THE PHYSICAL AND HISTORICAL FRAMEWORK

DECISION-MAKERS FIELD CONFERENCE 2009
The Albuquerque Region

The Rio Grande at Coronado State Monument.

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Resource Issues and Urban Development in the Albuquerque Region

V. B. Price

The national economy took so many hits in October 2008 that normally hard up New Mexico was worse off than it had been in decades. Gas prices had already made travel in the nation's fifth largest state prohibitively costly. Trucked-in goods, including food, have been getting pricier by the week. The Middle Rio Grande aquifer continued to shrink far faster than it was recharged. The implication for growth is hard to calculate, because no one knows the actual amount of water contained underground. Many worry that natural recharge areas, like arroyos, have been rendered useless by concrete linings and surface paving. Kirtland Air Force Base revealed it had been leaking fuel into the aquifer not a mile and a half away from the city's most important well field, the vortex of which draws water to it from all over the Middle Rio Grande valley. Air pollution from the Four Corners, where almost all of Albuquerque's power is generated, was drifting down past Cuba and threatening Rio Rancho and the North Valley. The unsold housing inventory was so large that builders stopped building and some parts of the city's edge looked like ghost towns.

This is clearly not a time to protect the status quo. Standard population predictions have the Middle Rio Grande valley growing by 30 percent or so to nearly 1.2 million people in 35 years. Given current realities, and lack of hard facts about water quality and quantity, such predictions seem unwarranted. Even the mayor of Albuquerque said, in a moment of idle candor a while back, that the city could run out of usable ground water in 25 years. He quickly retracted the statement. The worrisome reality facing every major city in the West, however, is the economic and social repercussions of a long-term water crisis, brought on by overpopulation, overuse of water resources, and prolonged, increasingly severe drought. Many cities in the West, Rio Rancho included, have large amounts of paper water but very little wet water. We've leveraged our aquifer to the breaking point. Western cities might actually lose population to the water-rich Midwest in the years ahead. In Albuquerque, the new Albuquerque Drinking Water Project is diverting San Juan–Chama Project water from the Rio Grande, but this will effectively diminish the flow of the river and could dry up farmland in the middle valley and even the Rio Grande bosque. It's time for Albuquerque to start thinking out loud again about what kind of city it not only wants to be, but needs to be.

Since the late 1960s Albuquerque residents have periodically come together to discuss and define what kind of city they'd be proud to live in. In the Goals Programs of 1969 and l975, and in the frequently updated Comprehensive Plan that evolved from those programs, city residents made it clear they wanted Albuquerque to preserve its open spaces, maintain and grow its neighborhood diversity, become a pedestrian- and bike-friendly city with greatly increased mass transit and infill development, embrace a conservation and green building ethic (though the term "green" was not in vogue at that time), and grow into something resembling a New Mexican metropolis, sensitive to the state's cultural richness, its aesthetic landscape, and its ecological complexity and high desert environment. Residents wanted Albuquerque to become something more than an Anyplace, U.S.A. That desire was always at odds with the views of traditional business interests that embraced a booster building ethic. Population growth and new housing starts of any kind, anywhere, were seen as the golden eggs of economic progress. The tension between those two views worked to create the often confusing mixed messages that Albuquerque's built environment conveys.

The city has long had a divided opinion about itself, but also a healthy sense of self-respect. Albuquerque residents wanted to be in charge of their own localized landscape. But national economic conditions and franchise planning and design conflicted with that desire. And despite Albuquerque's idealism, it grew more on the Los Angeles/Phoenix models than on the template created by local thinking.

I suspect if an expansive new Goals Program were undertaken this year, in the throes of the economic meltdown of 2008, many existing residents would place a premium on the environmental vision of Earth Day 1971 when conservation of resources became the object of intense national and local interest. Many would strongly advocate sustainable development, public works job creation to build and repair water infrastructure, and heightened conservation. While Middle Rio Grande planning practices are still stuck in the mentality of the boom years, with unrealistic plans for new developments cropping up from Los

Lunas to the northwestern edge of Rio Rancho, there is a fine historical precedent for twenty-first century Albuquerque to follow into a more sustainable perspective.

The year of the first Goals Program, 1969, was a bellwether year in which a proposal for a giant paper company on the Rio Grande was rejected outright by business groups, community organizations, and political leaders on environmental grounds. They feared the plant would befoul the Rio Grande. A plan by the Bureau of Reclamation to denude the Rio Grande bosque of all its trees to save water became the catalyst for the creation of the Rio Grande Nature Center State Park, preserving what is thought to be the world's longest cottonwood forest. The Disney Corporation didn't get approval for a Disneyland skiing mecca in the Sandias for fear of ruining the scenic grandeur of the mountain and its invaluable habitat. In 1969 La Luz, the world famous cluster housing community designed by Antoine Predock, was opened. La Luz preserved common lands owned by all residents, protecting both open spaces and the best view of the Sandia Mountains in the city. It created a model for future anti-sprawl community housing. Unhappily, also that year major new apartment complexes on a standard strip mall housing model were created on Montgomery Boulevard, setting the precedent for apartment construction for the rest of the city to this day.

A new plan for Albuquerque's future would have to embrace a fresh consensus definition of the meaning of growth. Growth can no longer mean an endless expansion of houses and services into the high New Mexican desert, heedless of public cost and heedless of the limits of the local ecosystem. Sustainable growth is infill growth, retrofitted growth, growth in public transit opportunities and usage, and per capita income growth. The creation of more low paying jobs does the economy no good. Sustainability embraces a strong, re-localized economy in which community entrepreneurs can supply local products to meet local demands in an economic climate in which fuel costs have out-priced many imported goods. Moreover, sustainability requires intellectual growth, the growth of community, civility, and diversity, and a maturation in a common understanding of the nature and conditions of our physical environment.

But before sustainable growth can gain momentum, a number of basic, but long invisible issues must be addressed. They include:

- A comprehensive assessment of water quality in the Middle Rio Grande aquifer
- Restoration of the natural recharge systems
- Concerted and coordinated water conservation and recycling efforts
- Decentralization of energy systems
- The dangers and economic consequences of desalinating brackish water in the desert
- An expanded renaissance in local agriculture and ranching

Desalinating brackish water from deep aquifers is not like desalinating salt water from the sea. Although both can involve variations on processes of reverse osmosis, or thermal distillation, both require large amounts of energy to operate, and if carbon fuels are used, including relatively clean natural gas, carbon emissions can become prohibitively large. Solarizing desalination seems like a benign approach, but nothing about removing salts and minerals from water in the desert is benign. Although would-be developers in Sandoval County are claiming they have discovered a gold mine of brackish water deep underground, beyond the reaches of regulation by the Office of the State Engineer, serious costs and environmental issues await any desert desalination efforts. Water rate-payers would not appreciate public subsidy of desalination if it increased their taxes to support a developer-initiated project. Whereas sea salts can be redeposited in the ocean, with proper precautions and dilutions, the residue from making brackish water potable must be stored safely so as not to invade fresh ground water, and transported to safe locations. Where those would be, I have no idea. Brackish water is not composed purely of salts like ocean water, so its waste is more troublesome. In fact, it contains not only sodium and calcium, along with silica, but, in New Mexico, there's also arsenic, which in concentrated amounts can be very dangerous.

An accurate assessment of ground water quality throughout the Middle Rio Grande basin does not exist at the moment. This is an absurd oversight, given that until a few months ago, when the San Juan–Chama Project came on line, the aquifer was Albuquerque's sole source of drinking water. But it was in no one's financial interest to find out, even when an initial assessment was handed to local government on a platter. In 1995 a report from the U.S. Agency for Toxic Substances and Disease Registry revealed that Bernalillo County had "over 150 documented ground water contamination events" that have polluted "vast amounts of ground water" and that "as much as 30 square miles of land area" here may "overlie" ground water supplies polluted from "septic tanks, underground storage tanks, landfills, industrial facilities, and releases of hazardous materials." The agency estimated that more than 20 of those 150 contamination events could well become superfund sites. Any realistic planning for sustainablity in the future requires that we know, as exactly as possible, the condition of our aquifer and the costs estimated to clean it up.

Restoration of natural recharge systems will be imperative for sustainability. If Colorado snowpacks continue to diminish, and the Sierra Nevadas in California continue to lose snow, not only will the Colorado River and its tributaries, like the San Juan, diminish in size and usefulness, but rich states like California, Colorado, and Arizona could wage a water war with New Mexico that might compromise the San Juan–Chama drinking water project. By more quickly recharging the aquifer, Albuquerque and New Mexico could shore up, to some extent, their sole reliable source of water. But recharge requires literally ripping up certain streets that overlie arroyos, and taking out concrete-lined ditches, as well as negotiating up and down the river for land and funds to artificially recharge the aquifer. This is a daunting prospect, but may prove to be the best long-term investment we could make, along with serious conservation measures, water price hikes, and recycling gray water. Drinking water in this country still costs on average $1.93 per thousand gallons. That's some nine cents lower than what it costs to desalinate water in Israel, a ridiculously low price for such a precious and diminishing resource in the Southwest. Gray water use requires considerable investments in plumbing, but is well worth a subsidy to private home owners. And I'm sure, with an aggressive effort in which everyone participated, we could squeeze our usage to far less than half of what we're using now.

The decentralization of energy is perhaps the best tool we have for both combating global warming and avoiding the hazards and vagaries of the national grid. Wind and solar power, which contribute nothing to global warming, are perfect for decentralized energy on a state and community level and on a micro personal level too. The Department of Energy contended in 1991 that the wind available in Kansas, North Dakota, and Texas could power the entire nation; surely a windy state like New Mexico could certainly begin to power itself off wind from the eastern plains. And homeowners, with a modest subsidized investment, could solarize themselves off the grid as well, should favorable regulations, incentives, and investments be in place.

As transportation costs have tripled since 2000, and even export behemoths like China are feeling the pinch of rising gas prices, local agriculture and ranching have a chance to compete in price and quality with trucked-in foods. It will be a long and costly process for many people (and businesses) to re-localize agriculture. Machinery, the requirements of niche marketing of organic foods, water security, refrigeration, and transport will all require solid capital outlay. But next to water conservation, securing something close to a self-sufficient food supply is essential to sustainability in a troubled and fast-changing world.

It seems clearer than ever to many people that the old way of doing business, which depended on a callous and dreadfully shortsighted disregard of natural systems and resources, is no longer practical in a long-term recessionary period dominated by rising fuel prices, a transition in energy technology and resources, and an undeniable water crisis in the West. The old question of what kind of city we want has been replaced by the questions of what kind of city do we need, and what kind of city can we get? Part of the answer lies in the past, nearly 40 years ago, when an environmental mind set helped to shape Albuquerque's future. Now it's time for a more sophisticated and detailed understanding of natural needs and systems, and the economies they generate, to take control of our planning processes.

Geology and Landscape of the Albuquerque Region

Sean D. Connell and Dave Love, *New Mexico Bureau of Geology and Mineral Resources*

The sediments are a sort of epic poem of the Earth. When we are wise enough perhaps we can read in them all of past history.

—Rachel Carson

Geology is the study of the earth in all of its aspects, and everyone has an intuitive grasp of many geologic concepts. We see rivers flowing through valleys and faulted basins, mountains rising above the plains, and we may even recognize volcanoes as the frozen remains of lava brought up from deep beneath our feet. Geology surrounds us. It informs our decisions and provides many of the basic necessities for civilization. The primary challenge of the earth sciences is to understand and communicate how the planet works and to apply this understanding in ways that benefit society.

The evidence of past events is recorded in the rocks around us. Much of this record is preserved as loose debris (called sediment) that has been moved by water, gravity, or wind into low-lying areas where it has accumulated in valleys and basins. Rocks form as sediment becomes buried, compressed, and hardened with natural cements. Fossils that are preserved in sediments provide a glimpse of ancient ecosystems. Volcanic ash and lava record prehistoric cataclysms and are useful in determining when sediment was deposited. Some types of rock form only in specific regions of the globe and can tell us something about the journey of New Mexico through the geologic past. The present landscape is the direct result of past and ongoing geologic processes operating over time spans ranging from milliseconds to billions of years.

The Albuquerque–Rio Rancho metropolitan area is the commercial center of New Mexico. It is a human-built environment that grew out of the natural landscape and depends on the availability of natural resources. People depend on geologic resources in many aspects of everyday living, and it is prudent to understand the limits of these natural legacies and to protect them from abuse or unnecessary loss. Natural processes occasionally produce damaging or catastrophic failures due to floods, earthquakes, volcanic eruptions, or land subsidence. These processes should be taken into account in order to maintain cultural integrity and commercial prosperity, and to avoid or mitigate losses. In this overview, we outline the geologic history of Albuquerque, from its prehistoric beginnings to the latest period of glass, asphalt, and steel. We look at the origins of these natural gifts by exploring how the types and pace of geologic processes assembled the natural foundation of the region.

Sandia Mountain Wilderness. The mineral composition of the Sandia "granite" is actually granodiorite, which has more biotite (black mica) and quartz than typical granite.

FEATURES OF THE LANDSCAPE

Much of the spectacular scenery around Albuquerque is due to its unique location at the junction of the southern Rocky Mountains, Colorado Plateau, Rio

Major physiographic features of the greater Albuquerque region. Darker shade delineates the Albuquerque Basin.

Grande rift, and southern Great Plains. The dominant physical features of the Albuquerque area include the Rio Grande valley and the Sandia Mountains (Spanish for watermelon). Other notable features include the broadly sloping piedmont (base of the mountains) of eastern Albuquerque and the dry, volcano-peaked tablelands to the west, including Mount Taylor, the remains of a large extinct volcano looming on the horizon.

The Rio Grande occupies a 2.5- to 4-mile-wide fertile floodplain that has been filling steadily since humans first entered the region following the last ice age, about 11,000 years ago. The Rio Grande valley is the lowest feature of the landscape, sloping south through the metropolitan area with elevations ranging from about 5,050 to 4,900 feet. Although the valley contains some of the oldest settlements in the region, it is one of the youngest features to have formed.

The Sandia Mountains rise more than a mile above the valley floor to frame the eastern skyline of Albuquerque. The steep, faceted western escarpment of the Sandia Mountains forms a broad arc about 14 miles in length that rises from about 5,950 feet in elevation in the village of Placitas, at the northern flank of the range, to 10,678 feet at Sandia Crest. The crest descends to the southern end of the range to about 6,200 feet in Tijeras Canyon.

A drive eastward across Albuquerque on I–40 highlights many features of the regional landscape. The highway descends from the Colorado Plateau into the valley of the Rio Puerco, a major tributary to the Rio Grande that has the dubious distinction of being the most sediment-laden river in the United States. After crossing the Rio Puerco (near Exit 140), the highway passes La Mesita Negra (an 8-million-year-old black basaltic lava flow) to the north and Cerro Colorado (a 7-million-year-old red volcano) to the south before climbing onto a gently rolling tableland called the Llano de Albuquerque, which formed about 1.8 million years ago. This prominent tableland abruptly ends just east of Paseo del Volcan (Exit 149), south of the Albuquerque volcanoes, before the highway begins its descent into the Rio Grande valley near milepost 156. The bluffs at Los Duranes (near the Coors Boulevard exit) are the remnants of a former floodplain of the Rio Grande called the Segundo Alto terrace, which formed about 128,000 years ago. The Rio Grande flows through an inner valley where the ground water table intersects the land surface. After crossing the inner valley, the highway begins to climb onto another Rio Grande terrace near the I–25 interchange before ascending the piedmont of the northeast heights. East of the Juan Tabo Boulevard off-ramp (Exit 166) the highway crosses a set of large-displacement faults that define the steep granitic front of the Sandia Mountains (just east of Exit 167). The highway leaves the basin and enters Tijeras Canyon, a large drainage that follows an ancient geologic break between the east-sloping Sandia Mountains to the north and the nearly flat-topped Manzanita Mountains to the south.

Cerro Colorado, south of I–40 to the west of Albuquerque.

GEOLOGIC SETTING

The geologically complex Albuquerque Basin, which accounts for only 3 percent of the land surface of the state, is home to more than half of its population. Generally speaking, a basin is a topographic depression created by subsidence of the land surface and consequently filled with sediment. The Albuquerque Basin is nearly 25 miles wide and about 100 miles long, making it one of the largest basins in New Mexico. It is also one of the deepest. The chain of fault-linked basins and mountains that cuts New Mexico in half is called the Rio Grande rift. The rift begins in the highlands of central Colorado and continues more than 680 miles south through western Texas into northern Mexico. The forces that caused the Rio Grande rift created many other alternating mountain ranges and valleys within the Basin and Range province.

The Rio Grande rift is a geologically recent feature that formed in response to stretching of the crust. In Albuquerque the crust is stretched nearly one-fifth (17 percent) beyond its original width. The Rio Grande rift is one of several major active continental rifts in the world and resembles the rift valleys of east Africa. Crustal stretching relieved vertical stresses, elevated the bordering mountains, and produced a deep asymmetrically faulted basin (called a half graben) that filled with more than 3 miles of sediment eroded from the basin-flanking uplands.

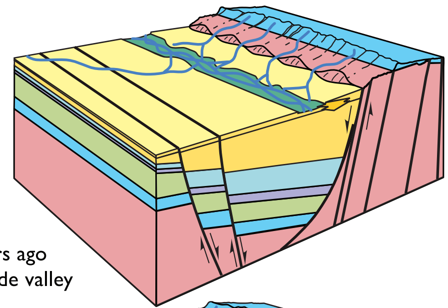
The rift is crucial to the development of Albuquerque because it altered the courses of older, east-flowing rivers to the southerly direction of the Rio Grande. Without the rift, rivers would have flowed east from the Continental Divide. There would be no Rio Grande, and the site where Albuquerque is today would resemble the semiarid mesa lands of the Colorado Plateau in western New Mexico. There would be no deep alluvial aquifer or fertile valley to support this metropolitan area.

Occasionally one may hear that the Sandia Mountains are a part of the Rocky Mountains, but the Sandias are much younger and rose in response to rift-related crustal extension. The Rocky Mountains are older and have risen more than twice from squeezing of the continental crust. The overall north-south arcuate profile of the western face of the Sandia Mountains exposes pinkish granite that is capped by bands of forested limestone and shale, giving the range the watermelon appearance of its Spanish namesake.

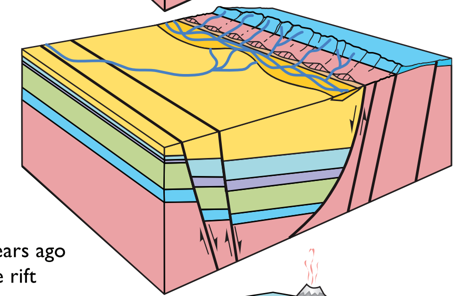
New Mexico is rich in volcanoes and volcanic landforms. In the Albuquerque region, examples of many different kinds of volcanic features can be seen. Mount Taylor and the Ortiz and Jemez Mountains are the remnants of large volcanic fields. Albuquerque is surrounded by many smaller volcanic fields such as the San Felipe volcanic field (on Santa Ana Mesa), Albuquerque volcanoes, and many individual volcanoes and volcanic fields near Isleta Pueblo and the village of Los Lunas (including Perea Mesa, Los Lunas volcano, Tomé Hill, Cat Hills, Wind Mesa, and Cat Mesa). The Albuquerque volcanoes erupted about 156,000 years ago and provided the lava substrate for the carved rock images at Petroglyph National Monument.

GEOLOGIC HISTORY

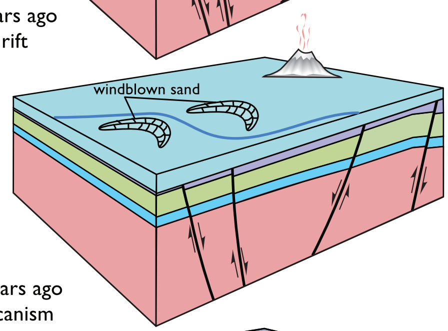
The cumulative thickness of the rock record preserved in sediments underneath Albuquerque is almost 7.5 miles. This record, however, contains many gaps, and large pieces of the local geologic record are missing.



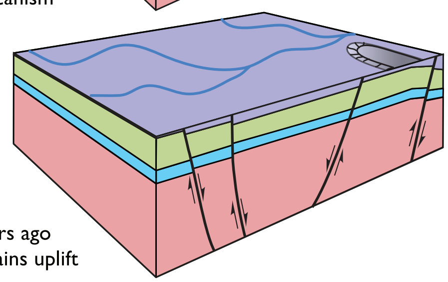
~800,000 years ago
The Rio Grande valley



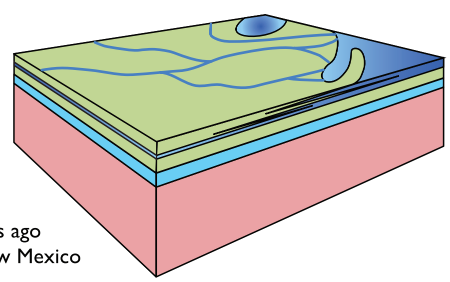
5 million years ago
Rio Grande rift



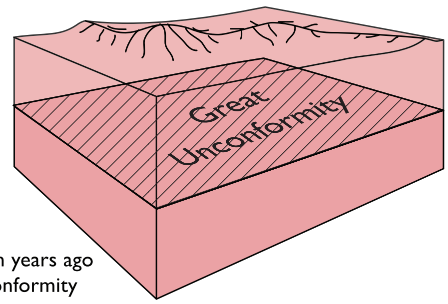
30 million years ago
Regional volcanism



40 million years ago
Rocky Mountains uplift



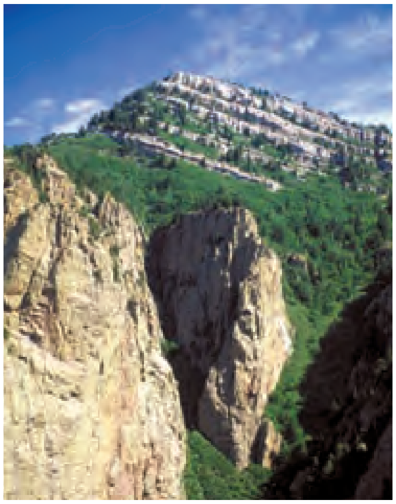
90 million years ago
Beachfront New Mexico



1400-325 million years ago
The Great Unconformity

The intervals of time recorded in these rocks represent only 20 percent of the geologic history of New Mexico.

Early New Mexico and the Great Unconformity— The igneous and metamorphic rocks exposed in the cores of the Sandia, Manzanita, and Manzano Mountains record the assembly of the North American continent through collisions of ancient island chains beginning 1.8 billion (1,800,000,000) years ago. About 1.4 billion years ago, the Sandia granite crystallized from molten rock injected into this older crust, which was buried about 6 miles below the surface. Distinctive rectangular, pink potassium feldspar crystals (as large as 2 inches across) grew as magma cooled below 1300°F (about the melting point of steel). Uplifts were followed repeatedly by erosion that beveled the ancient mountain ranges leaving low-relief plains. One such plain was flooded by a shallow tropical ocean and buried by seafloor sediments nearly 325 million years ago. The boundary between the older crystalline core of the Sandia Mountains and the overlying limestone and shale is known as the "Great Unconformity" and is all that remains of nearly 1.1 billion years of local history.



The Great Unconformity, on the crest of the Sandias.

Reefs and the Ancestral Rocky Mountains— During the later part of the Paleozoic Era, about 325 to 250 million years ago, New Mexico lay near the equator and was repeatedly bathed by shallow tropical seas with extensive limestone reefs and beaches. During this time, another range of ancient mountains, called the Ancestral Rocky Mountains, had risen and had eroded back into the sea. The rocks preserved from these events are now exposed on the crest and eastern slopes of the Sandia, Manzanita, and Manzano Mountains. Limestone from these rocks provides the sole local source of Portland cement for concrete construction. Rainwater percolating through these limestone beds ultimately carved much of the subterranean plumbing that the East Mountains area relies upon for drinking water.

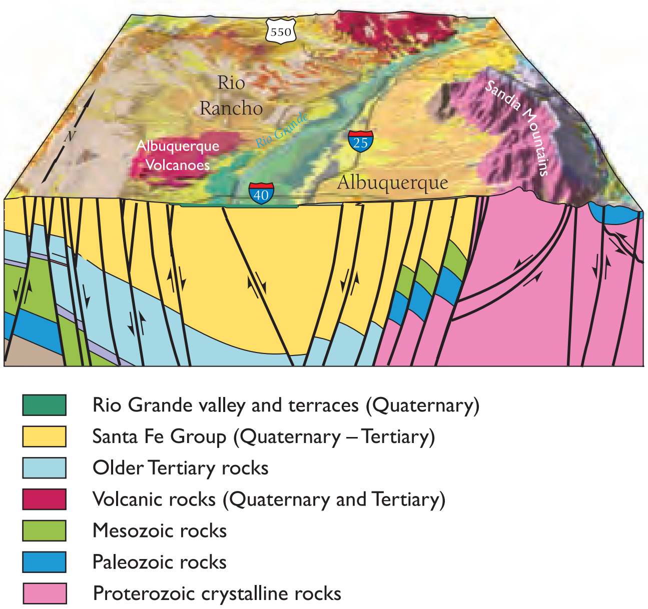
Beachfront New Mexico and the Transit of North America—During the Jurassic and Cretaceous Periods of the Mesozoic Era (164 to 65 million years ago), western North America was dominated by large rivers that flowed through plant-rich deltas into broad seas. The coal, oil, gas, and uranium resources of northwestern New Mexico were formed during this time. By the end of the Mesozoic Era (95 to 65 million years ago), New Mexico was coastal property and hosted vast forested and swampy lands that resembled today's Gulf of Mexico coast, but with giant lizards and fishes. North America moved north toward its present temperate-zone position by the Cretaceous Period, and then began moving west.

The Rocky Mountains—The Rocky Mountains formed during a time of intense compression of western North America that began near the end of the Mesozoic Era, about 70 to 40 million years ago during the Laramide orogeny. Evidence of this event is not obvious near Albuquerque, but it was largely responsible for raising the entire region above sea level and for lifting the Sangre de Cristo Mountains and Sierra Nacimiento. North America continued moving west toward its present position.

A period of widespread volcanic activity occurred between the uplift of the Rocky Mountains and the initiation of the Rio Grande rift, between 40 and 24 million years ago. Remnants of this volcanic episode include the Ortiz Mountains (northeast of Albuquerque), and the accumulation of nearly 8,000 feet of sediment underneath Albuquerque. This volcanism also formed many metallic ore deposits (including silver and gold) in central New Mexico.

The Rio Grande Rift—Much of the Albuquerque landscape developed as a consequence of the formation of the Rio Grande rift. Rifting began 30 to 25 million years ago and continues today. The rift gave rise to the Rio Grande, which entered the Albuquerque Basin before 7 million years ago. The early river flowed just east of the present location of Juan Tabo Boulevard before migrating west to carve the Rio Grande valley

TIME (MILLIONS OF YEARS)	PROCESSES	ENVIRONMENTAL FACTORS	GEOLOGIC LEGACY
.011–to present	Rio Grande floodplain and modern arroyos filled; bosque formed; floods, debris flows, and earthquakes continue.	Location of New Mexico and climate similar to today; plants and animals similar to today; humans arrive.	Modern landscape, farmland, shallow fresh groundwater, modern forests in mountains.
.780–to present (Quaternary)	Rio Grande valley cut as river alternated between sluggish interglacial muddy river and powerful ice age gravel-bedded river; tributaries from foothills and western valley slopes similar to today; Albuquerque and Cat Hills volcanoes erupt.	Location of New Mexico and semi-arid climate similar to today, but alternated between cold/wet and warm/dry periods during ice ages; large mammals: mammoth, camel, saber tooth cats; similar plants as present with pine forests extending down to valley during cooler times.	Cutting of Rio Grande valley, leaving abundant sand and gravel exposed, particularly along I—25; abundant fresh groundwater; nearly modern landscape and vegetation; Petroglyph National Monument.
5–1 (Tertiary–Quaternary)	Rio Grande flowed on broad plain east of present valley, trimming alluvial fans along mountain front; hazards similar to today, but with supervolcanoes in the Jemez Mountains and smaller volcanoes around Albuquerque.	Continued westward drift. Humid and semi-arid climate alternating between weak ice ages for past 2.5 million years; large and diverse animals; plant communities similar to modern riparian, grassland, and forest zones.	Broad mesas, including Sunport and Llano de Albuquerque; lava flows and abundant sand and gravel; major aquifer underneath Albuquerque.
30–5 (Tertiary)	Rio Grande rift split New Mexico, raising the Sandia Mountains and forming the Albuquerque Basin; streams flowed toward ephemeral lakes in basin; earthquakes lifted mountains.	Continued westward drift; humid climate gave way to semi-arid conditions; browsing animals dominant, drying climate and introduction of grasses created savannah conditions.	Major landscape elements begin to form: Sandia Mountains and mesa lands of the Colorado Plateau. Burial and preservation of oil- and gas-bearing older rocks. Saline water resources in deeper part of rift.
40–25 (Tertiary)	Sand dunes and volcanic debris cover region; vestiges of Rocky Mountain uplift eroded or buried in area.	New Mexico drifted west; climate slightly moister than today. Albuquerque in midst of sand dunes and sandy rivers along the edges of giant volcanic fields.	Metallic ore deposits in Ortiz Moutains and other volcanic regions; industrial mineral deposits in mountains.
70–40 (Late Cretaceous–Tertiary)	Rocky Mountain Laramide uplift: Nacimiento and Sangre de Cristo Mountains rose, and deep basins (San Juan, Galisteo, and Raton) formed; large east flowing rivers.	Western U.S. squeezed from west. New Mexico dominated by rising mountains subsiding basins with warm and subtropical climate; dinosaurs go extinct; very large mammals roam region; Colorado Plateau becomes distinct.	Scenery of the Rocky Mountains inherited from this time; basins bury rocks to generate oil and gas.
95–70 (Late Cretaceous)	Western shore of seaway that stretched from the Gulf of Mexico to the Arctic Sea; seaway moved back and forth across area; no mountains in Albuquerque area.	New Mexico at the latitude of Denver, Colorado; warm and wet climate with coal swamps. Large dinosaurs and marine reptiles and sharks common.	Rocks store organic matter for oil and gas sources; abundant coal seams; clay for pottery.
164–148 (Late Jurassic)	Streams flow northeast and large saline lake occupied northern New Mexico, depositing limestone and gypsum; sand dunes were common.	New Mexico lay in the "Horse Latitudes" and was drier than today, with strong southwest winds forming giant sand dunes; dinosaurs roamed along the streams.	Uranium ore deposits; abundant gypsum for wallboard.
225–202 (Late Triassic)	Streams crossed northern and central New Mexico flowing north-northwest into Utah to join seaway.	New Mexico was warmer and wetter than today and moved northward with North American continent; small dinosaurs and other reptiles dominated watercourses.	Copper and silver ore deposits; tabular sandstone for flagstones and walls; petrified wood abundant; used for yard decoration and to create jewelry.
299–260 (Early–Middle Permian)	Warm, shallow seas occupied southern New Mexico. Streams flowed south toward shallow; mountains reduced to plains.	New Mexico nears equator; large trees, insects, and amphibians dominated watercourses.	Tabular sandstone for flagstone and walls; gypsum and alabaster for sculptures.
311–299 (Middle–Late Pennsylvanian)	Ancestral Rocky Mountains rose and adjacent structural basins subsided; seas flood basins across New Mexico.	New Mexico nears equator; remote glaciers caused sea level to widely fluctuate; clams, snails, brachiopods, crinoids, and squid-like creatures in seaways.	Limestone for Portland cement and concrete, and clay for bricks and sculpture; blocky rocks for wall construction; abundant fossil seashells.
325–320 (Late Mississippian)	Warm, shallow sea and local streams crossed this area episodically, erosion continued in many places.	New Mexico just south of equator. Seas begin to inundate core of the transcontinental arch.	Local conduits for gold-bearing fluids.
1,400–325 (the Great Unconformity)	No record in this part of New Mexico, but the older deeply buried crumpled rocks was brought up to the surface and beveled by erosion. No direct record for more than 1.1 billion years!	New Mexico drifted from southern hemisphere to equator based on rocks preserved elsewhere. New Mexico near southwestern edge of Transcontiental arch.	Ancient basement brought to surface from a depth of 6 miles.
1,800–1,400 Precambrian	Thick volcanic rocks and river and shore-face deposits were crumpled and buried at least 6 miles; later injected by molten magma that cooled to form the Sandia granite.	Many different island arcs collided with continent. Location of New Mexico not well understood, but was very far from present location.	Hard crystalline rocks for building construction and aggregate; local metallic ore and industrial mineral deposits; source of alluvium underneath Northeast Heights.



Oblique view of the Albuquerque metropolitan area. Total offset along the basin-bounding faults, between the Precambrian/Paleozoic contact on Sandia crest and the same contact buried deep in the basin is well over 30,000 feet.

about 780,000 years ago. The waxing and waning of glaciers in the Rocky Mountain headwaters promoted cutting and partial filling by the ancestral Rio Grande. These cycles of cutting and filling formed a series of topographic benches along the valley flanks that provide sources of aggregate for construction. Humans began moving into the region just after the end of the latest valley-cutting event. Since the end of the last ice age, the river has not been able to move all its sediment downstream, so deposits have filled the valley by as much as 80 feet. Before confinement of the channel and modification of the floodplain by humans in the 1900s, large floods covered the inner valley several times per century. Subsequent modifications to the river largely put an end to frequent and damaging flood events and improved agriculture, but they also affected the ecology of the bosque and the quality of shallow ground water. Extensive replacement of natural land with asphalt and concrete cover has altered the hydrology of many of the arroyos in the Albuquerque area.

GEOLOGIC PROCESSES AND LANDSCAPE DEVELOPMENT

The physical setting of Albuquerque is the result of a dynamic balance between natural processes that build and destroy landscapes. As mountains rise, weathering and erosion wear them back down. Erosion counteracts uplift through the agents of ice, flowing water, landslides, and wind, which move sediment down the mountains and deposit the debris into low-lying areas, such as basins. Water is the principal agent of erosion and landscape change.

Mountains have distinctive shapes that commonly reveal their origin. Although some rocks are prone to forming mountains by resisting erosion more than the surrounding rocks, most mountains form through volcanic eruptions or by repeated movements across faults (which are accompanied by earthquakes). Different kinds of mountains are related to how heat is released from deep within the earth. Volcanoes are conduits for magma and hot fluids from the mantle, originating more than 20 miles beneath the surface of the earth. Mountains can also form through the cumulative effects of earthquake-generating offsets across faults that incrementally move geologic blocks. The rift-flanking Sandia, Manzanita, and Manzano Mountains are the cumulative products of many thousands of moderate-magnitude prehistoric earthquakes that incrementally ratcheted these mountain blocks skyward. Episodic movement along faults with associated earthquakes continues to the present day, and there are no compelling reasons to think that the region will not continue to experience these events far into the future.

The steep western front of the Sandia Mountains is a direct consequence of rift-related faulting that lifted rocks of this range nearly 6 miles. Yet, the highest point on the Sandia Mountains accounts for less than one of the six miles of uplift. Where is the rest of the offset and where did the eroded debris from the top of the mountains go? Both are buried beneath Albuquerque.

Uplifts and basins are complementary features resulting from geologic forces that raise one block while depressing the adjoining block. The depressed block forms the basin that receives sediment from the uplifting mountain block. Thus, it is not uncommon for the loftiest peak to sit beside the deepest basin. The heights of the Sandia Mountains are simply an expression of the very large depression in the Albuquerque Basin.

The past and future of Albuquerque are inextricably linked through the natural processes that sculpted the landscape and provided the rich legacy of essential geologic resources that its inhabitants rely upon. These natural processes place limits on how resources can be reasonably used. Continued reliance on these geologic resources will require increasingly detailed characterizations of the local geology to address current and future opportunities and challenges to our unique character and future prosperity.

Suggested Reading

Albuquerque Downtown from a Geologic Point of View—A Walking Tour of the City Center, George S. Austin, New Mexico Bureau of Geology and Mineral Resources, Scenic Trip 17, 1998.

Albuquerque—A Guide to Its Geology and Culture, Paul W. Bauer, Richard P. Lozinsky, Carol J. Condie, and L. Greer Price, New Mexico Bureau of Geology and Mineral Resources, Scenic Trip 18, 2003.

Geology of the Albuquerque Basin and tectonic development of the Rio Grande rift, north-central New Mexico, New Mexico, Sean Connell, *in The Geology of New Mexico, A Geologic History,* G. H. Mack, and K. J. Giles, eds., New Mexico Geological Society, Special Publication 11, 2004.

The Sandias, 1960–2000, produced for KNME-TV http://www.knme.org/sandias/, Michael Kamins, producer, 2007.

HUMAN NEEDS	MATERIALS REQUIRED	GEOLOGIC UNITS	GEOLOGIC LEGACIES IN NEW MEXICO
Food	Land for cultivation, water for irrigation	Rio Grande floodplain and arroyo bottoms	Arable land on floodplain and along tributary arroyos; caliche soils on uplands impede growth of some plants
Water	Sources in springs, river, or wells	Valley alluvium and older Rio Grande sediments; fractured bedrock	Rio Grande and springs in foothills and mountains
Energy	Wood, electricity, petroleum, and coal	Soils and mostly Cretaceous rocks	Foothills and mountains for wood; coal, oil, and natural gas from buried Cretaceous rocks.
Shelter	Wood, metals, stone, concrete, plaster, and adobe	Hard rocks in mountains, sediments in basin	Mountain forests, metallic ores; hard, workable rocks; limestone, gypsum, gravel, sand, and mud
Safety	Record of prehistoric events	Sediments and soils preserve hundreds of thousands of years of record	Natural hazards
Valuable media of exchange	Precious metals, gemstones, and land	Mostly mid-Cenozoic igneous rocks and placer gravels	Local ore deposits, gemstones, land
Transportation	Metals, plastics, fuel, and rubber	Sand and gravel pits, Cretaceous and Permian petroleum-bearing rocks, coal	Minor ore deposits, possible petroleum, coal, gravel for aggregates
Cultural traditions	Clay, mineral pigments, fibers, water, textured rocks for sculpture, metals, and gemstones	Variety of geologic sources	Clay; mineral pigments; arable land; hard rocks, ore deposits, gemstones

Human needs and geologic legacies in New Mexico.

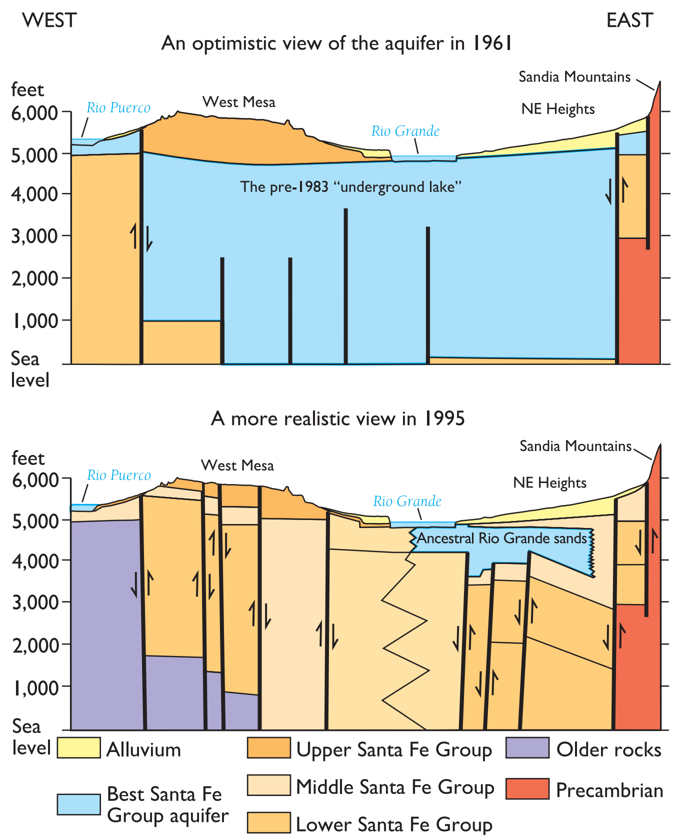
The Geology and Hydrology of the Albuquerque Area—How We Know What We Know

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

New Mexico and the Albuquerque area have a long history of imbalance between water demand and water availability. Availability, development, and management of water resources will be primary factors in determining how the Albuquerque area grows and develops in the future. Albuquerque is situated in the center of the Middle Rio Grande Basin, a large alluvial basin in the Rio Grande rift that contains the region's major aquifer (also known as the Albuquerque Basin). The Albuquerque Basin is a huge, faulted depression formed in the crust that was subsequently filled with material eroded from adjacent highlands, including the Sandia and Manzano Mountains. Deposits of this eroded material form complex sand and gravel aquifers that interfinger with clay and silt. The permeable, water-bearing sand and gravel deposits are tabular and wedge-shaped bodies that are truncated and offset by many faults and interfinger with fine-grained silt and clay deposits that can obstruct the movement and accessibility of ground water. This means that aquifer porosity, permeability, and productivity are highly variable. Although these basin-fill aquifers may store vast amounts of water, only a relatively small portion is retrievable. The upper portion of the aquifer is connected to the river, and development is subject to a complex assortment of legal constraints. Understanding the geology, hydrology, and land-surface characteristics of the Albuquerque Basin has been fundamental to successful exploration, development, and management of Albuquerque's water. During the last 20 years, through an ambitious, expensive, multi-agency research effort, we have made enormous advances in our knowledge of the hydrogeology of the Albuquerque Basin. This paper summarizes the principal methods used to reach our current level of understanding, and provides a glimpse of what we now know.

THE MIDDLE RIO GRANDE BASIN STUDIES

The hydrology and geology of the Albuquerque region have been extensively studied and in most areas are relatively well understood. This has not always been the case. In 1982 a prominent University of New Mexico geology professor proclaimed:



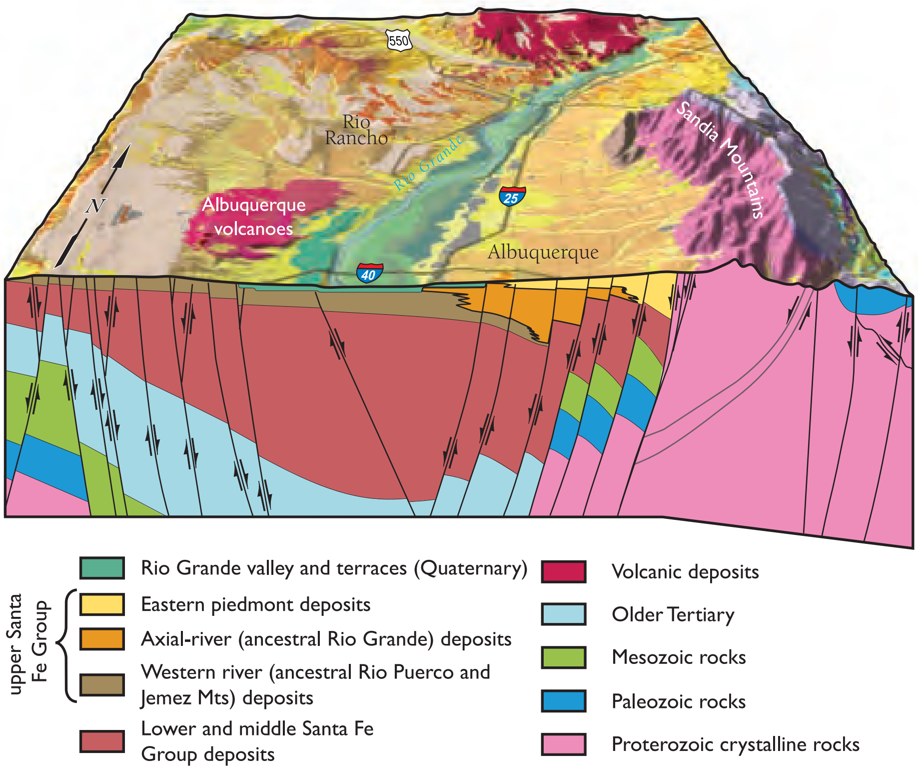
Past and more recent views of the aquifer in the Albuquerque region.

> *There is little or no chance of a water shortage, even with a substantial increase in population. Probably no other large city in the arid Southwest has such a bountiful supply of good water as Albuquerque. Water everywhere in the trough is no more than a few hundred feet beneath the surface.*

How could early views of the basin have been so flawed? Until the late 1980s the city of Albuquerque had little reason to be concerned about its water supply. When the city's first large supply wells were drilled in the northeast heights in the early 1960s, they were completed in relatively shallow, coarse-grained, permeable sand and gravel deposits of what was then an unknown and mostly unmapped basin and yielded large quantities of potable water. The success of these early wells led to the assumption that Albuquerque overlay a vast "underground lake." This assumption remained essentially unchallenged for nearly twenty years, until water levels began to drop more than 40 feet in parts of Albuquerque. These water-level declines prompted study of the deeper parts of the aquifer system that ultimately led to sobering reassessments of the regional aquifer system.

Detailed field and laboratory research initiated in 1992 by the New Mexico Bureau of Geology and Mineral Resources and the city of Albuquerque began to change the old assumption of the underground lake. Our current underground view of the Albuquerque Basin—the largest and deepest rift basin in New Mexico—took shape when geologists analyzed borehole geological and geophysical data from twelve city water wells and records from commercial oil and gas exploration wells. In 1993 the U.S. Geological Survey (USGS) combined this new geologic understanding with hydrologic data to develop the first geohydrologic conceptual model of ground water availability that was then used to develop a computer model of ground water flow. Together these studies demonstrated the limitations of Albuquerque's ground water supply and the effects of ground water pumping on the aquifer. This more realistic view of Albuquerque's aquifer showed that the productive zone was limited to a relatively thin wedge of river sands deposited by an ancient river system (an ancestral Rio Grande), which lie beneath northeast Albuquerque. Thus began the modern paradigm—that ground water supplies are limited in extent and are being extracted at a rate that is likely unsustainable.

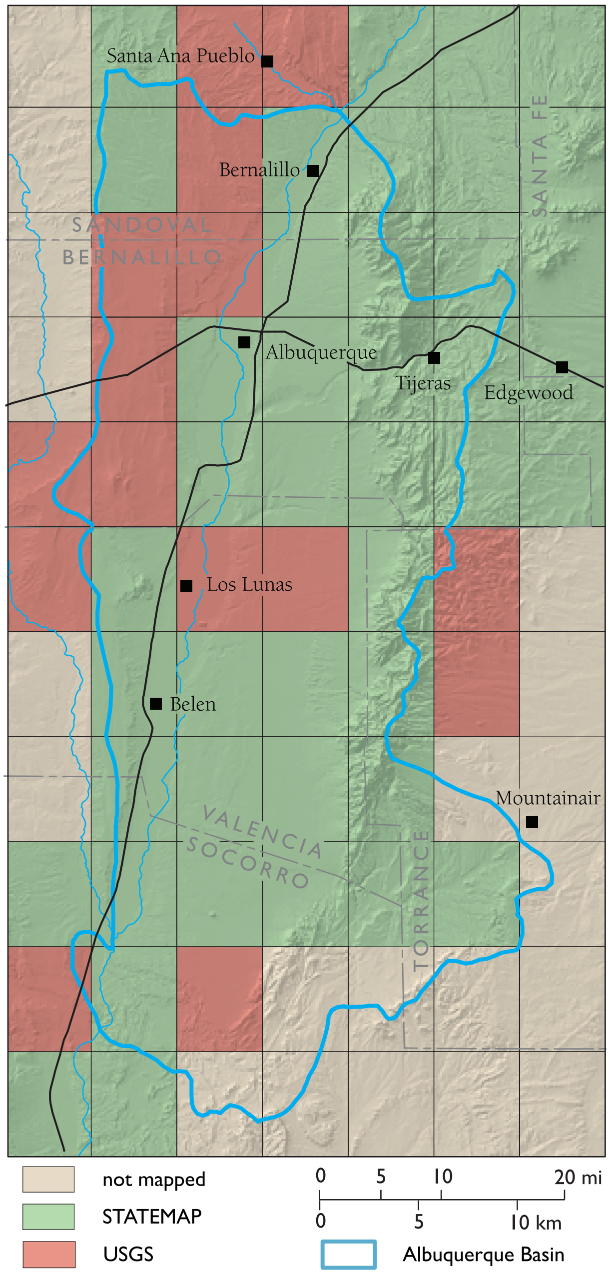
These early studies redefined Albuquerque's water supply problem: How can we manage ground water in a complex, poorly understood alluvial basin that is heavily impacted by current and historic ground water pumping, interconnected with a major interstate stream, and serving the largest metropolitan area in the state? With this perspective, in 1995 the New Mexico Office of the State Engineer declared the Middle Rio Grande Basin a "critical basin"—that is, a ground water basin faced with rapid economic and population growth for which there is less than adequate technical information about the available water supply. In response to this declaration, the state engineer, the New Mexico Bureau of Geology and Mineral Resources, USGS, and other state and federal agencies, municipalities, and pueblos initiated a six-year effort to advance the scientific understanding of the basin and to develop the management tools necessary to properly administer the resource. The so-called Middle Rio Grande Basin Studies were funded by the USGS (approximately $20 million), the state engineer (approximately $2 million), and other state and local sources.



Oblique 3D view of the Albuquerque region. The 1.4-billion-year-old Sandia granite is exposed in the Sandia Mountains on the east; the 140,000-year-old Albuquerque volcanoes are visible in red on the west. The axial river deposits (in orange) and the eastern piedmont deposits (in yellow) represent Albuquerque's most productive shallow aquifer.

THE KINDS OF SCIENTIFIC INFORMATION COLLECTED

Many earth scientists representing several disciplines and agencies collected a wide variety of information as part of the Middle Rio Grande Basin Studies. These individual scientific projects collectively revolutionized our understanding of water resources in the basin. Listed here are the types of information collected and



Index map showing progress of geologic mapping in the Albuquerque area. Individual quadrangles represent 1:24,000 (7.5-minute quadrangle) maps. Quadrangles mapped through the STATEMAP project have been accomplished with the support of the National Cooperative Geologic Mapping Program, in which the New Mexico Bureau of Geology has been an active participant since 1993.

some specific studies that were critical to advancing our knowledge of the Albuquerque area hydrogeology. In general, these data are required for any in-depth aquifer study and are currently being applied in other parts of New Mexico.

Geologic Mapping

Geologic maps provide detailed geologic information of the land surface, including the type and relative age of materials, and the presence of geologic structures such as faults, folds, and fractures, all of which influence where ground water is found, how it moves through the subsurface, and how ground water and surface water are connected. Thirty 7.5-minute (1:24,000) geologic quadrangle maps were produced in the Albuquerque Basin by the New Mexico Bureau of Geology and the USGS as part of the Middle Rio Grande Basin Studies. As of 2008, nearly 80 percent of the basin surface had been mapped in this detail.

Surface Geophysical Methods

Geophysical methods were used by the USGS to interpret different properties of the aquifer system. Ground measurements of variations in the earth's gravitational field were used to estimate the thickness of alluvial sediments that compose Albuquerque's primary aquifer. Airborne measurements of variations in the earth's magnetic field were used to identify buried faults that offset water-bearing units in the aquifer system and may affect the flow of ground water and to show the extent of buried igneous rocks, which have different hydraulic properties than the adjacent sedimentary deposits. Airborne electromagnetic surveys were used to infer variations in grain-size and hydraulic properties of aquifer materials. These geophysical methods cover large areas and provide critical data on the aquifer's extent, structure, and hydrologic properties.

Boreholes and Interpretation of Subsurface Geology

Core, cuttings, and geophysical logs from nearly 200 boreholes, ranging in depth from 40 to more than 19,000 feet in depth, provide important lithologic data and reveal glimpses of the geologic materials and strata in the subsurface. With multiple boreholes, distinctive buried geologic and geophysical features, such as faults and marker beds, can be identified and correlated across large distances. In the Albuquerque Basin, a prominent clay-rich interval in western Albuquerque, identified by a sharp change in electrical properties, was correlated for several miles between different well fields. Integration of surface mapping with well data led to the realization that this clay-rich interval marked the boundary between the productive aquifer units and the underlying, less productive units in .the aquifer system. Such correlations provide two- or three-di-

How Well Information Is Used to Understand the Hydrogeology of the Basin

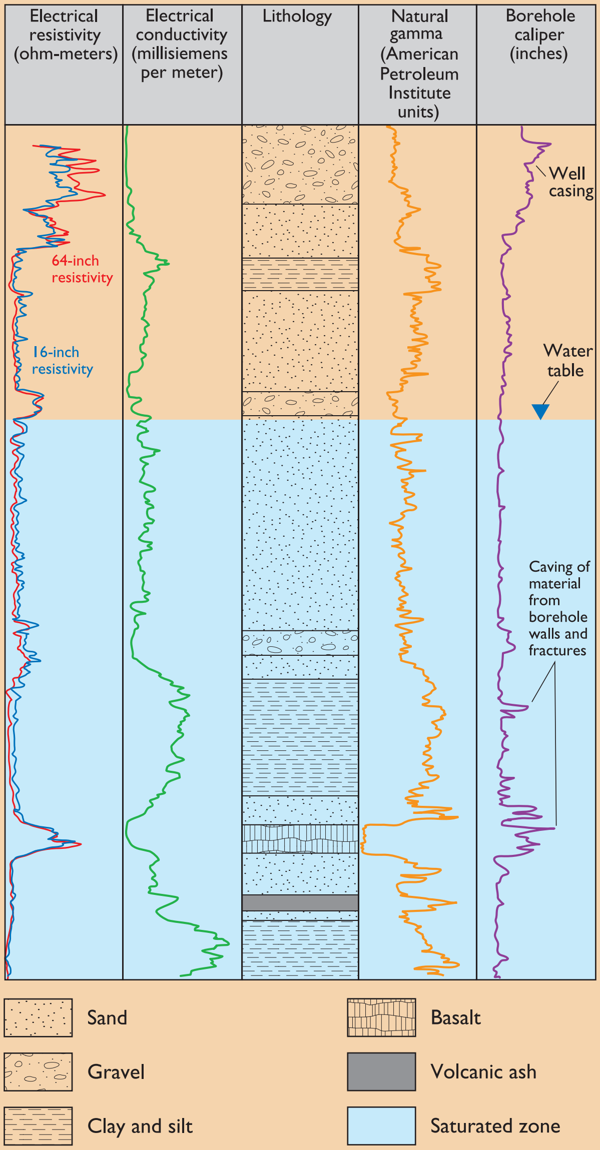
Subsurface information about an aquifer is routinely obtained from petroleum exploration and water wells, both from direct observation of well cores and cuttings, and using geophysical borehole logging tools. Geophysical log data and lithologic descriptions for wells in the Albuquerque–Rio Rancho metropolitan area have been used to interpret hydrogeologic conditions of the Santa Fe Group aquifer system in the Middle Rio Grande basin. Electrical resistivity and induction logs in freshwater aquifers are good indicators of the percentage of clay minerals in the deposit, because moist clays conduct electricity much better than freshwater alone. Sand and gravel units are generally poor conductors of electric current because they contain few clays.

The most common radioactivity log measures natural gamma-ray production in the rock surrounding the borehole and is used to determine rock type. In the Santa Fe Group, gamma-ray logs also respond to volcanic deposits and ash beds that contain potassium, uranium, and thorium.

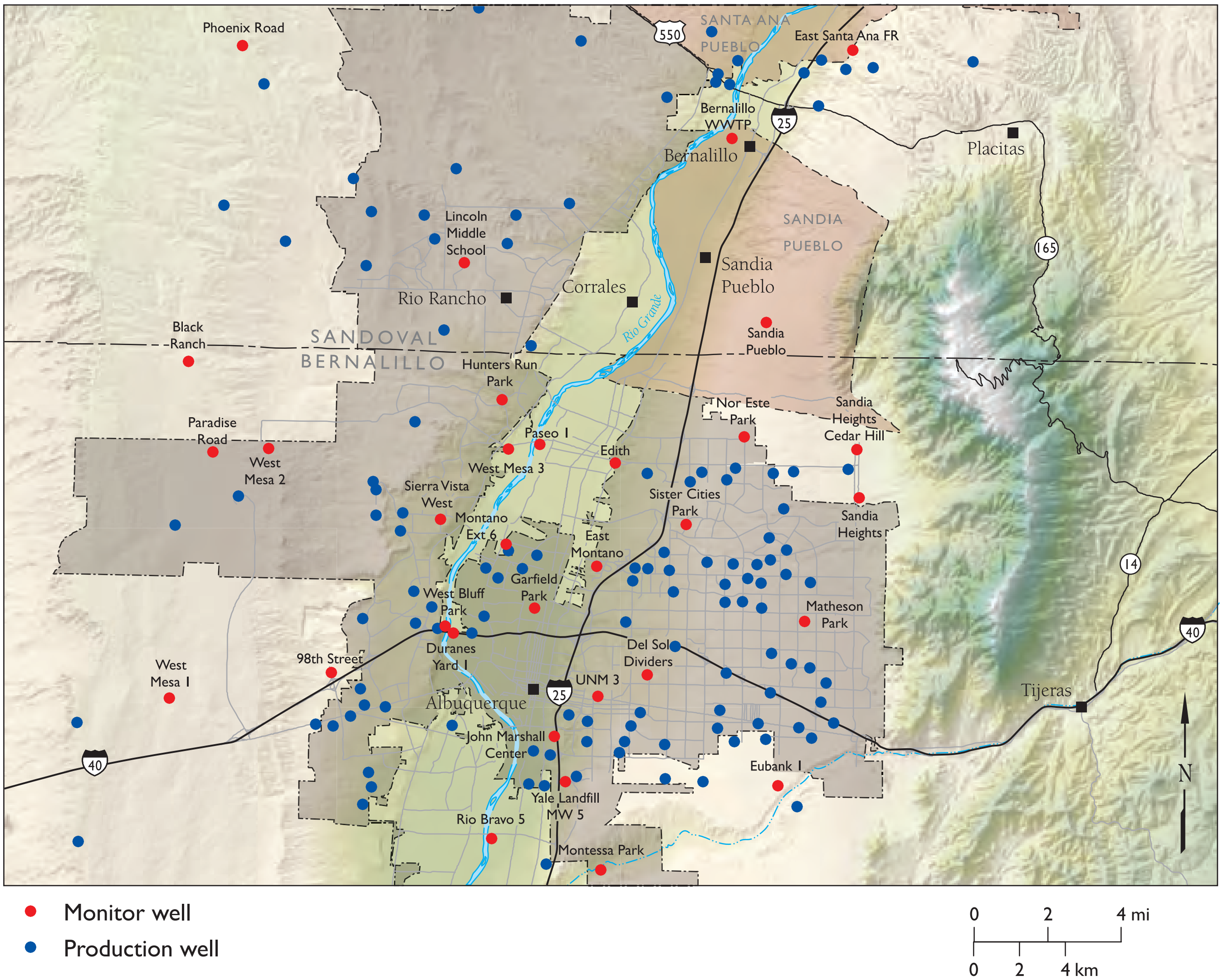
Caliper logs show the shape and size of the borehole and delineate zones of loose and caving rock or sediment caused by weak cementation (as in unconsolidated gravel and sand) or breakage by faults. Caliper logs are also used to correct and interpret other log data.

Evaluation of geologic and hydrogeologic information for wells involves a systematic approach that uses all available lithologic, geophysical, and geochemical information for a given borehole or well field. With multiple wells, distinctive geophysical features can be identified and correlated. An example in the Santa Fe Group aquifer system is the clay-rich interval in western Albuquerque identified by a sharp change in electric conductivity. The base of this unit, which demarcates a boundary between different aquifer zones, was correlated for several miles between different well fields. Such correlations aid in understanding the hydrogeology of the Santa Fe Group aquifer system.

—Excerpted from a piece by Sean D. Connell and David A. Sawyer that appeared in *Ground-Water Resources of the Middle Rio Grande Basin, New Mexico*, James R. Bartolino and James C. Cole, U.S. Geological Survey Circular 1222, 2002.



Hypothetical responses of various borehole geophysical tools to alluvial deposits of contrasting texture and saturation and to volcanic rock units.



Map of ground water production and monitor wells in the Albuquerque metropolitan area. The monitor well at West Bluff Park, on the west bank of the Rio Grande north of I–40, is an example of a group of two or more wells completed at different aquifer depths and installed by the U.S. Geological Survey as part of the Middle Rio Grande Basin Studies.

mensional views of the subsurface and help to interpret the nature, extent, and distribution of aquifer materials and properties.

Three-Dimensional Conceptual Hydrogeologic Model

A three-dimensional geologic view of the Albuquerque Basin was produced by the New Mexico Bureau of Geology and the USGS by integrating surface data from geologic mapping, geologic and geophysical information from an array of deep drill holes, and interpretations of airborne geophysical techniques. By interpolating between data points and two-dimensional views we can predict and illustrate aquifer properties between and beyond our points of observation and in three dimensions. This physical model then provides the basis for more quantitative ground water flow models that help us better understand and manage water resources.

Monitoring Wells and Water Levels

In 1996 the USGS, the city of Albuquerque, the state engineer, and Bernalillo County cooperatively installed specialized monitoring wells at 23 sites in the Albuquerque Basin. Most of these wells are groups, or nests, of two or more wells completed at different depths in the aquifer. This effort provided the first comprehensive information on ground water levels measured at different depths in the aquifer near production wells. These data, combined with other water level information, allowed scientists to produce the first water level decline maps for the Albuquerque metropolitan area that quantitatively depict the impact of ground water pumping on the regional aquifer. (One such map is reproduced in the paper by Dianna Crilley in this volume.) One such monitor well nest is located at West Bluff Park on the west bank of the Rio Grande.

Geochemistry and Water Quality

Water samples from 275 wells in the basin were analyzed by USGS scientists for environmental tracers and 30 chemical constituents in order to accomplish several things: (1) determine the age of ground water, (2) define zones of differing water quality, and (3) locate areas of recent recharge. This sampling determined that ground water along the western edge of the basin is largely unpotable, has high dissolved solids content, and is generally about 20,000 years old, having been recharged during the late Pleistocene, the time that glaciers existed in the Rio Grande headwaters. Ground water beneath the inner valley of the Rio Grande and beneath some arroyos and mountain-front areas is relatively young, having been recharged in the past 50 years, primarily from infiltration of surface water through stream and arroyo channels. These ages improved our understanding of ground water residence times in different parts of the aquifer and provided calibration data for ground water flow models of the basin.

Ground Water Flow Model

The culmination of the Middle Rio Grande Basin Studies was a numerical model of ground water flow. The model, developed collaboratively by the USGS and the state engineer, incorporates the new geologic and hydrologic information collected into a state-of-the-art tool for understanding the hydrogeology of the basin. This model is now one of the tools used to administer water rights in the Middle Rio Grande Basin.

Urban Growth Model

The future of the Albuquerque area was explored by researchers from the USGS, the U.S. Environmental Protection Agency, and the University of California, Santa Barbara using an urban-growth model to project the potential extent of the urbanized area in 2050. The goal was to help managers develop sound policies for guiding sustainable growth. Because the availability of water may ultimately be limited, better planning decisions on growth can be made through realistic and scientific projections of growth patterns.

WHAT WE HAVE LEARNED

Among the important findings of the Middle Rio Grande Basin Studies and the ground water flow model are:

- The geology of the Middle Rio Grande Basin is enormously complex and controls the subsurface distribution of water. The coarse-grained sand and gravel deposits that compose the basin's most productive aquifers are limited to relatively thin sheet- and wedge-shaped zones approximately 1,300 to 1,900 feet thick.
- Ground water levels are declining in many parts of the Albuquerque Basin. The water table has declined more than 160 feet since 1945 in eastern Albuquerque, indicating that water has been withdrawn faster than it can be replaced; that is, the aquifer is being "mined."
- Before ground water production in the basin and installation of the riverside drains along the Rio Grande, the river reach between Corrales and Belen was losing flow. This water was probably being used by vegetation and recharging the aquifer. Currently, the drains intercept much of this flow and divert it back into the river, increasing surface flow but reducing aquifer recharge.
- Recharge from the Sandia Mountains to the aquifer is substantially smaller than previously thought.
- Previous studies found the Rio Grande to be well connected to the aquifer system, but recent studies of the interaction between the river and aquifer indicate that the hydraulic connection is actually less than previously thought (see Crilley paper this volume) and dependent on the characteristics of the underlying geologic deposits.

WHAT WE STILL DON'T KNOW

The Middle Rio Grande Basin Studies revolutionized the scientific techniques applicable to studying New Mexico's aquifers, our understanding of the hydrogeology of the Albuquerque area, and the tools available to administer ground water resources. However, there is still much we don't know, particularly about the deeper parts of the aquifer that are not penetrated by water wells. About one-fifth of the basin has not been mapped in sufficient detail, and there are still many areas that have little or no high-quality well data. More than 300 wells, including domestic water supply, monitoring wells, and oil and gas exploration wells, have been examined in the basin. Although this seems like a large number, it represents a sample of less than 10 percent of the entire basin. Current challenges that still require information include: (1) the nature and extent of deep saline ground water, it's potential as an additional water resource, and its interconnection with the shallow aquifer system; (2) whether widespread contaminants of human origin, such as septic-system effluent or pharmaceuticals, exist in the aquifer; (3) an understanding of the long-term effects of ground water pumping on flow in the river; and (4) how the river, shallow aquifer, and deep aquifer can be conjunctively managed to sustain biological and agricultural resources while meeting the municipal and domestic supply needs of a rapidly growing metropolis.

Suggested Reading

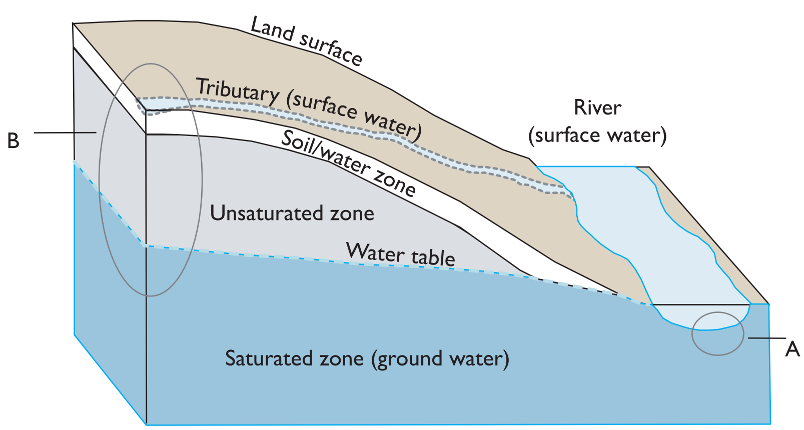
Ground-water Resources of the Middle Rio Grande Basin, New Mexico, J. R. Bartolino and J. C. Cole, U.S. Geological Survey Circular 1222, 2002.

Ground-water Resources of the Middle Rio Grande Basin, J. R. Bartolino, J. C. Cole, and D. J. Hester, U.S. Geological Survey Fact Sheet 088-02, 2002.

Surface Water/Ground Water Connections

Dianna M. Crilley, *U.S. Geological Survey*

Understanding the interaction between surface water and ground water in the Middle Rio Grande Basin is essential for effective management of land and water resources in the rapidly growing Albuquerque metropolitan area. Surface water and ground water systems are the two major components of the hydrologic system in the Middle Rio Grande Basin. The surface water system includes features such as rivers, lakes, canals, and streams. Ground water is water beneath the land surface that is stored in fully saturated sediment and rock. The ground water system includes the Santa Fe Group aquifer system, which is composed of the Santa Fe Group deposits that underlie the entire basin (the regional aquifer), and the post-Santa Fe Group valley fill deposits that primarily underlie the inner valley river floodplain (the shallow alluvial aquifer).



Generalized schematic showing surface water/ground water connections. Surface water can be directly connected to the ground water system (A) or separated from the ground water system by an unsaturated zone (B).

The movement and interaction of water between surface water features and the ground water system is complex. In some areas of the landscape, such as along the bed of the Rio Grande, surface water features are in direct contact with ground water. In most areas of the landscape, however, surface water features and the ground water system are separated by an unsaturated zone, which can store or transmit water between the two. The thickness of the unsaturated zone in the Middle Rio Grande basin can range from a few feet near the Rio Grande to several hundred feet in upland areas. Surface water features interact with the ground water system in two basic ways: surface water features can gain water from the discharge of ground water to the surface, or ground water systems can gain water from the seepage or infiltration of surface water. As an example, surface water diversions can deplete sources of recharge to the ground water system and conversely, ground water pumpage can deplete surface water from streams, reservoirs, or wetlands. Since surface water and ground water are interconnected, the contamination of one can result in degradation of water quality in the other.

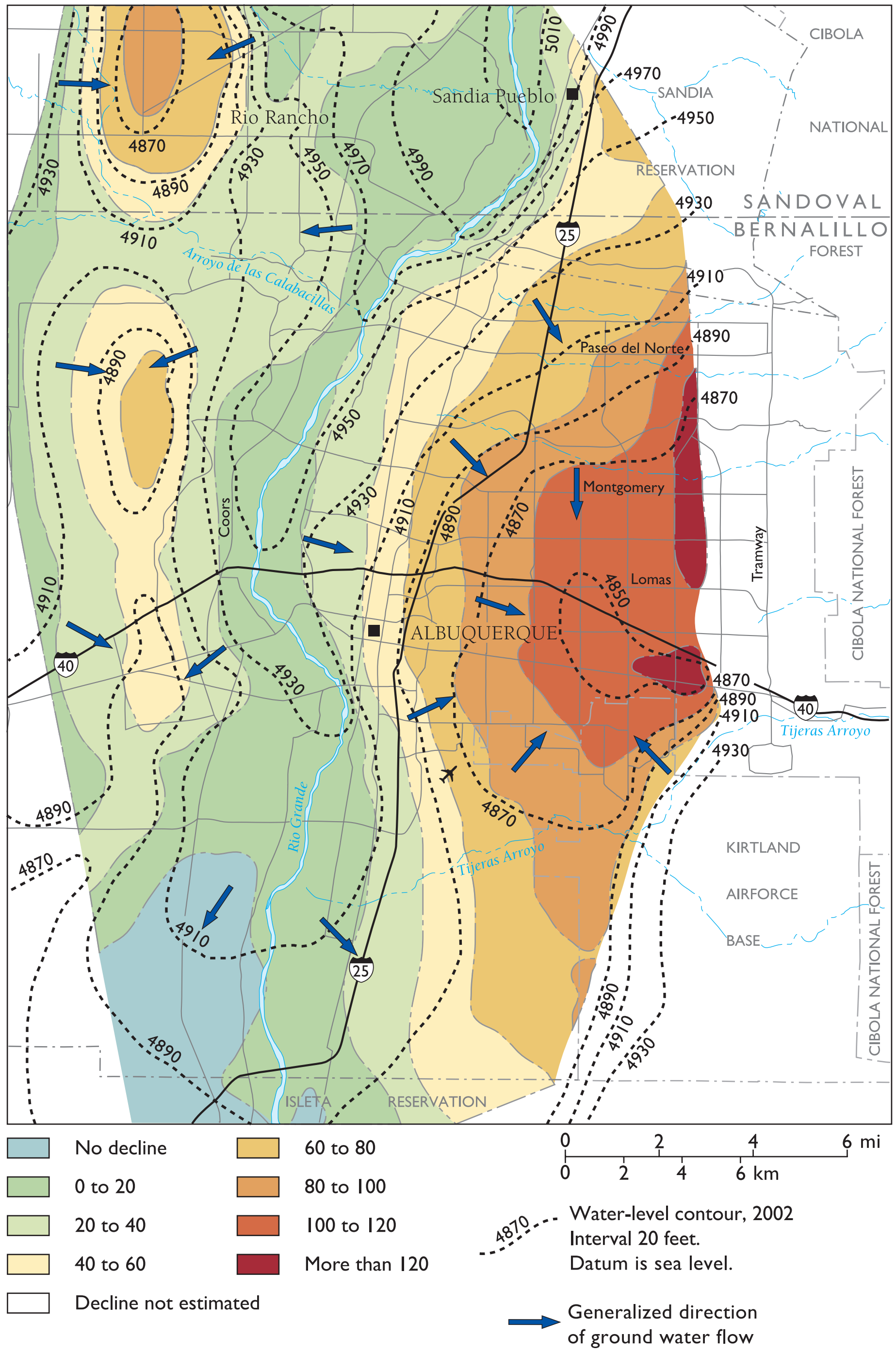
The population of Albuquerque's metropolitan area has increased more than tenfold since the 1940s, from 70,000 to 713,000 people. Population growth has led to an increase in water demands for urban, industrial and agriculture use. Agricultural development of the inner Rio Grande valley has resulted in large surface water diversions. Irrigation is the largest water use in the basin, accounting for almost three-quarters of all withdrawals. Urban development of former rangeland in the Rio Grande upper valley (area upland from the river called the east and west mesas) has resulted in substantial ground water pumpage for residential, industrial, and commercial use, accounting for about one-quarter of all water use in the basin.

Increased water demands have resulted in depletions of both ground water and surface water resources across the basin. Ground water-level declines of more than 120 feet in eastern Albuquerque as a result of pumping have altered ground water flow directions in the basin, causing increased seepage loss from the river within the Rio Grande inner valley. To better understand the complex connections between ground water and surface water in the basin, surface water and ground water systems must first be examined individually.

SURFACE WATER SYSTEM

The Rio Grande flows north to south through the Middle Rio Grande Basin, and is the most important surface water feature in New Mexico. It is the only surface water feature in the basin that flows continuously throughout the year with most of the flow coming from rainfall and snowmelt runoff and ground water discharge upstream from the basin. Flow in the river is regulated by dams and diversions upstream from the basin.

Between Cochiti Dam and San Acacia, the Rio Grande alternately gains and loses flow along successive reaches of the river. The Rio Grande receives flow from several different sources including streams and arroyos, flood-diversion channels from urban areas, effluent from wastewater treatment plants, and ground water discharge to drains in the inner valley (and to its own channel). Streams that contribute flow to the Rio Grande include the Jemez River, Santa Fe River, Rio Puerco, and Rio Salado. With the exception of the Jemez River, most rivers and arroyos are ephemeral, only carrying water after periods of rainfall or snowmelt. On the east mesa, two main flood-diversion channels, the North Floodway Channel and the South Diversion Channel, intercept flow from arroyos and concrete-lined channels and transport storm-water runoff to the Rio Grande north and south of Albuquerque.



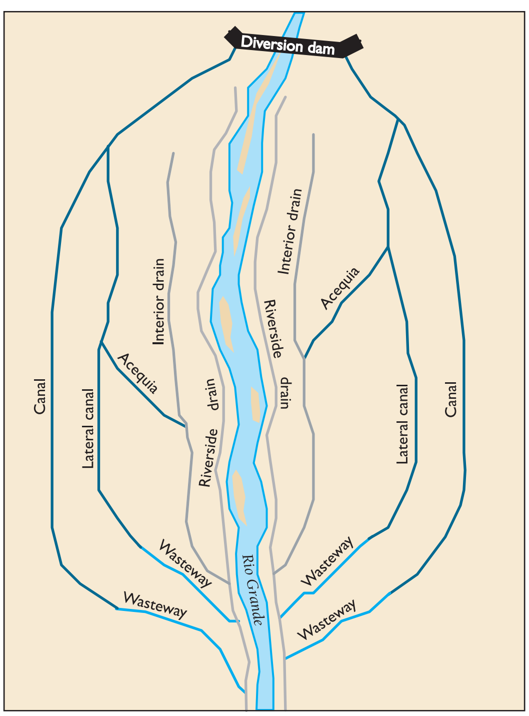
Contour map showing estimated ground water decline, in feet, from 1960 to 2002 in that part of the aquifer used for public water supply in the Albuquerque region. Note arrows showing generalized direction of ground water flow.

The Rio Grande loses water within the inner valley from irrigation diversions, leakage of surface water from the river and canals to the ground water system, evaporation from open-water surfaces, and evapotranspiration by riparian vegetation. Evapotranspiration is a process where by water is lost to the atmosphere through soil evaporation or plant transpiration. The inner valley contains an irrigation network that includes a system of irrigation canals that evolved from old acequia systems, along with a system of ground water drains designed to prevent soils from becoming waterlogged. Riverside drains capture ground water flow from river seepage, and interior drains capture ground water flow from the infiltration of crop irrigation water.

Both types of drains transport the captured ground water through the irrigation system with some of the drain water reused for irrigation and some drain water returned to the river. During the irrigation season, water is diverted from the Rio Grande at diversion dams into a series of irrigation canals throughout the Rio Grande inner valley. Between Cochiti and Socorro, there are irrigation diversion dams at four locations on the Rio Grande: Cochiti, Angostura, Isleta, and San Acacia. A recently constructed diversion dam at Alameda Boulevard in northern Albuquerque diverts surface water from the Rio Grande to a water-treatment plant that provides public drinking water to the Albuquerque metropolitan area, which historically used only ground water for public water supply.

GROUND WATER SYSTEM

In the Middle Rio Grande Basin, the Santa Fe Group regional aquifer is thousands of feet thick and includes a lower, middle, and upper unit. Ground water is withdrawn mostly from water stored in pore spaces between the sands and gravels in the upper parts of the regional aquifer; only about the upper 2,000 feet of the aquifer is used for ground water withdrawal for public water supply. Depth to ground water in the Middle Rio Grande Basin can range from just below land surface near the Rio Grande to more than 900 feet below land surface in the western parts of Rio Rancho and the mesa west of Albuquerque.



Features of the irrigation network in the inner Rio Grande valley (generalized).

Ground water recharge is the process by which ground water in the aquifer is replenished. Ground water recharge in many parts of the U.S. originates largely from the direct infiltration of precipitation and snowmelt. However, as in many other areas of the southwest U.S., the low precipitation and high evaporation in the Albuquerque area results in little or no direct infiltration of precipitation. Therefore, most ground water recharge in the Middle Rio Grande basin comes from the seepage of surface water from unlined natural and man-made features.

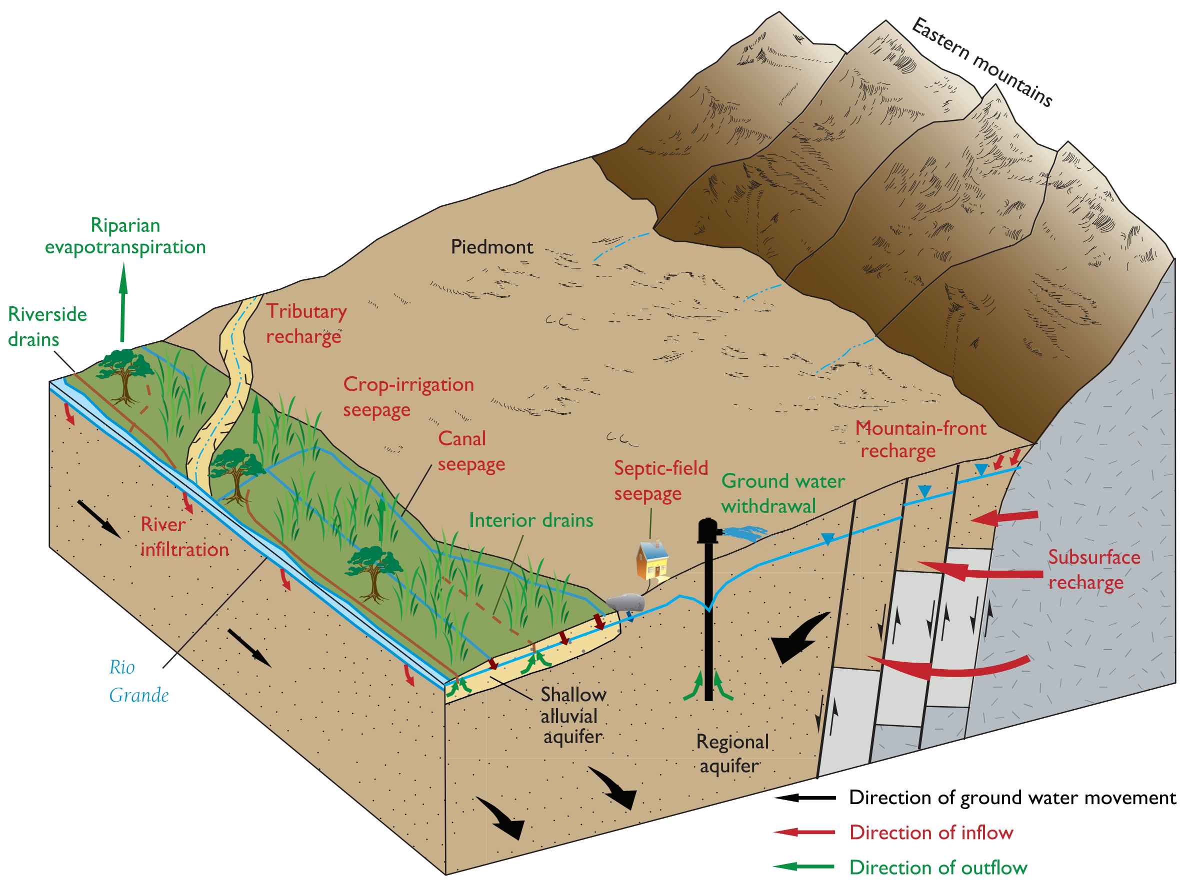
There are several different sources of recharge to and discharge from the ground water system in the Middle Rio Grande Basin. Ground water recharge occurs from the infiltration of surface water runoff along tributaries and arroyos. In addition, mountain-front recharge occurs along the edges of the basin when storm-water runoff or snowmelt along the base of the mountains infiltrates into the aquifer. Storm-water runoff from the mountains and from urban areas is diverted into arroyos where it can infiltrate and recharge the aquifer. Ground water can also be gained or lost through interbasin flow—the subsurface flow of ground water between adjacent basins. Ground water discharge (removal of water from the aquifer system) in the basin occurs from pumping, from ground water capture by drains, and through riparian evapotranspiration. Declining ground water levels in the Rio Grande inner valley have increased surface water seepage from the river and canals.

Within the inner valley, the shallow alluvial aquifer is the hydraulic connection between the surface water system and the regional aquifer. The degree of hydraulic connection between the surface water and ground water system varies spatially and with depth and is controlled by compositional variations in the shallow alluvial aquifer. The generalized cross section of the inner valley illustrates the complex hydraulic interactions between surface water, the shallow alluvial aquifer, and the regional aquifer that occur during the irrigation season. Ground water in the shallow alluvial aquifer is recharged by the seepage of surface water along irrigation canals and the channel of the Rio Grande and the infiltration of excess irrigation water applied to fields. Surface water seepage from the river that recharges shallow ground water also provides water to riparian plants. Some of the water that infiltrates is lost to evapotranspiration. Any remaining water becomes shallow ground water that can either recharge the regional aquifer or be captured by a drain and returned to the river.

SURFACE WATER / GROUND WATER INTERACTION

Scientists have long recognized the interaction between the surface water and ground water system in the Middle Rio Grande Basin. However, it is only in the past few decades that scientists have begun to understand the complex connection that exists between the two systems. The evolution of our current understanding of surface water and ground water interaction can be traced back to the 1950s and 1960s when increased population and development in the Middle Rio Grande Basin led to concerns about future surface water and ground water availability. Increased ground water use caused water levels to decline and surface water seepage from the Rio Grande to increase. Increased surface water use for irrigation also contributed to decreased flows in the Rio Grande threatening New Mexico's ability to meet its obligations under the Rio Grande Water Compact. In an effort to ensure future water availability, the City of Albuquerque commissioned studies in the basin to quantify the amount of ground water available and determine the effect of pumping on surface water seepage from the river. Findings reported that the Santa Fe Group regional aquifer was extensive (at least 5,000 feet deep) and that the Rio Grande is in good connection with the aquifer (Bjorklund and Maxwell in 1961, and Reeder and others in 1967). Although these studies only assessed the quantity of ground water in the regional aquifer and did not assess the quality or the economic feasibility of extracting deep ground water for public supply, their findings that the aquifer contained large quantities of ground water led people to believe there was a great underground lake beneath the city.

The City of Albuquerque still needed a solution to offset river seepage losses from ground water withdrawals. The San Juan–Chama Project, authorized in 1962, allowed for the interbasin transfer of Colorado River water from the San Juan basin in Colorado to the Rio Chama basin in New Mexico and eventually to the



Components of the ground water system, in a generalized composite of the Middle Rio Grande valley.

Middle Rio Grande basin. The City of Albuquerque's plan was to use the surface water/ground water connection to their advantage by allowing the San Juan–Chama water to infiltrate directly from the river into the aquifer, recharging the ground water lost to pumpage.

Deep test well drilling during the 1980s allowed scientists to examine the quality of water with depth in the regional aquifer and study the sediments that comprise the aquifer group. Scientists began to suspect that the portion of the aquifer used for public water supply was thinner and not as extensive as was previously thought. Study by the New Mexico Bureau of Geology and Mineral Resources and the U.S. Geological Survey (USGS) in the early 1990s confirmed this and reported that although the regional aquifer is thousands of feet thick, much of the middle and lower aquifer contains fine-grained sediments that do not yield as much water as the coarser-grained upper aquifer sediments.

Surface water and ground water in the basin had generally been thought to be well connected. In fact, the City of Albuquerque future water plan was banking on this connection. However, a study by Hawley and Haase in 1992 concluded that clay layers as thick as 15 feet in parts of the inner valley could substantially limit the flow of water between the river and the ground water system and that the connection between the river and the aquifer was not as good as previously thought. As a result of these new findings, the City of Albuquerque changed its plan for use of San Juan–Chama water from passive infiltration to water diversion and treatment for public supply.

Since the 1990s the USGS, with other agencies and organizations, has intensified study efforts throughout the Middle Rio Grande basin to characterize the interaction between ground water and surface water. These studies have included investigations of ground water recharge, surface water infiltration, river seepage, and ground water and surface water geochemistry. Results from these studies have greatly improved scientists' understanding of the hydrogeologic framework and the regional aquifer system and have substantially changed the conceptual model of surface water and ground water interactions in the Middle Rio Grande Basin.

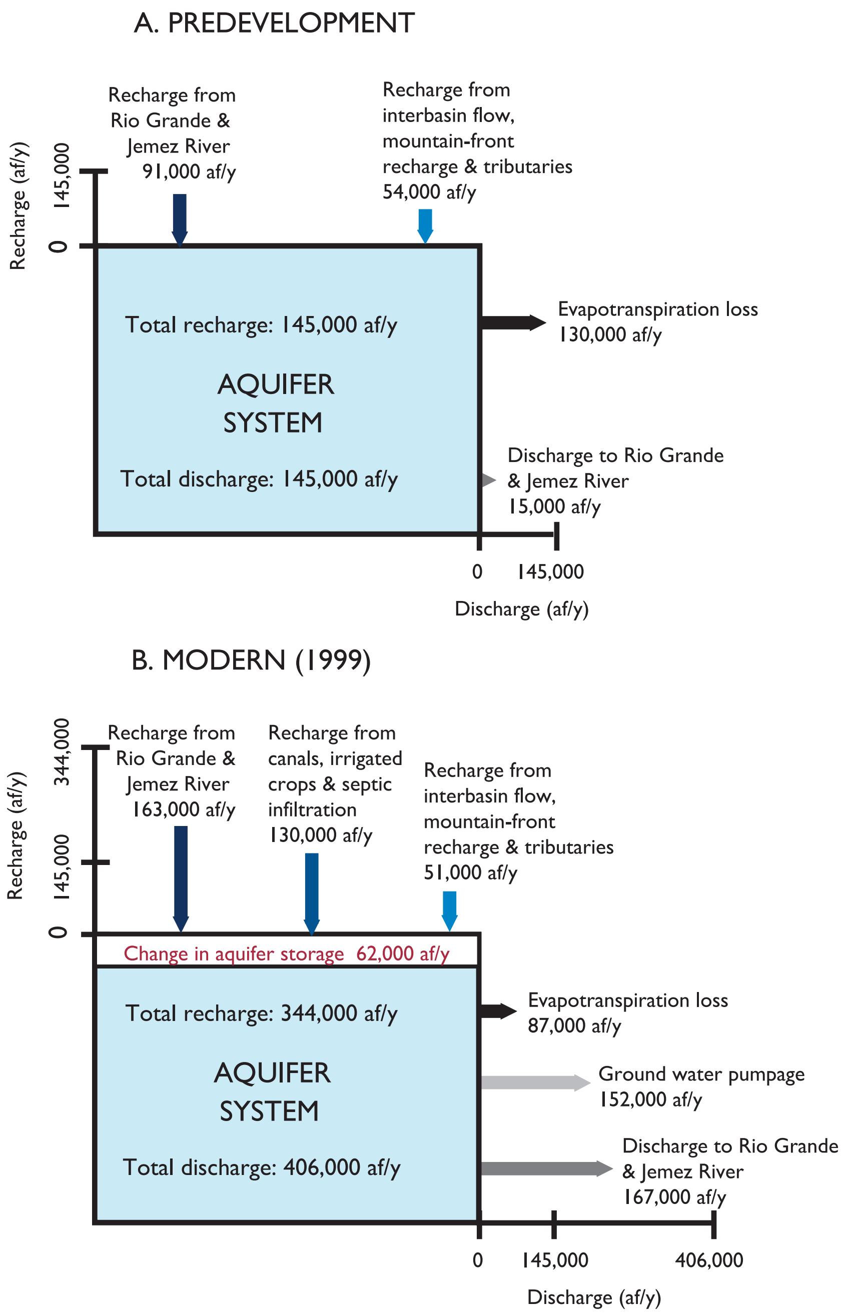
GROUND WATER MODELING

Our understanding of the complex connection between surface water and ground water in the Middle Rio Grande has greatly improved in recent years due to advances in computer technology that have allowed scientists to develop complex three-dimensional flow models. These models, capable of simulating ground water flow and other processes such as contaminant transport, canal leakage, infiltration from crop irrigation, ground water pumpage, and septic-field seepage, are powerful tools that help scientists understand the cause-and-effect relationship between various components of the hydrologic systems. Results from ground water models are used to develop ground water budgets that account for all the inputs and outputs of water to and from a hydrologic system and are useful in resource assessment and management.

The McAda and Barroll (2002) ground water flow model was developed from a cooperative study between the USGS, the New Mexico Office of State Engineer, and the City of Albuquerque to simulate the interaction between surface water and the ground water flow system in the Middle Rio Grande basin. Results from the McAda and Barroll model were used to calculate a ground water budget for the basin before development (1900) and for modern times (1999). Before major human activities in the basin the ground water system was in various states of equilibrium; the amount of natural ground water recharge was equal to the amount of natural ground water discharge, approximately 145,000 acre-feet per year. (An acre-foot is the amount of water that covers 1 acre of land to a depth of 1 foot, and is equivalent to 325,851 gallons or the amount of water a family of four would use over a year and a half, assuming the average person uses 150 gallons of water a day.)

Human development of the basin led to the construction of dams, irrigation canals, drains to prevent waterlogging of soils, and public supply wells that drastically altered the ground water budget. Development has resulted in increased recharge to and discharge from the aquifer system. The amount of discharge from the aquifer in modern times is almost triple the amount of discharge during pre-development time, increasing from 145,000 acre-feet per year before development to 406,000 acre-feet per year in modern times. Ground water pumpage accounts for 152,000 acre-feet per year and has resulted in ground water-level declines in many parts of the basin.

Increased ground water pumpage in modern times has induced greater surface water seepage from the Rio Grande than during pre-development times. The amount of recharge to the aquifer in modern times has more than doubled, from 145,000 acre-feet per year before development to 344,000 acre-feet per year in



Ground water budgets before and after development of the Middle Rio Grande Basin.

modern times. Agricultural and urban development in the basin has added new sources of recharge from canal leakage, crop irrigation infiltration, and septic-tank effluent infiltration. Currently, the modern budget for the ground water system is not in equilibrium; the amount of ground water discharge from the system is 62,000 acre-feet per year more than the amount of ground water recharge to the system. If the amount of ground water discharge from the aquifer continues to exceed the amount of ground water recharge to the aquifer, the result will be continued depletion of the resource.

SUMMARY

The interaction between surface water and ground water in the Middle Rio Grande basin is a dynamic relationship that is constantly changing. These changes are driven by development and the way in which we use water resources. Our understanding of the hydrogeologic framework and our conceptual model of surface water and ground water interactions in the Middle Rio Grande basin have changed substantially over the past few decades. We now know that (1) ground water suitable for public supply is a limited resource and (2) although ground water withdrawals induce seepage from the river, the degree of interconnection between surface water and ground water varies spatially and with depth depending on local geology.

Ground water models have increased our fundamental understanding of how various components of the hydrologic systems are related, and how changes in water use have affected past and may affect future surface water and ground water systems in the Middle Rio Grande basin. The McAda and Barroll (2002) ground water model demonstrated that:

- Increased development in the basin has altered how surface water and ground water interact.
- The Rio Grande is currently a major source of water to the ground water system.

Increased development in the basin has caused the amount of ground water discharge from the aquifer to exceed the amount of ground water recharge to the aquifer, resulting in a depletion of the resource. As population in the basin continues to grow, water managers are faced with the challenge of protecting the quantity and quality of both surface and ground water resources. Understanding the physical connection between these resources, and monitoring how this connection changes with human activities over time, will be essential for effective resource management.

Suggested Reading

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Hydrogeologic framework of the northern Albuquerque Basin, J. W. Hawley, and C. S. Haase, New Mexico Bureau of Geology and Mineral Resources Open-File Report 387, 1992. Available on the Web at http://geoinfo.nmt.edu/publications/openfile/

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Water Resources Management in the Albuquerque Urban Watershed

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J. Steven Glass, *Bernalillo County, New Mexico Water Quality Control Commission, Ciudad Soil and Water Conservation District*

Watersheds are defined by the land supplying surface water to a particular stream or man-made drainage structure. In some cases, this land is a roughly bowl-shaped structure and is easy to imagine. In most cases, a watershed is defined by deeply cut side streams or tributaries that could be considered smaller parts or subwatersheds of the larger area. In other cases, the watershed may be arbitrarily defined or broken by political or socio-geographic divisions, such as state, county, municipal, or other boundaries. In many urban settings, watersheds may be broken up into subwatersheds by man-made drainage structures, such as canals, street drains, and storm water ponds. Regardless of the way it is conveyed, all surface water eventually travels under gravity to the lowest elevation in the watershed. This lowest point is commonly called the discharge point. For the Albuquerque metropolitan area, many subwatersheds drain to the Rio Grande. The entire watershed ends, by political convention, at the northern boundary of Isleta Pueblo.

On its way to the Rio Grande, the urban surface water of Albuquerque travels a dynamic course. The upper parts of the eastern Albuquerque urban watershed begin on the western slopes of the Sandias, just under 10,000 feet above sea level. Much of this water travels quickly down creeks and canyons that are underlain by fractured but dense, impermeable rock. As these stream flows reach the base of the mountain, the mountain creeks turn into broader arroyos on (and sometimes cut into) the surface of the open space preserves and low-density neighborhoods east of Tramway Boulevard. Some of the flow slows and spreads out across this surface, creating what is called an alluvial fan. The alluvial fans of Albuquerque are made up of coarse, loose gravels and sands formed by millennia of erosion within the Sandia Mountains. As the surface water flows across the fan, some of the water seeps into the ground. An additional amount of water evaporates or is absorbed by plants.

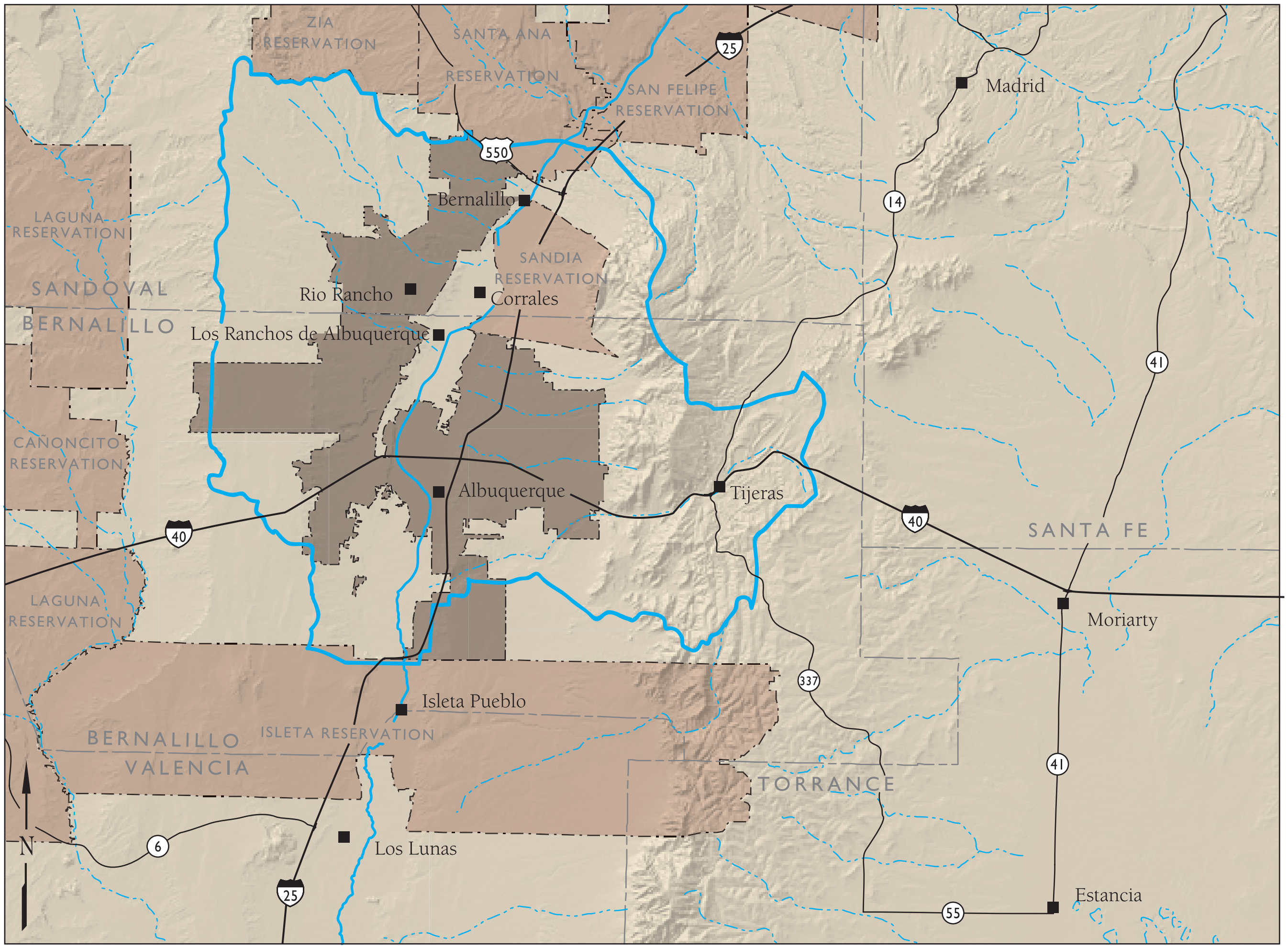
The elevation at the intersection of Tramway Boulevard and Bear Canyon Arroyo is about 6,000 feet above sea level. At about this elevation, the Albuquerque urban watershed changes dramatically. In order to protect homes, businesses, and other man-made structures, the surface water originating in the upper watershed is gathered and conveyed downstream over a 1,000-foot elevation drop by a series of natural and concrete-lined structures, primarily under the management of the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA). The east side drop is one of the steepest elevation changes in any American city and provides a serious engineering challenge.

On the west side of the Rio Grande, rainwater follows a much shorter distance from a lower elevation. The distance from the top of the West Mesa to the edge of the urbanized area is shorter and the ground is in most places less permeable. Much of the water from the west side is also collected and conveyed by AMAFCA structures. As water descends directly to the Rio Grande it drops 800 feet from the base of the West Mesa volcanoes and about 120 feet from the base of Petroglyph National Monument.

The result of these drops in elevation is the enormous and turbulent flows experienced by the Albuquerque arroyos during localized, high-intensity storms. As the arroyo-conveyed water descends, it is joined by flows from the city's streets, parking lots, building roofs, every urban surface where rain falls and where concrete, asphalt, or other hard surfaces direct this runoff water to the arroyos. Even on soil or on vegetated slopes, the water usually runs off faster than it can be absorbed by the soil.

As storm water roars across the urban environment, much in its path is swept along. This includes the litter, debris, and other pollutants accumulated by parks, sidewalks, streets, and parking lots. AMAFCA has worked hard to slow down flow in Albuquerque arroyos and separate the more serious pollutants. The most important AMAFCA structure is the North Diversion Channel, which intercepts east-side arroyos and conveys storm waters at a low gradient to the north end of the metropolitan area. Debris is allowed to separate and settle in a pond near the intersection of 4th and 2nd Streets. Despite this, much of the urban pollutant load is simply swept down the system and dumped directly into the Rio Grande, upstream of the city.

A portion of the water that does not flow to the Rio



The Rio Grande–Albuquerque watershed as delineated by the New Mexico Environment Department and the U.S. Environmental Protection Agency.

Grande seeps into the ground where it recharges the underlying aquifer. Because this seepage is very slow, ground water has resided in the aquifer for thousands of years. This ground water is pumped from wells to the surface for distribution to Albuquerque homes and businesses for drinking, washing, cooling, and irrigation. To accomplish this engineering feat, the Albuquerque Bernalillo County Water Utility Authority maintains a system of 89 wells, 54 reservoirs, and 2,700 miles of underground water pipelines to reliably deliver consistently safe water to 550,000 customers.

As the Albuquerque population has grown, the rate of ground water pumping has exceeded the rate at which the aquifer is recharged with water. This imbalance has contributed to reductions in ground water levels and in less ground water available to Albuquerque. Continued reductions in ground water could lead to depletion of affordable ground water, and to land subsidence that can cause structural damage to buildings, similar to what has occurred in Phoenix, Arizona, central Florida, and other locations of rapidly declining ground water levels.

To reduce further ground water decline, the Water Utility Authority has constructed facilities to collect and purify San Juan–Chama water from the Rio Grande for distribution to Albuquerque residents. Thanks to the foresight of the Albuquerque City Council, who purchased the necessary water rights in the 1960s, San Juan–Chama water, a sustainable source of drinking water, will soon be available to the city. In a significant example of human watershed modification, the water that will be collected and purified is transported to the Rio Grande from the San Juan River in southwestern Colorado. The water is conveyed through tunnels under the Continental Divide into the Chama River in northern New Mexico,

The Bear Canyon Recharge Demonstration Project

Stephanie J. Moore and John M. Stomp III

Aquifer storage and recovery is a water resources management tool that allows for the efficient and joint management of multiple sources of water, including surface water, ground water, and reclaimed water. A typical aquifer storage and recovery project includes at least three components: artificial recharge, or a method for adding water to an aquifer by engineered means such as direct injection or surface infiltration; storage, where water is stored in an existing aquifer; and recovery, where stored water is withdrawn from the aquifer for use at a later date. A successful aquifer storage and recovery project essentially increases storage capacity and thus allows for greater flexibility in handling both short-term and long-term surpluses and shortages in water supplies. Compared to storage in surface reservoirs, aquifer storage and recovery can reduce losses due to evaporation and, in many cases, has significantly fewer environmental impacts.

Despite the many benefits of artificial recharge, no government entity in New Mexico has been granted the right to recover recharged water, and few have begun to pursue permits, perhaps because of the complex regulatory requirements. Aquifer storage and recovery projects in New Mexico are subject to two sets of regulation: The Office of the State Engineer handles water rights issues and permits all recharge and recovery activities; the New Mexico Environment Department regulates water quality and issues discharge permits.

The Bear Canyon Recharge Demonstration Project is the first permitted and operating artificial recharge project in the State of New Mexico. As of December 2008, the project was permitted to recharge water but not yet permitted to recover water. The project was implemented by the Albuquerque Bernalillo County Water Utility Authority with funding provided by the state of New Mexico. Goals of the project are (1) to use surface water to recharge the aquifer via an in-stream infiltration system, (2) to use the aquifer to store surface water and establish a drought reserve, and (3) to establish the right to recover the recharged water. In preparation for the project, extensive work was conducted to characterize the vadose (unsaturated) zone, and to design and install a suitable monitoring plan to track recharged water along its entire flow path from land surface, through approximately 500 feet of vadose zone, to the regional aquifer. In addition to the technical work necessary to prepare for the project, much time was spent navigating the complex regulatory requirements, including several meetings with the Office of the State Engineer and the Environment Department over a two-year period.

Data collected during the first recharge period clearly demonstrated that in-stream infiltration is a viable option for recharge. The first recharge period was conducted in February and March of 2008, when approximately 420 acre-feet of water was recharged. Recharge water reached the regional aquifer in less than 54 days, almost no water was lost to storage in the vadose zone, and very little water was lost to evapotranspiration. Water levels in nearby monitoring wells did not change in response to recharge. However, water quality data indicate the arrival of recharge water at the water table. The second recharge period began on December 11, 2008 and is scheduled to continue through March, 2009, depending on water availability.

The Bear Canyon Recharge Demonstration Project on Bear Canyon Arroyo, approximately seven miles from the Rio Grande. Water is pumped from the river to the storage reservoir (visibile on the left) and is then discharged into Bear Canyon Arroyo, where it seeps into the subsurface within a mile of the reservoir, thus recharging the local aquifer.

then flows through three reservoirs, and finally enters the Rio Grande near Española.

The Water Utility Authority also has initiated studies to explore artificial recharge of the aquifer. The Bear Canyon Aquifer Recharge Project in the Northeast Heights will establish the rate at which water percolates toward the aquifer and what, if any, effects the artificial recharge may have on the ground water quality. Based on the outcome of the project, the authority plans to collect water from infiltration galleries under the Rio Grande and, after disinfection, pump it to recharge seepage ponds during the low-demand winter months.

Another example of human modification of the watershed is the network of diversion structures, irrigation canals, and ditches maintained along the central valley by the Middle Rio Grande Conservancy District. This extensive system redirects water from the Rio Grande through 1,200 miles of ditches, irrigating more than 70,000 acres of agricultural land during the growing season, enhancing infiltration into the shallow aquifer in the valley, and increasing evaporative and transpiration losses of water from the watershed. The Middle Rio Grande Regional Water Plan 2000–2050 estimates that agriculture and valley floor turf represent 33 percent of the consumptive water use in the middle Rio Grande watershed.

The Albuquerque wastewater (or “sewage”) collection and treatment systems have also changed the urban watershed. In some areas in the watershed, residents use septic tanks to store, partially treat, and discharge liquid waste from their homes. In theory, the partially treated wastewater is treated further by filtration and biological decomposition as it percolates through soil. However, in concentrated urbanized areas, especially near the river and in Sandia Heights, closely spaced septic systems can overwhelm the ability of the soils to provide treatment. Contaminants like nitrate and microbial pathogens can reach ground water or surface water.

To protect local water resources from such contamination, the Albuquerque Bernalillo County Water Utility Authority maintains more than 1,600 miles of underground sewer lines that convey wastewater to the Southside Water Reclamation Plant, where it is treated to remove nutrients, industrial contaminants, and potentially harmful bacteria before it is discharged to the Rio Grande under a stringent National Pollutant Discharge Elimination System permit issued by the U.S. Environmental Protection Agency (EPA). The Bernalillo County Public Works Department, using federal, state, and local funding, is working to extend municipal water and sewer services to areas within the watershed where residences are still served by septic tanks. However, much of the existing Albuquerque wastewater collection system was installed decades ago, and, due to erosion caused by acidic gases emanating from biological processes in sewage, the concrete in many miles of pipe has decomposed and needs repair or replacement. Estimates for the needed repairs run into the hundreds of millions of dollars.

Urban activity also affects the quality of surface water leaving the Albuquerque-area watershed. Some examples of pollutants that can originate on the surface are petroleum products spilled or leaked from vehicles, fertilizers and pesticides used in landscaping, and fecal material deposited by wildlife and domestic animals. Rapid conveyance of storm water via concrete-lined channels prevents absorption or biological decomposition of pollutants, which are discharged instead to the Rio Grande. Some examples of pollutants that could originate in the subsurface are gasoline leaking from underground storage tanks, trichloroethylene remaining from past poor waste disposal practices at dry cleaning shops, and untreated sewage leaking from poorly maintained septic systems. Very small quantities of these subsurface pollutants are capable of rendering large volumes of ground water unfit for human consumption.

The New Mexico Environment Department regularly monitors water quality in New Mexico streams and lakes. Based on data collected during 2000 and on established assessment protocols, the New Mexico Water Quality Control Commission in 2002 declared the Albuquerque reach of the Rio Grande “impaired” because, during storm events, levels of fecal coliform bacteria (an indicator of fecal matter) often exceed criteria set by the commission to protect recreation in and on the river. In 2004 the EPA issued a joint Municipal Separate Storm Sewer System (MS4) permit to a group of local agencies, including AMAFCA, the city of Albuquerque, the University of New Mexico, and the New Mexico Department of Transportation, targeted at reducing fecal matter discharges from the Albuquerque-area watershed. In response to these actions, the Environment Department and the EPA funded the Ciudad Soil and Water Conservation District to coordinate the formation of a local watershed group.

The multi-agency Rio Grande–Albuquerque Watershed Group, after lengthy consultations with stakeholders across the watershed, published in February 2007 a Watershed Restoration Action Strategy (WRAS), presenting a framework for implementing Best Management Practices in education, engineering, and enforcement over a 10-year period to reduce the discharge of fecal matter into the Rio Grande. A microbial source tracking study referenced in the document points to birds, domestic dogs, and humans as the sources of more than 80 percent of the fecal contamination entering the Rio Grande. Although control of fecal pollution from birds (33.5 percent) is difficult, reducing fecal pollution from domestic dogs (21.9 percent) and humans (15.9 percent) can be accomplished through responsible human behaviors. Public education about watershed improvement is a best-management practice addressed in the WRAS and recognized by the EPA, and in 2008 the MS4 joint permittees, joined by Bernalillo County, the Southern Sandoval County Arroyo & Flood Control Authority, and Ciudad Soil and Water Conservation District, embarked on a watershed information campaign, building on the precursor "Scoop the Poop" and "Keep the Rio Grand" campaigns coordinated by AMAFCA. Fecal matter follows similar transport paths through the environment as do many other pollutants, so reducing fecal pollution should also reduce the discharge of other types of pollutants transported from the Albuquerque-area watershed into the Rio Grande.

The Albuquerque metropolitan area watershed includes a wealth of geologic, social, and geographic complexity and requires innovative engineering and administration. Watershed health restoration is politically complex because six municipal governments, two county governments, two flood control authorities, and four sovereign Native American pueblos share or border the Rio Grande–Albuquerque watershed. Solving watershed problems is beyond unilateral or poorly coordinated action by any one of these entities. Only through a sustained, collaborative effort can the health of the Albuquerque-area watershed and habitat be improved and a more healthful way of life be assured for its residents.

Suggested Reading

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The Water Restoration Action Strategy, published by the Rio Grande-Albuquerque Watershed Group, and supporting documents can be downloaded from the Ciudad Soil and Water Conservation District Web site at: http://www.ciudadswcd.org

Middle Rio Grande Microbial Source Tracking Assessment Report, prepared by Parsons Water & Infrastructure Inc. for NMED, AMAFCA and Bernalillo County, October 2005. http://www.nmenv.state.nm.us/swqb/Rio_Grande/Middle/MST/MRG-MSTReport.pdf