Chapter 4: The hydrologic system of the Middle Rio Grande Basin

In discussions of the water resources of an area, the hydrologic system is commonly split into two components for convenience: surface water and ground water. However, in the Middle Rio Grande Basin, as in most other locales, the surface- and ground-water systems are intimately linked through a series of complex interactions. These interactions often make it difficult to recognize the boundary between the two systems. In this report, the surface- and ground-water systems are described separately, though one of the goals of the report is to show that they are both parts of the hydrologic system of the Middle Rio Grande Basin and that changes in one often affect the other.

The Rio Grande is the only river I ever saw that needed irrigation. –attributed to Will Rogers

As defined earlier, in this report "Middle Rio Grande Basin" refers to the geologic basin defined by the extent of deposits of Cenozoic age along the Rio Grande from about Cochiti Dam to about San Acacia. This definition includes nearly the entire ground-water basin; however, the extent of the surface-water basin is delimited topographically by drainage divides and is consequently somewhat larger than the ground-water basin.

Surface-water system

The most prominent hydrologic feature in the Middle Rio Grande Basin is the Rio Grande, which flows through the entire length of the basin, generally from north to south. The fifth longest river in the United States, its headwaters are in the mountains of southern Colorado. The Rio Grande is the largest river in New Mexico, with a drainage area of 14,900 square miles where it enters the Middle Rio Grande Basin. It gains about 12,900 square miles of drainage area as it flows through the basin; much of that gain is from the Rio Puerco drainage basin.

Though flow in the Rio Grande is currently (2002) regulated by a series of dams and storage reservoirs, now, as historically, the greatest flows tend to occur in late spring as a result of snowmelt and for shorter periods during the summer in response to rainfall. Historically, the Rio Grande has flowed year-round through much of the basin, "except for those periods of severe, extended drought" (Scurlock, 1998).

Within the Middle Rio Grande Basin, tributary streams, wastewater-treatment plants, flood-diversion channels from urban areas, and a large number of arroyos and washes contribute flow to the Rio Grande. Among the major tributaries are the Santa Fe River, Jemez River, Rio Puerco, and Rio Salado. Of these four tributaries, only the Santa Fe River is perennial, and most of its flow is treated effluent from the City of Santa Fe wastewater-treatment plant. The cities of Bernalillo, Rio Rancho, Albuquerque, Los Lunas, and Belen discharge treated effluent directly into the Rio Grande. Two main flood-diversion channels, the North Floodway and South Diversion Channels, east of the Rio Grande intersect many smaller arroyos and divert the flow to the river at outlets north and south of Albuquerque. Among the major ephemeral arroyos that are tributary to the Rio Grande are Galisteo Creek, Arroyo Tonque, Las Huertas Creek, Arroyo de las Calabacillas, Tijeras Arroyo, Hells Canyon Wash, and Abo Arroyo (fig. 4.1).

Ephemeral streams are those that flow occasionally, usually in direct response to precipitation. *Perennial* streams are those that flow year-round from either upstream flow or the contribution of ground water.

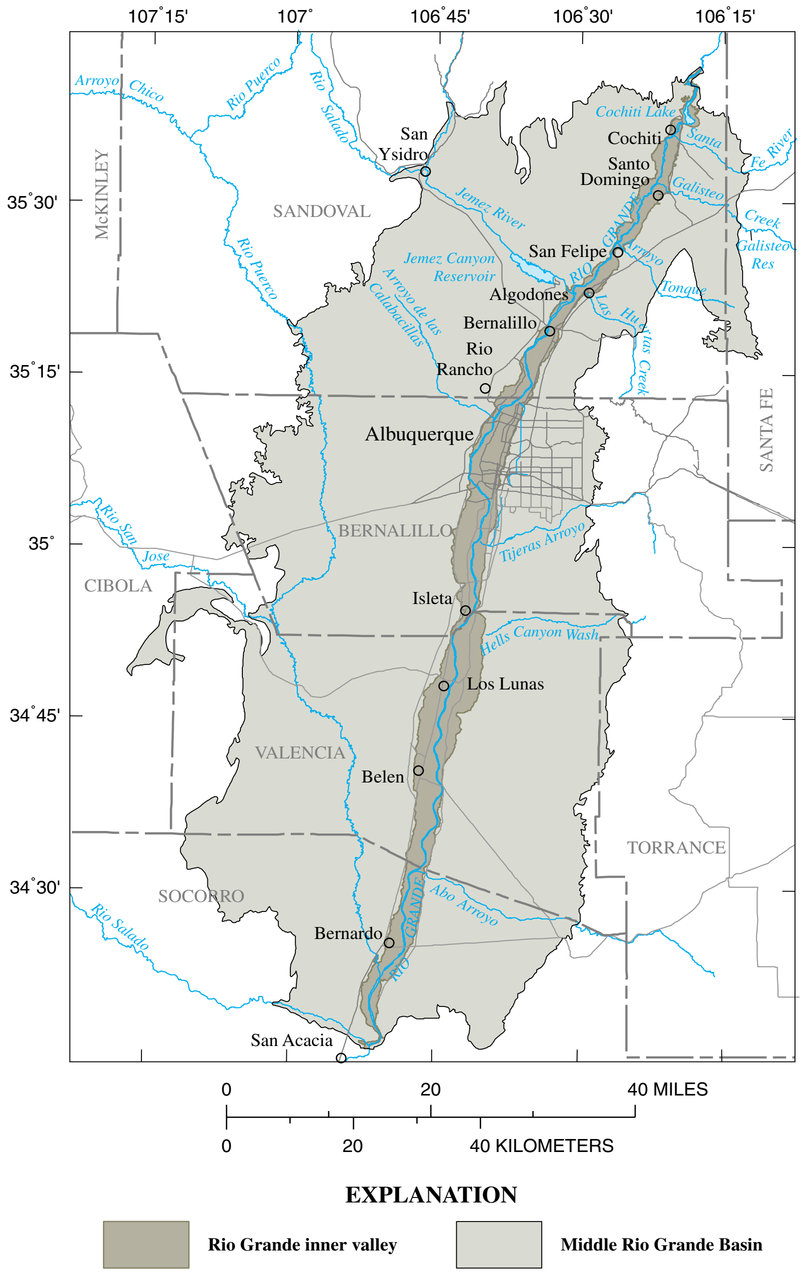


Figure 4.1.—*Major surface-water features of the Middle Rio Grande Basin.*

Three major reservoirs are in the Middle Rio Grande Basin: Cochiti Lake, Jemez Canyon Reservoir, and Galisteo Reservoir. Cochiti Lake is located in Sandoval County on the Rio Grande at its confluence with the Santa Fe River and began filling in 1973. In 1981, the reservoir capacity was 596,400 acre-feet. Though originally authorized for flood and sediment control, the authorization was subsequently modified to establish a permanent pool of 50,000 acre-feet for wildlife and recreational purposes. In addition, because the construction of Cochiti Lake destroyed a Middle Rio Grande Conservancy District irrigation diversion structure, irrigation water is now diverted at the dam. Approximately 5,900 acre-feet of water is lost to evaporation annually from Cochiti Lake. The reservoir is operated and maintained by the U.S. Army Corps of Engineers (Bullard and Wells, 1992).

Jemez Canyon Reservoir is located in Sandoval County on the Jemez River approximately 2.5 miles upstream from its confluence with the Rio Grande. The dam was finished in 1953 and is authorized to be operated solely for flood and sediment control; thus, there is no provision for maintenance of a permanent pool, and lake level consequently fluctuates over a wide range. Jemez Canyon Reservoir has a capacity of 102,700 acre-feet and is operated by the U.S. Army Corps of Engineers (Bullard and Wells, 1992).

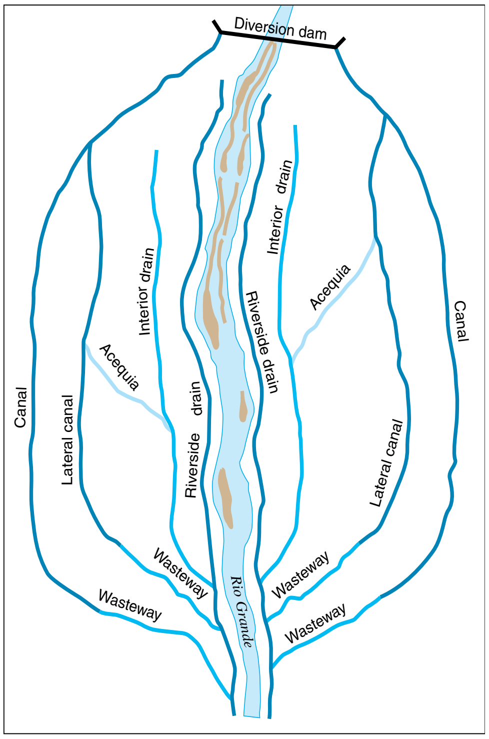
A third reservoir, Galisteo Reservoir, is located in Santa Fe County on Galisteo Creek, approximately 12 miles upstream from its confluence with the Rio Grande. The reservoir was authorized for flood and sediment control, and the dam was finished in 1970. Though empty most of the time, the reservoir has a capacity of 88,900 acre-feet and also is operated by the U.S. Army Corps of Engineers (Bullard and Wells, 1992).

A number of small flood-retention dams in the Albuquerque-Rio Rancho area are operated by the Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA) and the Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA). These dams were constructed for the downstream reduction of peak flows and contain water for only short periods following precipitation.

The inner valley of the Rio Grande contains a complex network of irrigation canals, ditches, and drains that has evolved from the original acequia system. The Middle Rio Grande Conservancy District administers this irrigation system and diverts Rio Grande water at four points in the basin: Cochiti Dam, Angostura, Isleta, and San Acacia (which serves an irrigation area downstream from the basin). During irrigation season, water is diverted from the river and flows through the Rio Grande inner valley in a series of irrigation canals and smaller ditches for application to fields. This water recharges ground water, is lost to evaporation, is transpired by plants, or is intercepted by interior drains or wasteways and returned to the river. Figure 4.2 is a schematic showing the generalized inner valley irrigation network (Bullard and Wells, 1992; Kernodle, McAda, and Thorn, 1995; Anderholm, 1997).

The other main component of the inner-valley surface-water system is a network of riverside drains, which are deep canals that parallel the river immediately outside the levees. They are designed to intercept lateral ground-water flow from the river, thus preventing waterlogged conditions in the inner valley. The riverside drains then carry this intercepted ground-water flow back to the Rio Grande. Within the basin, riverside drains and levees are usually present on both banks of the river, except where bluffs adjoin the river.

Several different types of conveyance channels (fig. 4.2) make up the irrigation system in the Middle Rio Grande Basin. *High-line canals* run along the hills bordering the inner valley at relatively shallow grades. *Low-line canals* run along the valley floor. *Laterals* are somewhat smaller and usually have a heading in a canal. *Acequias* (or *ditches*) are the smallest channels. *Wasteways* and *drains* return unused or excess irrigation water to the river (Bullard and Wells, 1992).



Modified from Bullard and Wells (1992)

Figure 4.2.*—Schematic diagram of the inner valley irrigation network in the Middle Rio Grande Basin.*

Surface-water quantity

Streamflow-gaging stations are the means by which hydrologists monitor the flow of water in streams and rivers. Gaging stations typically consist of a shelter that encloses a recorder to monitor water height (or stage). A correlation (known as a rating curve) can be made between stage and discharge by periodically measuring the streamflow rate (or discharge) of the stream and comparing it to the stage. An increasing number of recorders in gaging stations broadcast their stage data in real time or near real time by satellite or telephone. These data are used to automatically calculate discharge, and the discharge is then made available over the Internet. This streamflow information is useful not only for resource management and flood warning but also for recreational purposes such as fishing and boating. New Mexico streamflow information can be found on the Internet at http://nm.water.usgs.gov.

The North Floodway at Paseo del Norte in northern Albuquerque.

Information collected from streamflow-gaging stations can be used to estimate how much water is flowing through the surface-water system of the Middle Rio Grande Basin. Currently (2002) 38 USGS streamflow-gaging stations are being operated in or adjacent to the Middle Rio Grande Basin; 37 gaging stations have been operated in the past but have been discontinued (fig. 4.3). The sites with gaging stations include the Rio Grande and other streams tributary to the Rio Grande, irrigation canals and drains, arroyos and washes, and reservoirs. In addition to streamflow information, some of these gaging stations provide information about water chemistry and reservoir levels in the basin.

Table 4.1 shows surface-water inflows into and outflows from the Middle Rio Grande Basin for both the period of record for selected gaging stations or sites and for 1974–2000 (1974 is the first full water year in which flows in the Rio Grande were regulated by Cochiti Dam).

Streamflow in arroyos and washes is by definition ephemeral, and measuring ephemeral streamflow is problematic. For this and other reasons, most of the arroyos and washes tributary to the Rio Grande are not gaged; thus, the amount of water they contribute to the Rio Grande is an estimate. Streamflow in Galisteo Creek and Tijeras Arroyo is measured close enough to their confluence with the Rio Grande that their contribution to the flow of the Rio Grande is known. Streamflow in Abo Arroyo is also measured; however, the gaging station (Abo Arroyo near Blue Springs) is located where the arroyo enters the basin many miles upstream from the Rio Grande. This gaging station was installed to estimate recharge to ground water at the basin margin, and because many flows recorded at this station infiltrate or evaporate before they reach the Rio Grande, measurements are not a reliable indicator of Abo Arroyo's contribution to Rio Grande flow, though it is included in table 4.1. The North Floodway and the South Diversion Channels in Albuquerque were designed to convey ephemeral flow to the Rio Grande, but the North Floodway now flows continuously at about 1 to 5 cubic feet per second in its lower reaches. The flow is the result of return flow from turf-grass irrigation and the City of Albuquerque's practice of discharging municipal-well water to arroyos during the first few minutes of operation (Ground-Water Science, Inc., 1995).

Treated sewage effluent contributes a volume of water to the Rio Grande. Because this water was originally withdrawn from the aquifer system rather than the river, it is counted as tributary inflow. The major municipalities in the basin have sewage-treatment plants: Bernalillo, Rio Rancho, Albuquerque, Los Lunas, and Belen. All discharge at least part of their treated effluent to the Rio Grande. Rio Rancho discharges a limited volume of its effluent into the Albuquerque system. Both Albuquerque and Rio Rancho use some of the treated effluent for turf-grass irrigation. Areas of the basin not served by a sewage system use septic tanks, cesspools, or open-pit toilets for waste disposal (Ground-Water Science, Inc., 1995).

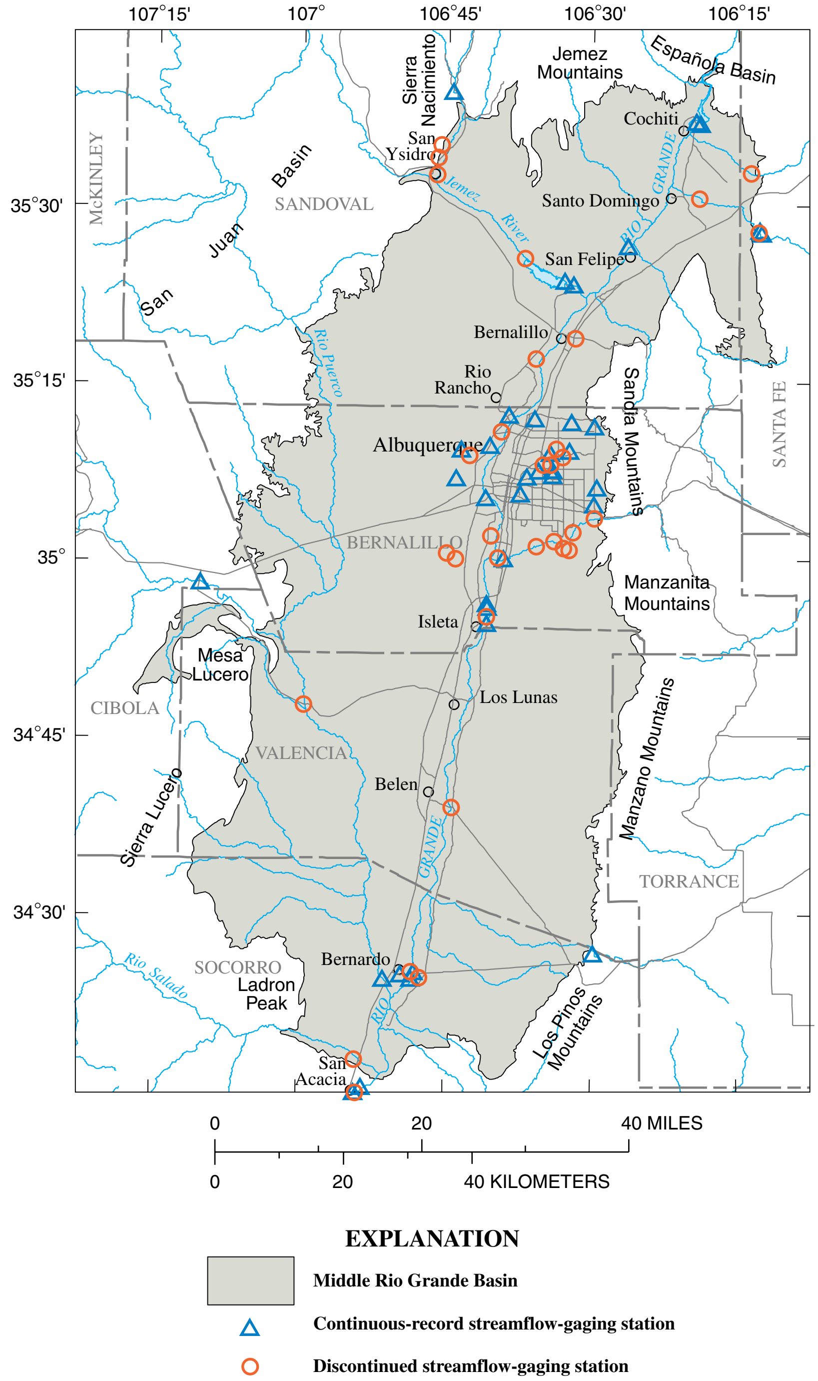


Figure 4.3.*—Current and discontinued streamflow-gaging stations in and adjacent to the Middle Rio Grande Basin.*

Water year describes the 12-month period from October 1 through September 30 of the following year. The water year is designated by the calendar year in which it ends. Thus, the 12 months ending on September 30, 2002, are water year 2002.

Cubic feet per second is the unit of measurement used to report discharge in the United States. Discharge is an instantaneous measurement of the volume of water that passes a given point in a set amount of time. One cubic foot of water is equivalent to 7.48 gallons.

Table 4.1.—Mean annual surface-water inflows into and outflows from the Middle Rio Grande Basin. Streamflow of the Santa Fe River above Cochiti Lake gaging station is not included in total inflow because it is included in streamflow for the Rio Grande below Cochiti Dam station. Streamflow for the Jemez River below Jemez Canyon Dam gaging station is not included in total inflow because it is downstream from the Jemez River near Jemez gage

[--, no data; period of record is in water years unless otherwise indicated]

Station name (station number) and period of record	Annual mean streamflow			
	Water years 1974–2000		Period of record	
	Cubic feet per second	Acre-feet per year	Cubic feet per second	Acre-feet per year
Inflow to the Middle Rio Grande Basin				
Rio Grande at Cochiti (08314500); 1924–70	--	--	[1,2] 1,300	[1,2] 945,000
Rio Grande below Cochiti Dam (08317400); 1970–present	1,460	1,060,000	[3] 1,430	[3] 1,030,000
Sili main canal (at head) at Cochiti (08314000); 1954–present	47.6	34,400	35.7	25,800
Cochiti east side main canal at Cochiti (08313500); 1954–present	84.2	61,000	66.9	48,400
Galisteo Creek below Galisteo Dam (08317950); 1970–present	5.62	4,070	[2] 6.15	[2] 4,450
Jemez River near Jemez (08324000); 1936–41, 1949–50, 1951–52, 1953–present	86.0	62,200	77.8	56,300
Santa Fe River above Cochiti Lake (08317200); 1970–99	[2] 11.7	[2] 8,500	[2] 11.3	[2] 8,160
Jemez River below Jemez Canyon Dam (08329000); 1936–39, 1943–present	[4] 72.1	[4] 52,200	[2] 63.6	[2] 46,000
Abo Arroyo near Blue Springs (08331660); 1996–present	[3] 17.1	[3] 4,670	[3] 17.1	[3] 4,670
North Floodway Channel near Alameda (08329900); 1968–89, 1990–present [seasonal record 1968–89]	11.8	8,510	10.5	7,630
South Diversion Channel above Tijeras Arroyo near Albuquerque (08330775); 1988–present	0.83	601	0.83	601
Tijeras Arroyo near Albuquerque (08330600); 1952–68, 1974–present [annual maximum only 1952–68; seasonal record 1974–98]	0.68	492	0.68	492
Rio San Jose at Correo (08351500); 1943–94	9.97	7,220	[4] 11.3	[4] 8,190
Rio Puerco near Bernardo (08353000); 1940–present	30.4	22,000	[3] 41.9	[3] 30,400
Rio Salado near San Acacia (08354000); 1947–84	[5] 8	[5] 5,900	[6] 14	[6] 10,400
Inflow from treated sewage effluent				
Town of Bernalillo wastewater-treatment plant, 1985–2000	[7] 0.7	[7] 530	[7] 0.7	[7] 530
City of Rio Rancho wastewater-treatment plant, 1985–2000	[7] 2.5	[7] 1,780	[7] 2.5	[7] 1,780
City of Albuquerque wastewater-treatment plant, 1985–2000	[7] 80.4	[7] 58,200	[7] 80.4	[7] 58,200
Village of Los Lunas wastewater-treatment plant, 1985–2000	[7] 0.9	[7] 659	[7] 0.9	[7] 659
Town of Belen wastewater-treatment plant, 1985–2000	[7] 1.3	[7] 938	[7] 1.3	[7] 938
Total inflow into the Middle Rio Grande Basin				
Total streamflow and sewage effluent measured	**1,830**	**1,330,000**	**1,790**	**1,290,000**
Outflow from the Middle Rio Grande Basin				
Rio Grande Floodway at San Acacia (08354900); 1964–present	1,100	793,000	[8] 801	[8] 580,000
Rio Grande Conveyance Channel at San Acacia (08354800); 1958–present	230	167,000	[8] 345	[8] 250,000
Socorro Main Canal North at San Acacia (08354500); 1936–present	125	90,400	[3,8] 117	[3,8] 84,500
Total outflow from the Middle Rio Grande Basin				
Total streamflow measured	**1,450**	**1,050,000**	**1,260**	**914,000**

[1] U.S. Geological Survey (1971).
[2] Not included in total inflow because of other downstream station or replacement.
[3] Ortiz, Lange, and Beal (2001).
[4] Borland and Ong (1995).
[5] Thorn, McAda, and Kernodle (1993).
[6] Denis, Beal, and Allen (1985).
[7] Upper Rio Grande Water Operations Model (2002).
[8] Period of record values are for water years 1964 through 2000.
Data not footnoted were retrieved directly from the USGS National Water Information System database.

Ground-water system

Most water-bearing units of the Middle Rio Grande Basin are unconsolidated deposits of the Santa Fe Group. Post-Santa Fe Group deposits (basin and valley fill) of Quaternary age formed during the last 1.6 million years. These deposits are present on mountain slopes, in the incised valley of the Rio Grande, and along flood plains of tributaries to the Rio Grande. They are locally used as aquifers, although the deposits are generally saturated only in flood plains or the inner valley of the Rio Grande. Because the Santa Fe Group and basin and valley-fill deposits are hydraulically connected, they are commonly grouped together as the Santa Fe Group aquifer system, following the informal usage of Thorn, McAda, and Kernodle (1993). Though the aquifer is under confined conditions locally, it is considered to be an unconfined aquifer as a whole. (For ground-water-flow modeling, the upper part of the aquifer system is treated as unconfined and the lower part as confined.)

The geology of the Santa Fe Group aquifer system was described in detail in the previous chapter. To review, the thickness of the Santa Fe Group in the Middle Rio Grande Basin ranges from about 1,400 feet at the basin margins to approximately 14,000 feet in the center of the basin (Lozinsky, 1988; Hawley and Haase, 1992; Grauch, Gillespie, and Keller, 1999). The Santa Fe Group is divided into three parts: upper (less than 1,000 to 1,500 feet thick), middle (250 to 9,000 feet thick), and lower (less than 1,000 to 3,500 feet thick). In places, either the upper part or the upper and middle parts have eroded away. Because of the depositional history of the Santa Fe Group, much of the lower part may make a poor aquifer. For this and economic reasons, ground water is withdrawn mostly from the upper and middle parts; only about the upper 2,000 feet of the aquifer is used for ground-water withdrawal. The depth to water in the aquifer system varies widely, from less than 2 feet near the Rio Grande to as much as 1,180 feet in an area west of Albuquerque.

In an *unconfined* aquifer, the water level (water table) is free to rise and fall. The pressure is atmospheric at the water table. An aquifer bounded above and below by confining beds and completely filled with water under pressure is known as a *confined* aquifer (or an artesian aquifer) (Lohman and others, 1972; Heath, 1983; Jackson, 1997).

The ground-water level in a well completed in an unconfined aquifer rises to the level of the top of the saturated zone, or water table. In a well completed in a confined aquifer, the ground-water level in the well rises to an elevation higher than the top of the aquifer, but not necessarily to the land surface. Differences in the ground-water levels in multiple wells completed at different depths in a single location indicate the general direction of vertical flow within an aquifer (Heath, 1983). See Box *F* for a discussion of ground-water-level maps and flow.

Ground-water-level declines

The main method by which ground-water managers and scientists track changes in the volume of water in an aquifer is comparing changes in ground-water levels in wells. These data are typically shown as ground-water-level maps or hydrographs. Box *F* describes how ground-water scientists use water levels to study an aquifer.

The earliest ground-water-level maps of the Middle Rio Grande Basin were of 1936 conditions (Theis, 1938). Theis' detailed maps are limited to the inner valley of the Rio Grande between the Jemez River and a few miles north of San Marcial. No effects of ground-water pumping in the basin can be seen on these maps.

Bexfield and Anderholm (2000) constructed the most complete ground-water-level map of predevelopment conditions in the Middle Rio Grande Basin (fig. 4.4) using a number of sources. As expected for predevelopment conditions, no effects of ground-water production in the basin are evident. On the basis of shapes of the ground-water-level contours, the river reach between Corrales and Belen appears to be losing water from the river into the aquifer. This losing reach during predevelopment conditions was probably not due to ground-water production but may in fact indicate evapotranspiration from vegetation in the inner valley or, as geochemical data suggest, long-term water movement into the Santa Fe Group aquifer system.

The terms *steady-state* or *predevelopment* conditions refer to the hypothetical, unchanging state of the aquifer prior to ground-water production. It is the starting point that ground-water-flow models use to assess the effect of ground-water development. However, because ground-water-level measurements are seldom available for the early years of aquifer development and because natural climatic fluctuations affect water levels, predevelopment conditions are often speculative. Commonly, the earliest water-level measurements are assumed to represent predevelopment conditions.

F

Ground-water-level maps and how they are used to understand the aquifer

Laura M. Bexfield[1]

A ground-water-level map is an essential tool to achieve a thorough understanding of a ground-water-flow system. This kind of map generally is used to indicate the elevation and shape of the water table. A carefully constructed map can be used to infer many distinct characteristics of a ground-water-flow system that are particularly important for the accurate construction of ground-water-flow models and the interpretation of hydrologic and geochemical data.

A ground-water-level map is constructed by measuring the depth to water in as many similarly constructed wells as possible. The part of an aquifer where all the rock openings and pores between sediment grains are completely filled with water is known as the saturated zone (fig. *F.1*). In an unconfined aquifer, such as the Santa Fe Group aquifer system, the upper surface of the saturated zone, the water table, is free to rise and fall. The water table is mapped using water-level measurements collected from wells that are open to the aquifer at or just below the water table. The measurements of depth to water obtained from these wells must be referenced to the same datum (commonly defined relative to sea level). For any particular well, a measuring point is defined as the elevation of the point from which the depth to water is always measured. After the depth to water in the well is measured, the value obtained is subtracted from the elevation of the measuring point to obtain the elevation of the water table above (or below) sea level (fig. *F.1*). When water-table elevations are plotted on a map of well locations, the values can be contoured to indicate the configuration of the water table (fig. *F.2*). Because the position of the water table varies in response to changes in the quantities of water entering and leaving the aquifer, a ground-water-level map should use only measurements from a time interval during which such changes are expected to be minimal.

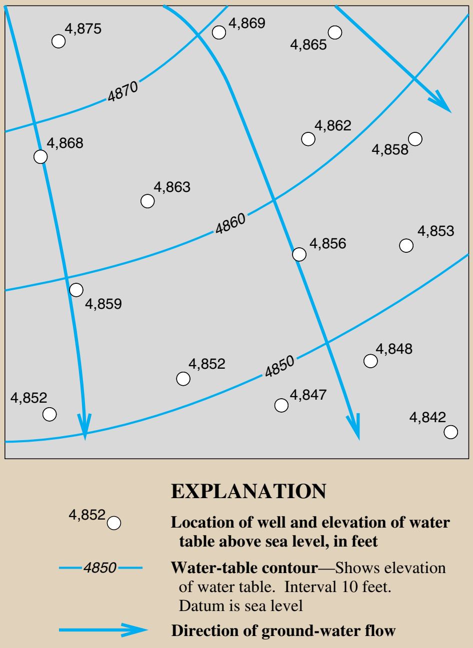


Figure F.1.*—Information needed to determine water-table elevations and to calculate hydraulic gradients.*

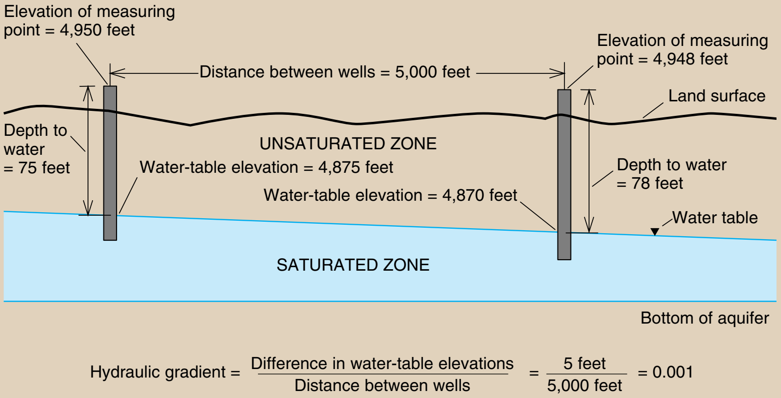


Figure F.2.*—Hypothetical well locations, water-table elevations, water-table contours, and approximate directions of ground-water flow.*

[1]U.S. Geological Survey, Albuquerque, New Mexico.

One of the most common uses of a ground-water-level map is to infer the direction of ground-water flow in the aquifer. Water generally flows from areas of higher hydraulic head (higher water-table elevations) to areas of lower hydraulic head (lower water-table elevations) along the path of the steepest gradient. Lines drawn perpendicular to the water-table contours approximate the direction of ground-water flow (fig. *F.2*). Flow lines delimited in this manner are not exact because they assume that the aquifer is isotropic (that is, aquifer materials allow water to move with equal efficiency in all directions), which is often not the case, and because they do not reflect the vertical component of ground-water movement (Domenico and Schwartz, 1990). However, such flow lines generally are reasonably representative of ground-water-flow directions, particularly in the upper part of the aquifer. Changes in flow directions through time can be determined by comparing ground-water-level maps constructed using water-level measurements from different time periods. Flow directions may change as the result of sustained ground-water pumping, which can lower water levels both locally and regionally.

Areas where water recharges to and discharges from the aquifer can be inferred from the configuration of water-table contours. The water table slopes from areas of recharge to areas of discharge. Where water-table contours bend across a stream channel to form a “V” pointing downstream, the stream is losing water to (recharging) the aquifer and ground-water flow is away from the stream (fig. *F.3*). Conversely, where the contours bend to form a “V” pointing upstream, the aquifer is discharging water to the stream and ground-water flow is toward the stream. If there is no deflection of the water-table contours across a stream channel, there may be little or no interaction between the stream and the aquifer or the type of interaction may not be determined from the available data.

The spacing of water-table contours with a defined contour interval also provides important information about the hydraulic gradient of the aquifer, which is the difference in the elevation of the water table over a known horizontal distance (fig. *F.1*), and is a necessary component in determining how fast ground water moves through the aquifer. Differences in the hydraulic gradient (spacing in the water-table contours) across an area of interest generally indicate differences in the physical properties of the aquifer. For example, a flatter hydraulic gradient (greater spacing between contours) often indicates an area of larger aquifer thickness or greater hydraulic conductivity, which is a measure of the ability of aquifer materials to transmit water.

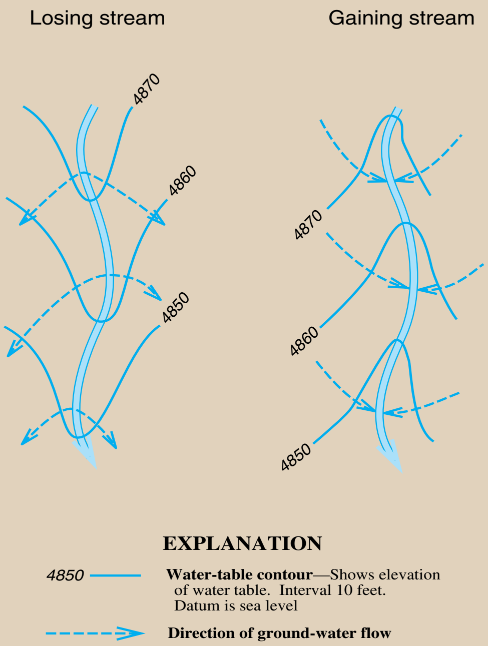


Figure F.3.*—Examples of water-table contours and directions of ground-water flow in the vicinity of losing and gaining streams. Streamflow is toward bottom of the diagram.*

A pumping well lowers the ground-water level around the well in a funnel-like shape known as a *cone of depression*. In more permeable areas of an aquifer, the size of the cone of depression is smaller. Similarly, at larger pumping rates, the cone of depression is larger. As the diameter of the cone of depression around a pumped well increases, it may intersect other wells, lowering the water level in those wells. Because a pumped well locally depresses ground-water levels, ground-water-level measurements made in a recently pumped well show a lower water level than the undisturbed *static* water level outside the cone of depression. For this reason, ground-water-level measurements are best made in nonpumped *observation* or *monitoring wells*—also called *piezometers*.

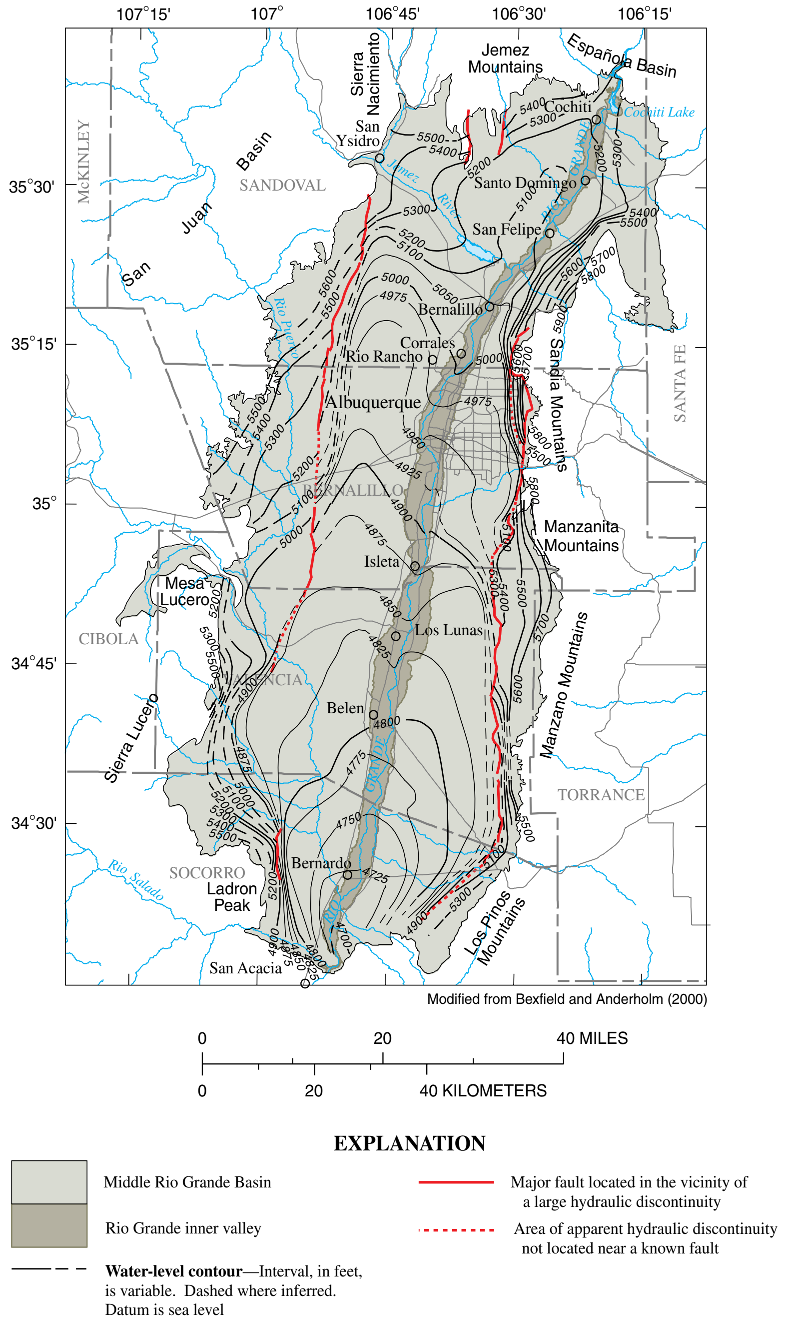
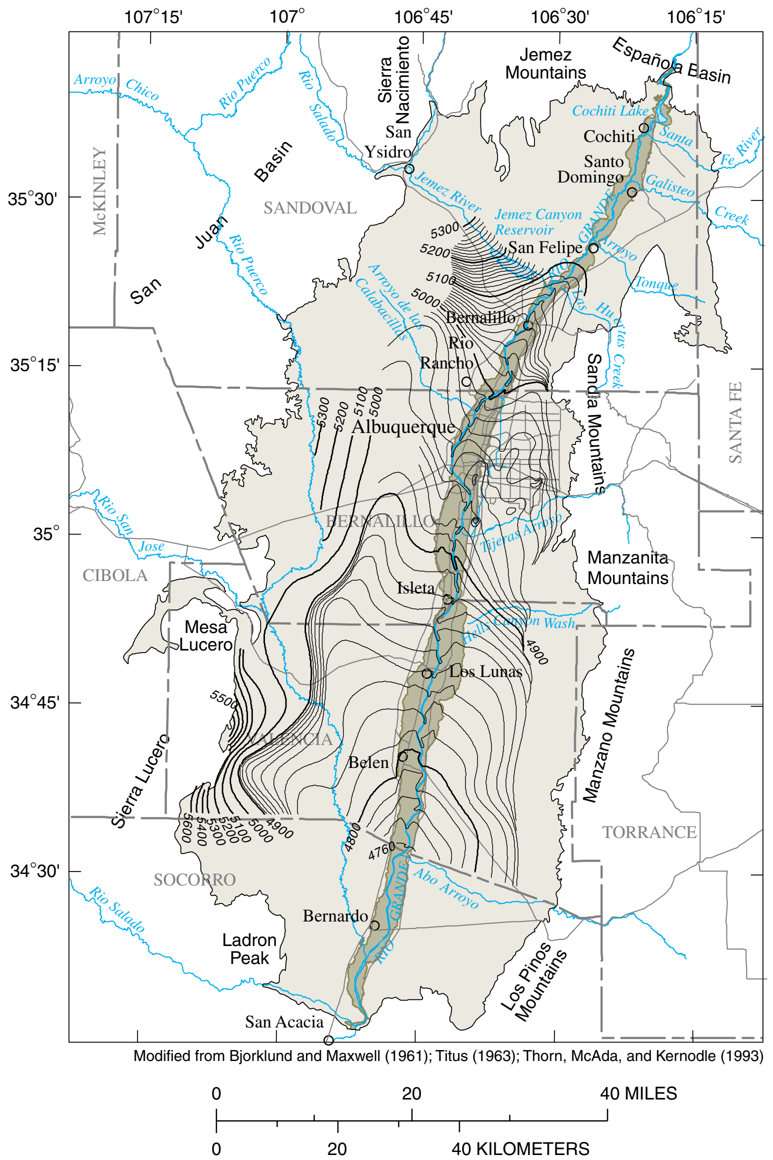


Figure 4.4.—*Ground-water levels that represent predevelopment conditions in the Santa Fe Group aquifer system in the Middle Rio Grande Basin.*

Thorn, McAda, and Kernodle (1993) combined ground-water-level maps of the Albuquerque area by Bjorklund and Maxwell (1961) and of Valencia County by Titus (1963) to construct a ground-water-level map for most of the Middle Rio Grande Basin that represented conditions in 1960–61 (fig. 4.5). The effects of ground-water production by City of Albuquerque wells are shown by the presence of circular, closed water-level contours on the south side of Albuquerque and large deflections in the water-level contours in northeast Albuquerque. For this time period in most of the mapped area, the ground-water-level contours indicate water



EXPLANATION

Middle Rio Grande Basin

Rio Grande inner valley

Water-level contour—Interval, in feet, is variable. Dashed where inferred. Datum is sea level

Figure 4.5.*—Ground-water levels that represent 1960–61 conditions in the Santa Fe Group aquifer system in the Middle Rio Grande Basin.*

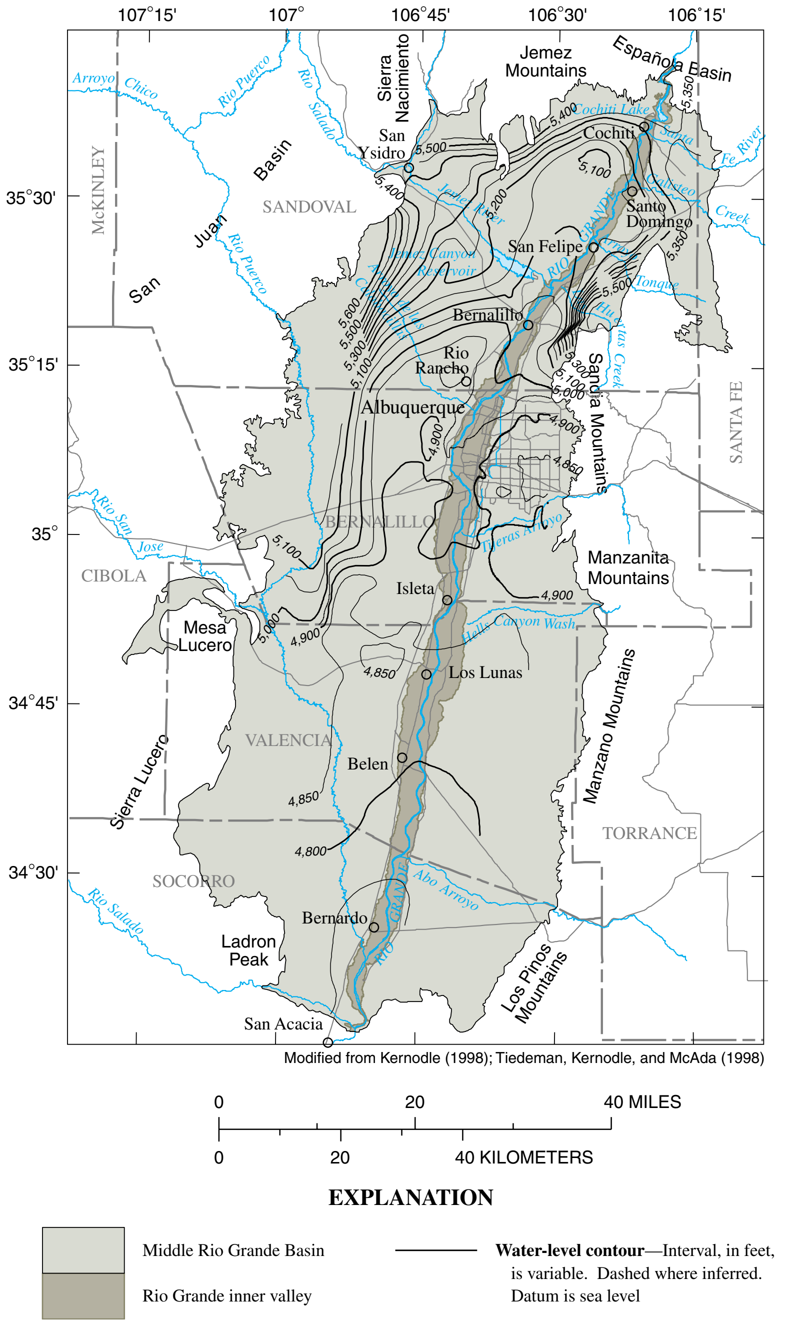


Figure 4.6.—Ground-water levels that represent winter 1994–95 conditions in the Santa Fe Group aquifer system in the Middle Rio Grande Basin.

A USGS hydrologist collecting ground-water levels at the Sierra Vista monitoring well. Frequent and consistent measurements of ground-water levels are crucial for understanding the aquifer system and tracking water-level declines.

movement from the river into the aquifer. Titus (1961) published a ground-water-level map of 1958–61 conditions using much of the same data but included areas outside and adjacent to the Middle Rio Grande Basin.

Several ground-water-level maps have been constructed showing conditions in the Albuquerque area in the late 1980's (Summers, 1992) and early 1990's (Thorn, McAda, and Kernodle, 1993). The ground-water-level map of the entire Middle Rio Grande Basin showing the most recent conditions was constructed by Tiedeman, Kernodle, and McAda (1998) and represents winter 1994–95 conditions (fig. 4.6). Well-defined cones of depression in the Albuquerque and Rio Rancho areas and marked distortion of water-level contours in the Albuquerque area are visible on this map.

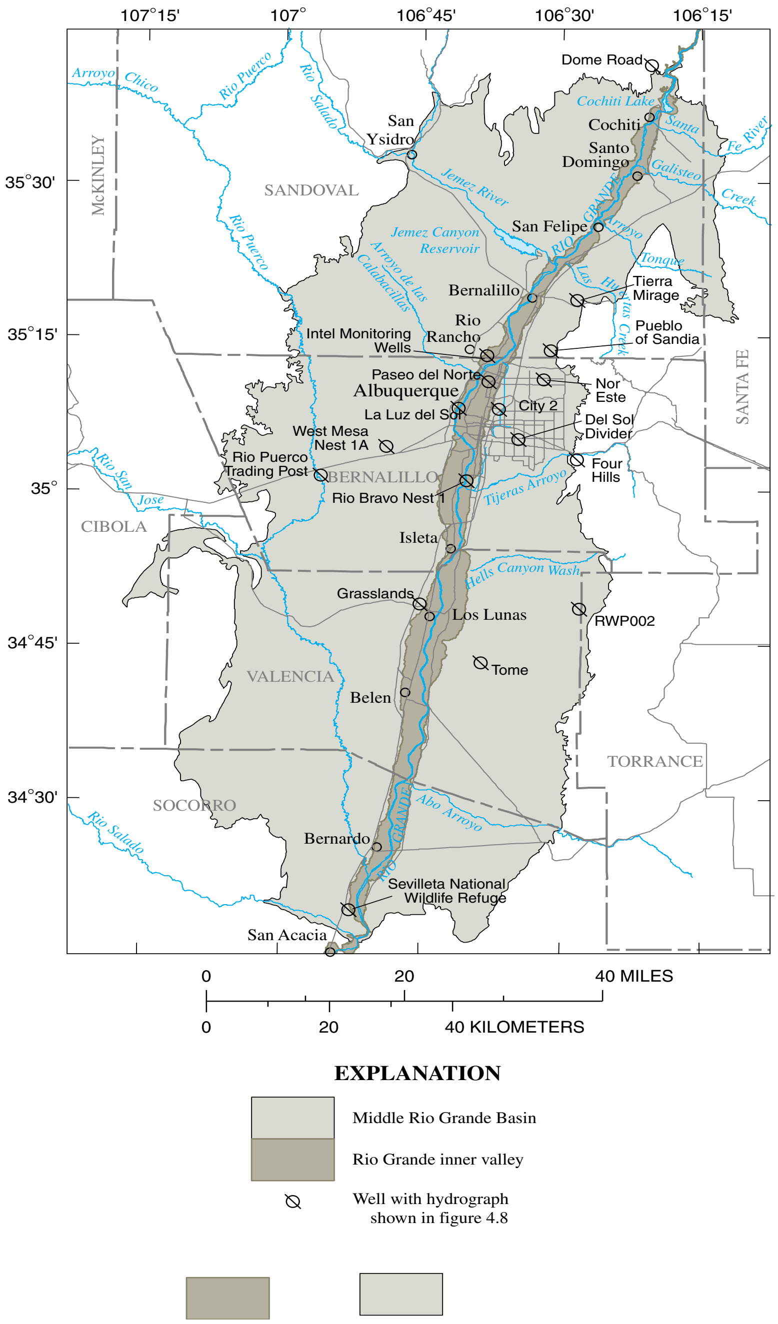
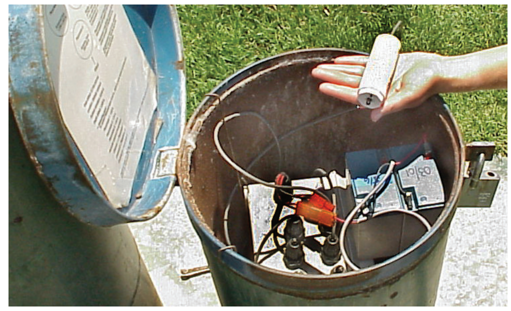


Figure 4.7.*—Location of selected wells in the Middle Rio Grande Basin. Hydrographs for these wells are shown in figure 4.8.*



Electronic equipment used to automatically record ground-water levels. The white cylinder being held is a pressure transducer that is placed below the water surface in a well. As water levels fluctuate, the transducer detects changes in pressure and transmits the data to the electronic recorder.

Currently (2002), ground-water levels in the basin are monitored through two main programs conducted by the USGS: one in cooperation with the New Mexico Office of the State Engineer (NMOSE) and the other in cooperation with the City of Albuquerque. The NMOSE program is part of a monitoring network of selected wells in 34 areas in New Mexico and adjoining States that are measured periodically (usually every 5 years) or are equipped with continuous water-level recorders. The Middle Rio Grande monitoring area of this program extends from about Jemez Canyon Reservoir to about 35 miles south of Socorro and included 123 wells in 1995 (Wilkins and Garcia, 1995).

A graph showing water levels over time at a single site is known as a *hydrograph*. Hydrographs can be constructed for either ground- or surface-water levels, and they are a common way to visualize water-level changes over time. See figure 4.8 for examples of hydrographs.

The City of Albuquerque program encompasses the Albuquerque Basin (or Middle Rio Grande Basin as defined in this report) and includes 255 wells. Ground-water levels in these wells are measured by the USGS and other agencies, and the measurement interval for wells in the network varies from continuous (collected by water-level recorder) to multiyear (Rankin, 2000).

Because of the limitations of ground-water levels measured in or near production wells, the USGS in cooperation with the City of Albuquerque, NMOSE, and Bernalillo County began a program in 1996 to install a number of specialized monitoring wells in the Middle Rio Grande Basin. Most of these wells are groups, or nests, of several wells completed at different depths in the aquifer. The locations for these wells were chosen to be at least 1 mile away from high-capacity production wells, and the goal was to monitor changes in the static water level of the aquifer over an extended period of time. (Because of the production-well density in much of the basin, however, the placement of the monitoring wells can only minimize the short-term fluctuations caused by pumped wells.) Currently (2002), 59 such monitoring wells have been installed at 23 sites. Continuous water-level recorders have been installed on nearly all these wells, and all have been incorporated into the City of Albuquerque ground-water-level monitoring program.

The USGS monitoring well at Sister Cities Park.

Locations of selected well nests and single wells in the Middle Rio Grande Basin are shown in figure 4.7. Hydrographs associated with these wells are shown in figure 4.8. Ground-water levels in wells located away from pumping centers generally do not show a continually declining trend over time, though some variation is present. However, wells located in areas near pumping centers have had a general decline in water levels. (Because of the high variability of aquifer conditions, not all wells show the same trends.)

Seasonal water-level fluctuations can be clearly seen in the hydrographs for three sites: Nor Este, Del Sol Divider, and Rio Bravo nest 1. These water-level fluctuations reflect increased municipal pumping from nearby wells during the summer months, when demand is greatest, and water-level recovery during the winter months, when demand is least. Wells completed at different depths at the same site do not always respond in the same manner, which indicates that the aquifer is not of uniform composition and that vertical water movement may be somewhat restricted.

Hydrographs from the eight sites with multiple wells can be used to determine the vertical direction of ground-water flow because water generally flows from areas of high hydraulic head (lesser depth to water) to areas of low hydraulic head (greater depth to water). Thus, at five sites (such as Paseo del Norte nest 1) flow appears to be downward; at three sites (such as West Mesa nest 1A) flow generally appears to be upward.

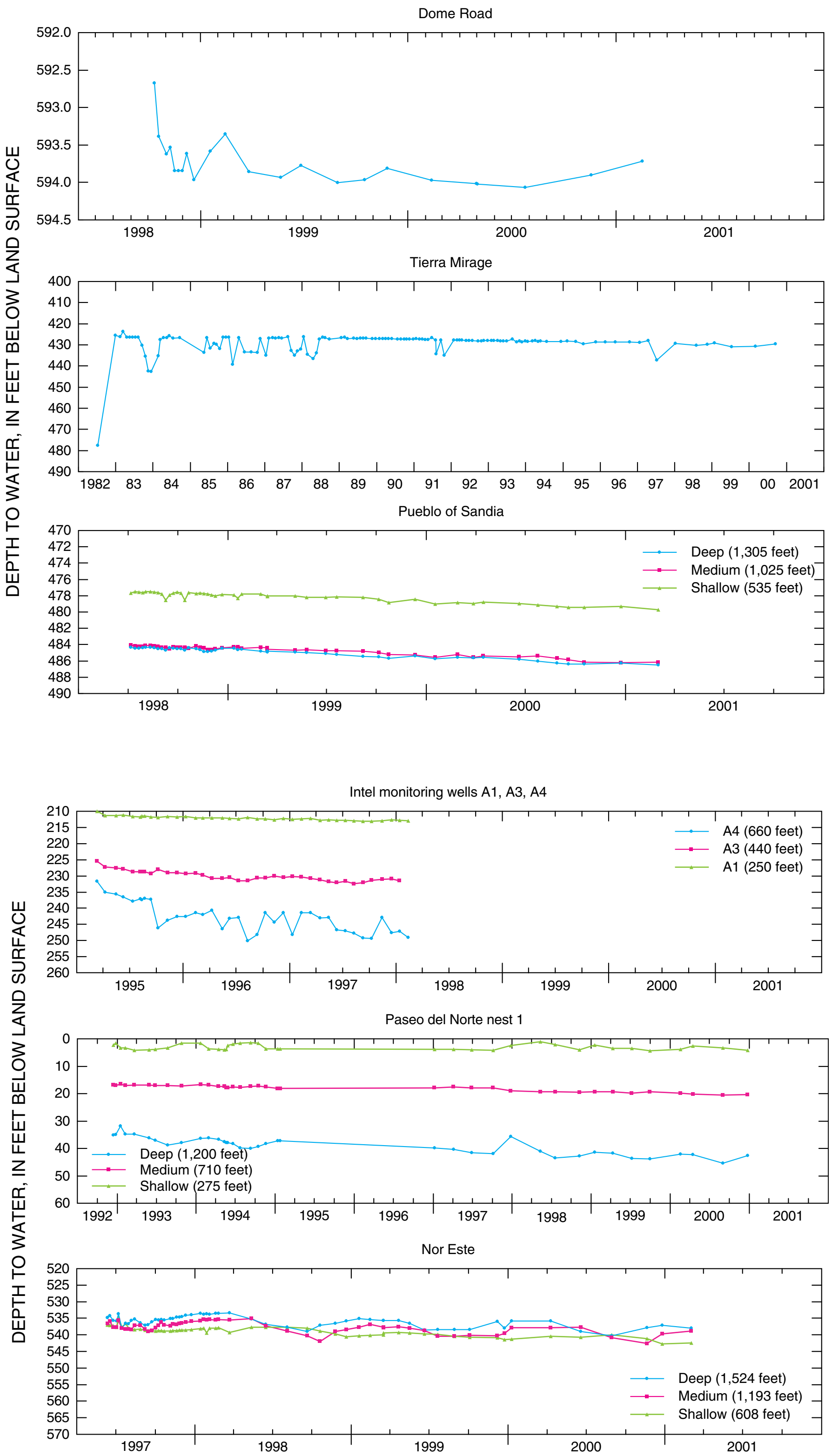


Figure 4.8.*—Water levels in selected wells in the Middle Rio Grande Basin. Water levels for separate wells in a single well nest are differentiated by total well depth.*

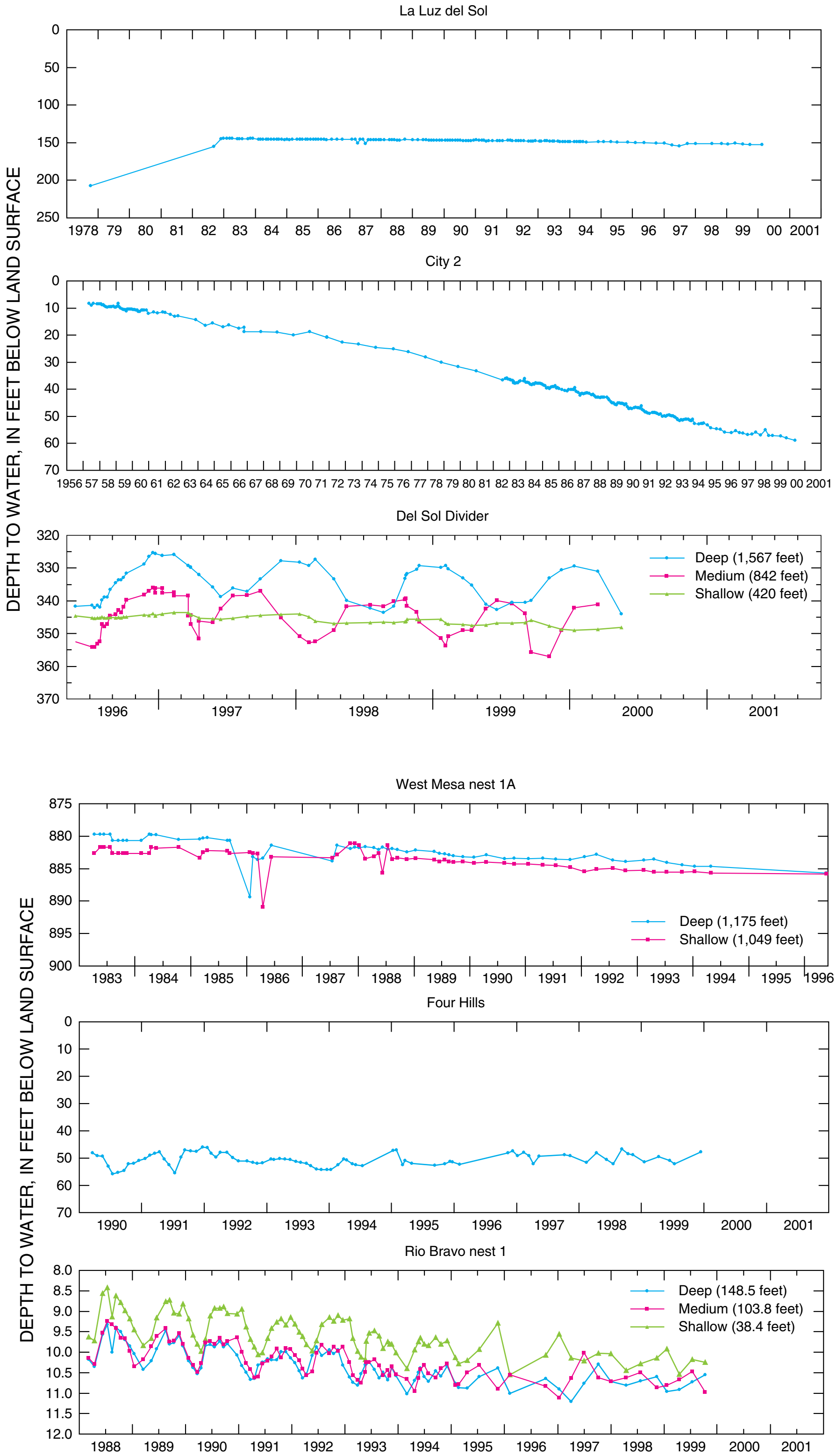


Figure 4.8.*—Water levels in selected wells in the Middle Rio Grande Basin. Water levels for separate wells in a single well nest are differentiated by total well depth—Continued.*

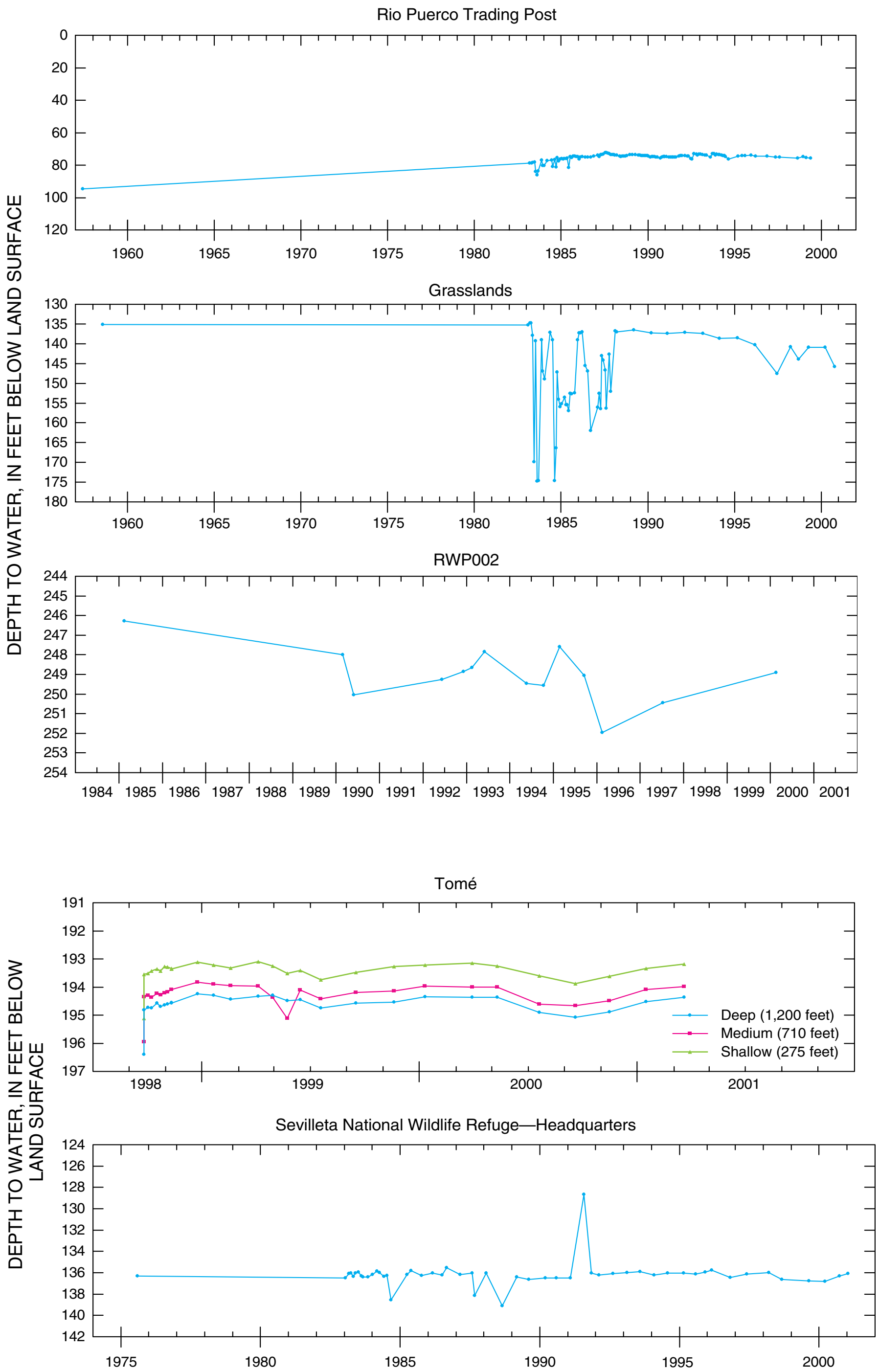


***Figure 4.8.**—Water levels in selected wells in the Middle Rio Grande Basin. Water levels for separate wells in a single well nest are differentiated by total well depth—Continued.*

Aquifer productivity

Perhaps the most important parameter that ground-water scientists use to characterize an aquifer is its *hydraulic conductivity,* which is a measure of how quickly water can move through a rock unit. In English units, hydraulic conductivity is commonly defined as the volume of water (in cubic feet) that will move in a unit of time (1 day) under a unit of hydraulic gradient (1 foot per foot) through a unit of area (1 square foot), but is simplified to units of velocity (distance divided by time or feet per day). This report uses feet per day to report hydraulic conductivity. The larger the value of hydraulic conductivity, the more water an aquifer is able to yield to wells and springs. Sand and gravel typically have values in the range of 1 to 10,000 feet per day, whereas silt and clay can have values ranging from 0.0000001 to 1 foot per day. In general, the coarser and more uniform the aquifer material, the higher the hydraulic conductivity (Heath, 1983).

Measurements of hydraulic conductivity can be made in several ways, the most common methods being aquifer tests, laboratory measurements of drill cores, and air permeameter measurements of the rock units where they crop out on the surface. All these methods have their limitations, and because they are expensive, usually only a limited number of hydraulic-conductivity values are obtained for a given rock unit. Typically, the estimated values of hydraulic conductivity for a rock unit are applied to large areas of the unit in the subsurface.

The aquifer definition stated previously on page 23 is quite subjective—there is no absolute standard that defines whether a rock unit is usable as an aquifer. Other than the presence of potable water, the most important characteristics that contribute to the productivity of an aquifer are hydraulic conductivity and saturated thickness.

As mentioned in the previous chapter, sediments in each of the three parts of the Santa Fe Group were deposited in a range of different depositional environments that influence the hydraulic conductivity of the aquifer. For convenience, the Santa Fe Group is subdivided into units with similar characteristics and depositional history—these units are known as lithofacies. Because of their similarities, rock units within a lithofacies tend to have similar values of hydraulic conductivity. Thus, maps of lithofacies can be converted to maps showing the distribution of hydraulic conductivity in an aquifer or hydrostratigraphic units, as discussed in Chapter 3. Such maps are a necessary step in the creation of a ground-water-flow model.

Because actual measurements of hydraulic conductivity are scarce, any map of the hydraulic conductivity of an aquifer is an approximation at best. Zones of estimated values of horizontal hydraulic conductivity (in the east-west direction) in the upper part of the saturated zone of the aquifer (as used in the ground-water-flow model of McAda and Barroll [2002]), are shown in figure 4.9. This map shows that the aquifer beneath eastern Albuquerque has some of the highest hydraulic conductivity in the basin. Because Albuquerque's post-Second World War growth was largely in this area, most of the new municipal-supply wells drilled to support the growth were completed in an area of high hydraulic conductivity, which led to the popular belief that the entire Middle Rio Grande Basin was underlain by a very productive aquifer and that the aquifer contained a volume of water equivalent to one of the Great Lakes (*Albuquerque Living*, 1984; Thorn, McAda, and Kernodle, 1993; Niemi and McGuckin, 1997).

Because of the large values of hydraulic conductivity, the City of Albuquerque has been able to complete wells that yielded large quantities of water. This is in stark contrast to other areas of New Mexico that have less productive aquifers. For instance, some wells in the Buckman well field in Santa Fe are completed in a portion of the Santa Fe Group aquifer system with hydraulic conductivity values approximately 100 times less than those in Albuquerque (Black and Veatch, 1978; Thorn, McAda, and Kernodle, 1993).

Hydraulic conductivity in a rock unit usually differs in the horizontal and vertical directions, a property referred to as *anisotropy.* Sedimentary deposits, such as in the Middle Rio Grande Basin, are usually deposited in a series of beds with varying grain sizes. This bedding is responsible for lower hydraulic-conductivity values (by as much as several orders of magnitude) in the vertical direction. Generally, rock units with smaller values of hydraulic conductivity control vertical hydraulic conductivity; rock units with larger values of hydraulic conductivity control horizontal hydraulic conductivity (Ingebritsen and Sanford, 1998). The difference between vertical and horizontal hydraulic conductivity also varies with the scale on which it is examined: the greater the thickness or areal extent of the rock unit, the greater the difference tends to be (Freeze and Cherry, 1979).

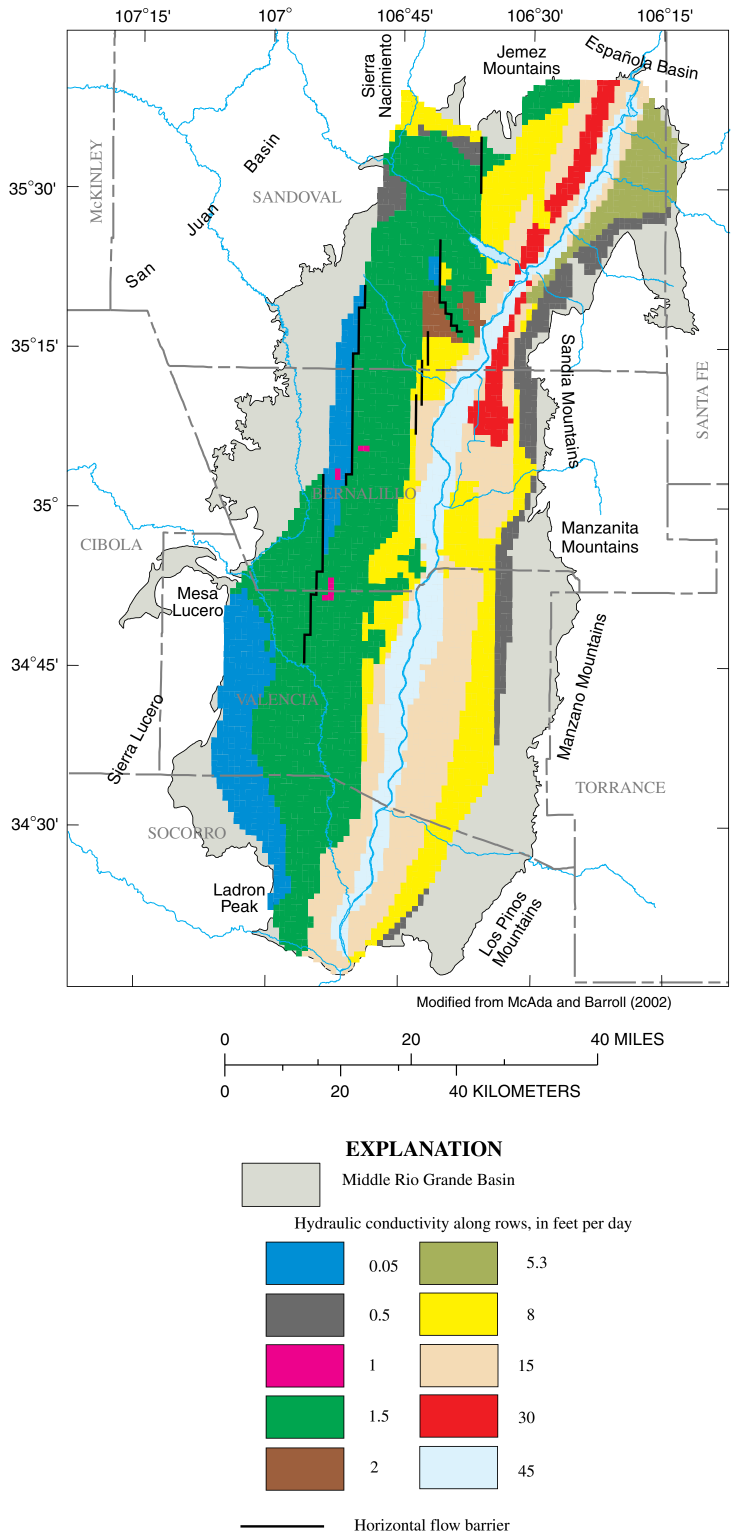


Figure 4.9.*—Distribution of east-west horizontal hydraulic conductivity in the upper part of the Santa Fe Group aquifer system in the ground-water-flow model of McAda and Barroll (2002). View is of layer 1 (30 to 50 feet below the predevelopment water table).*

Ground-water quantity

Porosity is the ratio of openings (or voids) to the total volume of a rock, such as between sedimentary grains or within fractures, and is usually expressed as a percentage. Such openings may not be connected; thus, a rock with significant porosity may have a low value of hydraulic conductivity. In general, the more uniform the rock material, the greater the porosity. Additionally, fine-grained materials tend to be better sorted than coarser materials. Thus, sands typically have porosity values in the range of 25 to 50 percent, whereas clays typically vary between 40 and 70 percent. As shown on page 58, this relation between fine- and coarse-grained materials is opposite of that seen in typical values of hydraulic conductivity (Freeze and Cherry, 1979; Heath, 1983).

One of the most common questions about the Santa Fe Group aquifer system in the Middle Rio Grande Basin is "How much water is left?" This question is difficult to answer or, perhaps, the answer is of little use. It is comparatively easy to make assumptions about the porosity and saturated thickness of the Santa Fe Group aquifer system and thus estimate a volume of water. However, the composition of the aquifer remains an educated guess in much of the basin, and little is known about the water quality in much of the aquifer. In addition, silty units with large amounts of clay and low values of hydraulic conductivity will not conduct usable quantities of water to wells, so the water contained in these deposits is virtually unobtainable. Thus, any estimate of the volume of water remaining in the aquifer would include large volumes that are unusable or unobtainable, and a large uncertainty would be associated with the estimate.

Water use in the basin

At the current time (2002), the main direct consumptive use of surface water in the Middle Rio Grande Basin is irrigation in the inner valley of the Rio Grande. Water is also consumed by reservoir evaporation, recharge to ground water, and evapotranspiration by riparian vegetation. Other nonconsumptive uses include recreation, esthetics, and ceremonial use by Native Americans.

Ground water from the Santa Fe Group aquifer system is currently (2002) the sole source of water for municipal supply and domestic, commercial, and industrial use in the Middle Rio Grande Basin. The municipalities of Bernalillo, Rio Rancho, Albuquerque, Bosque Farms, Los Lunas, and Belen have water-supply wells and distribution systems. A number of smaller communities such as Algodones and Cochiti Lake have formed Mutual Domestic Water Consumers Associations (MDWCA) to provide a public supply of water. Several private utilities such as Sandia Peak Utility Company or New Mexico Utilities Incorporated serve single or multiple subdivisions or parts of municipalities. Most of the pueblos in the Middle Rio Grande Basin have public-supply wells that serve at least part of the pueblo. Kirtland Air Force Base in southeast Albuquerque uses its own supply wells. A large number of domestic-supply wells in the basin furnish water for single households. In addition, small production wells scattered throughout the basin supply water for livestock. Finally, a number of commercial firms have their own wells to provide ground water for industrial use, the largest being Intel Corporation in Rio Rancho.

Every 5 years the NMOSE compiles and publishes water-use estimates for New Mexico, aggregated by counties and river basins. A summary of water use from 1995 estimates in the seven counties that make up the Middle Rio Grande Basin is listed in table 4.2 (Wilson and Lucero, 1997). Neither county boundaries nor river-basin boundaries correspond to the boundaries of the Middle Rio Grande Basin, so estimates based on entire counties overestimate water use. However, the estimates are useful for a rough comparison of the source and use of water in each county. The relative ground- and surface-water use by category for the counties in the Middle Rio Grande Basin is shown in graph form in figure 4.10.

Saturated thickness is the thickness of the aquifer saturated with water. In an unconfined aquifer, the saturated thickness varies with the position of the water table.

Table 4.2.—Water withdrawal estimates during 1995 for counties in the Middle Rio Grande Basin

[Wilson and Lucero, 1997]

County	Category	Surface-water withdrawal (acre-feet)	Ground-water withdrawal (acre-feet)	Total withdrawal (acre-feet)
Bernalillo	Public water supply	0.00	135,467.80	135,467.80
	Domestic	0.00	2,162.33	2,162.33
	Irrigated agriculture and livestock	65,261.43	4,661.87	69,923.30
	Commercial, industrial, mining, and power generation	0.00	5,107.96	5,107.96
	Reservoir evaporation	0.00	0.00	0.00
	County totals:	**65,261.43**	**147,399.96**	**212,661.39**
Cibola	Public water supply	0.00	2,840.01	2,840.01
	Domestic	0.00	968.76	968.76
	Irrigated agriculture and livestock	3,131.31	2,534.07	5,665.38
	Commercial, industrial, mining, and power generation	0.00	407.42	407.42
	Reservoir evaporation	1,080.00	0.00	1,080.00
	County totals:	**4,211.31**	**6,750.26**	**11,961.57**
Sandoval	Public water supply	125.95	15,201.07	15,327.02
	Domestic	0.00	2,529.00	2,529.00
	Irrigated agriculture and livestock	54,629.41	1,166.95	55,796.36
	Commercial, industrial, mining, and power generation	10.00	1,987.60	1,997.60
	Reservoir evaporation	15,033.00	0.00	15,033.00
	County totals:	**69,798.36**	**20,884.62**	**90,682.98**
Santa Fe	Public water supply	5,365.55	10,039.81	15,405.36
	Domestic	0.00	2,341.46	2,341.46
	Irrigated agriculture and livestock	18,971.28	13,766.43	32,737.71
	Commercial, industrial, mining, and power generation	19.54	544.09	563.63
	Reservoir evaporation	143.00	0.00	143.00
	County totals:	**24,499.37**	**26,691.79**	**51,191.16**
Socorro	Public water supply	0.00	2,183.55	2,183.55
	Domestic	0.00	323.23	323.23
	Irrigated agriculture and livestock	122,610.61	38,596.13	161,206.74
	Commercial, industrial, mining, and power generation	0.00	1,079.76	1,079.76
	Reservoir evaporation	7,570.00	0.00	7,570.00
	County totals:	**130,180.61**	**42,182.67**	**172,363.28**
Torrance	Public water supply	0.00	982.72	982.72
	Domestic	0.00	745.39	745.39
	Irrigated agriculture and livestock	29.82	45,449.74	45,479.56
	Commercial, industrial, mining, and power generation	0.00	104.66	104.66
	Reservoir evaporation	0.00	0.00	0.00
	County totals:	**29.82**	**47,282.51**	**47,312.33**
Valencia	Public water supply	0.00	4,917.37	4,917.37
	Domestic	0.00	3,302.98	3,302.98
	Irrigated agriculture and livestock	182,737.03	9,361.22	192,098.25
	Commercial, industrial, mining, and power generation	0.00	1,116.73	1,116.73
	Reservoir evaporation	0.00	0.00	0.00
	County totals:	**182,737.03**	**18,698.30**	**201,435.33**
Totals	Public water supply	5,491.50	171,632.33	177,123.83
	Domestic	0.00	12,373.15	12,373.15
	Irrigated agriculture and livestock	447,370.89	115,536.41	562,907.30
	Commercial, industrial, mining, and power generation	29.54	10,348.22	10,377.76
	Reservoir evaporation	23,826.00	0.00	23,826.00
	Total for all counties:	**476,717.93**	**309,890.11**	**786,608.04**

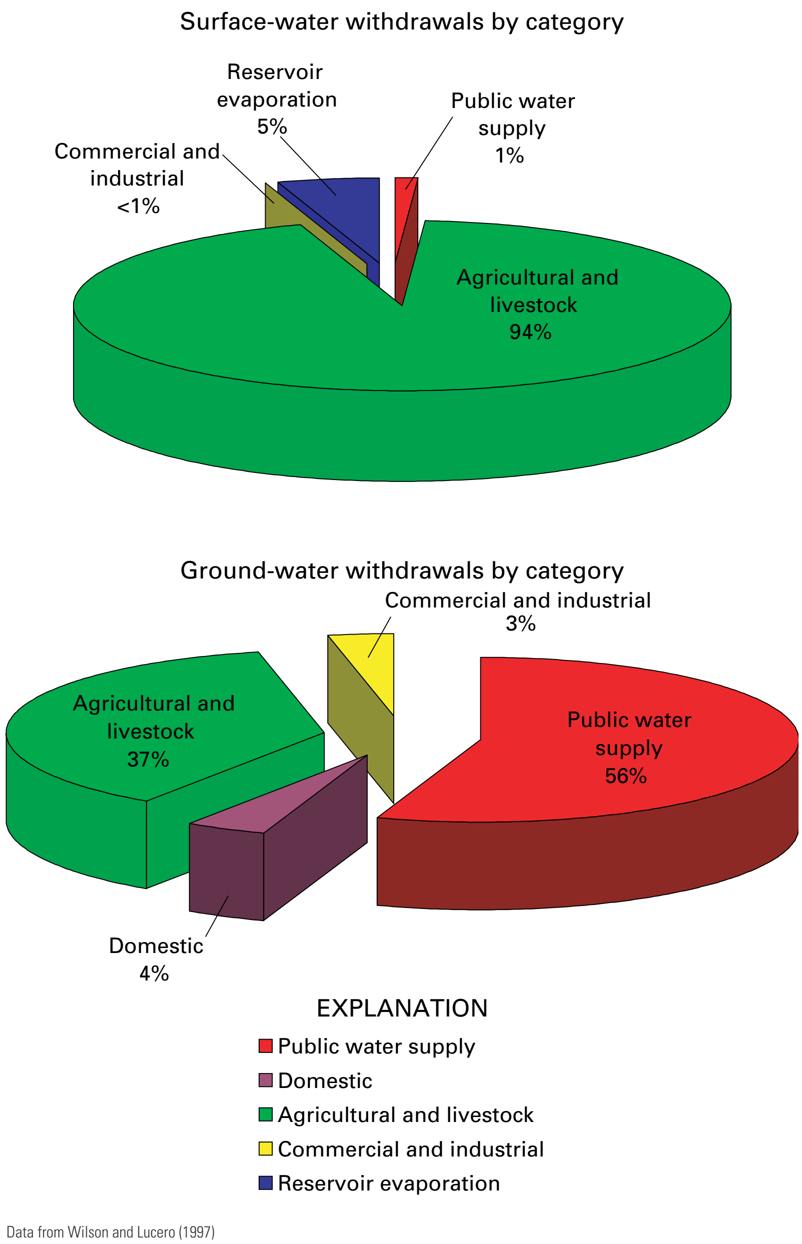


Figure 4.10.—*Water withdrawal estimates by category for surface and ground water during 1995 for counties in the Middle Rio Grande Basin. See table 4.2 for the data by county.*

One of the most important data gaps in our understanding of the water resources in the Middle Rio Grande Basin is an exact accounting of ground-water withdrawals. The NMOSE requires a permit for the construction of all water wells and, in many cases, each well must be metered and the volume of water produced must be reported. However, production data that are reported are often incomplete or production totals are combined for a number of wells. Consequently, the locations and amounts of much of the ground-water withdrawal in the basin are poorly constrained estimates.

The NMOSE permits as much as 3 acre-feet per year to be withdrawn from single household domestic or stock wells, though pumpage does not have to be reported for either these wells or wells on pueblo lands. Consequently, no production information is available for a large number of wells in the basin. In addition, only about 60 to 70 percent of permits issued for these types of wells result in a completed well (Larry Webb, City of Rio Rancho, oral commun., 2000). Thus, the number of domestic-supply and stock wells and the amount of ground water pumped from them in the Middle Rio Grande Basin are unknown.

Wilson and Lucero (1997) estimated the volume of water pumped from domestic-supply wells by county (table 4.2) by multiplying the population not served by municipal or private water systems in an area by an average per capita use of 85 gallons per day (0.095 acre-foot per day). In addition, communities such as Bosque Farms encourage the construction of domestic-supply wells by stipulating that municipally supplied water cannot be used for outside watering. The large number of unmetered domestic-supply wells in communities served by municipal water probably leads to underestimation of per capita water use in those communities. Wilson and Lucero (1997) used a similar process for estimating ground-water pumping for livestock uses, though in table 4.2, it is grouped with irrigated agriculture.

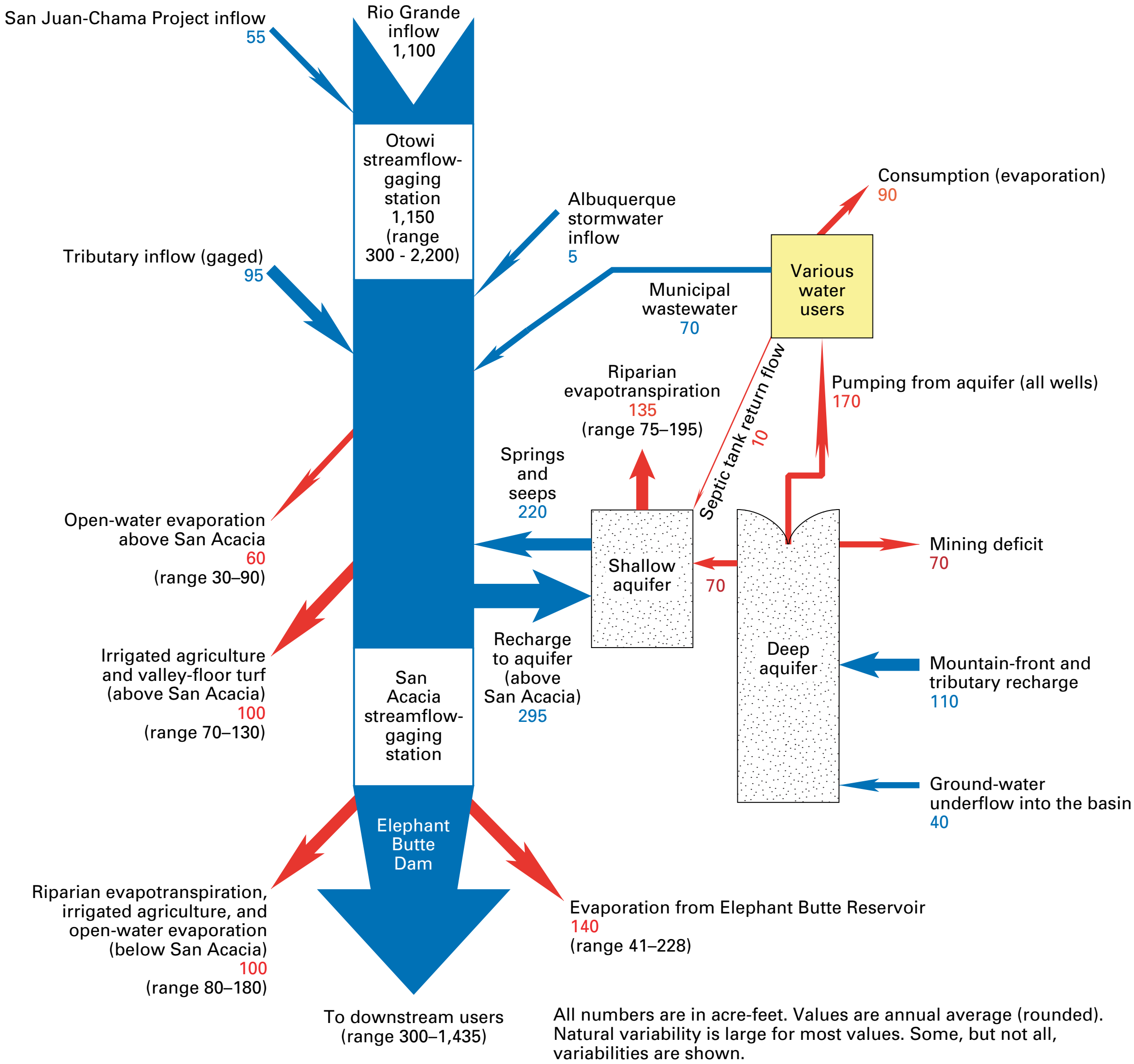
Water budgets

A water budget is essentially an accounting of water and its movement in a hydrologic system. It can be as simple as a few numbers representing water added to and subtracted from the system or as complex as a numerical simulation of the hydrologic system. This system can range in scale from global to site specific and may include only ground water, only surface water, or both. A water budget is a useful tool for helping water-resource scientists and managers conceptualize the hydrologic system. Because some of the inflows and outflows from the system cannot be measured directly, however, they must be estimated. Thus, the resulting water budget is only an approximation of the physical system, and the measured inflow and outflow totals may not balance exactly.

Several water budgets have been developed for the Middle Rio Grande Basin with varying ranges of complexity and with different areas of emphasis. Water budgets by Thorn, McAda, and Kernodle (1993), Gould (1995), and the Action Committee of the Middle Rio Grande Water Assembly (1999) are quite comprehensive because they address the surface- and ground-water components of the hydrologic system. The essential values for inflows, outflows, and indirect parameters of the hydrologic system are the same for these three budgets, though the latter

The USGS streamflow-gaging station on the Rio Grande at San Felipe. Such gaging stations provide critical streamflow data for water budgets and water management.

two reports used a slightly different areal extent of the Middle Rio Grande Basin. A report by S.S. Papadopulos and Associates, Inc. (2000) attributes differences among the budgets to differing timeframes and to whether the ground- or surface-water system was emphasized. A new comprehensive water budget was not done as part of the USGS Middle Rio Grande Basin Study because of the relative agreement among these water budgets. The water budget for the Rio Grande between the Otowi streamflow-gaging station and Elephant Butte Dam (fig 3.1), as developed by the Action Committee of the Middle Rio Grande Water Assembly (1999), is shown in figure 4.11.



Water delivery calculated from this water-budget analysis: 850
Average water deliveries from Rio Grande Compact records (1972–97): 729
Average water deliveries mandated by the Rio Grande Compact: 786
Average Elephant Butte effective supply (delivery plus change in storage): 799

Modified from the Action Committee of the Middle Rio Grande Water Assembly (1999)

Figure 4.11.*—Middle Rio Grande water budget for the reach from the Otowi stream-gaging station to Elephant Butte Dam as prepared by the Action Committee of the Middle Rio Grande Water Assembly (1999). Annual values are averages for 1972–97.*

The ground-water-flow model of McAda and Barroll (2002) produced the latest ground-water-specific water budget of the Middle Rio Grande Basin. Previous versions of ground-water-specific water budgets were presented by Kernodle and Scott (1986); Kernodle, Miller, and Scott (1987); and Kernodle, McAda, and Thorn (1995).

Major legal and institutional controls on water in the basin

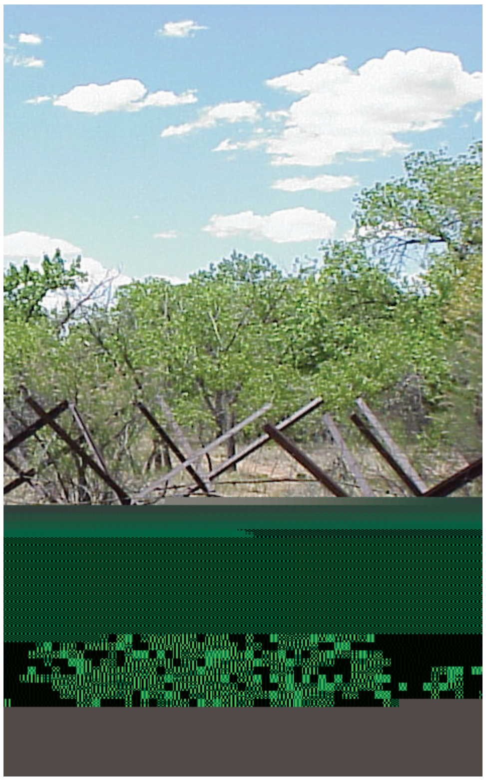
New Mexico water law forms the basis for water-resource management in the Middle Rio Grande Basin. Based on Spanish water law (as developed in the generally arid climate of Spain), its main feature is the ownership of unappropriated surface and ground water by the public (to be administered by the State). Also called the doctrine of prior appropriation, the first person to put the water to beneficial use has the appropriation right to that water before the users of subsequent claims, sometimes summarized as “first in time, first in right.” Water rights are permitted by the State on the basis of “beneficial use,” including irrigation, livestock, municipal, domestic, and industrial uses. Rights are issued for “consumptive” use, though they sometimes take into account water returned to the stream for use by others. Rights are also issued by date of their permit application, with older (or senior) rights receiving priority. For rights claimed prior to enactment of the New Mexico Water Code in 1907 (or the declaration of a ground-water basin), the priority date is when the water was first put to beneficial use; these rights are called “vested.” Water users with pre-1907 rights are not required to have a water-use permit unless changes are made in use or withdrawal. Water-use permits issued later cannot impair older rights; thus, during times of low flow, there may be no water remaining for the more junior users after holders of the oldest rights receive their water. Water rights cannot be detrimental to the public welfare and cannot be wasteful of water. If a water right is not put to beneficial use for 4 years (with some exceptions), after notice and an additional year, it expires and reverts to the public, though water rights may be transferred as long as other claims are not affected. Nearly all uses are considered beneficial, regardless of the economic value produced by the use (with the exception of willful waste). Currently (2002), New Mexico law does not recognize water remaining in a stream for the preservation of plants and animals as a beneficial use (Harris, 1984; Niemi and McGuckin, 1997).

The Middle Rio Grande Conservancy District diversion dam on the Rio Grande at Isleta Pueblo. This structure diverts water from the Rio Grande for irrigation between Isleta and San Acacia.

In 1927 and 1931, the New Mexico Legislature included ground water in certain State Engineer-demarcated “declared basins” to be under prior appropriation regulations as well, thus subjecting it to similar laws as surface water. In 1956, the NMOSE declared the Rio Grande Underground Water Basin, thus formally bringing the development of ground water in the basin under the jurisdiction of the State. An important change in the laws affecting ground water was made in the 1999 New Mexico legislative session when the Ground Water Storage and Recovery Act was passed to allow local governments to store surface water underground by artificial recharge and to later withdraw that water for beneficial use.

The sovereignty of the pueblos in New Mexico differs from that of other Indian tribes in the United States, largely because the Spanish and Mexican governments recognized their sovereignty prior to New Mexico’s incorporation into the United States. Pueblo water rights are not subject to New Mexico water law, and some obviously predate 1907. Because of these and other issues, the extent of pueblo water rights is currently (2002) unknown, though the collective recognized rights of the pueblos are 18,579 acre-feet of consumptive use (Niemi and McGuckin, 1997). (For the purpose of comparison, tables 4.1 and 4.2, in addition to figure 4.11, may be used to gain an idea of the significance of the water volumes discussed in this section.)

In 1925, after lobbying by the local community, the Middle Rio Grande Conservancy District (MRGCD) was formed as a political subdivision of the State in response to the reduction of productive farmland (mainly due to waterlogging) and an increase in flooding in the Middle Rio Grande Basin. The MRGCD, in cooperation with the Bureau of Reclamation and U.S. Army Corps of Engineers, has constructed flood and irrigation structures along the river and is responsible for delivering Rio Grande water to irrigators in the area between Cochiti Dam and San Marcial, about 43 miles downstream from San Acacia. The MRGCD delivers most of the surface water for consumptive use in the Middle Rio Grande Basin by delivering irrigation water to Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta Pueblos as well as many other irrigators with vested or senior water rights. The MRGCD claims water rights to irrigate 123,267 acres with 2.1 acre-feet of water per year, for a total consumptive use of 258,861 acre-feet per year (Bullard and Wells, 1992; Niemi and McGuckin, 1997).



Kellner jetties in the bosque near Paseo del Norte. More than 100,000 Kellner jetties have been installed upstream from Elephant Butte Reservoir for bank stabilization (Bullard and Wells, 1992).

Though many communities, subdivisions, and individuals withdraw water from the Santa Fe Group aquifer system, the largest user of ground water in the Middle Rio Grande Basin is the City of Albuquerque. Consequently, its water-management strategy is of the most importance. Since the 1960's, Albuquerque's water plan has consisted of meeting water demand solely by pumping ground water. The scientific understanding of the hydrogeology of the Middle Rio Grande Basin in the 1960's suggested that seepage from the Rio Grande replenished the water in the aquifer withdrawn by pumping. To this end, Albuquerque began acquiring and retiring surface-water rights to offset the perceived depletion of the river caused by ground-water withdrawals. A substantial portion of this water was obtained with the purchase of 42,700 acre-feet annually of San Juan-Chama Project water. The revised understanding of the hydrogeology of the basin, including the connection between the Rio Grande and Santa Fe Group aquifer system, spurred Albuquerque to revise its water-use strategy: in addition to the direct use of the San Juan-Chama Project water, this revised plan calls for significant conservation and water reuse/recycling (City of Albuquerque Public Works Department, 1997b).

Rio Grande Compact

Perhaps the most important single document governing flow in the Rio Grande is the Rio Grande Compact—an agreement between Colorado, New Mexico, Texas, and Mexico that attempts to allocate the water in the Rio Grande upstream from Fort Quitman, Texas, in a fair and impartial manner. Though Congress gave permission to negotiate the Compact in 1923, the three States and Congress did not approve it until 1939. The

Compact is overseen by a board of commissioners with representatives from the three States and is chaired by a nonvoting Federal representative appointed by the President. The main feature of the Compact is explicit water-delivery requirements by the upstream State to the downstream State and Mexico. Since the Compact went into effect in 1939, there have been a number of years in which Colorado and New Mexico have been unable to meet their downstream obligations and have consequently been in debt (Bullard and Wells, 1992).

San Juan-Chama Transmountain Diversion Project

Though the San Juan-Chama Transmountain Diversion Project is outside the Middle Rio Grande Basin, it contributes to the amount of water that flows through the basin (fig. 4.12). In 1971, the San Juan-Chama Project was completed to move water from the Colorado River Basin over the Continental Divide into the Rio Grande Basin. On the Rio Blanco in Colorado, the Blanco Diversion Dam and the Blanco Tunnel convey water to the Oso Tunnel. On the Little Navajo River, the Little Oso Diversion Dam diverts water into the Oso Tunnel. On the Navajo River, the Oso Diversion Dam diverts water into the Azotea Tunnel, where it is joined with water from the Oso Tunnel. The Azotea Tunnel then moves the water into the Rio Chama Basin in New Mexico. Once in the Rio Chama Basin, San Juan-Chama Project water is stored in Heron and El Vado Reservoirs (Bureau of Reclamation, 2001d). The San Juan-Chama Project is authorized to divert a maximum of 270,000 acre-feet in any year, limited to a total of 1.35 million acre-feet in any 10-year period. The governmental agencies that have contracted with the U.S. Department of the Interior for San Juan-Chama Project water include the U.S. Department of Energy, Albuquerque, MRGCD, Santa Fe Metropolitan Water Board, Española, Taos, Twining, Pojoaque Valley Irrigation District, Los Lunas, and Bernalillo. The Bureau of Reclamation controls the remainder of the water, some of which is used to offset evaporation losses from the permanent pool at Cochiti Lake. Though San Juan-Chama Project water is generally not subject to regulation under the Rio Grande Compact, its release is controlled by the Compact under certain conditions (Bullard and Wells, 1992).

Rio Grande silvery minnow. (Courtesy of U.S. Fish and Wildlife Service.)

Endangered species

The declaration by the U.S. Fish and Wildlife Service of the Rio Grande silvery minnow (*Hybognathus amarus*) as an endangered species in 1994 and the southwestern willow flycatcher (*Empidonax traillii extemus*) as endangered in 1995 have introduced new constraints on the management of water resources in the Middle Rio Grande Basin. For the Rio Grande silvery minnow, critical habitat has been proposed for the river reach immediately downstream from Cochiti Dam to near San Marcial, about 43 miles downstream from San Acacia, though 95 percent of the

Southwestern willow flycatcher. (Courtesy of Suzanne Langridge, USGS.)

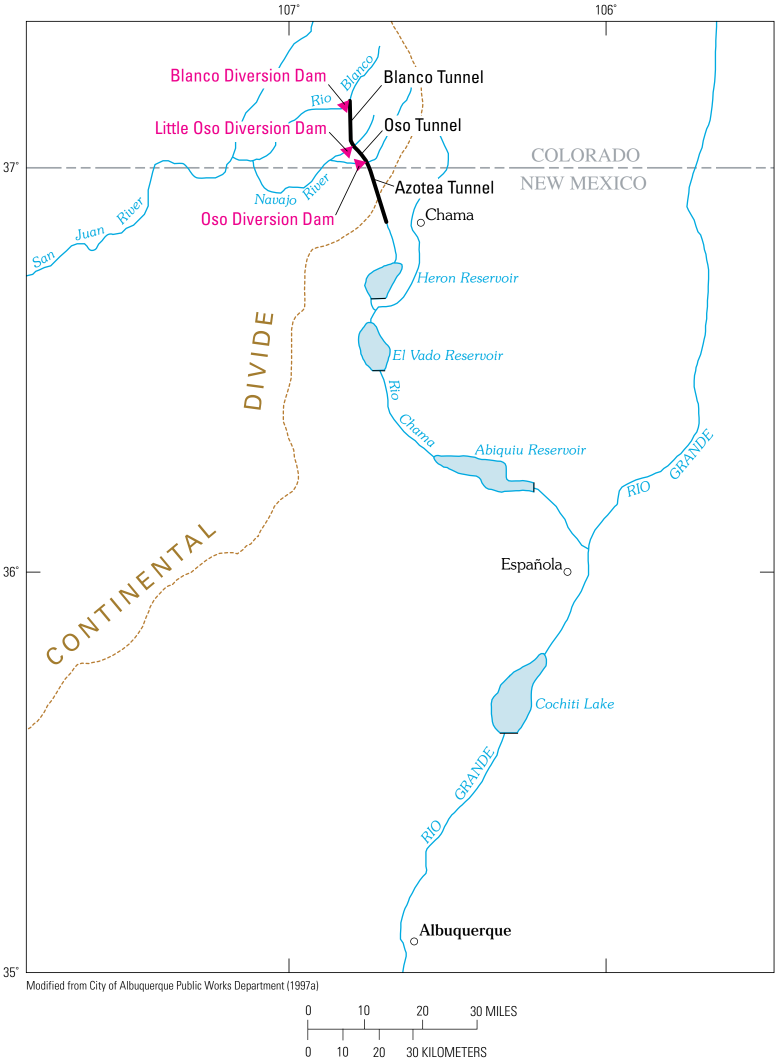


Figure 4.12.—*Diversion dams and tunnels of the San Juan-Chama Transmountain Diversion Project.*

extant population is concentrated downstream from the San Acacia diversion dam (Soussan, 2000). Among the actions proposed for its preservation and recovery are maintenance of minimum streamflows through certain reaches of the river and operation of reservoirs on the Rio Grande to more closely mimic natural streamflow conditions (U.S. Fish and Wildlife Service, 1999).

The population of the southwestern willow flycatcher has declined primarily because of the loss of native riparian vegetation, though in Southwestern States other than New Mexico, the flycatchers have been found to nest in areas composed primarily of tamarisk. Parasitism by the brown-headed cowbird (*Molothrus ater*) and predation have also contributed to the population decline (U.S. Fish and Wildlife Service, 2001a). The U.S. Fish and Wildlife Service released a draft recovery plan in June 2001 (U.S. Fish and Wildlife Service, 2001b). The recovery plan prioritizes 38 implementation tasks including water acquisition, research, water-use efficiency gains, and additional regulations.

Water appropriation

Even though water rights in the Middle Rio Grande Basin are divided into senior and junior classes, they have not been adjudicated. Surface flows of the Rio Grande are considered fully appropriated by the NMOSE, and an equivalent surface-water right must be obtained to offset any ground-water withdrawals that deplete the river. Because the Rio Grande is fully appropriated and additional supply cannot be created for new uses, competing water demands in the Middle Rio Grande Basin exceed the available supply.

Water-rights adjudication is the process that "determines the extent and ownership of each water right in a specific geographical area, usually a river-drainage or ground-water basin" (New Mexico Office of the State Engineer, 2001b). There are two phases to the adjudication process in New Mexico: a technical phase in which a hydrographic survey maps and reports water rights in the adjudication area, and a legal phase in which the court system determines the amount, priority, and use of water to which each right holder is entitled. Because adjudication is complicated, the process can take many years; for example, the Upper Pecos stream system adjudication was begun in 1956 and has yet to be completed (New Mexico Office of the State Engineer, 2001a). Currently (2002), only 3 of the 33 declared ground-water basins in New Mexico have been adjudicated (New Mexico Office of the State Engineer, 2001a).