consultations on the Rio Grande and Pecos River. Since 1995 he has focused on Rio Grande silvery minnow issues on the middle Rio Grande. He recently moved into a position as special projects officer and assists in the coordination of middle Rio Grande activities for the area office.

Source-to-Sea Protection for the Rio Grande: Strategic Concepts for Re-watering a Thirsty Basin

by *Steve Harris*, Rio Grande Restoration

The great challenge for water managers in the Rio Grande is to somehow balance important environmental, economic, and development goals for the basin's water and to integrate competing interests into a strategy that sustains uses of the river and its water into the foreseeable future. Today we are failing to answer this fundamental challenge, as witnessed by the fact that the ecological benefits of streamflow, in at least four segments of the river (Table 1), have been sacrificed to diversionary uses. This suggests that the river is not being considered in its proper role as a water user and provider of essential services.

The river has not yet been accorded real recognition or protection in the legal constructs governing the waters of the basin. The river has no effective seat at the table in our strategic forums. This concept paper, in suggesting a basin-wide strategy for protecting streamflows, is based on four assumptions: (1) the present state of affairs on the Rio Grande is not sustainable; (2) water uses by the river and the natural environment should be balanced with consumptive uses; (3) present consumptive uses can be balanced with environmental requirements; and (4) contrary to tradition, water is actually for cooperating over.

Rio Grande "Hydro-Reality Check"

The basic environmental condition of the Rio Grande basin has been accurately described as "a state of drought, occasionally mitigated by periods of abundance," Before the present one million acres of irrigated agriculture were developed in the basin, the river flowed with great springtime surges from the melting of mountain snow packs, receded in the hot months of summer, then often filled again during the monsoons of July through October. At approximately 20-yr intervals, the moisture from winter storms would fail to come, as it still does, quite often for periods of 2–5 yrs.

On an annual average, less than 2.5 million acre-ft were (and are) produced by the river's headwaters. Years of abundance, with up to twice this amount were (and are) balanced by years of scarcity, with as little as half the average quantity. Diversions of water for irrigation claim nearly 95% of the average annual flow of the river. Water rights claims to the waters of the Rio Grande, most of which are legally unadjudicated, exceed the actual supply. The basin's water supply picture would be even bleaker without the addition of 96,000 acre-ft of San Juan River water imported into the Rio Grande, groundwater subsidies through wastewater discharges, and the 20,000-plus annual acre-ft salvaged by the Closed Basin Project in Colorado. Today, on average, just 5% of the river's production of water survives diversion to appear as streamflow at Fort Quitman, the division point between the upper and lower Rio Grande basins.

TABLE 1—Upper Rio Grande stream segments presently subject to dewatering.

River reach	Length (mi)	Typical minimum flow (cfs)	Recurrence frequency	Season
Colorado above NM state line	~60	25	4 yrs in 10	July–Oct
San Acacia to Elephant Butte	~60	0	1 yr in 2	July–Oct
Below Caballo Reservoir	~40	0	Annual	Nov–Feb
Below Fort Quitman	~160	0	Intermittent	May–Aug

Institutional Stakeholders

It is estimated that 89% of the basin's water resources are devoted to irrigation (Ellis et al., 1993). Since about 1870 the basin's economic dependence on irrigated agriculture and the waters supplied by the river meant that security against the caprices of nature was intensely desired. In a watershed plagued with frequent shortages and wildly variable precipitation, the Federal Reclamation Service addressed the need for water storage by constructing the Rio Grande Project, including Elephant Butte (1916) and Caballo (1936) reservoirs, with 2.5 million acre-ft in storage capacity. Today, the U.S. Bureau of Reclamation plays an essential role in managing the basin's water resources, including El Vado Reservoir (1936), Heron Reservoir (1963), and the Rio Grande Project. Its sister agency, the U.S. Army Corps of Engineers, also manages two large reservoirs, whose primary purpose is flood control: Abiquiu (1963) and Cochiti (1975).

After decades of conflict, the U.S.–Mexico Treaty of 1906 and the Rio Grande Interstate Compact of 1938 apportioned water among the major irrigation sections in the states of Colorado, New Mexico, Texas, and Chihuahua. As a result, the flow of the Rio Grande in its upper basin is largely determined by water delivery requirements of the Rio Grande Compact.

Major irrigation districts further apportion water among farmers in the basin's major valleys. These quasi-governmental local districts include: Rio Grande Water Conservation District (San Luis Valley, CO), the Middle Rio Grande Conservancy District (Albuquerque, NM), Elephant Butte Irrigation District (Las Cruces, NM), and El Paso County Water Improvement District #1 (El Paso, TX).

New surface water uses continue to increase demand on the river. The burgeoning cities of Albuquerque and El Paso are busily planning projects to help them convert from groundwater mining to "renewable" surface water uses. The river, already at a competitive disadvantage, will soon shoulder the burden of new depletions for urban uses.

Why Streamflow Protection? Why Now?

Dry rivers equate to dead fish. The least hardy species that evolved in the river have disappeared, and the most hardy are considered threatened or endangered. Compliance with the Endangered Species Act will require water. Rio Grande pueblos have "prior and paramount water rights" that have never been quantified. It is but a matter of time before tribes seek to quantify their entitlements. The resolution of Pueblo Nations' water claims will require water. Even New Mexico's ability to honor its obligations under the Rio Grande Compact may be in doubt, as consumption of water increases.

The institutional arrangements that arose in response to 19th-century needs recognized only the irrigation economy as a purpose for the water supplied by the river. Today's realities include vastly larger demands for urban drinking water, new industries, and new social values, such as equity for Native American tribes and environmental quality. The sum of these demands presently subjects four critical reaches of the Rio Grande to dewatering in most years (Table 1).

Today, we are at the threshold of an important decision—will we attempt to belatedly include the river in our water supply strategies? If this region insists upon clinging to the institutional status quo, the river simply will cease to live. Only a bold, intentional change in the way we do our water business will offer hope of preserving existing uses, and balancing them with developmental aspirations and the river ecosystem. Whether we realize it or not, the decision we are making is between a living river and a dry ditch.

An honest effort to satisfy this full range of modern-day water demands will require difficult institutional adjustments and shifts in the allocation of legal rights to Rio Grande water. Securing beneficial streamflow regimes will, in large measure, depend upon some agreeable modifications in existing institutional arrangements, and small but significant accommodations by current users. Such an effort will satisfy the public interest in protecting the river-dependent natural environment from further degradation, or else we will dry up the river and flood the courtrooms.

Ironically, the basin's brightest hope is that so much of the Rio Grande's water is so inefficiently used (85% of the basin's farms use the least water-efficient methods available). If, as a basin, we could realize our water conservation potential, we could shift the savings to the environment and other new uses.

Wet Water's for Drinkin', Paper Water's for Fightin' Over

In the Western United States today, two kinds of water exist. Most citizens understand "wet water", the kind that flows downhill in response to the laws of God or nature or gravity. Wet water moves through the natural landscape in rivers and streams, and around the human landscape in ditches and pipes. Fewer understand about the second kind of water, which is paper water. Paper water, it is said, "flows uphill to money", a nifty feat whose accomplishment requires lawyers. Paper water flows through courthouses and statehouses. Unfortunately, our paper-water-rights system has over-allocated the river (assigned more rights than wet water) and given the region its knottiest problem.

Wet water, like the air around us, is an absolute requirement of life on our beautiful, blue-green planet, an entitlement that all creatures share. Paper water is too often a commodity to be captured and consumed, haphazardly, for short-term economic purposes. Our society could clearly be more deliberate in our use of water, more thoughtful of our neighbors, both natural and human.

Presently, water rights are unadjudicated in large sections of the river. In the present context of legal uncertainty, immediate progress toward legitimate river restoration goals must be made with the voluntary cooperation of a broad range of affected institutions. But time in which to make the critical adjustments to our water management institutions grows short.

In the event that we cannot place the river into the proper management context, society within the basin will likely be forced to sacrifice some or all of the environmental benefits the river has historically provided. Failure to maintain a functioning ecological base will make continued human occupation of the basin problematic. Much is at stake.

This paper suggests that a thoughtful combination of reservoir re-operations, water conservation, and water rights acquisitions, applied in the broadest interests of the users and environment, can reverse the Rio Grande's unmistakable trend toward extinction.

Streamflow Protection? How?

Maintaining Rio Grande streamflow requires maintenance of a precarious, wet-water balance. The river clings for its life to a small wet-water surplus and the obligation of several states to provide agreed-to consumptive amounts to their downstream neighbors. The wet water that accrues to the river today is entirely subject to tomorrow's consumptive uses. To achieve sustainable water for environmental needs, three conceptual criteria must be met: (1) acquisition of 8% of Rio Grande basin water resources (150,000 acre-ft) by purchase or donation; (2) obtain dedicated storage pools in major reservoirs, explicitly for environmental water; and (3) utilize the regulating capacity of reservoirs for timed releases to the greatest social and environmental benefit

It is important to note that the amount of wet water proposed for protection is small relative to the Rio Grande basin's average water production. A basin-wide water conservation target of 8% of existing uses is believed to be achievable, with sufficient incentives. To offset impacts of acquisitions on existing systems will require the most efficient possible use of water in cities and farms, and application of conserved wet water to the environmental pool.

Securing conserved water and protecting it from future depletion will require a serious public commitment to provide water explicitly for the environment. The path of least resistance in our present free market view of the resource is to secure, by purchase, lease, or other voluntary transfer, a sufficient quantity of water for the river's minimum survival needs. Whereas considerable resources may be required to fund water acquisition and capital improvements for water conservation, not all environmental water needs must be purchased. Delivery of downstream entitlements form part of the conceptualized future streamflow regime. The process will require a unified commitment by the public, decision makers, and water management officials for funding, data acquisition, and monitoring.

It will also require some storage in the basin's reservoirs and an increased understanding of delivery systems and ability to manage flows. Congressional reauthorization of some if not all facilities would be required to enable storage set-asides specifically for environmental use. Storage may, in some cases, need to be purchased. With a dedicated storage pool and improved water management operations, 210,000 acre-ft of environmental water in the upper basin is attainable (Table 2) without impacting existing users.

Finally, the river's own share of the river must be shepherded through a complex natural system and a maze of man-made diversions. An increased understanding of the river's natural system will be necessary to optimize streamflow regimes, protect existing beneficial uses, mimic the shape of the natural hydrograph, and prevent desiccation of the river. In other words, the science of the Rio Grande must continue.

A Last Word

The difficult task of balancing the Rio Grande's existing uses and development goals with the needs of a declining natural

TABLE 2—Major storage reservoirs on the Rio Grande, storage capacities, and proposed storage for environmental water.

Reservoir	Total storage (1,000 acre-ft)	Owner/Operator	Primary use	Proposed environmental storage (1,000 acre-ft)
Heron	400	USBOR	Storage/delivery of San Juan–Chama Project water	10
El Vado	180	MRGCD	Irrigation storage	None
Abiquiu	500	USCOE	Flood/sediment control and storage	50
Cochiti	5.34	USCOE	Flood/sediment control, fish and wildlife, recreation	<10 in recreation pool
Jemez Canyon	115	USCOE	Flood/sediment control	>10
Elephant Butte	2,000	USBOR	Flood/sediment control, irrigation storage	50
Caballo	330	USBOR	Irrigation storage	10
Amistad/Falcon	5,900		Flood control, irrigation storage	70
Aquifers	Unknown	Permitted water rights	Domestic/municipal supplies	80
Upper Basin	**3,530**			**210**
Lower Basin	**5,900**			**70**

environment demands that the leaders of the basin devise new strategies to sort through the conflicts among competing water uses and integrate conflicting management institutions.

Today we see urban leaders confidently planning the future conversion and ultimate consumption of tribal water, agricultural water, and the river's water. Individual water users recognize few connections to other user groups and to the river. Agriculture, already at the mercy of capricious markets, continues to build bunkers around existing water institutions, which includes their own massive diversions. Water management institutions are long on paper-water administration tools, and short on substantive knowledge about the wet-water system.

Like a fault line in an earthquake zone, great pressures are building around the Rio Grande's scarcity of water. The basin's headlong slide into the crack might be arrested gradually by application of good faith by many water users and the hard work of collaboration. The alternative, of course, is a cataclysm, the old fashioned rumble over water and a conflict with many potential losers. The living river would surely be one of the first casualties.

Perhaps we will continue to hide behind the strict constructions of our water management institutions and argue that the proposals contained here won't work—that we can't afford to devote water to rivers. We must recognize that these are rationalizations that focus on our fear of losing things that water rights holders can't bear to lose. To be sure, there are risks to water users and other decision makers in the Rio Grande basin in shouldering this task, but there are much greater risks in failing to try.

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Harris got his baptism in the Rio Grande at Boquillas, Coahuila, Mexico, in 1964: "I walked from Texas to Mexico and scarcely got my calves wet." Since 1975 he has been owner-operator of Far-Flung Adventures, a Rio Grande-based outfitting company. For the past 25 years, this has enabled him to observe the workings of the river first-hand. In 1994 he founded Rio Grande Restoration, a basin-wide streamflow protection group. With his 13 year-old daughter, Viola, he inhabits a riverside cottage in Pilar, New Mexico, from which he makes forays to forums as various as irrigation districts, legislatures, and schools, promoting awareness of the importance of the Rio Grande to people, communities and ecosystems.

"Today, the consequences of the last century of river development are coming into focus: and the picture is of a river in steep decline. It's apparent that, to change the grim prognosis for the Rio Grande, water users and managers must act purposefully, collaboratively, and soon if a living Rio Grande is to continue to serve as the life support system for our descendants."

The Value of Water in the Middle Rio Grande

by *F. Lee Brown*, Professor Emeritus of Economics, University of New Mexico

Use of the natural flow of the Rio Grande has been apportioned among the republic of Mexico and the states of Colorado, New Mexico, and Texas by international treaty and interstate compact. Under those rules, the middle Rio Grande region of New Mexico (from Otowi Bridge to Elephant Butte Dam) is entitled to consume approximately 393,000 acre-feet of water in an average water year. This natural flow has been fully appropriated since the 1950s, with regional growth accommodated since that time through the import of San Juan–Chama Project water from the Colorado River and through increased pumping of ground water.

In the last decade, however, as a result of research conducted by the New Mexico Bureau of Mines and Mineral Resources and the U.S. Geological Survey, it became apparent that the region's ground water was much more hydrogeologically limited than had previously been understood. The region has been mining ground water at an average rate of 70,000 acre-ft annually, and its total water consumption is now so great that in many years New Mexico probably would not meet its treaty and compact obligations at Elephant Butte without the return flow from ground-water pumping, a situation that is inherently non-sustainable. As a consequence, the region has been struggling to find ways to reduce its dependence on ground water and live within its limited supply of surface water.

This condition of water scarcity has given rise to markets for water rights in the middle Rio Grande, and the price of surface water rights in the region has risen steadily in recent decades, most sharply in the last few years. At this writing, the right to consume 1 acre-ft of surface water annually sells for about $4500 in the middle Rio Grande valley. Annualizing this sum at, say 6%, imputes a market value for an acre-ft of water itself of $270.

For most other commodities traded in reasonably competitive marketplaces, this type of number would be the bottom line measure for their economic value. For water in the middle Rio Grande, this figure may understate the actual opportunity cost of water use, possibly by a substantial increment. As discussed more thoroughly in a 1996 report for the city of Albuquerque titled *The Value of Water*, which I co-authored, opportunity cost is economic terminology for the opportunities foregone by using water in a particular way. As defined, it is the appropriate measure of the value of water in both private and public decision making about its use. Indeed, one of the major benefits provided by competitive markets is their ability to establish a price that reasonably measures the value of foregone opportunities. If the market price of water understates its opportunity cost—the likely historical situation in the middle Rio Grande—individuals and society collectively will tend to consume more of it than they would otherwise.

Consider the following factors, which collectively combine to create market values for water and water rights that are likely lower than their opportunity costs.

(1) Contracts or leases for water, as contrasted with water rights, tend to be tied to Bureau of Reclamation repayment costs, which reflect the capital and operation and maintenance costs of constructing and operating water storage and delivery structures but not the scarcity value of the water itself.

(2) Water rights in the main stem of the middle Rio Grande have never been adjudicated, and some informed observers believe that there may be two or three times the number of paper rights to water as there is actual wet water.

(3) Surface and ground water have been conjunctively administered in New Mexico since the 1950s, in that the state engineer requires that pumping effects on the Rio Grande be offset by the retirement of existing uses. Recent changes in his administrative rules are likely to increase the current market value of existing water rights as contrasted with past values.

(4) At the same time, moreover, ground-water pumping in the region is largely unrelated to what economists call in situ values, e.g., the prevention of subsidence, the maintenance of a drought reserve, etc. As these latter values are increasingly recognized, incorporated into water decisions, and surface water begins to be substituted for ground water, the price of surface water rights will also be bid up. (For more information on in situ values, see *Valuing Ground Water*, referenced below.)

(5) Until recently, the value of leaving surface water in the river for riparian purposes was not reflected in the marketplace for water rights because New Mexico water law has not recognized water left in-stream as beneficially used. The water needs of endangered species are now forcing change in this institutional limitation on water markets.

(6) New Mexico has enacted but not implemented a public welfare criterion in its water law that permits the state engineer to deny a water right transfer if it is deemed to be contrary to the public welfare. Some traditional water users in New Mexico, most notably Hispanic acequias, often oppose transfers of water rights as destructive of traditional culture and thereby contrary to the public welfare. To the extent that public welfare values have not previously been incorporated into market prices, those prices have understated the opportunity cost of water.

The factors above have tended to create a market price for water and water rights that is lower than the respective opportunity cost. Furthermore, there are some offsetting factors in the middle Rio Grande that tend to push the price of water and water rights artificially higher rather than lower, so that it is difficult to project what the market price of water and water rights would be if water were freely traded in a truly competitive marketplace in the middle Rio Grande. As the marketplace for water and water rights in the middle Rio Grande matures, hopefully this divergence between market prices and opportunity costs will disappear.

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Brown's professional interests are resource economics and econometrics with a specialization in water resources. In addition to his faculty positions at the University of New Mexico, he has also served as Director of the Bureau of Business and Economics Research, Director of the Natural Resources Center, Director of the Division/School of Public Administration, and Executive Director of the International Water Resources Association.

He currently serves as chair of the Middle Rio Grande Water Assembly, a volunteer non-profit organization whose mission is the development and implementation of a regional water plan for the counties of Sandoval, Bernalillo, and Valencia. This commitment reflects his view that water is key to the future of New Mexico and that the creation of institutions and policies for managing this scarce resource is one of the most important issues facing our state.

Water Planning on a Local Development Scale—The Placitas Area Microcosm

by *Robert M. Wessely*, Friends of Placitas

Placitas serves as a harbinger of water concerns that will surely surface across New Mexico. Many of the water issues that individually affect various portions of the state come together in Placitas. Placitas water planning is an opportunity, allowing us to choose to heed the scientific messages or keep our collective heads in the sand. Through a local water planning effort, Placitas is trying to make the right choice. We cannot do it alone; we need both funding and regulatory reform.

This article identifies problems and suggests paths toward solutions. Topics include Placitas land development pressure, Placitas water planning issues, how Placitas water planning fits into the state's planning picture, and actions that we urge top-level decision makers to take. While this article deals with water planning for the Placitas area, we believe the process identifies important actions needed on a statewide basis.

We suggest: (1) establishing close coordination between land-use and water-use decision making; (2) closing the regulatory loopholes that subvert resource management; (3) encouraging planning approaches and actions to focus on the long term; (4) recognizing and financing the complexity of public water-planning processes; and (5) performing the basic hydrological studies and maintain continued monitoring.

What Are Placitas' Key Development Issues?

Urban overflow—The city of Albuquerque and surrounding area is rapidly growing. Albuquerque serves as the concentration point for the state's 134,400 annual new residents—about 104,600 (78%) via immigration and 29,800 (22%) via birth. Placitas has the fortune/misfortune to lie within practical commuting distance of the urban center. And the urban center is boxed in by adjacent public and pueblo lands, limiting the quantity of private land that is available to house the growth.

A richly historic area—The numerous and historic springs in the area have given Placitas a long history of human occupation. There is archaeological evidence of settlement dating back several thousand years. There has been a Hispanic acequia community here for 200 years, characterized by extensive farming activities. Starting in the mid-1980s, the open spaces, mostly west of the village, were rapidly built out into an extensive commuter exurbia. This has exerted pressure on Placitas' rich archaeological and historically agrarian culture.

Weak water management—Recent growth has imposed a serious stress on the local water supply. Several springs have run dry. Most water is now obtained by mining ground water, either through community wells for subdivisions or through individual or shared domestic wells. Much of the development has occurred through cascading "four-lot split" subdivisions and their shared domestic wells (Section 72-12-1, NMSA 1978). Frequent and large-scale uses of these "exemptions" has enabled rapid development to evade the county and state engineer scrutiny intended by state subdivision and water legislation.

Local–state disconnects—There has been a tradition of disconnects between local government and state government in managing the impacts of growth on water. Local governments point to the Office of the State Engineer (OSE) for water policy wisdom, the OSE abdicates decisions to the local governments, and neither has been able to concentrate on the area's long term future. Similarly, the local governments depend upon New Mexico Environment Department (NMED) for inspection and enforcement of wastewater requirements, yet NMED is not sufficiently staffed to perform the function well.

What Are Placitas' Key Water Planning Issues?

Attracting public involvement—The first planning hurdle is attracting the attention of the populace. The diversity of aquifer types across the Placitas area encourages rumors, both of dearth and of plenty, which propagate without qualification. In Placitas, we now have people from relatively water-rich areas, who are accustomed to water being an automatically provided commodity. We find a general apathy toward our water future, exacerbated by the popularity of denial and fed by the multiplicity of rumors. The tendency is for the general public, as well as officialdom, to consider only the issues that directly bear on their immediate future.

Achieving constituency balance—Water planning requires balancing demand (as reflected in the needs and desires of various constituencies) against supply, in a way that will work for the long term. With New Mexico's legal structure and history of over-appropriation, the water planning balance must come from negotiation and agreement among multiple constituents. Obtaining the needed participation of the diverse constituents is tricky, and understanding what represents a reasonable and balanced compromise is even trickier.

Water sources—Water in Placitas is obtained by single or shared domestic wells, small community water systems, and springs. These withdrawals are from aquifers that recharge the Rio Grande. Some of the springs are fed through annual precipitation recharge (with water ages in months or years), whereas other springs have been measured to contain ancient water (up to 4,000 years old). Some are drought sensitive, others are not. In substantial parts of the area, the aquifers are already being mined, and water tables are dropping.

Limitations on supply—Rapid residential growth, coupled with ground-water mining, gives rise to concerns for the long-term viability of the water supply at any tolerable price. As a part of the already-stressed middle Rio Grande region and the desert Southwest, Placitas cannot expect to import water. Planning must depend upon local water, and withdrawal of local water is being authorized through land-use law, not water law, at dramatic rates.

Water-oblivious expansion—Each transfer of water rights into the area is evaluated only on its individual impact to neighbors and aquifers, with no view to the cumulative effect of multiple transfers. Furthermore, domestic wells (Section 72-12-1, NMSA 1978) are being authorized in large clusters to support large developments, each individual well being considered "de minimis." Within this environment, developers seek profits and local governments look forward to additional tax revenues.

Planning is complex—Water planning for an area such as Placitas is costly, both in effort and in dollars. We are fortunate to have an extensive hydrology study available—New Mexico Bureau of Mines and Mineral Resources (NMBMMR) Phase II study. Despite that, there exists a need for more work: quantifying water in storage, relating supply to current and future demand, and most costly, the process of obtaining proper constituency involvement to make the difficult balancing decisions.

Water rights—Another issue affecting water planning is numerous, often-competing, water rights. Placitas is bordered by tribal lands that have substantial unquantified rights to the water flowing underground from the Sandia Mountains. The village of Placitas has long-standing acequia systems with relatively senior rights. But the majority populations in the newly developed communities have junior water rights.

Balancing is not mathematical—Finally, we see before us the task of balancing the social costs against the financial costs. How do we assign values to Placitas' extensive riparian areas, agriculture and acequia traditions, and rural qualities of life versus more easily quantifiable dollar values of immigration and rising exurban property values? We need a whole community to provide the wisdom of one Solomon.

How Does Placitas Fit into Statewide Water Planning?

We are not alone—The overall context for water planning is a rapidly growing desert Southwest. New Mexico lives among thirsty and growing neighbors on all sides. State water planning faces four major hazards: drought, growth, affluent neighbors, and federal mandates.

Our state—New Mexico has established a minimally funded but urgent mandate for regions within the state to develop water plans. The plans are to address the hazards within the region. They reflect how we will manage to survive on our limited supply. These regional plans will be assembled into a statewide plan to address the same hazards on a broader scale.

Our region—The middle Rio Grande (Sandoval, Bernalillo, and Valencia Counties) is an exceptionally diverse and populous region. Like many other regions, its water resources are overallocated (by an estimated factor of three or four). All of the water in the Rio Grande is already being used, albeit perhaps not at maximum efficiency. On average, the wet water use already exceeds the renewable supply by 70,000 acre ft/yr (Water Assembly and S.S. Papadopulos & Assoc, 2000).

Our watershed—Placitas is a piece of the middle Rio Grande region. Located at the base of the Sandias, Placitas is seen by hydrologists as a major ground-water tributary of the Rio Grande. Historically supplied by springs, Placitas is now mostly supplied by its ground water. As shown by the recent hydrology studies, some areas have localized ancient aquifers that will run dry. Other areas will continue to draw from the flow toward the Rio Grande. Meanwhile, we keep increasing the rate of ground-water extraction through domestic well authorizations.

Scientific basis—The geohydrology at the north end of the Sandias is complex (Connell, Geology of the Northern Sandia Mountains and Albuquerque Basin, Placitas, and Bernalillo Area, Sandovol County, New Mexico, this volume; and Johnson, Geologic Limitations on Ground-Water Availability in the Placitas Area, this volume). A $10,000 Phase I hydrological study in 1996 laid the groundwork for special subdivision regulations and a follow-up study. The $100,000 Phase II study, 1998–2000, provided necessary details on the complex hydrology and a foundation for detailed water planning.

Public involvement—In summer 1999 three community water planning workshops were conducted by Del Agua Institute under a $5,000 grant from River Network. These workshops developed a set of local values and an approach to the water planning process. As an outgrowth of the workshops, an ongoing all-volunteer core committee has been meeting monthly. To date, the committee projects and products include: draft program plan for area water planning; initial draft water plan outline; supply and demand model, based upon Phase II hydrology (Johnson, 2000) and assessor data; public outreach and education; and draft agreement with regional water planners. This effort is progressing slowly under a $1,000 grant from Sandoval County.

What Are Placitas' and the State's Future Needs?

Water information model—The primary need is a model of water availability for specific locales in the Placitas area. The model should provide information in a form that a county commissioner can easily use to understand the effects of his/her decisions on permitting development. The Placitas-area planning group is working on a preliminary version of such a model. The current model uses the hydrologic regions defined in the Phase II study (Johnson, 2000) and an estimate of water per acre in storage for each region. Then development-based subregions are defined within each hydrologic region, from an overlay of actual assessor maps. From these an approximate lifetime of water at 125, 250, 500, and 1,000 ft well depths can be calculated for the currently authorized array of lots. Finally, the model can then estimate a projected shortening of aquifer lifetime for each additional lot or building that is authorized within the subregion.

Sound scientific and public basis—The vehicle for achieving effective land-use decision making is a water plan based upon both sound science and bona fide consideration of informed public opinion. Without impartial hydrogeologic studies, land-use decisions unavoidably disregard wise water-management practices. Water supply and demand assessments are too often based upon guesses, insufficient data, and/or developer-supplied analyses. Politicians are unwilling to make the hard decisions that look innovatively toward the future because thorough public involvement and support are not there. Placitas fortunately now has the detailed NMBMMR data that allow for competent, impartial modeling analysis and provide a reasonable assurance that decisions are based on valid information. This technical credibility is enabling and encouraging public participation and collaborative decision making, which will, in turn, control our fate.

Ongoing science—Another important need is maintenance of the hydrologic database. The Phase II study monitored water levels and their changes over a 1½ year period. These data provide the scientific basis for ground-water and water development models. However, to ensure that model predictions actually reflect reality, it is important to maintain and update the current data sets with periodic measurements of the actual behavior of the aquifers under ongoing use and development.

Regulatory feform—Understanding water availability is essential but not sufficient. Placitas has been subject to substantial unmanaged growth, resulting in stress on many of the aquifers. Placitas' decision makers need to implement land-use decisions that rigorously respect the limited water resources. We need more effective regulations at both the state and county levels. An overall vision for statewide management of water resources needs to be created and implemented. Support and advice are needed from the state level for encouraging proper local regulations and for technical evaluations. Regulatory agents, both state and local, need better handles on the development process, better coordinated roles, better technical knowledge, and better controlling legislation—the loopholes to managed water deployment need to be closed.

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Wessley works to widen scientific understanding of New Mexico water issues among elected officials and the general public. Active in designing, organizing, and executing water planning activities for the middle Rio Grande region and for the Placitas area watershed. He is co-founder, chairman, and technical director of SciSo, incorporated 1971–2001. SciSo is a systems engineering management consulting compan, serving government and industry, with large-scale client projects across the United States, in Europe, and on the Pacific rim. Having coordinated diverse interest groups in developing large-scale engineering projects, his current interest is in helping New Mexico optimize its limited water resources with an eye toward future generations.

Sandoval County Subdivision Regulations—A Development Plan for the Placitas Area

by *John T. Romero*, New Mexico Office of the State Engineer

Before the 1995 amendment of the New Mexico Subdivision Act, Sandoval County had no subdivision regulations specific to the Placitas, New Mexico, area. Existing regulations required only minimal water-use and water-availability information. The disclosure statement in place in 1994 had more requirements than the subdivision regulations themselves. For example, the disclosure statement for a proposed subdivision required type and quantification of water use, delivery method, life expectancy, and water source. In the case of domestic wells the statement even required maximum and minimum depths to water, the total depth and the estimated yield of a proposed well, and a recommended pump setting. The current county subdivision regulations require essentially the same information as required by the original disclosure statement.

After the 1995 amendment of the New Mexico Subdivision Act, Sandoval County developed detailed and comprehensive land subdivision regulations that addressed water issues and concerns. The new regulations included requirements for summary review proposals and presented standards for quantification of annual water requirements, conservation requirements, non-residential demand, and community demand, as well as water availability assessments for all types of proposals. In addition to these water-related requirements, the county developed a separate set of regulations to deal with subdivision proposals in the Placitas area. These regulations are attached as Appendix A to the land subdivision regulations for Sandoval County.

A Development Plan for the Placitas Area

Appendix A to Sandoval County's land subdivision regulations is a development plan for the Placitas area. The Sandoval County Commissioners approved Appendix A on October 17, 1996, following a review by the Office of the State Engineer (OSE).

Appendix A attempts to take into account and to balance the diverse geographic area of Placitas, limitations on water supply, desires of the local inhabitants, traditional land uses, traditional cultural practices, constitutional rights of property owners, and development trends within the area. The appendix applies only to new subdivision proposals not previously reviewed and filed. The purpose of the appendix is to provide the Sandoval County Planning and Zoning Commission with sufficient information to reasonably determine the impact that a proposed subdivision will have on the terrain, water table, water availability to pre-existing water users, and drainage courses associated with ground water.

Appendix A has requirements that are generally more stringent than the Sandoval County Subdivision Regulations. For instance, a subdivider in Placitas must notify all abutting property owners and neighborhood associations before submitting a proposal to the county. In addition, the regulations require that "all new subdivisions within the Placitas area shall form a Landholders Association or Water Association which shall impose and enforce Restrictive Covenants which . . . limit the amount of water consumed per household to a range of 85 . . . to 160 gallons per day per person, plus 132 gallons per day for outdoor landscaping and require metering of all wells within the proposed subdivision." These covenants are also required to provide a penalty clause, that shall be imposed on individual households which exceed the combined indoor and outdoor domestic use.

Water Assessment Requirements for Preliminary Plat Proposals

A subdivider must prove that water exists within the boundaries of a proposed subdivision in sufficient quantities to deliver 85–160 gallon per capita per day per dwelling, plus 132 gallons per day for the irrigation of 1,600 ft^2 of landscape. This may be accomplished by drilling a well within the boundaries of the proposed subdivision, if a well does not already exist, and testing by a qualified professional to demonstrate an adequate 50-year water supply. This water supply assessment should include preliminary work such as performing demand calculations, field geologic reconnaissance, identification of known aquifers, plotting all known domestic wells, constructing a well at or above industry standards, if one does not exist, and testing the well via a step drawdown test before a constant discharge test while measuring water levels and monitoring the recovery to at least 90% of initial drawdown.

The data gained from the water supply assessment are intended to provide reliable estimates of aquifer transmissivity, storativity, specific yield, thickness, hydraulic conductivity, and an evaluation of the potential effects on nearby surface water courses. The water assessment requires review by the OSE to ensure compliance with the county's requirements for the determination of minimum lot size.

The above criteria are applied only in the Placitas area, with the purpose of managing development and lot sizes in order to control the rate of ground-water depletion and to ensure that sufficient ground water will be in storage over the next 50 years. Since not all ground water in storage in an aquifer can be withdrawn, the appendix provides a methodology to estimate the percentage of ground water in storage that can be withdrawn based on aquifer characteristics. The method is based on the following equations:

$$S = Ac \times SY \times ST \times RC$$

S = ground-water storage (acre-ft)
Ac = size of tract (acre)
SY = specific yield (unconfined aquifer) or storativity (confined aquifer)
ST = saturated thickness (ft)
RC = recovery factor, usually 0.8

$$MLS = U / (A + RE)$$

MLS = minimum lot size (acre)
U = water use per lot per 50-year period (acre-ft)
A = water availability per acre (ft) = S/Ac
RE = recharge per acre per 50 year period (ft)

These calculations will be used to determine the number of lots that can be safely sustained by each domestic well. It should be noted that the county regulation encourages multiple well connections between lots located in the Placitas area.

Requirements for Summary Review Proposals

This summary procedure applies to Type III subdivisions containing five or fewer lots any one of which is less than 3 acres in size. This is the most common type of subdivision in New Mexico.

Subdivider shall prove that water exists within the proposed subdivision boundaries sufficient in quantity to deliver 85 gallons per capita per day per dwelling, plus 132 gallons per day for outdoor irrigation of 1,600 ft^2 of landscape.

Each lot shall be equipped with a water meter in addition to all wells.

Quantity will be determined by utilizing an existing well or drilling a new well within the boundaries of the proposed subdivision and by conducting a well test for a period of 24 hrs at a rate of 0.3 gpm per dwelling proposed to be serviced by that well with water level measurements taken before the test, at 3, 6, and 24 hrs, at the end of the test, and 24 hrs after the end of the test.

A well test report will be completed by the person completing the test. (There is no requirement for a qualified professional performing the test.)

Lot size will be determined by New Mexico Environment Department (NMED) requirements for liquid waste disposal.

References

Appendix A to Sandoval County Land Subdivision Regulations, 1997.
Sandoval County Land Subdivision Regulations, 1997.
New Mexico Subdivision Statutes, NMSA 1978, Amended.

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A flume measures discharge from El Oso Spring near the village of Placitas. In Placitas, water rights applications require the Office of the State Engineer to determine whether springs would be affected by the new water use. Photo by Peggy S. Johnson, November 1997.

Ground-Water Administration in the Middle Rio Grande Basin, New Mexico

by *Peggy Barroll*, New Mexico Office of the State Engineer

The Office of the State Engineer (OSE) is responsible for regulating water rights in New Mexico, including ground-water rights. When evaluating applications related to ground-water withdrawal, we must consider the potential depletion of ground water (or a drop in water levels in the aquifer), the potential for the proposed ground-water pumping to diminish the flows of streams and rivers, and whether the water requested is available for use by the applicant.

When ground water is pumped from an aquifer, water levels in that aquifer decline. This decline can cause wells to produce less water and may cause some wells to dry up altogether. In some cases it is possible to mitigate these effects by drilling deeper wells, but if the productive aquifer is limited in extent, this may not be possible. Deeper water is also more expensive to lift to the surface, and may not be of suitable quality. In Albuquerque, for example, deeper wells tend to produce water with higher concentrations of arsenic. If water levels decline too much, the overlying land may subside. This has occurred already in parts of Arizona and California, causing expensive damage to buildings and infrastructure. The economy of many parts of New Mexico depends on ground water either for municipal and industrial use, as in the Albuquerque Basin, or for irrigation use, as in the Estancia and Roswell Basins. If ground water is to continue to be a reliable water source, its development must be conducted in a controlled, sustainable fashion.

Ground-water pumping can also reduce the surface-water flow in adjacent rivers, often by intercepting ground water that ordinarily would have discharged to the river as baseflow. This reduction in surface-water supply can affect downstream surface-water users and may cause serious problems on interstate streams. New Mexico is required by interstate compact to deliver prescribed amounts of river water to downstream states, and, if we fail to do so, there are serious consequences. In 1974 Texas sued New Mexico for under-delivery on the Pecos River, resulting in a lengthy and expensive lawsuit in the U.S. Supreme Court. New Mexico lost this suit and has since spent tens of millions of dollars in fines and actions to prevent further under-delivery on the Pecos River.

When evaluating a ground-water application, the OSE must estimate the potential effects of the application on water levels in the aquifer and on stream flows (in addition to other statutorily defined considerations). To do this we must develop and use predictive ground-water models, which allow us to estimate the physical effects of ground-water pumping. The OSE does not typically perform such analysis for domestic wells, for which the OSE is required to issue permits upon request.

The Placitas area straddles two very different hydrologic regimes. The village of Placitas is up out of the valley, and wells in the area obtain ground water mostly from fractures and porous zones in hard rock (Johnson, Geologic Limitations on Ground-Water Availability in the Placitas Area, Sandoval County, New Mexico, this volume). The area is very complex, and productive aquifer zones are limited. Water rights applications in this area have typically been evaluated using models designed to represent this complex region, which provide estimates of how much drawdown a proposed well would cause and by how much the flows of Placitas Springs would be reduced. These models are designed based upon the hydrogeologic data collected by agencies such as the U.S. Geological Survey, New Mexico Bureau of Mines and Mineral Resources, and other investigators.

West of Placitas we enter the Albuquerque Basin where wells obtain water from the spaces between grains of sand, gravel, and silt of an alluvial aquifer. This aquifer is hydrologically connected to the Rio Grande, and ground-water pumping from the aquifer can diminish the flows of the Rio Grande. Hydrologic effects associated with this aquifer can be calculated using a numerical model originally developed by the U.S. Geological Survey and modified for OSE use. This model includes vast amounts of hydrologic and geologic data, which have allowed us to use the model to reproduce the past behavior of the aquifer with some accuracy, thus giving us confidence that future predictions using the model will be fairly realistic.

The Middle Rio Grande Guidelines for Review of Water Right Applications (Year 2000) describe how this model is to be applied by the OSE. These guidelines also define Critical Management Areas (Fig. 1), areas of extensive ground-water development where observed and/or predicted drawdown rates are very high (greater than 2.5 ft/yr) and where the OSE has determined that ground-water withdrawal rates should not be allowed to increase.

In addition, serious consideration has been given to the problematic effects of ground-water pumping upon the Rio Grande. The Rio Grande is the subject of a compact with Texas just as the Pecos River is. To ensure compact compliance, it is crucial that all new pumping effects on the flows of the Rio Grande be offset by the retirement of valid water rights and uses. For many years the OSE has required that estimated impacts to the Rio Grande be offset at the time the effect is calculated to reach the river. But because there is a time lag between initiation of ground-water pumping and its effect on the river, many ground-water users have not yet acquired all the rights that they will eventually need to retire. Large ground-water applications are currently pending with the OSE and more continue to be filed. Concerns have been raised as to whether there will be sufficient water rights available to offset the effects of presently permitted ground-water users. Offset of future ground-water permits is an even greater concern.

To address this issue, the OSE's Middle Rio Grande Guidelines require new ground-water permittees to obtain, before pumping, the water rights they will eventually need to offset the effects of that pumping. Since the total effects of that pumping will not actually reach the Rio Grande immediately, the permittee may lease back the use of the offset water to its original use until needed to offset the stream effects calculated by the model. This requirement to obtain water rights up front is deemed necessary to prevent the Albuquerque Basin from becoming overdrawn at the water bank. This requirement is prudent when one considers that the price of water rights within the basin is only likely to increase, and there may be additional allocation of water to pueblos and to meet endangered species requirements, which will further limit the availability of water rights for offset.

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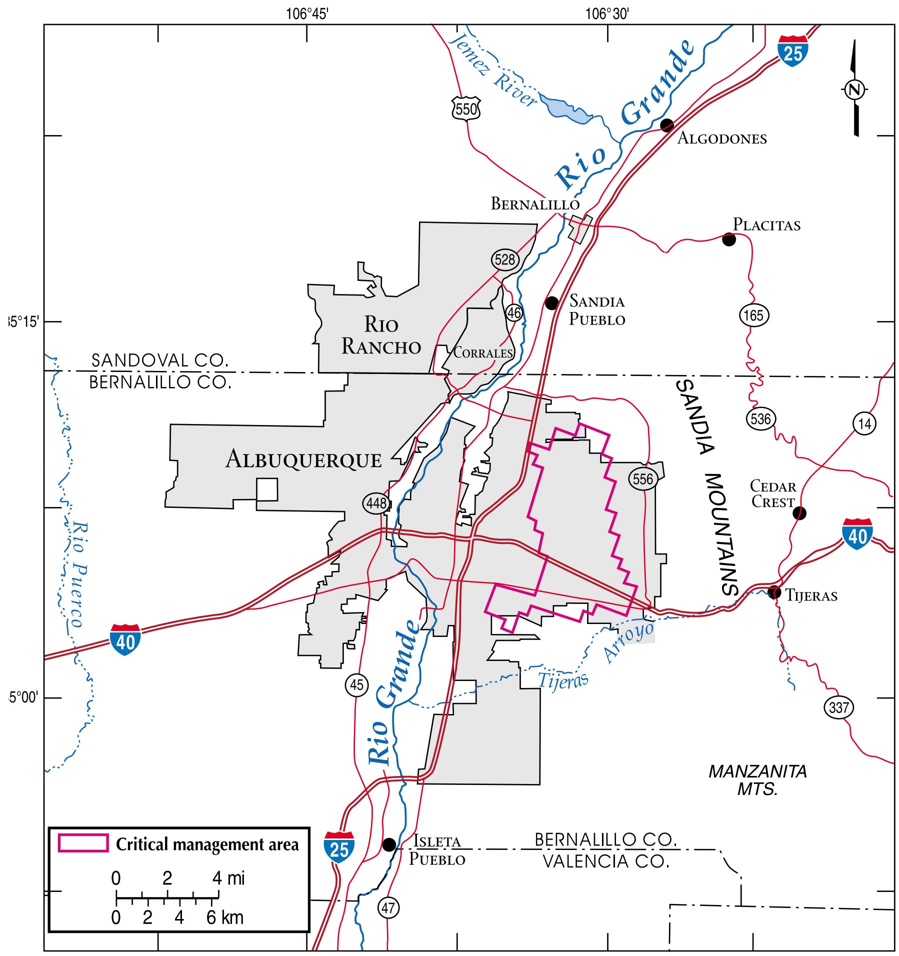

FIGURE 1—Location of the middle Rio Grande basin critical management area (CMA).

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After finishing her PhD, Barroll worked briefly for D. B. Stephens & Associates, modeling contaminant transport. For the last 9 years, she has worked at the Hydrology Bureau of the Office of the State Engineer, doing ground-water modeling and evaluating the hydrologic effects of water rights applications. Much of her work involves simulating the interaction between ground-water and surface-water systems. She has worked extensively in the Carlsbad area of the Pecos River basin, and more recently has been working on the lower Rio Grande and middle Rio Grande areas. She is collaborating with Doug McAda on a new ground-water model of the middle Rio Grande, which will incorporate the new hydrogeologic data collected over the last several years. Her lower Rio Grande work is related to ongoing and potential litigation related to the lower Rio Grande adjudication and disputes with Texas over the flows of the Rio Grande. She lives in Santa Fe with her husband, Hans Hartse, and their two children, Sara and Jeremy.

Geology of the Northern Sandia Mountains and Albuquerque Basin, Placitas, and Bernalillo area, Sandoval County, New Mexico

by *Sean D. Connell*, New Mexico Bureau of Mines and Mineral Resources

The northern flank of the Sandia Mountains contains a diverse array of rocks and geological structures that form the outstanding landscape of the Bernalillo–Placitas area. The Bernalillo–Placitas area was formed as sediments were preserved during successive geologic cycles of deposition, partial erosion, folding, and faulting. The distribution and character of the rocks and crosscutting geological structures strongly influence the availability and flow of ground water in the subsurface. Geologic structures such as faults often form obstacles to ground-water flow and generally serve as boundaries for ground-water aquifers. In particular, faults can juxtapose aquifers with different yields and can control the locations of springs and ground-water recharge areas.

Due to rapid residential development in southeast Sandoval County and resulting concerns regarding the long-term availability of potable ground water, the New Mexico Bureau of Mines and Mineral Resources and the University of New Mexico have been investigating the geology and ground-water resources of the Placitas area. These studies resulted in the completion of detailed geologic maps depicting the locations of major faults and geologic units (Connell et al., 1995; Connell, 1998; Johnson, 2000). A simplified geologic map (Fig. 1) illustrates the surface distribution of faults, folds, and geologic units (see inside back cover), which are grouped in order to illustrate the general geologic framework of the area. Geologic units are projected below the ground surface on geologic cross sections to determine the depth of buried formations and the influence of faults and folds (Fig. 2). Geologic cross sections can then be used to predict where and at what depth a particular well should be drilled in order to intersect a particular formation.

The Bernalillo–Placitas area lies at a geologically complex transition between the Albuquerque Basin and Sandia Mountains uplift. The Placitas area, on the north flank of the Sandia Mountains, is underlain by north-sloping rock layers that are broken and deformed by numerous faults. On a traverse from Tunnel Spring north to Las Huertas Creek (Fig. 1), one can walk through the rock section and examine rocks that represent the major hydrogeologic units of the Placitas area (Figs. 2, inside back cover). The Rincon-Placitas-San Francisco faults delineate the geological (structural) boundary between the Sandia Mountains and upland areas of the East Mountains, where the oldest rocks in the region are exposed. These rocks consist mainly of granites that form much of the Sandia Mountains (Fig. 1). Water typically flows through these rocks along rare open fractures and near faults. These old crystalline rocks are overlain by younger sedimentary rocks of the Pennsylvanian and Permian Periods, which contain limestone, mudstone, evaporites, and some conglomerate and sandstone. The oldest of these rocks form the banded crest of the Sandia Mountains. Water flowing through fractures in the limestone typically contains calcium carbonate resulting in increased hardness of the water. With time, these fractures develop into larger channels potentially capable of transmitting large quantities of water. Water wells drilled into these fractured and faulted zones commonly have high yields; elsewhere, wells drilled into non-fractured rock typically yield little water or are dry. Rocks of the Mesozoic Era (Age of Dinosaurs; Fig. 2) are exposed east and southeast of the Ranchos, Lomos, and Escala faults. These rocks represent deposition during the Triassic, Jurassic, and Cretaceous Periods and contain fine-grained sediments that only locally contain significant sources of ground water, generally near north-trending fault zones (Johnson, 2000). The youngest of the Mesozoic sedimentary rocks contain mudstone and sandstone of the Cretaceous Period, which typically are the poorest aquifer units of the area. Sandstone interbeds can locally be exploited for ground water, but commonly yield poor-quality water.

Deposits of the Santa Fe Group of the Cenozoic Era (Age of Mammals) comprise the regional aquifer of the Albuquerque Basin. The thickest and most productive layers in the Santa Fe Group lie west of the Ranchos, Lomos, and Escala faults, which form the eastern boundary of the middle Rio Grande ground-water basin. Alluvial deposits of the Santa Fe Group are present east of these faults, but are typically thin, moderately cemented, and are poorer aquifer units in comparison to alluvial deposits west of the faults. The communities of Rio Rancho, Albuquerque, Bernalillo, and the pueblos of Sandia, San Felipe, and Santa Ana obtain their water from Santa Fe Group alluvial sediments. The Santa Fe Group is thousands of feet thick and was laid down by streams originating in the Sierra Nacimiento and Jemez Mountains, the ancestral Rio Grande, and from smaller streams draining the Sandia Mountains watershed. Deposits of the ancestral Rio Grande, which flowed 2–4 mi east of the present valley, in the Bernalillo–Placitas area, form a relatively narrow belt of sediments that form the most productive aquifer beneath the city of Albuquerque (Connell et al., 1999). These ancient river deposits interfinger with sand and gravel deposits derived from the Sandia Mountains, which generally contain potable water but do not transmit water as effectively as the clean sand and gravel deposited by the ancient Rio Grande.

The youngest deposits record episodic erosion, deposition, and recycling of sediments as the ancestral Rio Grande began to cut the modern river valley approximately 1.2–0.7 million years ago, in response to climatic changes in northern New Mexico and Colorado during glacial episodes. This ice-aged entrenchment lowered the water table in the Santa Fe Group and partially drained the uppermost part of the Santa Fe Group alluvial aquifer.

Detailed geologic mapping of the region, studies of exposed rocks, and examination of well borings has greatly improved the level of understanding of the architecture of the Albuquerque Basin and its ground-water resources. Ongoing studies of the Santa Fe Group basin fill will eventually result in a better understanding of the entire basin and its ground-water resources.

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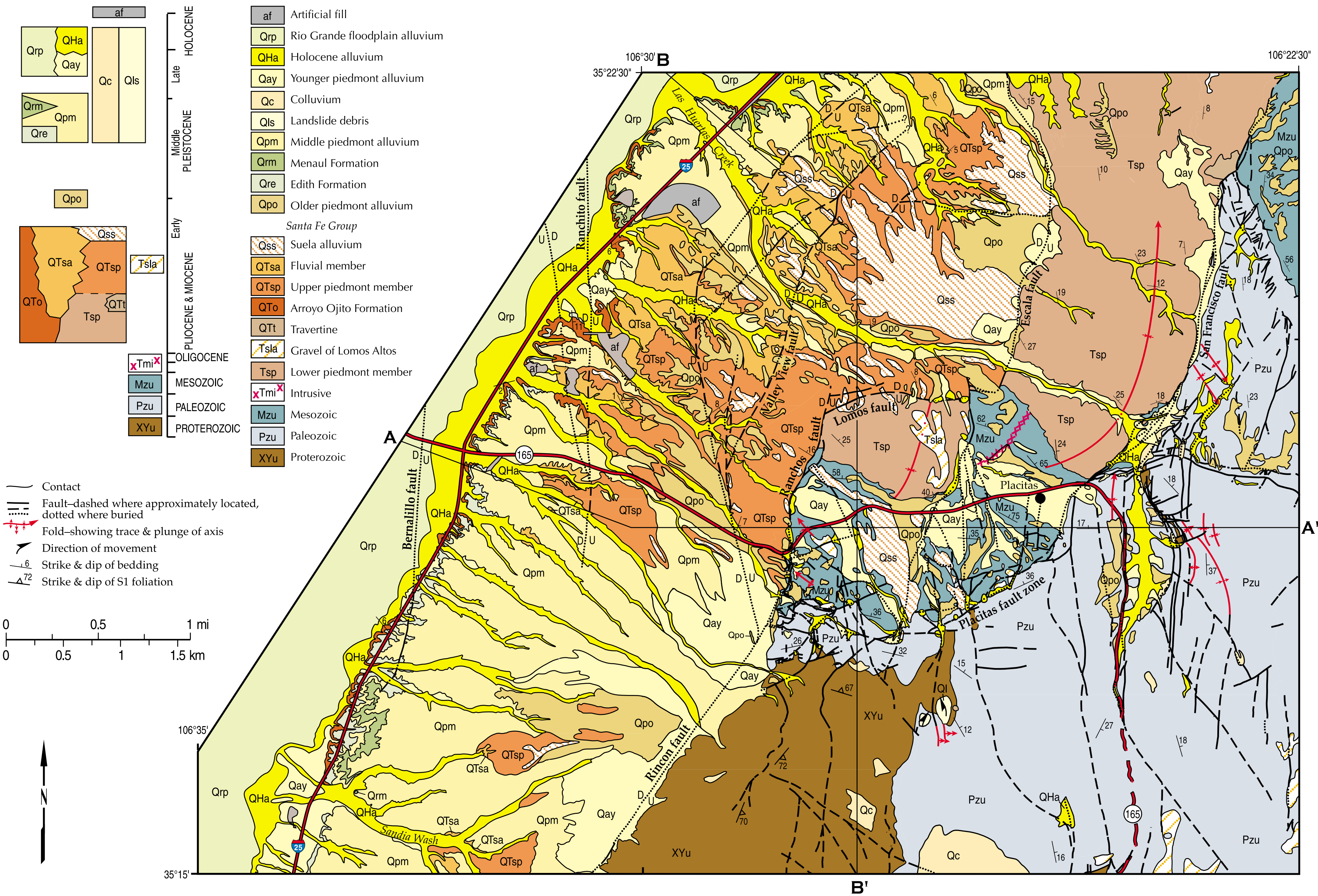

FIGURE 1—Simplified geologic map of the Bernalillo and Placitas 7.5-min quadrangles (modified from Connell et al., 1995; Connell, 1998).

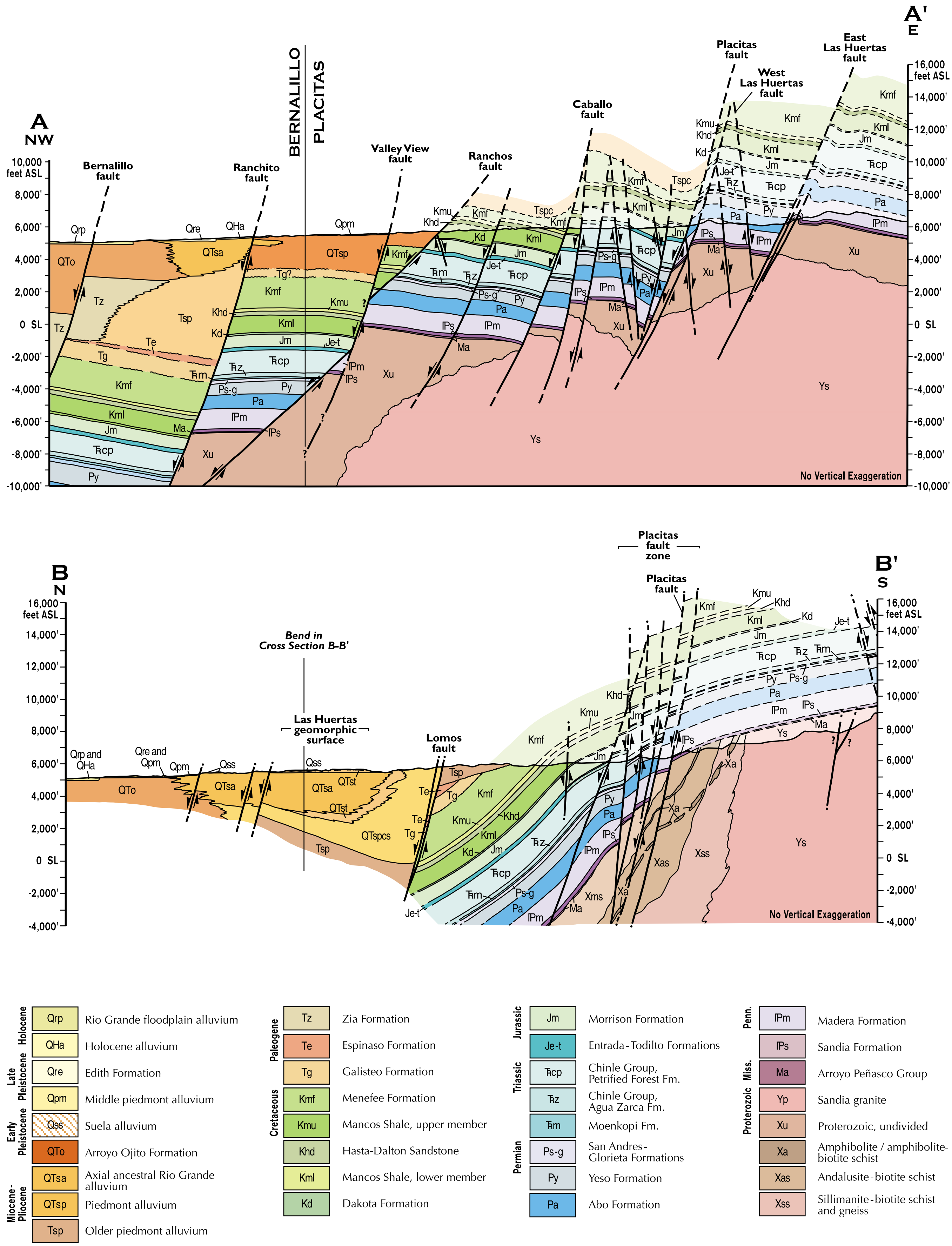

FIGURE 2—Simplified geologic xross sections of the Placitas area (modified from Connell et al., 1995, Connell, 1998).

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Before joining the NMBMMR, Connell worked for a consulting engineering geology firm in southern California, where he was involved in the evaluation and development of property for residential, commercial, and light-industrial tract development, including investigations of active faults. Connell was also involved in contract work involving soil-stratigraphic and geomorphic studies of Quaternary active faults and reconnaissance geologic and geomorphic mapping for archaeological studies in southern California.

Since joining the NMBMMR in 1996, Connell has contributed to 11 geologic quadrangle maps, encompassing an area of about 1,100 km^2. He has also been studying the stratigraphy of the alluvial aquifers of the Santa Fe Group, and has been an active participant in an ongoing program to analyze the geology at nested piezometers in the Albuquerque Basin. Connell is currently involved in regional geologic map compilations, and stratigraphic and environmental geological studies in the Albuquerque Basin, including compilations of geologic maps of the Isleta Reservation, and the Albuquerque-Rio Rancho metropolitan area.

Geologic Limitations on Ground-Water Availability in the Placitas Area, Sandoval County, New Mexico

by *Peggy S. Johnson*, New Mexico Bureau of Mines and Mineral Resources

The Placitas area, situated in the picturesque northern Sandia foothills, has been intensively developed during the past three decades. The region has evolved from a sparsely populated, rural agricultural area, to a mixed suburban environment. Population growth of 85% during the 1970s and from 20% to 30% during the 1980s and early 1990s (Middle Rio Grande Council of Governments, 1992) has relied entirely on development of ground water for a domestic water supply (Fig. 1). Increased ground-water withdrawals combined with a 2-year drought in 1995 and 1996 resulted in numerous dry wells and raised awareness of the potential for over-development of the area's limited ground-water resources. A thorough understanding of the hydrogeology of the Placitas area is essential to achieving sustainable ground-water development. Before detailed geologic mapping of the area in 1995 (Connell et al., 1995) and a comprehensive hydrologic study in 1997–1999 (Johnson, 2000), this understanding was hampered by a general absence of detailed hydrologic and geologic data and by the area's complex geology.

The Placitas area is geologically complex because it straddles the geologic boundary between the Sandia Mountains and the Albuquerque Basin of the Rio Grande rift. Major rift-margin faults, including the San Francisco-Placitas fault zone and numerous smaller faults, cut through much older (360–66 million years old) Paleozoic and Mesozoic sedimentary rocks, rotating them downward (to the north) below younger (23.7 million–700,000 years old) Santa Fe Group basin fill (Fig. 2). These faults behave both as barriers to and conduits for ground-water movement. Older layered rocks have been deformed by some faults into a nearly vertical orientation. In some cases, vertical, low-permeability rock layers such as fine-grained shales and mudstones form stratigraphic barriers that also compartmentalize ground water into small isolated aquifers.

This geologic setting of layered rocks with dramatically different aquifer properties, broken and deformed by faulting, is what makes identification of Placitas' aquifers such a challenge to scientists, well-drillers, developers, and home buyers. These characteristics are not unique to Placitas; they are quite common in other mountainous, developing areas of New Mexico such as the East Mountains and southeast Santa Fe County. By studying surface and subsurface geology, well hydrographs (measurements of ground-water levels over time), and chemical tracers in ground and surface water, hydrologists have identified an assortment of confined (under pressure) and unconfined (open to the atmosphere) aquifers near Placitas. These aquifers possess a wide range of water quality, productivity, ground-water age, and varying degrees of hydraulic connection and recharge (water replenishing an aquifer).

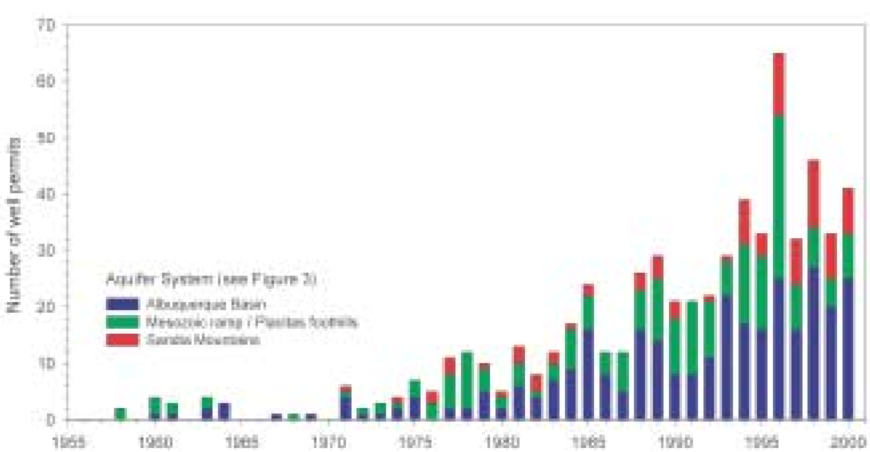

FIGURE 1—Number of wells drilled in the Placitas area, 1958–2000, from records of the New Mexico Office of the State Engineer.

Placitas' Aquifers

The Placitas area contains three distinct aquifer systems: the Sandia Mountains, the Placitas foothills (known as the Mesozoic ramp), and the Albuquerque Basin (Fig. 3). In general, large supplies of ground water are not available in the mountain system or in the Mesozoic ramp. Only aquifers in the Santa Fe Group deposits that fill the Albuquerque Basin are capable of supporting large-scale ground-water withdrawals.

The most important aquifer in the mountain system is contained in the Madera Limestone, the layered rock that caps the Sandia Mountains. This limestone aquifer stores and transmits water through fractures in the rock as well as small pores, and thus is called a dual-porosity aquifer (Johnson, 1999). Because the flow of ground water is concentrated along discrete fractures or cracks in the rock, its availability is highly variable, and dry holes are relatively common. On a regional scale, the Madera Limestone possesses very high transmissivity (it transmits large volumes of water) but relatively low storage. These are properties that allow the Madera Limestone to efficiently transmit fresh ground water from the Sandia Mountains down towards the basin, but which also limit the amount of water stored in the aquifer.

Exposures of Madera Limestone in the Sandia Mountains form major ground-water recharge areas that are fed by snowmelt, winter-spring precipitation, and surface water from Las Huertas Creek and other drainages. This recharge water flows through the limestone along fracture systems in the subsurface until it is intercepted by a low-permeability barrier such as the Placitas fault zone or a fine-grained rock, where it either discharges as spring flow, or continues on through a few permeable windows in the rock. Tunnel Springs, the Placitas Springs, and Old San Francisco Springs are examples of springs that discharge from the Madera Limestone along a fault barrier. This recharge water also possesses unique water chemistry characterized by dissolved calcium and bicarbonate, low concentrations of total dissolved minerals, a temperature less than 61° F (or 16° C, the area's mean annual temperature), a high dissolved oxygen content, and no significant trace elements. By mapping these chemical characteristics we have identified pathways for ground-water movement and aquifers that are connected to or isolated from sources of recharge.

The Mesozoic ramp is a region of older (240–60 million year old) sedimentary rock, situated in the Placitas foothills, that is broken and deformed by many faults. Ground water here is limited to isolated sandstone aquifers and rocks that are highly fractured. Rotation of layered rock by up to 65° has created a network of subvertical strip aquifers,

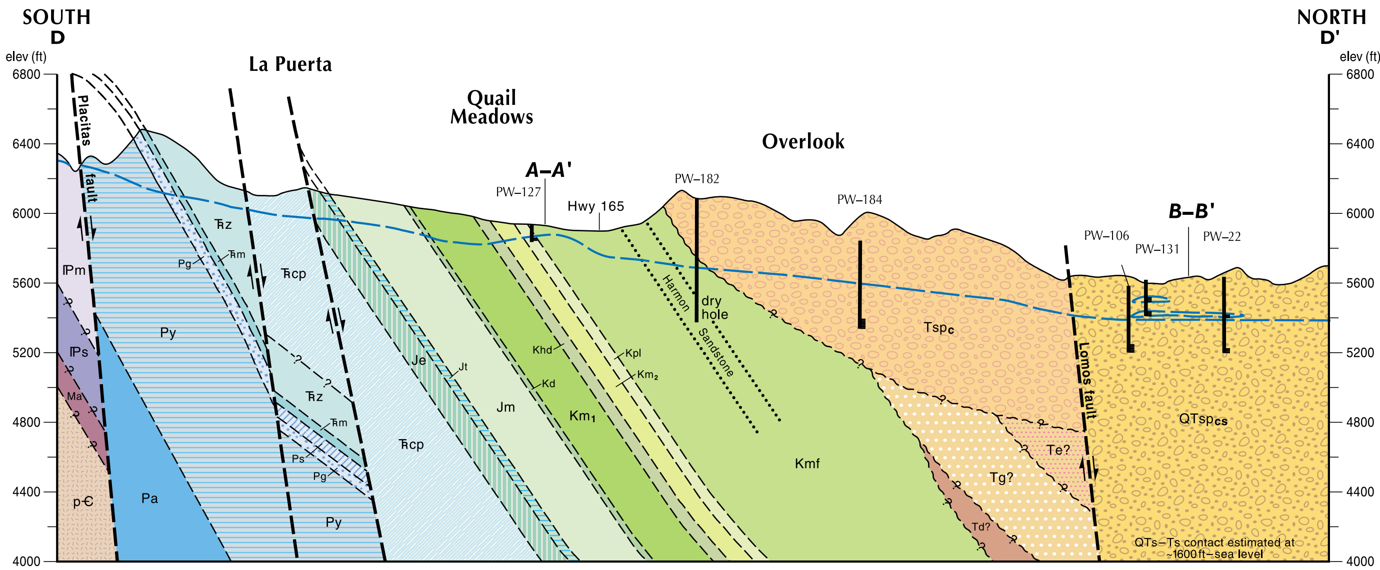

FIGURE 2—Geologic cross section through the La Puerta, Quail Meadows, and Overlook communities of Placitas showing subvertical strip aquifers layered between aquitards.

many of which are isolated by aquitards (geologic units incapable of transmitting significant quantities of water) of mudstone, shale, and siltstone, and by north-south faults (Fig. 2). Many of the aquifers produce ground water with elevated temperatures up to 77° F (25° C), low dissolved oxygen, and elevated concentrations of dissolved minerals (sodium, sulfate, iron, copper, manganese, zinc, and arsenic), all characteristics of very old water. Dating Placitas' ground water using carbon-14, a radioactive isotope of carbon, indicates a wide range of ages within this relatively small area, from recent to over 35,000 years (Fig. 3). This chemistry indicates that ground water in many of these isolated aquifers is disconnected from active recharge and has been sequestered for thousands to tens of thousands of years (Johnson et al., in press).

Ground-Water Mining

The age of ground water has important implications for water resource management and development. The ground-water ages shown in Figure 3 represent the average time elapsed since the water entered the aquifer. These ages indicate that much of the ground water stored in Placitas' aquifers is not actively recharged, and hence is susceptible to overdraft (withdrawal of ground water at excessive rates resulting in overdevelopment and other undesirable effects). Depleting ground water that is not actively recharged typically results in a progressive decrease in the amount of water stored in the aquifer, and when accompanied by a progressive decline in water levels constitutes ground-water mining. Whereas this practice may be necessary in certain circumstances, it is certainly not sustainable and can lead to other harmful consequences such as reduced flows to streams and springs, drying of wetlands, and land subsidence. On the other hand, ground waters that are actively recharged are part of the modern hydrologic cycle and are constantly being renewed. Exploitation of these sources is potentially sustainable.

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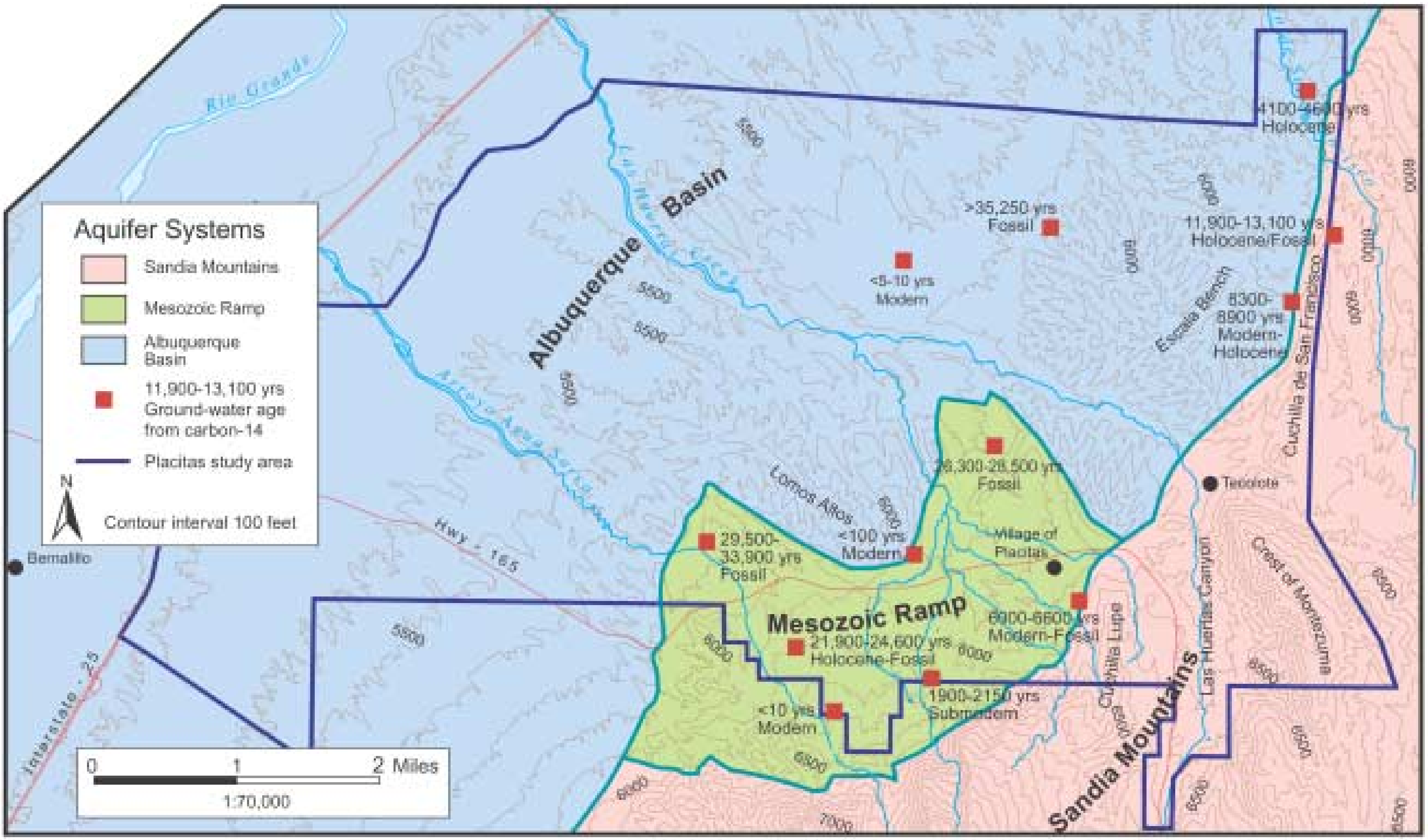

FIGURE 3—Ground-water ages in aquifers near Placitas, New Mexico.

The Challenge of Sustainable Ground-Water Development

by *Peggy S. Johnson*, New Mexico Bureau of Mines and Mineral Resources

Ground water is one of New Mexico's most important geological resources. Withdrawals of ground water supply 90% of the state's drinking water. Ground water constitutes the state's principal store of fresh water and most of our future potential water supply. Most rural communities such as Placitas rely totally on ground water for their current and future domestic supply (Johnson, Geologic Limitations on Ground-Water Availability in the Placitas Area, this volume). Ground water is also linked to flow in rivers, streams, and springs and supports our limited but treasured riparian areas. Ground water is not a nonrenewable resource like a mineral deposit or a petroleum reserve, but neither is it completely renewable within a short time frame. Ground-water resources may appear ample, but availability actually varies widely, and only a portion of the ground water stored in the subsurface can be withdrawn economically without adverse consequences. In the past decade attention has been placed on how to manage New Mexico's ground water (and surface water) in a sustainable manner—that is, in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences (Alley et al., 1999). In this paper we examine the concept of sustainable development of ground-water resources, but first we must understand the aquifer.

Understanding the Aquifer

Aquifers are dynamic—Under natural conditions, aquifers are in a state known as dynamic equilibrium—that is, recharge or replenishment of the aquifer approximately equals discharge. Ground water moves along flow paths from areas of recharge, such as mountains, rivers, or arroyos, to areas of discharge, like springs, wetlands, and streams. Water withdrawn for human activities affects the amount and rate of movement of water entering, leaving, and stored in the system. Pumping from a well diverts ground water that was moving slowly to its natural, possibly distant, area of discharge. Whereas the source of water pumped from wells is primarily aquifer storage, eventually that diversion means a decrease in discharge to streams, springs and wetlands, and less water available to plants.

Recharge from precipitation continually replenishes ground water, but typically at much smaller rates than rates of pumping. In New Mexico the amount of recharge from precipitation is both small and relatively fixed, with estimates ranging from 0.03% to 20% of mean annual precipitation (Stephens et al., 1996). Water levels in undeveloped aquifers fluctuate seasonally and from year to year in response to natural changes in recharge (precipitation) and discharge. A seasonal rise and fall in water levels indicates that the aquifer is well connected to a seasonal source of recharge, such as snowmelt, presipitation, irrigation, or ephemeral streamflow. Significant recharge is extremely localized along streams, arroyos, mountain fronts, and faults. By mapping natural ground-water fluctuations, hydrologists can determine which aquifers, or portions of aquifers, are actively replenished. High ground-water use in areas of little recharge eventually causes widespread declines in ground-water levels and a significant decrease in storage in the ground-water reservoir.

Aquifers are complex—Aquifers are not simple,rather they are complex, three-dimensional flow systems, with subsystems at local, subregional, and regional scales (Fig. 1). The rate of movement of ground water through an aquifer ranges from 1 ft per day or greater to as little as 1 ft per year or even 1 ft per decade. Aquifer systems are made up of complicated arrangements of high and low conductivity aquifer units operating on scales of tens of feet to hundreds of miles within time frames of days to hundreds, thousands, or tens of thousands of years. Development of regional aquifers may take place over a number of years and the effects of ground-water pumping tend to manifest slowly over time. The full effects of ground-water development may not become obvious until undesirable effects are evident. It's no wonder that sustainable development of ground-water resources is a challenging and somewhat unpredictable process.

Ground-Water Mining in New Mexico

In some areas of New Mexico, decades of ground-water pumping have resulted in prolonged and progressive depletions of ground-water storage and declining water tables indicative of ground-water mining. For example, water level declines of up to 140 ft occurred in northeast Albuquerque between 1960 and 1992, a condition that will ultimately reduce flow in the Rio Grande raise grave concerns about drinking water supplies, riparian bosque, critical habitat, and land subsidence. Other mined ground-water basins include the Mimbres and Estancia Basins, portions of the Española Basin, and the Ogallala aquifer in eastern New Mexico. Ground-water development in the area surrounding Placitas, New Mexico has occurred at an exponential rate over the last 30 years (Fig. 2), resulting in water level declines of up to 120 ft in the area of Quail Meadows (Fig. 3). These declines in water levels, and associated reductions in storage, are large compared to natural fluctuations in water levels. Widespread pumping that results in regional water level declines can also result in other undesirable effects such as large decreases in

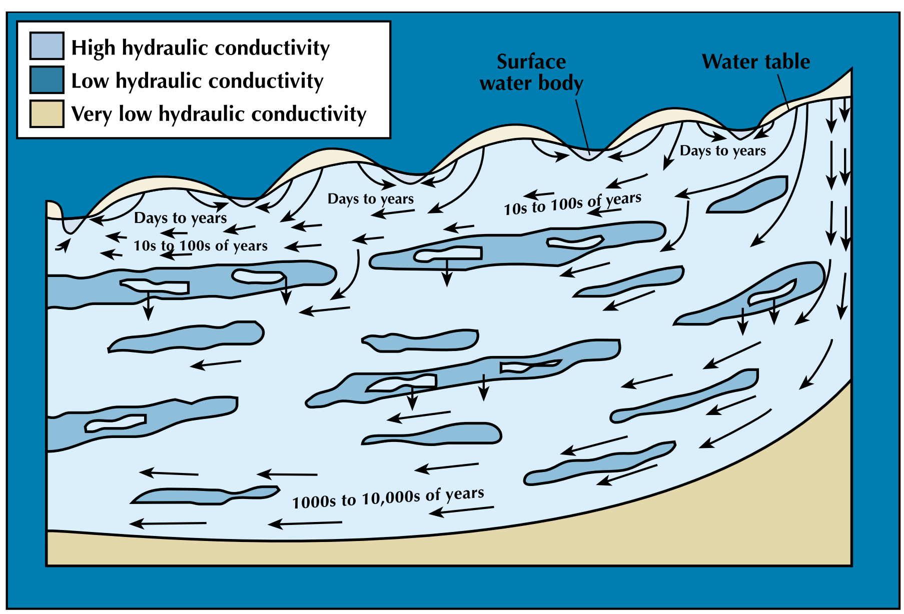

FIGURE 1— A regional ground-water flow system is made up of subsystems at different scales in a complex hydrogeologic framework (after Alley et al., 1999).

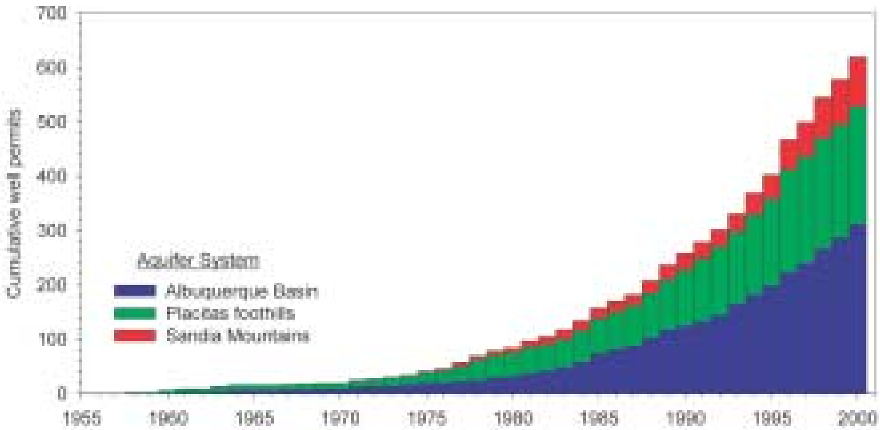

FIGURE 2—Exponential growth in number of wells drilled in the Placitas area, 1958–2000, from New Mexico Office of the State Engineer records.

aquifer storage, particularly in unconfined aquifers, shallow wells that go dry when the water level drops below the screened or open intervals of wells, increased costs of pumping or drilling of additional wells, less water flowing to rivers, streams, springs, and wetlands, less water available for vegetation as the water table declines, and increased risk of a pumping well intercepting contaminated or poor-quality ground water.

Ground-Water Sustainability and Public Policy

Implicit in the concept of ground-water sustainability is a definition of unacceptable consequences, which can be subjective and open to public debate. The various effects listed above illustrate the potential societal costs of ground-water mining and, by a public standard, may be defined as unacceptable. The tradeoffs between ground-water pumping and environmental impacts must be evaluated on a public stage with input from scientists, engineers, citizens, and policy makers. Scientists and engineers must provide the necessary, high-quality hydrogeologic data (Table 1) and sound evaluations of aquifers and ground-water systems. Each ground-water system and development scenario is unique and requires a site-specific analysis in the context of local water, cultural, economic, and legal issues. Citizens, through public dialogue, must make known their vision of the community's future and provide direction as to what constitutes unacceptable consequences. Policy makers play a crucial role and must contribute on multiple fronts:

(1) Commit to fund necessary data collection and objective scientific evaluation
(2) Solicit public participation regarding water use and environmental priorities
(3) Incorporate scientific findings and public opinion into a water management strategy that honors both
(4) Continue to monitor the aquifers and extend the hydrologic database through time
(5) If necessary, revise the plan to achieve sustainable development and minimize or eliminate unacceptable consequences.

The key challenge is to present clear and accurate hydrologic data and frame hydrologic implications of ground-water development and management strategies so they can be properly evaluated. Scientists are continually challenged to refine their analyses and address new problems and issues when they arise, using improved and innovative techniques. Citizens are challenged to self-educate and participate in public forums on water issues. Decision makers are challenged to evaluate alternative management strategies and implement those that honor both sound scientific data and public welfare (as defined by local residents, not outside interests). These are daunting challenges for everyone—challenges that are far easier to ignore than address. However, the path and process are well defined. The first step is a realization that if we choose a path of ignorance, future generations will suffer the unacceptable consequences.

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Johnson is a hydrogeologist with the New Mexico Bureau of Mines and Mineral Resources. She has over 10 years of consultant and research experience in ground-water hydrology and related fields. Her diverse background includes practical research in basin hydrogeology, karst hydrology, mountain-front recharge, surface-water, and ground-water resource assessments, isotope hydrology, and aquifer delineation. She specializes in integrating geology with hydrologic, geochemical, and stable isotope data in studies of ground-water availability, recharge, geologic controls of ground-water flow, and ground-water surface-water interactions. Her projects are designed to gather and assess complex hydrologic and geochemical data in a geologic framework. Results of one such study on the hydrogeology and water resources of the Placitas area of north-central New Mexico provide the scientific framework for the area's regional water planning effort. Johnson has considerable previous experience in private consulting, and conducts hydrogeologic and water supply investigations for the New Mexico Office of the State Engineer, the Interstate Stream Commission, and various counties and municipalities throughout the state.

TABLE 1—Types of hydrogeologic data required for analysis of ground-water systems (modified from Alley et al., 1999).

Physical Framework

Topographic maps showing the stream drainage network, surface-water bodies, landforms, and locations of structures and activities related to water
Geologic maps of surficial deposits, bedrock, and geologic structures (faults and folds)
Hydrogeologic maps showing extent and boundaries of aquifers and confining units
Saturated-thickness maps of unconfined (water table) and confined aquifers
Maps showing average hydraulic conductivity, transmissivity, and variations in storage coefficients for aquifers and confining units
Estimates of ground-water age at selected locations in aquifers

Hydrologic Budgets and Withdrawals

Precipitation and evaporation data
Streamflow data, including measurements of gains and losses of streamflow
Maps of the stream drainage network showing extent of normally perennial flow, normally dry channels, and normally seasonal flow
Estimates of total ground-water discharge to streams
Measurements of spring discharge
Measurements of surface-water diversions and return flows
Quantities and locations of interbasin diversions
History and spatial distribution of pumping rates in aquifers
Amount of ground water diverted for each use and the quantity and distribution of return flows
Well hydrographs and historical water-level maps for aquifers
Location of recharge areas and estimates of recharge

Chemical Framework

Geochemical characteristics of the aquifer materials, and naturally occurring ground water
Distribution of water quality
Temporal changes in water quality, particularly for contaminated or potentially vulnerable unconfined aquifers
Sources and types of potential contaminants
Chemical characteristics of artificially introduced waters or waste liquids
Maps of land cover and land use
Streamflow quality, particularly during periods of low flow

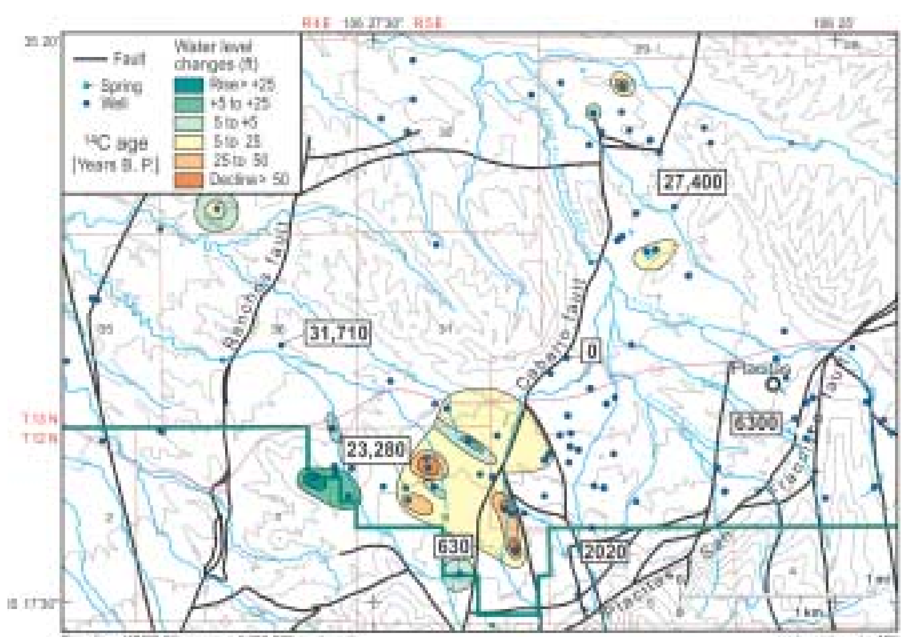
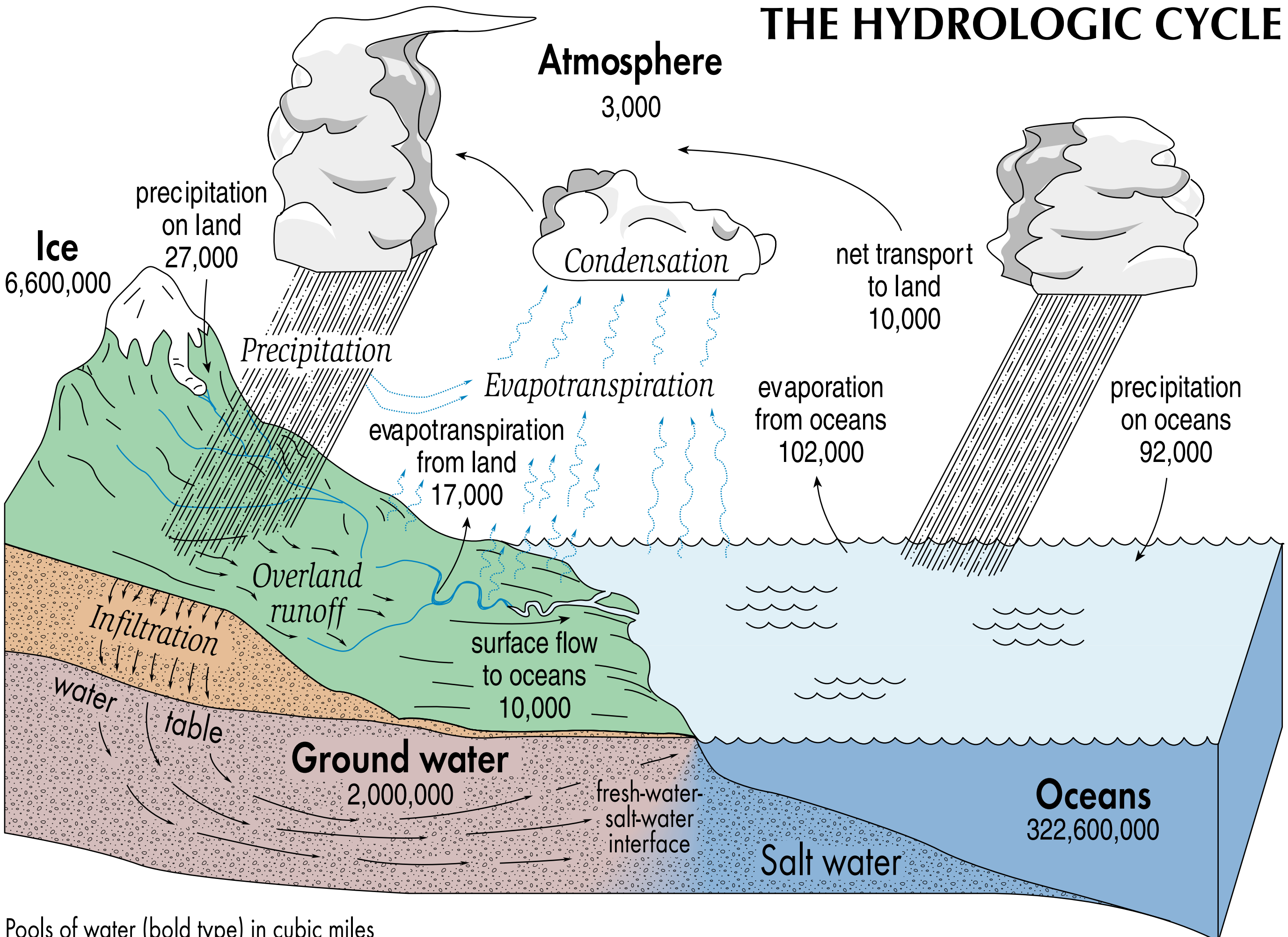


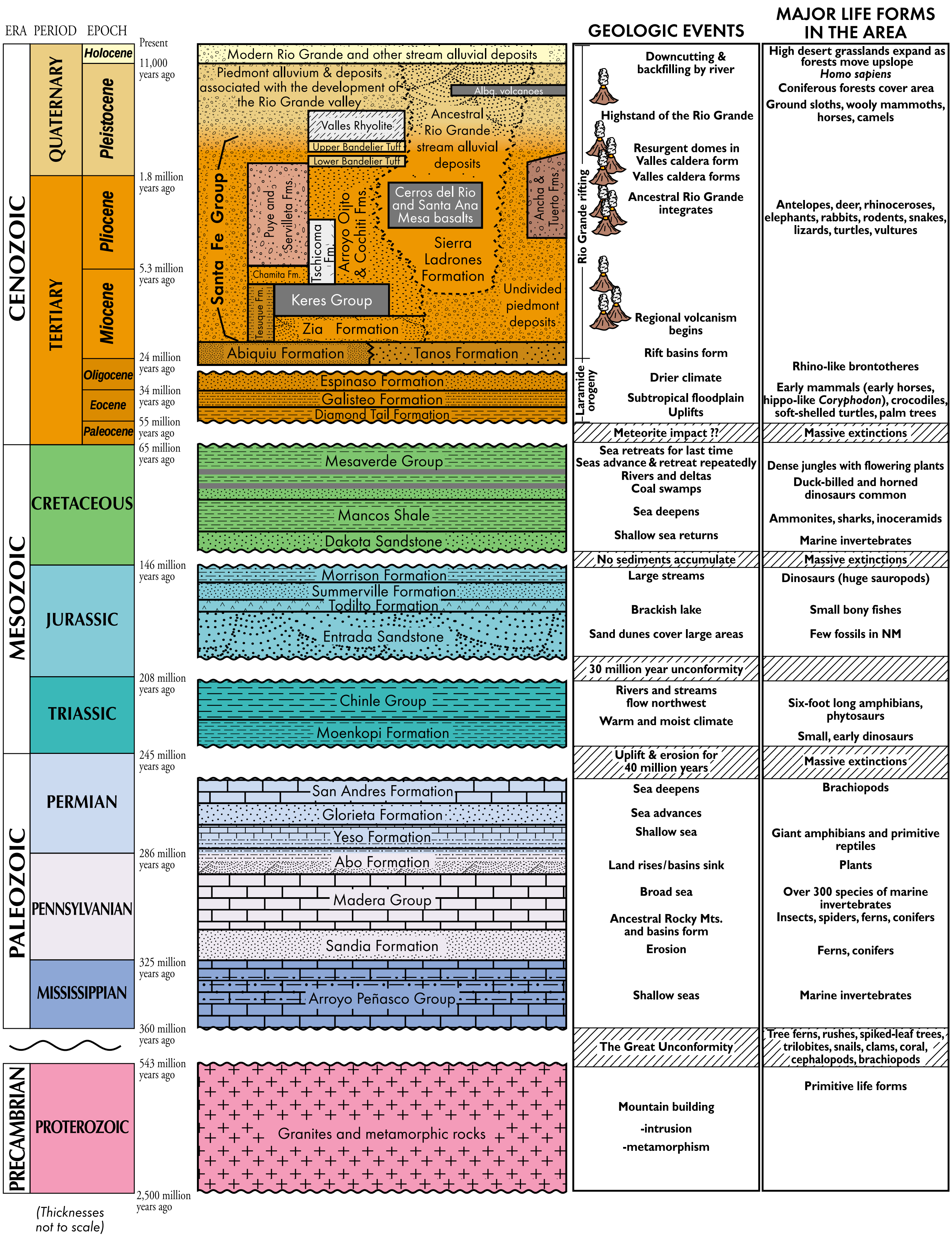
FIGURE 3—Long-term water level changes in the Placitas area.

THE HYDROLOGIC CYCLE



Pools of water (bold type) in cubic miles
Fluxes between pools in cubic miles per year

Geologic History and Stratigraphy of the Santa Fe Region



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- Environmental impacts of dams
- Effects of endangered species legislation
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