GEOHYDROLOGIC FRAMEWORK AND HYDROLOGIC CONDITIONS IN THE ALBUQUERQUE BASIN, CENTRAL NEW MEXICO

By Condé R. Thorn, Douglas P. McAda, and John Michael Kernodle

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 93-4149

Prepared in cooperation with the
CITY OF ALBUQUERQUE PUBLIC WORKS DEPARTMENT,
WATER UTILITY DIVISION

Albuquerque, New Mexico
1993

U.S. DEPARTMENT OF THE INTERIOR
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Plates 1 and 3 reprinted with permission from the New Mexico Bureau of Mines and Mineral Resources.

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.4	millimeter
foot	0.3048	meter
mile	1.609	kilometer
acre	0.4047	hectare
square mile	2.590	square kilometer
acre-foot	0.001233	cubic hectometer
	43,560.	cubic foot
acre-foot per year	0.001233	cubic hectometer per year
	0.0013803	cubic foot per second
	0.6184	gallon per minute
million gallons	3,785	cubic meter
million gallons per day	0.04381	cubic meter per second
foot per day	0.3048	meter per day
foot squared per day	0.09290	meter squared per day
cubic foot	7.48	gallon
	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) by the equation:

$$^{o}C = 5/9\ (^{o}F - 32)$$

Sea level: In this report sea level refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

GEOHYDROLOGIC FRAMEWORK AND HYDROLOGIC CONDITIONS IN THE ALBUQUERQUE BASIN, CENTRAL NEW MEXICO

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ABSTRACT

Recent investigations indicate that the zone of highly productive aquifer, on which the City of Albuquerque has depended for its water supply, is much less extensive and thinner than was formerly assumed. The investigation described in this report focused on gathering recent information to requantify the ground-water resources of the Albuquerque Basin in Central New Mexico. This report describes the geohydrologic framework and current (1993) hydrologic conditions in the Albuquerque Basin.

The Santa Fe Group aquifer system in the Albuquerque Basin is comprised of the Santa Fe Group (late Oligocene to middle Pleistocene) and post-Santa Fe Group valley and basin-fill deposits. The Santa Fe Group and post-Santa Fe Group deposits recently have been divided into four hydrostratigraphic units by other investigators: the lower, middle, and upper parts of the Santa Fe Group, and post-Santa Fe Group valley and basin-fill deposits. The hydrostratigraphic units were further divided into lithofacies units characterized by bedding and compositional properties that exhibit distinctive geophysical, geochemical, and hydrologic characteristics. The Santa Fe Group ranges from less than 2,400 feet in thickness near the margins of the basin to 14,000 feet in the central part of the basin.

The most productive part of the Santa Fe Group aquifer system is the upper part of the Santa Fe Group and to some extent the middle part of the Santa Fe Group. The most productive lithologies are axial channel deposits of the ancestral Rio Grande and, to a lesser extent, pediment-slope and alluvial-fan deposits. The most productive part of the aquifer system is 2 to 6 miles wide and has a remaining saturated thickness of about 600 feet. The basin-floor playa lake deposits of the lower part of the Santa Fe Group generally do not yield large quantities of water to wells.

Water levels in the east Albuquerque area declined 140 feet from 1960 to 1992. Water levels declined 40 feet from 1989 to 1992 in eastern, northwestern, and south-central Albuquerque. The magnitude of these declines is due in part to shifts in pumping centers, the presence of fault barriers, and the limited extent of the axial channel deposits.

On the basis of an assumed storage coefficient of 0.2, the water-level declines in the Santa Fe Group aquifer system in the Albuquerque area represent a decrease in storage from ground-water withdrawal of an estimated 994,000 acre-feet from 1960 to 1992. The decrease in storage from ground-water withdrawal from 1989 to 1992 is estimated to be 305,000 acre-feet.

The average total annual surface- and ground-water inflow to the basin from 1974 through 1992 was estimated to be 1,458,400 acre-feet and the total outflow and consumptive loss was estimated to be 1,459,100 acre-feet. The average annual change in storage was independently estimated to be minus 31,100 acre-feet.

INTRODUCTION

Since the late 19th century many hydrologic studies, both qualitative and quantitative, have been undertaken concerning the Albuquerque Basin (fig. 1). Investigations sponsored by the City of Albuquerque Public Works Department, Water Utility Division during the last 5 to 10 years indicate that the zone of highly productive aquifer on which the population of the Albuquerque Basin has depended is much less extensive and thinner than was formerly reported (Bjorklund and Maxwell, 1961; Reeder and others, 1967). Because of this recent information, a better understanding of the hydrologic systems in the basin is needed if the population of the basin is to be provided with an adequate future water supply. In 1992 the U.S. Geological Survey, in cooperation with the City of Albuquerque, began an investigation designed to reevaluate the water resources of the Albuquerque Basin in Central New Mexico.

The study described in this report is the second part of a three-phase study to quantify the ground-water resources in the Albuquerque Basin. The first phase, conducted by the New Mexico Bureau of Mines and Mineral Resources in cooperation with the City, was to describe the geologic framework of the basin based on recent data. The report by Hawley and Haase (1992) describes the results of the first phase. This report, a part of the second phase, describes the geohydrologic framework and the current (1993) hydrologic conditions in the basin. Another part of the second phase of the study is to develop a ground-water flow model of the basin that is based on the concept of the geohydrologic system in the Albuquerque Basin described in the report by Hawley and Haase (1992) and in this report. The third phase is to use the model to evaluate water-resource management and recharge-enhancement alternatives.

The Santa Fe Group (late Oligocene to middle Pleistocene) is the principal aquifer in the Albuquerque Basin. Post-Santa Fe Group valley and basin-fill deposits (Pleistocene to Holocene) are in hydraulic connection with the Santa Fe Group. For the purpose of this study, the post-Santa Fe Group deposits are included as part of the Santa Fe Group aquifer system.

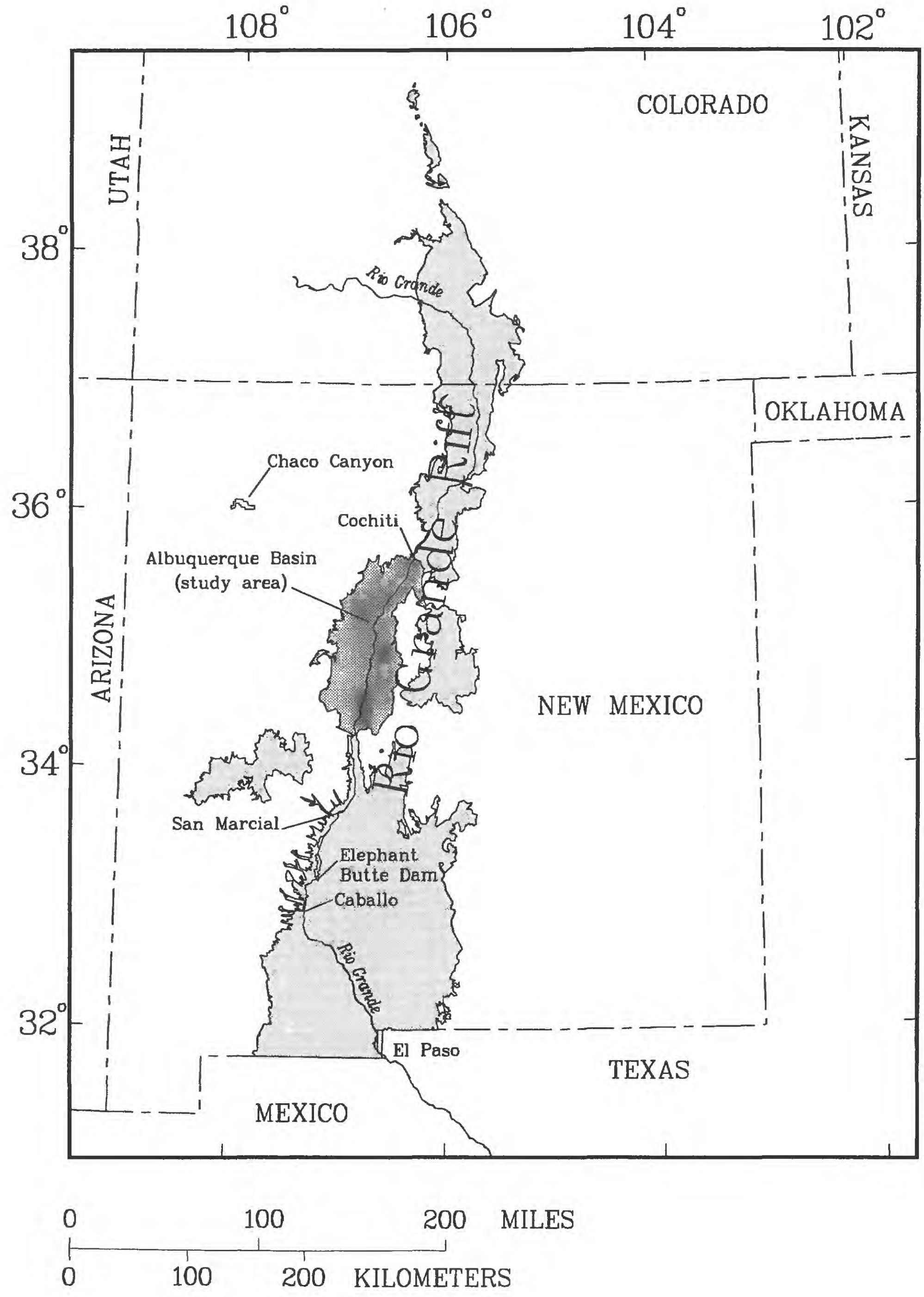


Figure 1.—Location of the Albuquerque Basin and the Rio Grande Rift.

Purpose and Scope

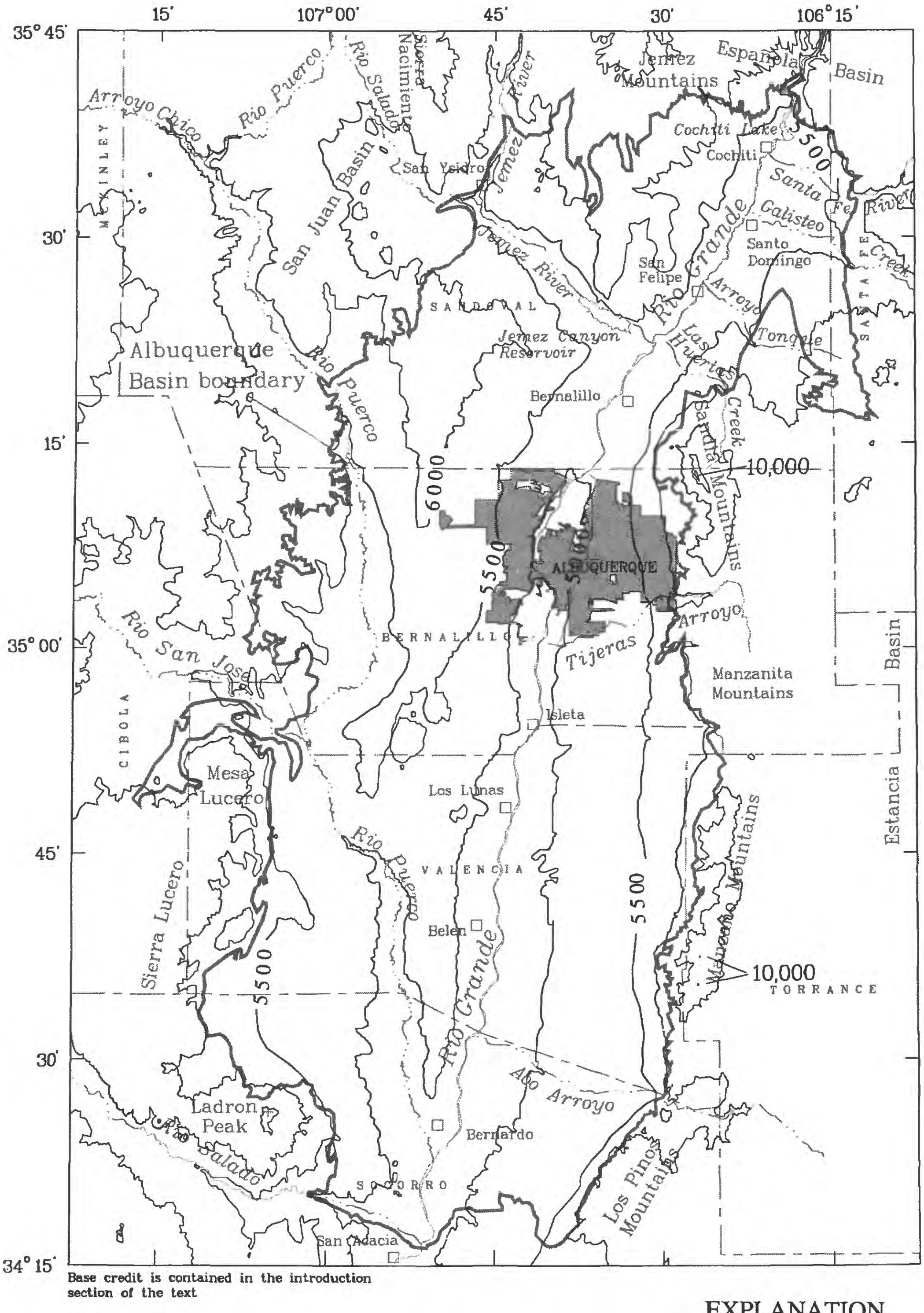
This report describes the current (1993) conceptual geohydrologic framework and the hydrologic conditions in the Albuquerque Basin. The framework is based on recent investigations, notably the geology described by Hawley and Haase (1992). Data collected through 1992 are used to describe the hydrologic characteristics of the basin, including ground-water withdrawal, water levels and water-level change, and surface- and ground-water inflow and outflow. To place the current concept of the geohydrologic system in its proper context, a brief description of the history of water development and use is presented.

Historical Background

New Mexico and the Albuquerque Basin have had long histories of imbalance between water needs and availability. The climate in New Mexico is such that naturally occurring surface-water supplies are not dependable. Ground-water supplies provide a buffer to seasonal and climatic changes, but they too are ultimately subject to the limits imposed by an arid environment.

According to a generally accepted hypothesis, the first known culture to be widely affected by a water shortage in what is now the State of New Mexico was the Anasazi in the 1270's. This period, known as the Great Drought (1276-1299), may have been the primary reason for abandonment of the Four Corners Region by the Anasazi (Thomas C. Windes, National Park Service, oral commun., August 7, 1993). As the result of an earlier drought in the 1100's, Chaco Canyon, the hub of the Chacoan Anasazi Culture in what is now northwestern New Mexico, was abandoned. The descendants of the Anasazi had already become established in the upper drainage of the Rio Grande and the southern and eastern perimeter of the San Juan Basin (fig. 2) where water supplies were more plentiful and reliable. Most modern pueblos, whose inhabitants are probable descendents of the Anasazi, were established near reliable sources of water for irrigation of crops.

The pueblos had an estimated 25,600 acres of irrigated land in the middle Rio Grande Valley (between San Marcial and Cochiti, fig. 1) in 1600 (C.R. Hedke, written commun., December 1924; cited in Stafford and others, 1938, p. 71). Under Spanish influence, elaborate systems of canals and acequias were developed to bring water to the fields in the river valley. Irrigated land in the middle Rio Grande Valley increased to about 73,600 acres in 1700 and 100,400 acres in 1800 (Stafford and others, 1938, p. 71). Development of the valley extended generally from north to south as Spanish land grants were made progressively down the valley. Bernalillo was founded in 1700, Albuquerque was founded in 1706, the land grant where Los Lunas is located was made in 1716, and Tome (between Los Lunas and Belen) was founded in 1739 (fig. 2). The land grant where Belen is located was made earlier, in 1642. Irrigated land in the middle Rio Grande Valley peaked at about 124,800 acres in about 1880 (Stafford and others, 1938, p. 71).



EXPLANATION

5500 LAND–SURFACE ALTITUDE––Shows land–surface altitude, in feet above sea level. Contour interval 500 feet below 6,000 feet and 2,000 feet above 6,000 feet

Figure 2.––Land–surface altitude in the Albuquerque Basin and vicinity, Central New Mexico.

A shortage of water in the Rio Grande downstream from El Paso, Texas, lead to a survey of all irrigated land in the Rio Grande Valley upstream from the international border in 1896 (Follett, 1898). The objective of the survey was to determine the feasibility of a dam on the Rio Grande upstream from El Paso. Follett (1898, p. 87-88) reported 31,700 acres of irrigated land in the middle Rio Grande Valley in 1896. The reduction in irrigated land from the 1880's was attributed to a shortage of water, waterlogging of soil, and the diversion of labor from agriculture to railroad construction (Follett, 1898, p. 89). In 1916 Elephant Butte Dam, the object of Follett's survey, was built to provide storage of irrigation water for the lower Rio Grande (fig. 1).

In 1907, Lee's report "Water resources of the Rio Grande Valley in New Mexico and their development" was published. Whereas Follett's (1898) earlier report was a snapshot of surface-water use and availability, Lee's report was the first truly comprehensive water-resources investigation of the Rio Grande Basin.

Waterlogging continued to be a problem through the 1920's. In 1928, irrigated land was about 45,600 acres in the middle Rio Grande Valley (Stafford and others, 1938, p. 71). Two factors contributed to the waterlogging problem. The first was the extensive network of leaking unlined canals that were used to convey the irrigation water diverted from the Rio Grande. Leakage from these canals and from applied irrigation on the remaining fields caused a progressive increase in shallow ground-water levels. The second factor was the change in channel sediment conveyance and geometry brought about by the extensive diversion of water. The Rio Grande began to aggrade as a result of its reduced energy, causing a high surface- to ground-water gradient. Without flood-control levees to control spring runoff, several devastating floods occurred (Bloodgood, 1930).

The Middle Rio Grande Conservancy District (MRGCD) was formed in 1925 to control floods and lower the water table so that waterlogged land could be reclaimed. In the late 1920's and early 1930's the MRGCD constructed hundreds of miles of interior and riverside drains, levees, and several irrigation-diversion dams. The MRGCD also took over the operation and maintenance of the numerous private and community acequia systems. Before and throughout this project, extensive ground-water investigations were conducted (Bloodgood, 1930; Theis, 1938). Bloodgood oversaw the installation of about 1,200 monitor wells in the Albuquerque area. These wells continued to be monitored by the U.S. Bureau of Reclamation until 1957. Botanical inventories (Van Cleave, 1935) were also conducted to monitor changes in habitat. The reclamation project was a success and virtually all of the waterlogged land became usable again, although not necessarily returned to agriculture. In 1980 there were about 77,000 acres of irrigated land in the Albuquerque Basin. In 1992, that number had been reduced to about 63,000 acres.

The late 1920's and early 1930's saw other cultural changes taking place. The first deep wells in the City's Main Well Field were completed in the late 1920's. The initial expansion of the city of Albuquerque out of the inner valley to the east began a few years later. This eastward expansion marked a change for Albuquerque from a modest urban area that was still rural and very agricultural in character to a hub for commerce and depression-era migration to the West Coast along Route 66.

Albuquerque's growth accelerated during and after World War II. Expansion along the Route 66 corridor both east and west of the inner valley required new wells and water supplies. No longer could lawns, gardens, and shade trees be easily watered by opening a head gate. During the 1950's the City began to experience water-supply problems because of declining water levels (Theis, 1991). As a result several wells were deepened and new wells were constructed.

Several ground-water investigations were initiated in the 1960's in response to the problems that the City was experiencing (Bjorklund and Maxwell, 1961; Spiegel, 1962; Reeder and others, 1967). Studies conducted during the late 1970's (U.S. Army Corps of Engineers, 1979) and mid-1980's (Kernodle and Scott, 1986; and Kernodle and others, 1987) were based on the same conceptual model of the aquifer system as the 1960's investigations; therefore, they offered no improved fundamental understanding of the aquifer system.

Previous Investigations

Many hydrologic investigations in both the Albuquerque area and Albuquerque Basin have produced ground-water-level maps. Ground-water levels in the Albuquerque area are reported in Bjorklund and Maxwell (1961), U.S. Army Corps of Engineers (1979), Hudson (1982), Kelly (1982), Kues (1986; 1987), Anderholm and Bullard (1987), Peter (1987), and Summers (1992). Peter (1987) also presented an analysis of shallow-aquifer properties in the valley south of Albuquerque. Projected water-level declines are presented in Reeder and others (1967). Ground-water levels in areas outside of Albuquerque are presented in Titus (1961; 1963) and Bjorklund and Maxwell (1961). Bjorklund and Maxwell (1961) studied the availability of water in Bernalillo and Sandoval Counties, and Spiegel (1955) studied ground-water levels in northeastern Socorro County. Bloodgood (1930) described ground-water conditions in the middle Rio Grande Valley. Theis (1938) and Theis and Taylor (1939) presented ground-water levels in the middle Rio Grande Valley.

Ground-water modeling has been used in previous investigations of the Albuquerque Basin. Kernodle and Scott (1986) developed a three-dimensional model simulation of steady-state ground-water flow in the Santa Fe Group aquifer system underlying the Albuquerque Basin. A three-dimensional model simulation of transient ground-water flow, also in the Santa Fe Group aquifer system underlying the Albuquerque Basin, is presented in Kernodle and others (1987).

Investigations that describe the structure and fill deposits of the Albuquerque Basin are numerous and only a few are presented here. The hydrogeologic framework of the northern Albuquerque Basin was described by Hawley and Haase (1992). Heywood (1992) presented isostatic residual gravity anomalies of New Mexico that provided a data base for the development of three-dimensional gravity models for assessing the quantity of ground water stored in basins filled with alluvial material. Russell and Snelson (1990; 1991) described the deep structure of the Albuquerque Basin. Birch (1980a; 1980b; 1982) presented gravity models to determine the thickness of Neogene sediments in the basin, and Kaehler (1990) described the lithology of the basin-fill deposits. Lozinsky (1988) characterized the stratigraphy and tectonic framework of the Albuquerque Basin, and Kelley (1977) described the geology of the basin. Galusha and Blick (1971) described the stratigraphy of the Santa Fe Group, and Lambert (1968) described the Quaternary stratigraphy of the Albuquerque Basin.

Aquifer tests and the lithology of drill cuttings from wells in the Albuquerque area have been described in recent years. Shomaker (1990; 1991) conducted aquifer tests and described the lithology of the Love 8 and Gonzales 2 wells, respectively. Summers and Shomaker (1989) presented results of deep (1,489 - 3,376 feet) ground-water tests of the Santa Fe Group in the Albuquerque area, and Shomaker (1988) described the geology and aquifer tests for the City of Albuquerque's SAF-1 well. Groundwater Management, Inc. (1988a-v) reported aquifer properties for many of the City of Albuquerque's current production wells. Wilkins (1987) documented the lithology of three test holes from drill cuttings and the results of aquifer tests conducted on two test wells drilled in the Albuquerque area west of the Rio Grande.

Selected geochemistry and water-quality studies of the Albuquerque Basin are as follows. Hiss and others (1975) described chemical quality of ground water in the northern part of the Albuquerque Basin. Anderholm (1987) studied the effects of land use on ground-water chemistry in the Albuquerque Basin. Anderholm (1988) presented the ground-water geochemistry of the Albuquerque Basin and Logan (1990) presented geochemical data for City wells in Albuquerque.

Base Credits

All page-size maps in this report are in the Lambert Conformal Conic projection with standard parallels 33° 00′ and 45° 00′ north latitude, and central meridian 106° 00′ west longitude. The base for figure 1 was compiled from U.S. Department of Commerce, Bureau of Census TIGER/line Precensus Files, 1990, scale 1:100,000.

The base for the page-size maps of the Albuquerque Basin was compiled from several sources. The hydrography is from 1977-78 U.S. Geological Survey digital data, scale 1:100,000. Cultural features are from 1992 City of Albuquerque digital data, scale 1:2,400, and digitized from 1977-78 U.S. Geological Survey maps, scale 1:100,000.

The base for the page-size maps of the Albuquerque metropolitan area was compiled from the following sources: the hydrography is from 1977-78 U.S. Geological Survey digital data, scale 1:100,000; the roads are from 1992 City of Albuquerque digital data, scale 1:2,400, and 1977-78 U.S. Geological Survey digital data, scale 1:100,000. Cultural features are from 1992 City of Albuquerque digital data, scale 1:2,400, and digitized from 1978, 1980, and 1983 U.S. Bureau of Land Management maps, scale 1:100,000, and 1977-78 U.S. Geological Survey maps, scale 1:100,000.

Acknowledgments

The authors wish to acknowledge the following members of the technical review team who met monthly to provide advice and constructive criticism during the course of the investigation: Thomas E. Shoemaker and Norman Gaume, City of Albuquerque; Linda Logan, New Mexico State Engineer Office; John Hawley, New Mexico Bureau of Mines and Mineral Resources; and Steve Hansen, U.S. Bureau of Reclamation.

DESCRIPTION OF THE STUDY AREA

The Albuquerque Basin covers 3,060 square miles in Central New Mexico (fig. 1). The basin is defined as the extent of Cenozoic deposits, which encompasses the structural Rio Grande Rift within the basin (fig. 1). The major part of the basin is within Sandoval, Bernalillo, Valencia, and Socorro Counties (fig. 2). Small portions of the basin are within Santa Fe, Cibola (part of Valencia County prior to 1981), and Torrance Counties. Land-surface altitude in the basin ranges from about 4,800 feet above sea level in the southern part of the basin to more than 6,500 feet above sea level in the northern part of the basin at the margin of the Jemez Mountains (fig. 2). The Sandia, Manzanita, Manzano, and Los Pinos Mountains to the east and the Jemez Mountains to the north form dramatic topographic rises at the basin margins. The Jemez Mountains rise to a peak altitude of 11,561 feet above sea level, and the Sandia Mountains, the highest mountains on the east, rise to a peak altitude of 10,678 feet above sea level (fig. 2).

The Albuquerque metropolitan area includes a population of about 502,100, or 89 percent of the approximate 563,600 people in the basin (U.S. Department of Commerce, 1991). The 1990 population density throughout the basin is shown in figure 3. The basin population was about 314,900 in 1970 and about 419,000 in 1980. The increasing population in the basin primarily reflects the increase in population in the Albuquerque metropolitan area.

Surficial geology of the Albuquerque Basin and vicinity is shown in figure 4. Cenozoic basin-fill deposits of the Santa Fe Group, pediment deposits, and terrace deposits are exposed in most of the basin. Primarily Paleozoic and Mesozoic rocks crop out to the west of the basin. Cenozoic volcanics crop out in the Jemez Mountains to the north. Precambrian and Paleozoic rocks form the outcrops in the Sandia, Manzano, and Los Pinos Mountains to the east.

EXPLANATION

POPULATION DENSITY, IN PEOPLE PER SQUARE MILE-- Theisen polygons constructed around centroids of census tracts. Data from U.S. Department of Commerce, 1991

- 0 to 1
- More than 1 to 10
- More than 10 to 100
- More than 100 to 1,000
- More than 1,000 to 10,000
- More than 10,000

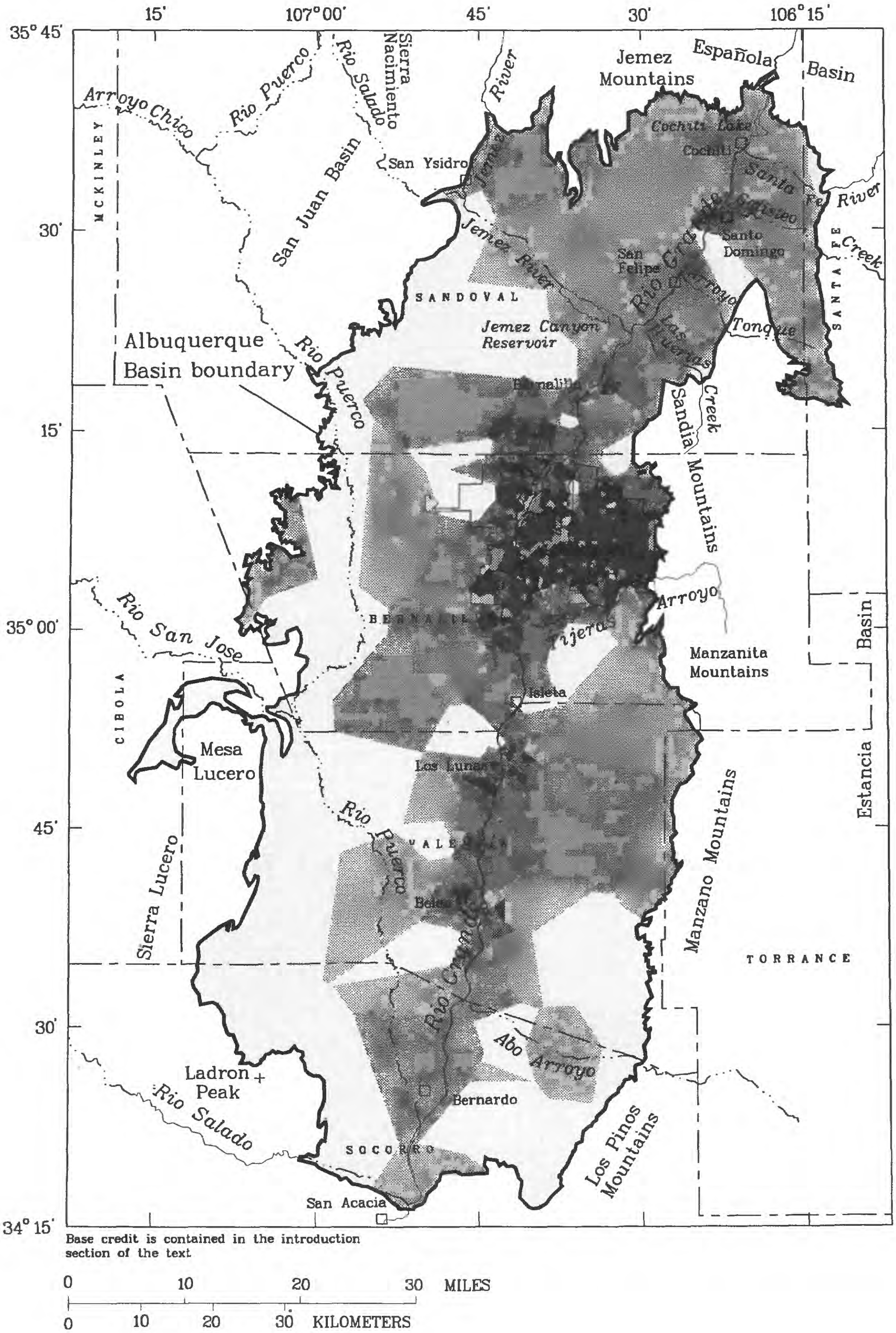


Figure 3.—Population density in the Albuquerque Basin, Central New Mexico.

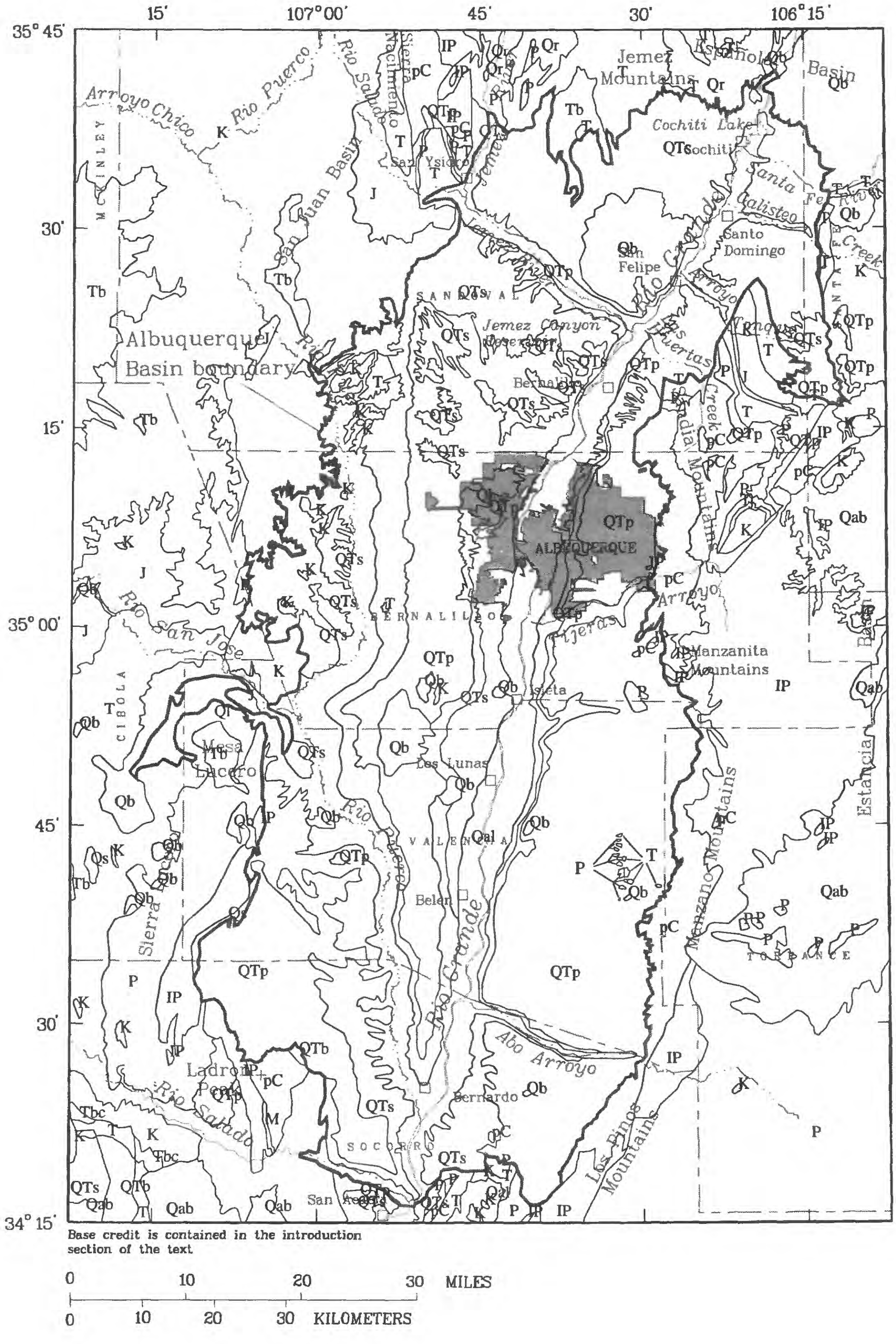


Figure 4.—Generalized surficial geology of the Albuquerque Basin and vicinity, Central New Mexico (Modified from Dane and Bachman, 1965).

EXPLANATION

	Qal	Quaternary alluvium
	Qab	Quaternary alluvium, bolson deposits, and other surficial deposits
	Qb	Quaternary basalt flows
	Qs	Quaternary spring deposits
	Qr	Quaternary Bandelier Tuff
	QTp	Quaternary and Tertiary pediment, terrace, and other deposits of gravel, sand, and caliche
Cenozoic	QTs	Quaternary and Tertiary Santa Fe Group
	QTb	Quaternary and Tertiary basalt and basaltic andesite flows
	Tb	Tertiary basalt and basaltic andesite flows
	Tp	Tertiary Potosi Volcanic Series
	Tbc	Tertiary Baca Formation and Cub Mountain Formation
	T	Tertiary rocks, undivided
Mesozoic	K	Cretaceous rocks, undivided
	J	Jurassic rocks, undivided
	P	Permian rocks, undivided
Paleozoic	IP	Pennsylvanian rocks, undivided
	M	Mississippian rocks, undivided
Precambrian	pC	Precambrian rocks, undivided

Figure 4.--Generalized surficial geology of the Albuquerque Basin and vicinity, Central New Mexico--Concluded.

Climate

The climate in the Albuquerque Basin varies with altitude. Although most of the basin is semiarid, climate in the mountains bordering the basin ranges from semiarid to humid continental. The climate is characterized by sunny days and low humidity.

Precipitation varies considerably within the basin. The normalized 1931-60 mean annual precipitation in the basin, adjusted for altitude, is shown in figure 5 (U.S. Department of Commerce, no date). Mean annual precipitation ranges from about 6 inches in central Valencia County to about 16 inches within the basin boundary and as much as 30 inches in the highest altitudes of the Sandia and Manzano Mountains. The weighted mean annual precipitation for the study area is 9.40 inches for 1931-60. Mean annual precipitation at long-term climatic stations in the area ranges from about 8 inches along the Rio Grande in the southern part of the basin (first two stations in table 1) to almost 23 inches at the crest of the Sandia Mountains (table 1). Most precipitation at the lower altitudes of the basin is from thunderstorms during July through September. Precipitation in the mountains on the east side of the basin is more equally split between summer and winter. Much of the precipitation in the mountains occurs as snow.

Table 1.--Climatic data for selected stations in the Albuquerque Basin and vicinity, Central New Mexico, 1951-80

[Data from U.S. Department of Commerce (1948-92) and U.S. Department of Commerce (1990) digital data]

Station name	Station altitude, in feet above sea level	Mean annual temperature, in degrees Fahrenheit	Mean January temperature, in degrees Fahrenheit	Mean July temperature, in degrees Fahrenheit	Mean annual precipitation, in inches
Albuquerque WSFO AP	5,326	56.5	35.0	78.9	8.12
Belen[1]	4,800	56.4	34.4	78.7	7.81
Bernalillo	5,070	54.6	34.0	74.2	9.07
Sandia Crest[2]	10,680	37.5	19.9	56.8	22.89
Sandia Park	7,106	50.0	30.9	70.0	17.98

[1] Station discontinued in 1976. The 1951-75 period was used for calculation of mean values.
[2] Station in operation 1953-79. The 1954-78 period was used for calculation of mean values.

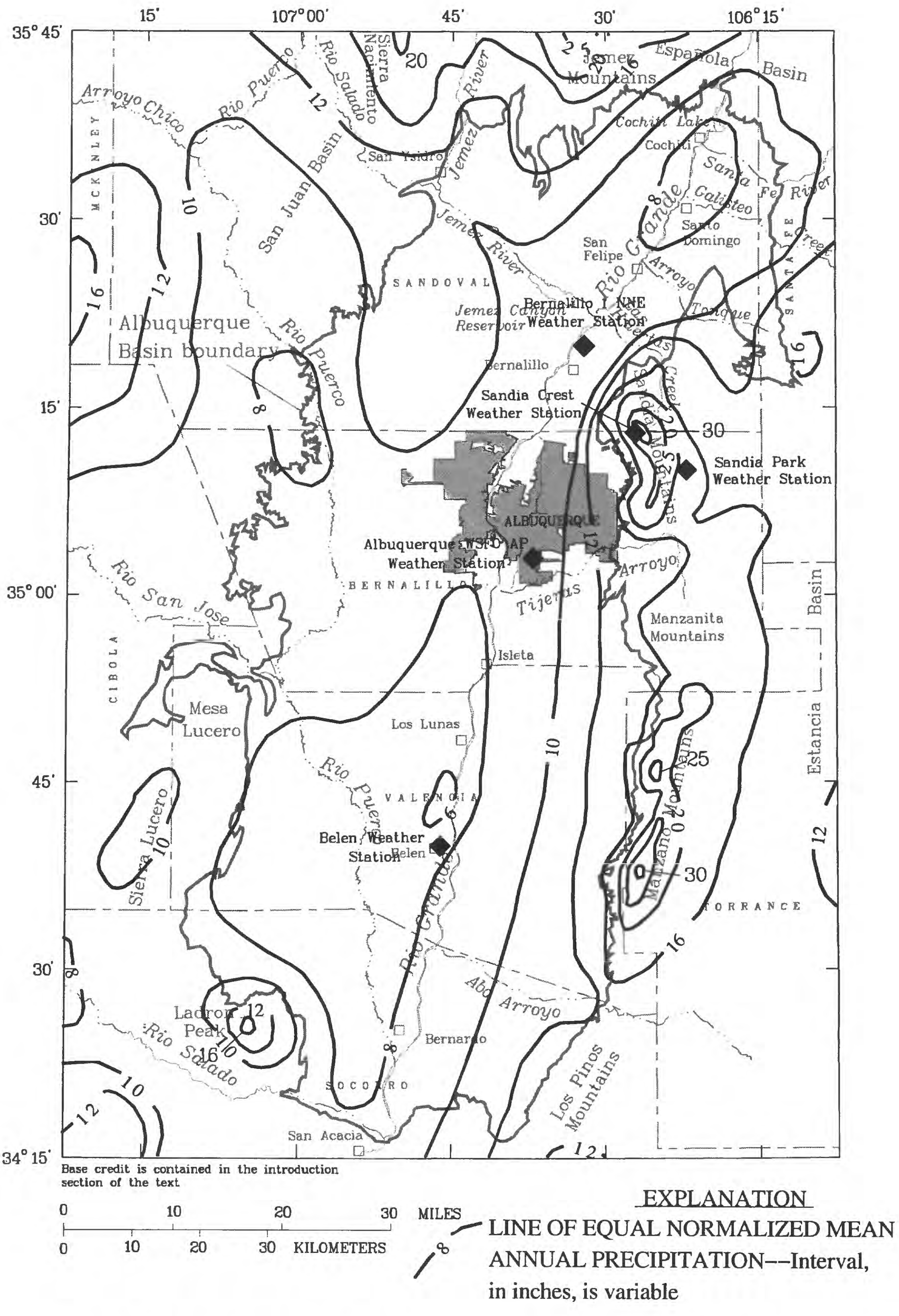


Figure 5.--Normalized mean annual precipitation in the Albuquerque Basin and vicinity, Central New Mexico, 1931–60 (From U.S. Department of Commerce, no date).

Variation in mean annual precipitation in the Albuquerque area is shown in figure 6. Mean annual precipitation ranges from less than 8 inches to almost 16 inches within the city boundary. The orographic effect of the Sandia Mountains substantially increases precipitation on the east side of Albuquerque. Precipitation in the Albuquerque area varies greatly from year to year. Total precipitation in the Albuquerque area for November 1991 through October 1992 is shown in figure 7. The wide variation of precipitation in the Albuquerque area over one particular time period is shown in this figure.

Precipitation at particular locations also varies from year to year. The distributions of annual precipitation at Albuquerque and Bernalillo are shown in figure 8. Since 1900, annual precipitation at the Albuquerque station has ranged from 3.29 inches in 1917 to 15.88 inches in 1941 (fig. 8A). Although the period of record for Bernalillo is shorter than that for Albuquerque, annual precipitation extremes for this station show similar variation. Annual precipitation in Bernalillo ranged from 4.39 inches in 1956 to 16.72 inches in 1941 (fig. 8B).

The 5-year running average of annual precipitation (for the year shown and preceding 4 years) measured at Albuquerque and Bernalillo is shown in figure 9. The data from Albuquerque (fig. 9A) show significant dry periods about 1900, in the mid-1920's, and in the 1950's. These dry periods are separated by relatively wet periods and some minor dry periods. The dry period of the 1950's can also be seen in the 5-year running average of precipitation measured at Bernalillo (fig. 9B).

Mean annual temperatures range from about 38 degrees Fahrenheit at the crest of the Sandia Mountains to about 56 degrees Fahrenheit at Albuquerque and Belen. The coldest month is January and the warmest is July. Mean January and July temperatures from long-term climatic stations are listed in table 1. Winter minimum temperatures commonly are below freezing throughout the basin and can decline to below 10 degrees Fahrenheit. Summer maximum temperatures at lower altitudes can exceed 100 degrees Fahrenheit but more commonly range from 90 to 100 degrees. The average length of the frost-free period ranges from about 140 days in the north near the Jemez Mountains to about 200 days in the southern part of the basin (Tuan and others, 1969, p. 87).

Evaporation from shallow reservoirs and annual potential evaporation vary within the Albuquerque Basin. Mean annual evaporation from shallow reservoirs ranges from about 54 inches near the Jemez Mountains in the northern part of the basin to about 66 inches in the southern part of the basin (Hale and others, 1965, p. 19). Annual potential evapotranspiration calculated by Gabin and Lesperance (1977) is 41.19 inches at Bernalillo, 47.58 inches at Albuquerque, 42.29 inches at Los Lunas, 45.25 inches at Belen, and 39.97 inches at Bernardo. The distribution of annual potential evaporation (National Oceanic and Atmospheric Administration, no date) is shown in figure 10. The weighted annual potential evaporation within the delineated study area (fig. 10) is 57.07 inches. The difference between the values listed above and those shown in figure 10 illustrates the range in plausible values of evaporation.

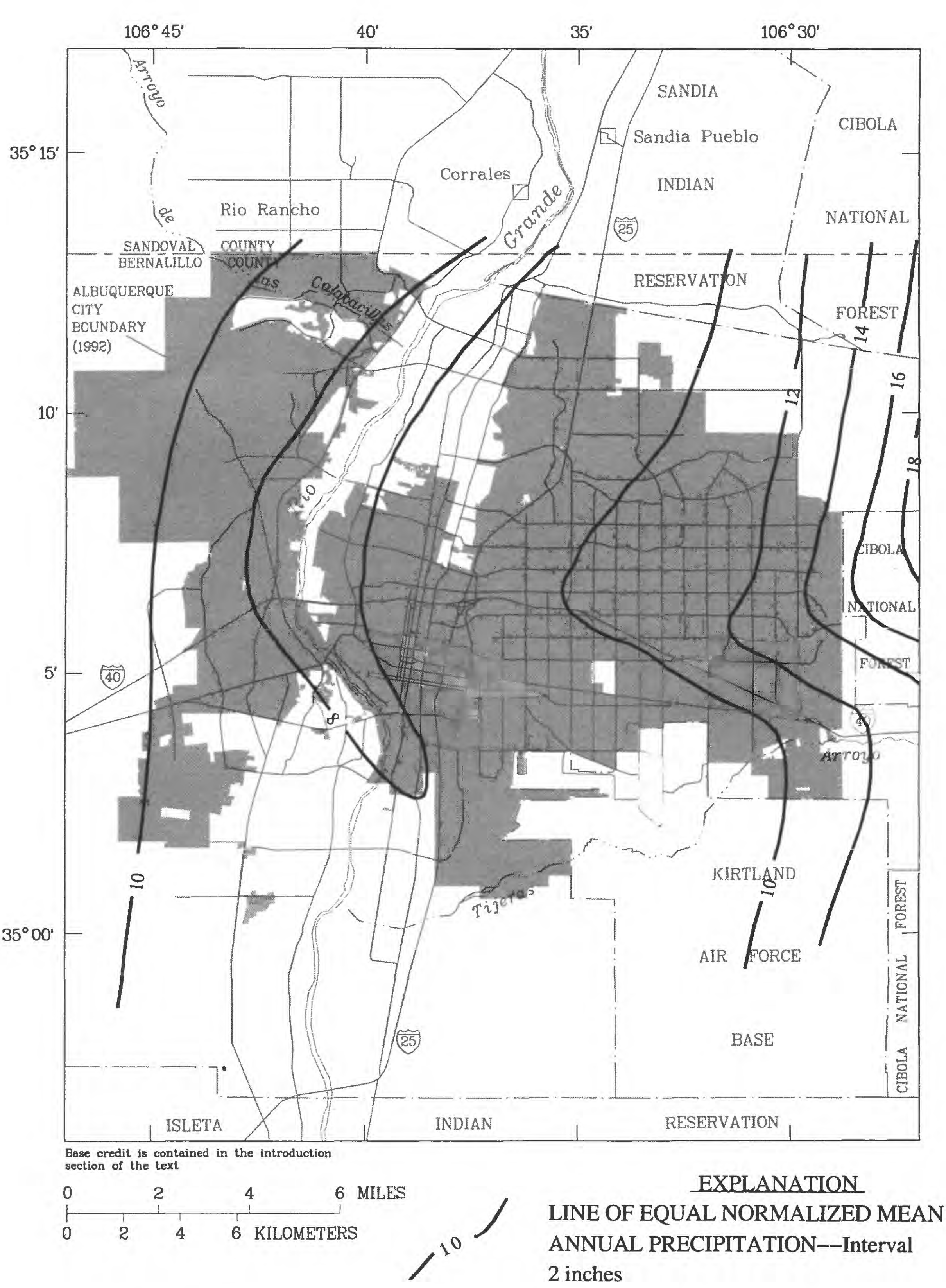


Figure 6.--Normalized mean annual precipitation in the Albuquerque area, Central New Mexico, 1951–80 (National Weather Service, written commun., 1993).

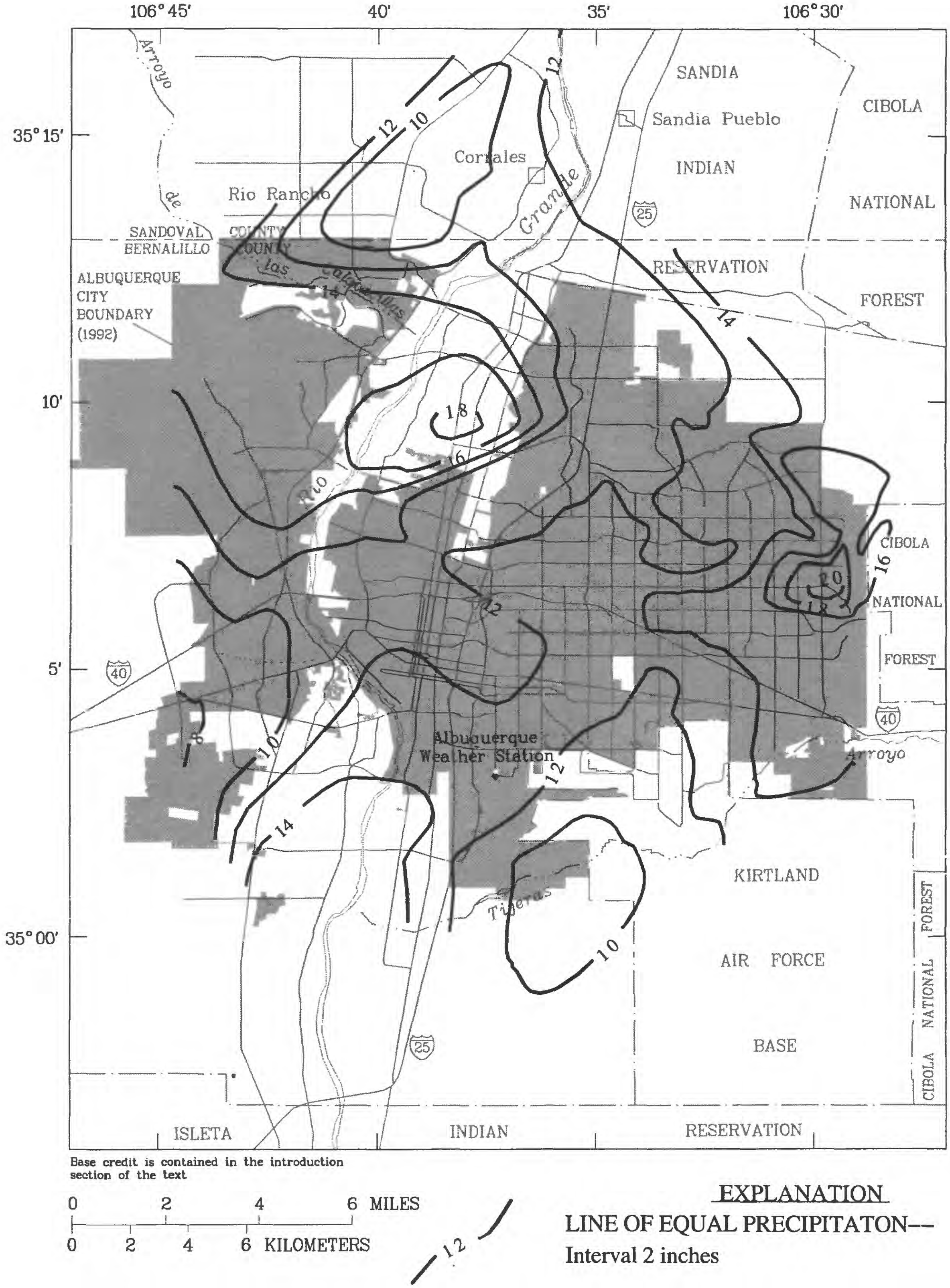


Figure 7.--Total precipitation in the Albuquerque area, Central New Mexico, November 1991 through October 1992.

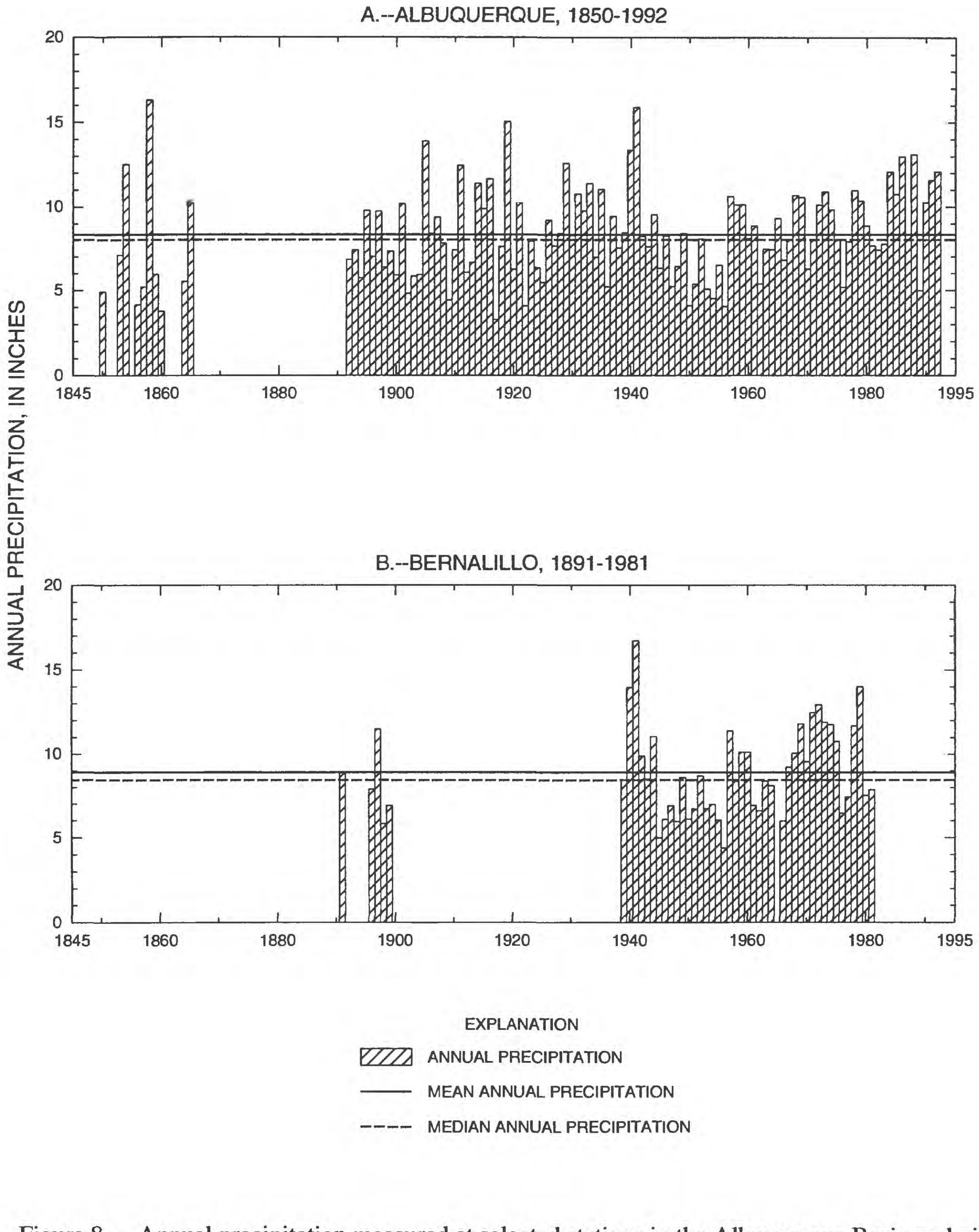


Figure 8.—Annual precipitation measured at selected stations in the Albuquerque Basin and vicinity, Central New Mexico (data from U.S. Department of Commerce, 1948–92; New Mexico State Engineer, 1956; and U.S. Department of Commerce 1990 digital data).

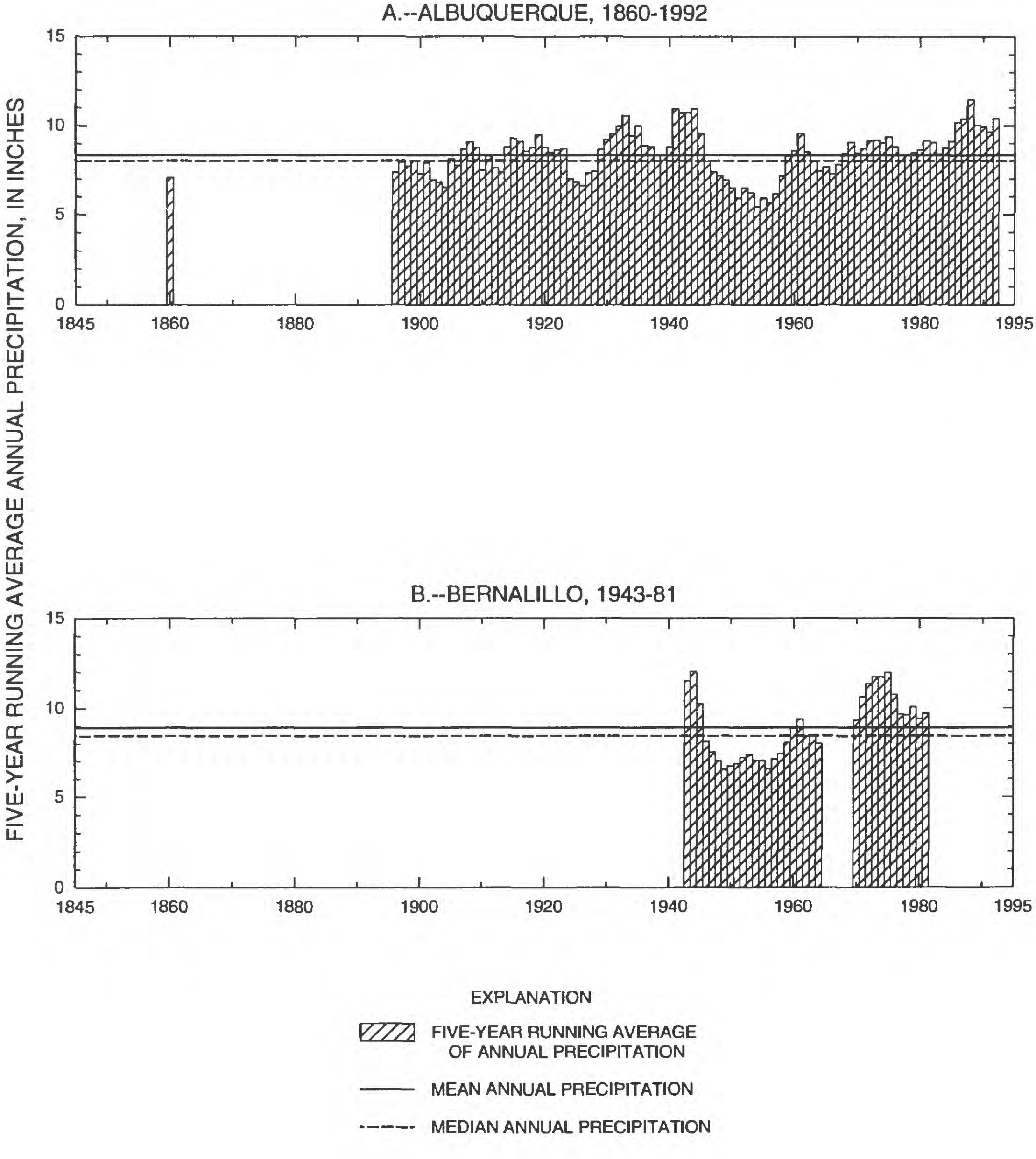


Figure 9.--Five-year running average, ending on year shown, of annual precipitation measured at selected stations in the Albuquerque Basin and vicinity, Central New Mexico (source data from U.S. Department of Commerce, 1948–92; New Mexico State Engineer, 1956; and U.S. Department of Commerce 1990 digital data).

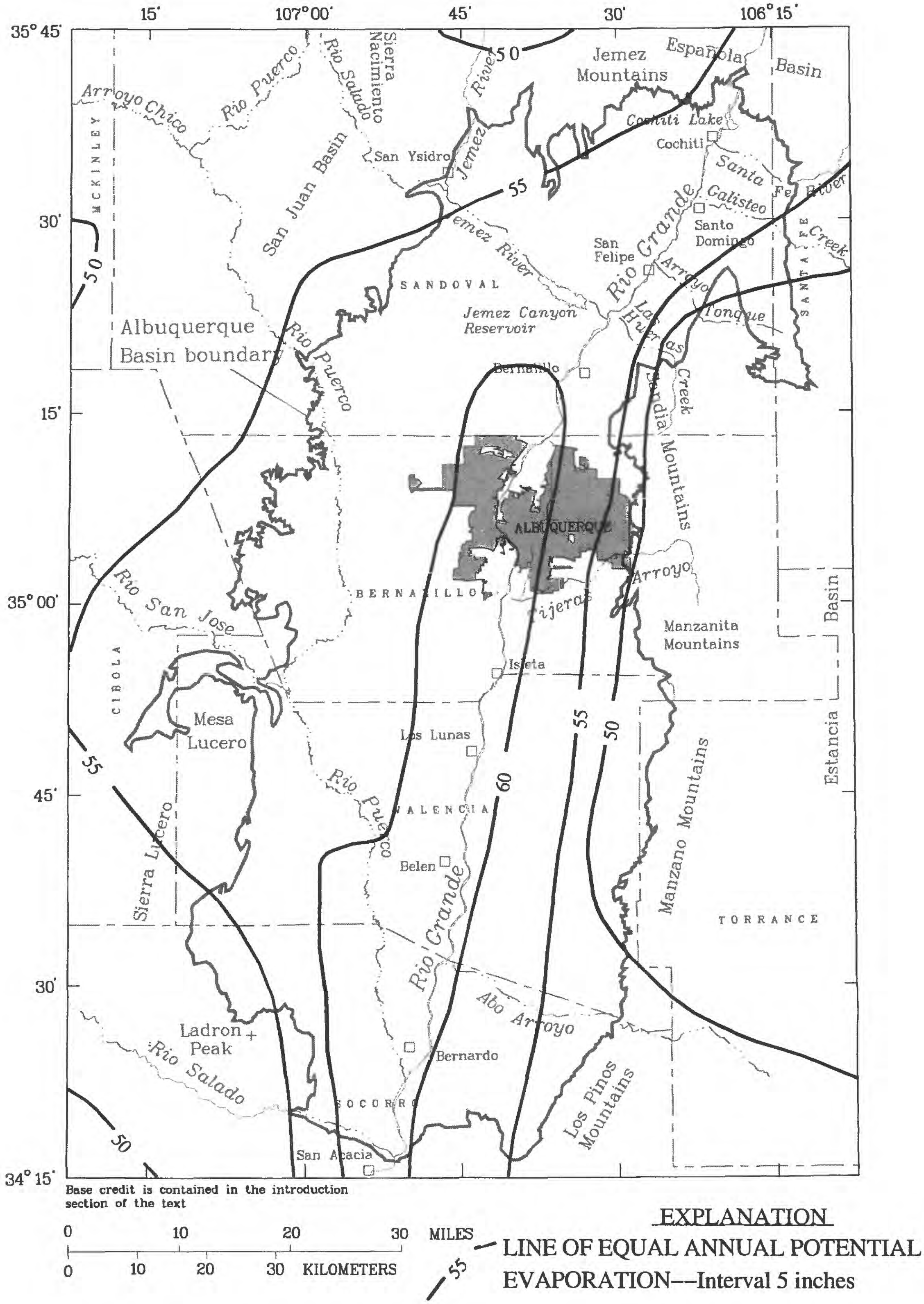


Figure 10.--Annual potential evaporation in the Albuquerque Basin and vicinity, Central New Mexico (From National Oceanic and Atmospheric Administration, no date).

Land Use and Land Cover

The generalized land-use and land-cover classifications for the Albuquerque Basin and vicinity (fig. 11) were derived from data obtained from the U.S. Geological Survey's Geographic Information Retrieval and Analysis System (GIRAS) (U.S. Geological Survey, 1983). These data were compiled at a scale of 1:250,000 from 1980 (Albuquerque 1° by 2° map) and 1982 (Socorro 1° by 2° map) inventories. The largest land-use and land-cover classification for the study area is rangeland (63 percent of the study area). The percentages of the other land-use classifications in the study area are: forest, 24 percent; urban, 6 percent; agriculture, 4 percent; barren land, 2 percent; and water, 1 percent. A later section of the report describes some of the influences that land use has on the water resources of the basin.

The most dominant land use in the study area, rangeland, has three subclasses in the Albuquerque Basin: mixed rangeland, 50 percent; shrub and brush rangeland, 10 percent; and herbaceous rangeland, 3 percent. Most rangeland is used for livestock grazing. Forested land also has three subclasses: evergreen forests, 22 percent; riparian deciduous forests, 1.9 percent; and mixed forest, 0.1 percent. Most evergreen forest is intermediate-altitude piñon-juniper forests. Riparian deciduous forest consists of cottonwoods, tamarisk, russian olives, and other phreatophytes. Phreatophytes consume much more water than is contributed by precipitation although they occupy only a small percentage of the area of the basin.

EXPLANATION

GENERALIZED LAND USE AND LAND COVER

Rangeland

Forest

Urban

Agriculture

Barren land and water

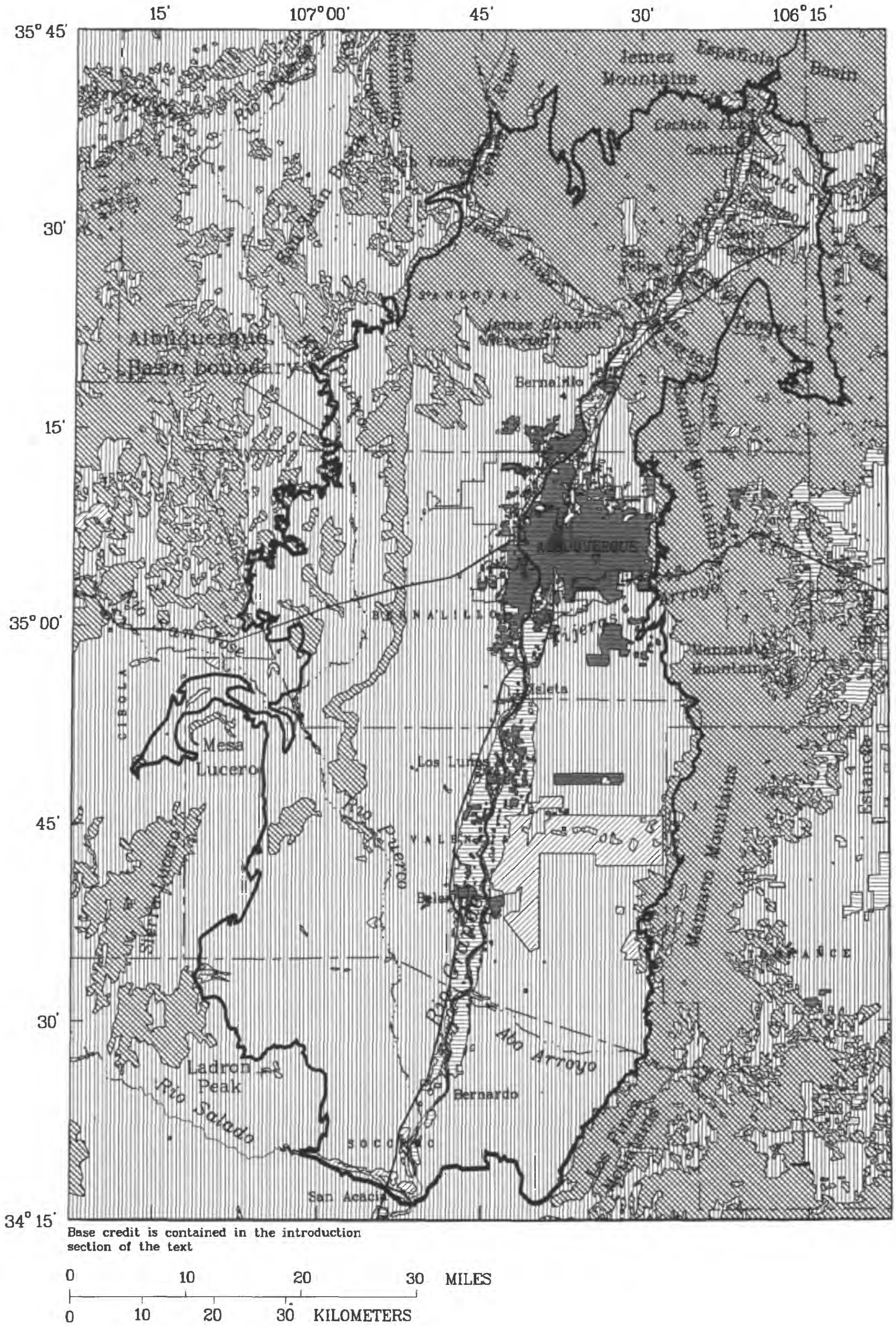


Figure 11.--Generalized land use and land cover in the early 1980's in the Albuquerque Basin and vicinity, Central New Mexico (Modified from U.S. Geological Survey Geographic Information Retrieval and Analysis System data, U.S. Geological Survey, 1983).

Urban and agricultural land uses together constitute only 10 percent of the total area of the basin. However, the yearly changes in the net percentage in these categories are relatively large. A comparison of data obtained for 1992 from the City of Albuquerque with the 1980's GIRAS data indicates that about 14,000 acres of land in Bernalillo County have been reclassified from agricultural to some other land use. The replacement uses include urban fallow or vacant land, residential, and commercial. Similar decreases in agricultural acreage likely are occurring near other urban areas in the study area.

A large block of land (all land classified as barren) east of Belen (fig. 11) had been cleared for development in 1982 and was classified as barren land in the GIRAS data base. This land has not been developed to date (1993) and probably has returned to rangeland.

GEOHYDROLOGIC FRAMEWORK

As mentioned in the introductory section, the conceptual model of the geohydrologic framework of the Albuquerque Basin has been extensively revised in recent years. The following sections are based on the works of Lozinsky (1988), Russell and Snelson (1990), and Hawley and Haase (1992).

Tectonic Framework

The Rio Grande Rift, originally named the Rio Grande depression by Bryan (1938), represents an area of Cenozoic crustal extension originating in central Colorado and extending south through New Mexico to south of the Mexico/Texas border area (fig. 1). Crustal extension began in the late Oligocene (about 30-32 mega-annum or million years before present (Ma)) and continued into the late Miocene (5-10 Ma), with minor activity continuing to the present (Lozinsky, 1988; Russell and Snelson, 1990). The Rio Grande Rift can be described as a north- to south-trending downdropped area (relative to the adjacent uplifted areas) extending for more than 600 miles. A series of north- to south-trending basins linked end to end comprises the central part of the Rio Grande Rift. The north and south boundaries of many basins within the Rio Grande Rift are formed by the convergence of the eastern and western structural boundaries or by relative uplift. These areas of convergence form topographic restrictions through which the Rio Grande flows, linking the basins in the Rio Grande Rift. Bryan (1938, p. 198) described the relation of the Rio Grande and the basins within the Rio Grande Rift as "a stream flowing from one sand-filled tub to another through narrow troughs."

The Albuquerque Basin, located in the central part of the Rio Grande Rift, is the third largest basin in the rift. The Albuquerque Basin extends about 100 miles in length from north to south and to about 35 miles in width, an area of about 3,060 square miles (fig. 12). In this report, the Albuquerque Basin includes the Santo Domingo Basin and Hagan Embayment as described by Kelley (1952) and Spiegel (1962). The northern boundary of the Albuquerque Basin is defined by the Nacimiento and the Jemez Uplifts (fig. 12). The Nacimiento Uplift is characterized by Precambrian plutonic and metamorphic rocks overlain by Paleozoic and Mesozoic strata. Cenozoic volcanic rocks form the Jemez Uplift (Hawley and Haase, 1992). The boundary between the Albuquerque Basin and the Española Basin to the northeast is La Bajada Escarpment (Kelley, 1952). The topographically prominent eastern boundary is the eastward-tilted fault blocks of the Sandia, Manzano, and Los Pinos Uplifts; the Sandia Uplift is the largest and highest (fig. 2). These three uplifted areas are composed of Precambrian plutonic and metamorphic rocks unconformably overlain by Paleozoic limestone and sandstones (Hawley and Haase, 1992). The southern boundary between the Albuquerque Basin and the Socorro Basin is defined by the Joyita and Socorro Uplifts. This area, often referred to as the "San Acacia constriction," is formed by the convergence of the eastern and western structural boundaries of the Albuquerque Basin. The Ladron and Lucero Uplifts define the southwestern boundary (fig. 12). Precambrian granite and metamorphic rocks compose the Ladron Uplift. The westward-tilted Lucero Uplift is composed of Paleozoic limestone, sandstone, and shale capped by late Cenozoic basalt flows (Hawley and Haase, 1992). The topographically subdued northwestern boundary is defined by the Rio Puerco Fault Zone (fig. 12). Thus the Albuquerque Basin appears as a single broad basin having a distinct eastern boundary, a subdued western boundary, and the Rio Grande flowing down the middle (fig. 13).

Recent work by Russell and Snelson (1990) and Cather (1992) indicates that the Albuquerque Basin is not a single basin but two smaller basins (half-grabens) that have opposing structural dip and extensive structural benches existing along or adjacent to the margins. In this report the term "half-graben" means a large downdropped area (graben) that has been separated by a fault to form two separate blocks (northern and southern half-grabens), each with opposing dips. Rosendahl (1987) described this half-graben morphology of other continental rifts with special reference to East Africa.

Evaluation of deep drilling and geophysical data indicates that the Albuquerque Basin consists of a northern half-graben that dips to the east and a southern half-graben that dips to the west (fig. 14; Russell and Snelson, 1990; Cather, 1992). A southwestern extension of the Tijeras Fault, recently referred to as the "Tijeras accommodation zone" by Cather (1992), separates the half-grabens (figs. 12 and 14). A recent investigation by Heywood (1992) further supports the existence of a northern and southern half-graben within the Albuquerque Basin (fig. 15). The gravity anomalies in the central part of the basin (fig. 15), represented by the two separate, closed contours of -20 milligals, tend to correspond with the northern and southern half-grabens described by Russell and Snelson (1990) and Cather (1992). In figure 15 the steep gradient is associated with the eastern basin boundary and the gradual gradient is associated with the western basin boundary. The bedrock is thought to descend in a series of shallow steps from the basin margins to a deeper inner graben (fig. 14; Russell and Snelson, 1990; Hawley and Haase, 1992).

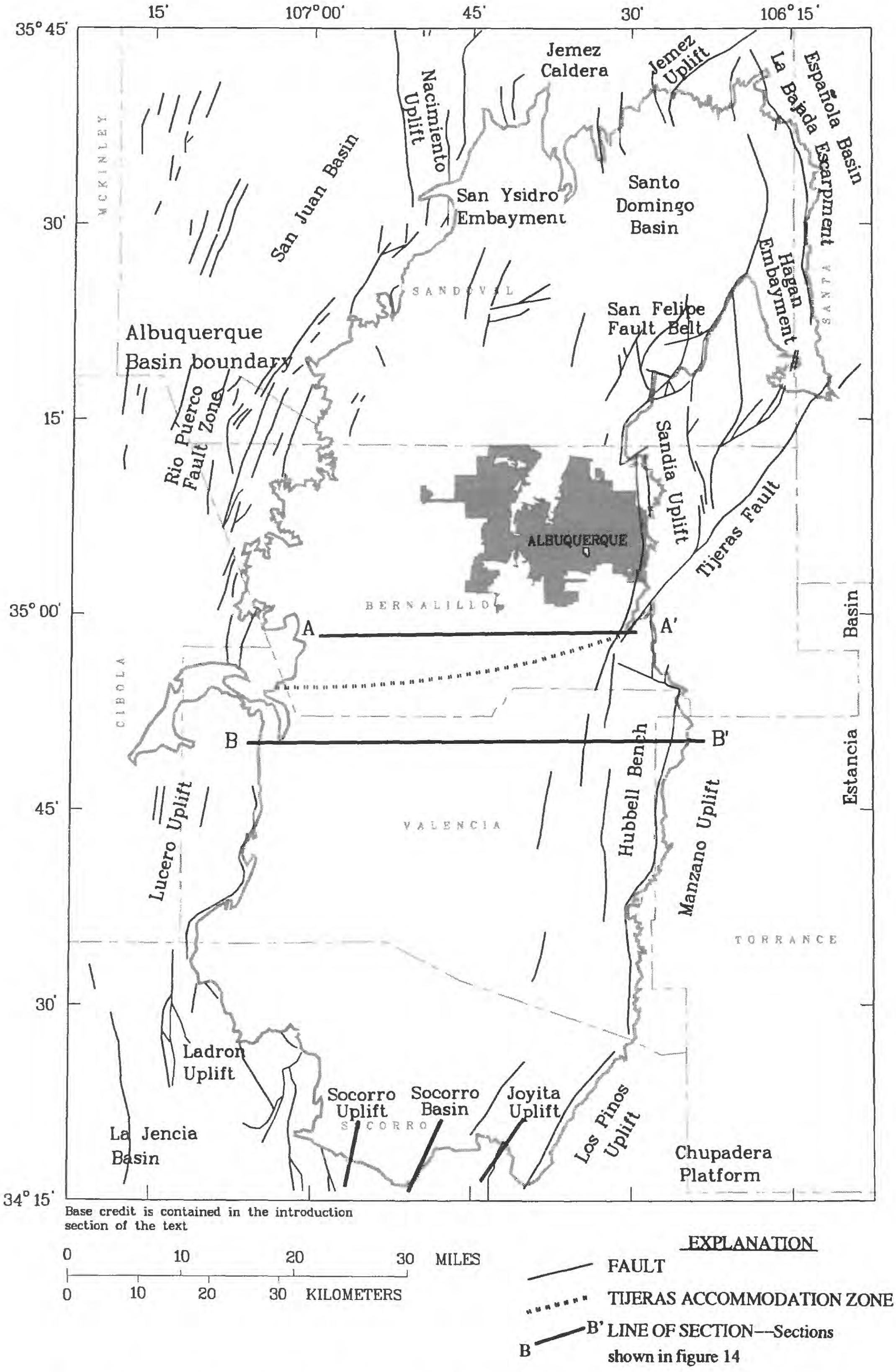


Figure 12.—Major tectonic features defining the Albuquerque Basin and vicinity, Central New Mexico.

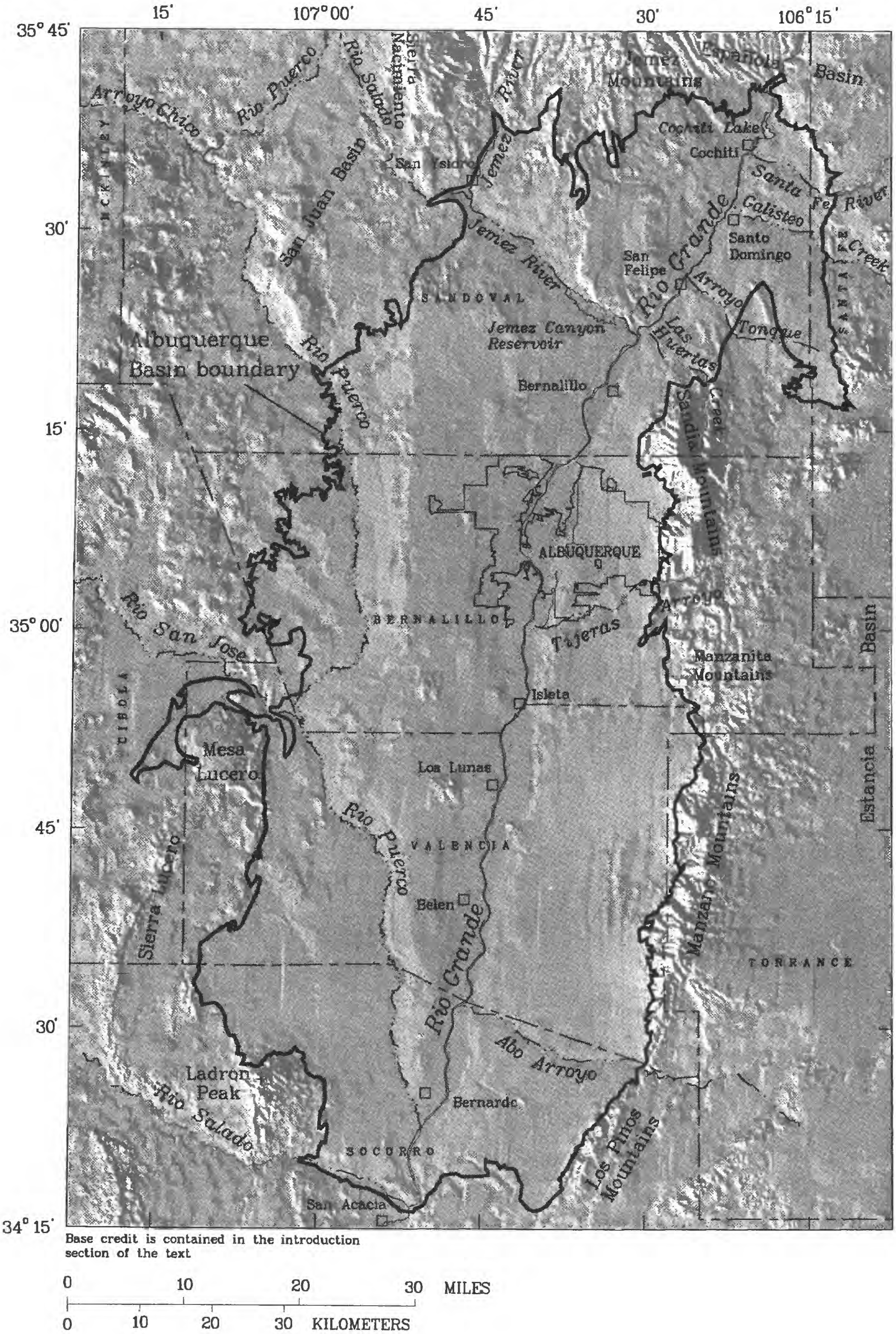


Figure 13.—Shaded relief of the Albuquerque Basin and vicinity, Central New Mexico.

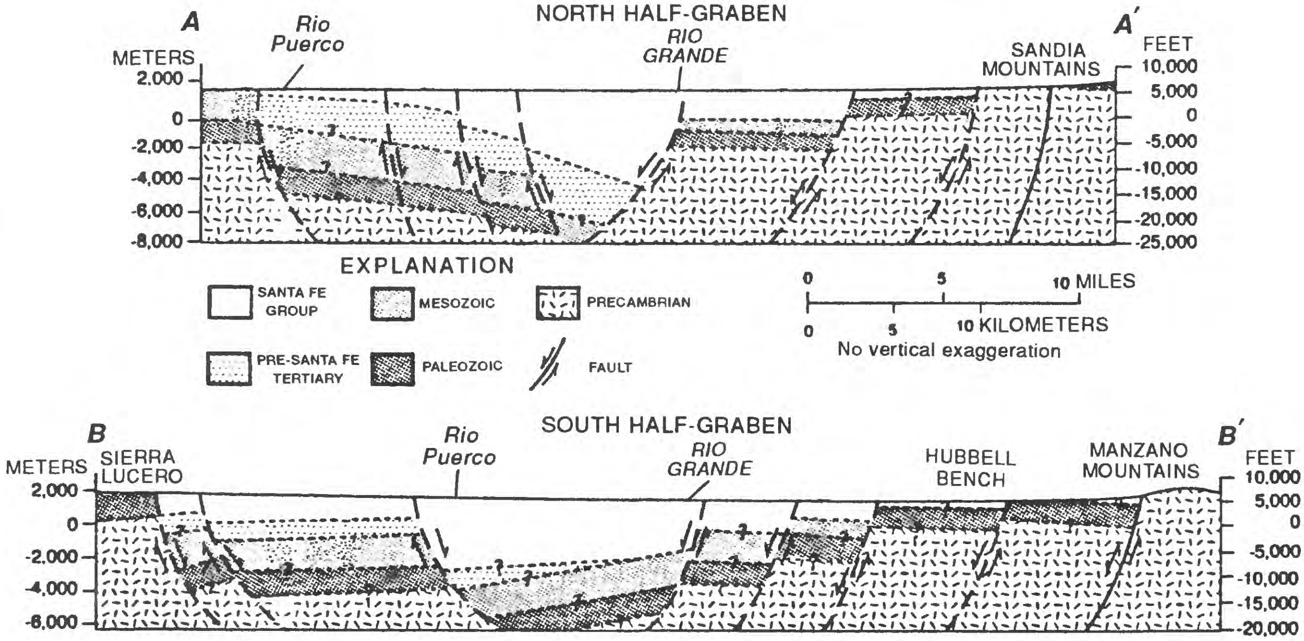
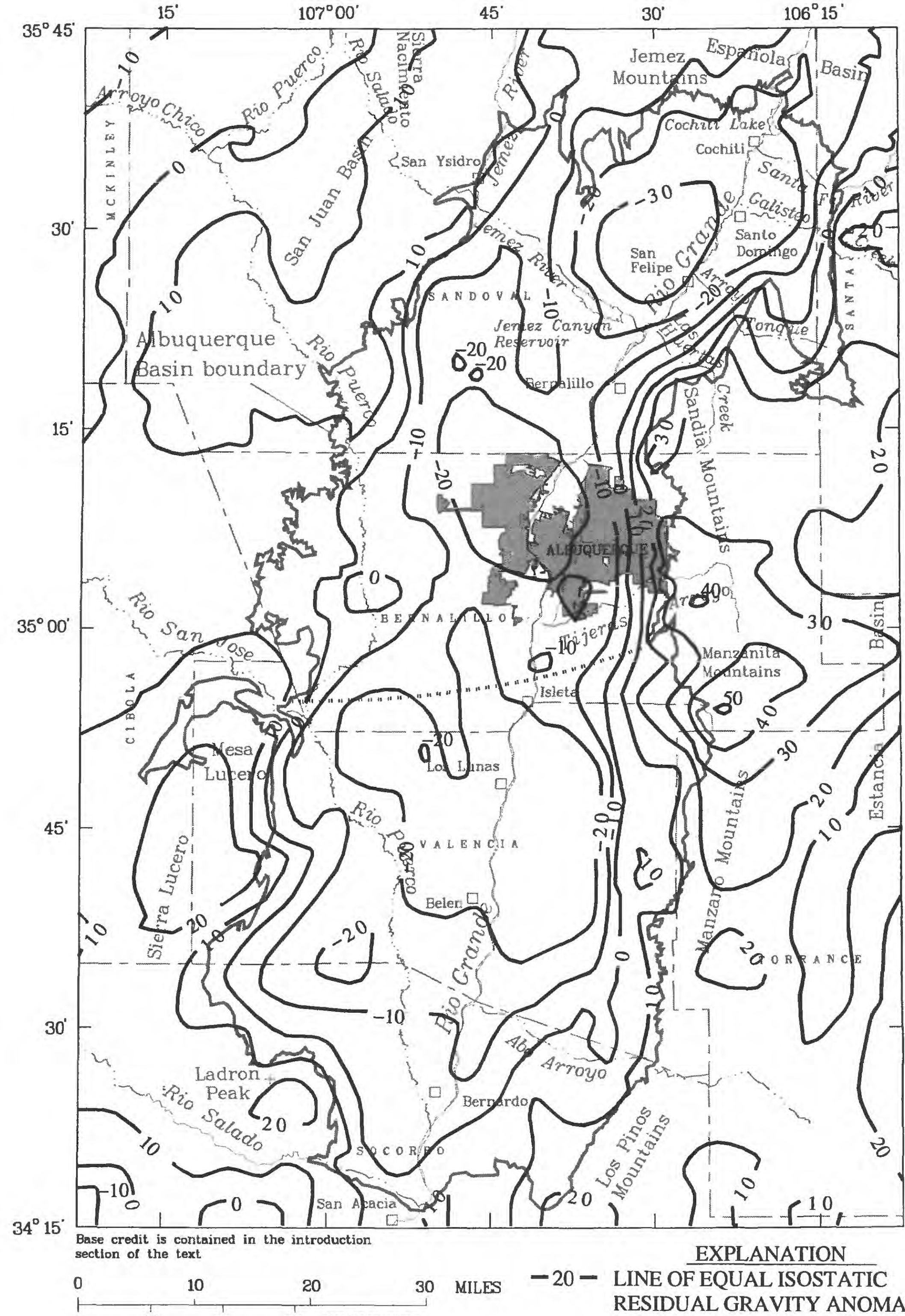


Figure 14.—Generalized geologic sections of the central Albuquerque Basin, north and south of the Tijeras accommodation zone (Modified from Hawley and Haase, 1992). See figure 12 for section locations.



EXPLANATION

—20— LINE OF EQUAL ISOSTATIC RESIDUAL GRAVITY ANOMALY—Interval 10 milligals

.... TIJERAS ACCOMMODATION ZONE

Figure 15.—Isostatic residual gravity anomalies in the Albuquerque Basin and vicinity, Central New Mexico (Modified from Heywood, 1992, fig. 9).

The isostatic residual gravity anomaly map (Heywood, 1992) shows that a third basin (the Santo Domingo Basin) is also a part of the Albuquerque Basin. The basin-fill deposits of this area mostly consist of the pre-Santa Fe Eocene Galisteo Formation overlain by Santa Fe Group deposits.

The inner graben of the Rio Grande Rift in the Albuquerque area has been identified only in the northern half-graben and is between the Isleta and the Rio Grande Faults (fig. 16). This area ranges in width from about 3 to 5 miles and has the thickest accumulation of Santa Fe Group sediments (figs. 17-20). Vertical distances measured from exposed Precambrian rocks in the eastern uplifted areas to Precambrian rocks in the northern half-graben indicate displacement of greater than 30,000 feet (Lozinsky, 1988). This northern half-graben is the deepest known part of the Albuquerque Basin, and contains the greatest thickness of sediments (Lozinsky, 1988; Russell and Snelson, 1990; Hawley and Haase, 1992).

Hydrostratigraphic Units

As defined previously in this report, the Santa Fe Group aquifer system is comprised of the Santa Fe Group (late Oligocene to middle Pleistocene) and post-Santa Fe valley and basin-fill deposits (Pleistocene to Holocene). The primary water-yielding zones are within the upper part of the Santa Fe Group (5 to 1 Ma), to a lesser degree the middle part of the Santa Fe Group (25 to 5 Ma), and valley and basin-fill deposits.

The occurrence and movement of ground water and the response of the upper and middle parts of the Santa Fe Group to ground-water withdrawal are dependent on several hydraulic properties of the aquifer: hydraulic conductivity, saturated thickness, transmissivity, anisotropy, specific storage, specific yield, and inelastic compaction of aquifer material. These terms are briefly explained below. Examples related to the Santa Fe Group are mentioned when warranted.

Hydraulic conductivity, in common units, is defined as the volume of water, in cubic feet, that can pass through a cross-sectional area of 1 square foot under a hydraulic gradient of 1 foot per foot in a day's time (Lohman, 1979, p. 6). In this report, hydraulic conductivity is reported in feet per day.

The saturated thickness is defined as the thickness of aquifer material that is saturated with ground water. Under confined conditions, the saturated thickness of a particular aquifer will remain constant regardless of the hydraulic head. Under unconfined (water-table) conditions the saturated thickness is dependent on the hydraulic head of the aquifer and therefore can vary.

The transmissivity of an aquifer is defined as the product of the saturated thickness and hydraulic conductivity. Transmissivity, in common units, is defined as the volume of water, in cubic feet, that can pass through a 1-foot-wide column of aquifer under a 1-foot-per-foot hydraulic gradient in a day's time (Lohman, 1979, p. 6). In this report, transmissivity is reported in feet squared per day.

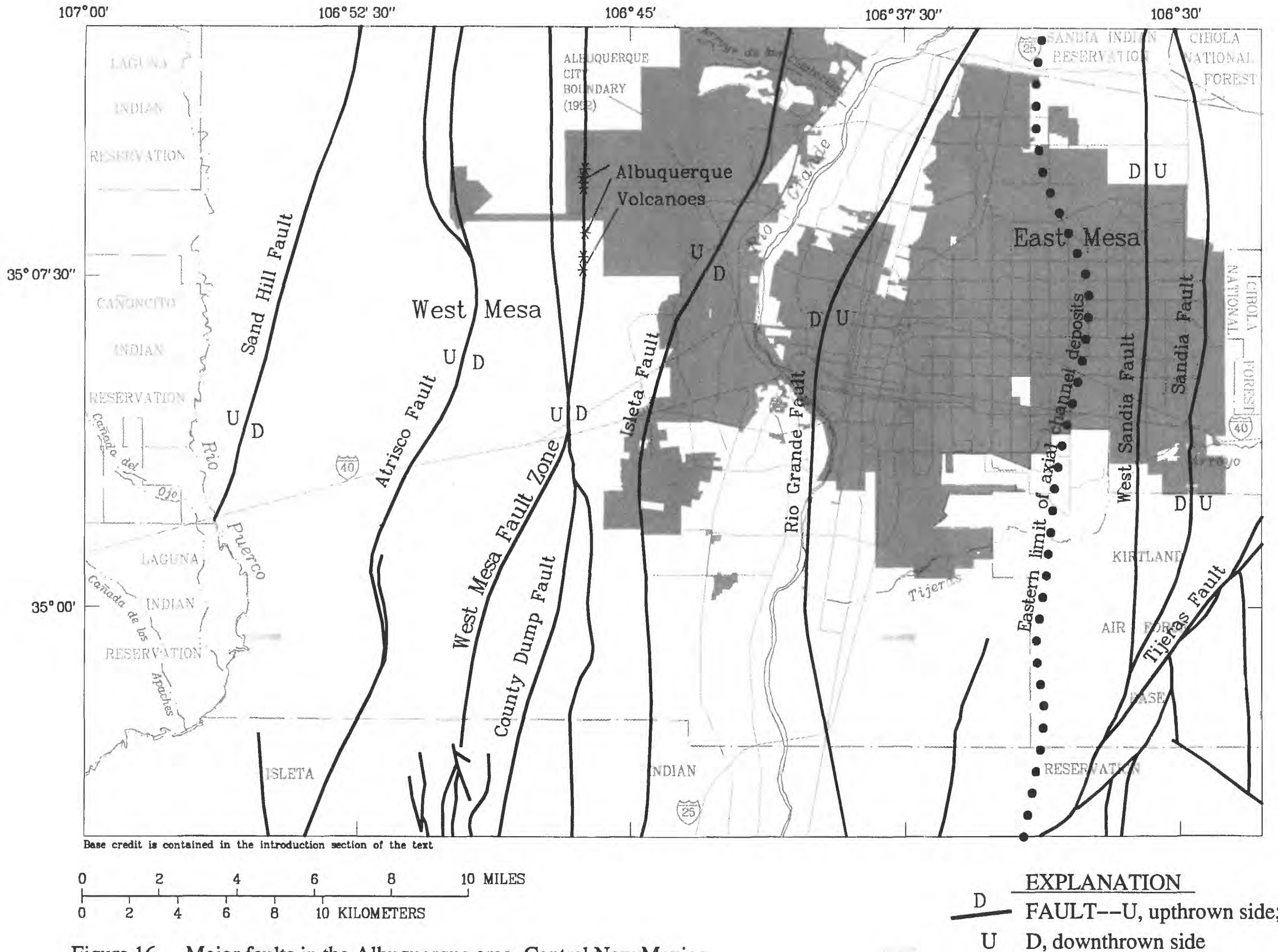


Figure 16.--Major faults in the Albuquerque area, Central New Mexico.

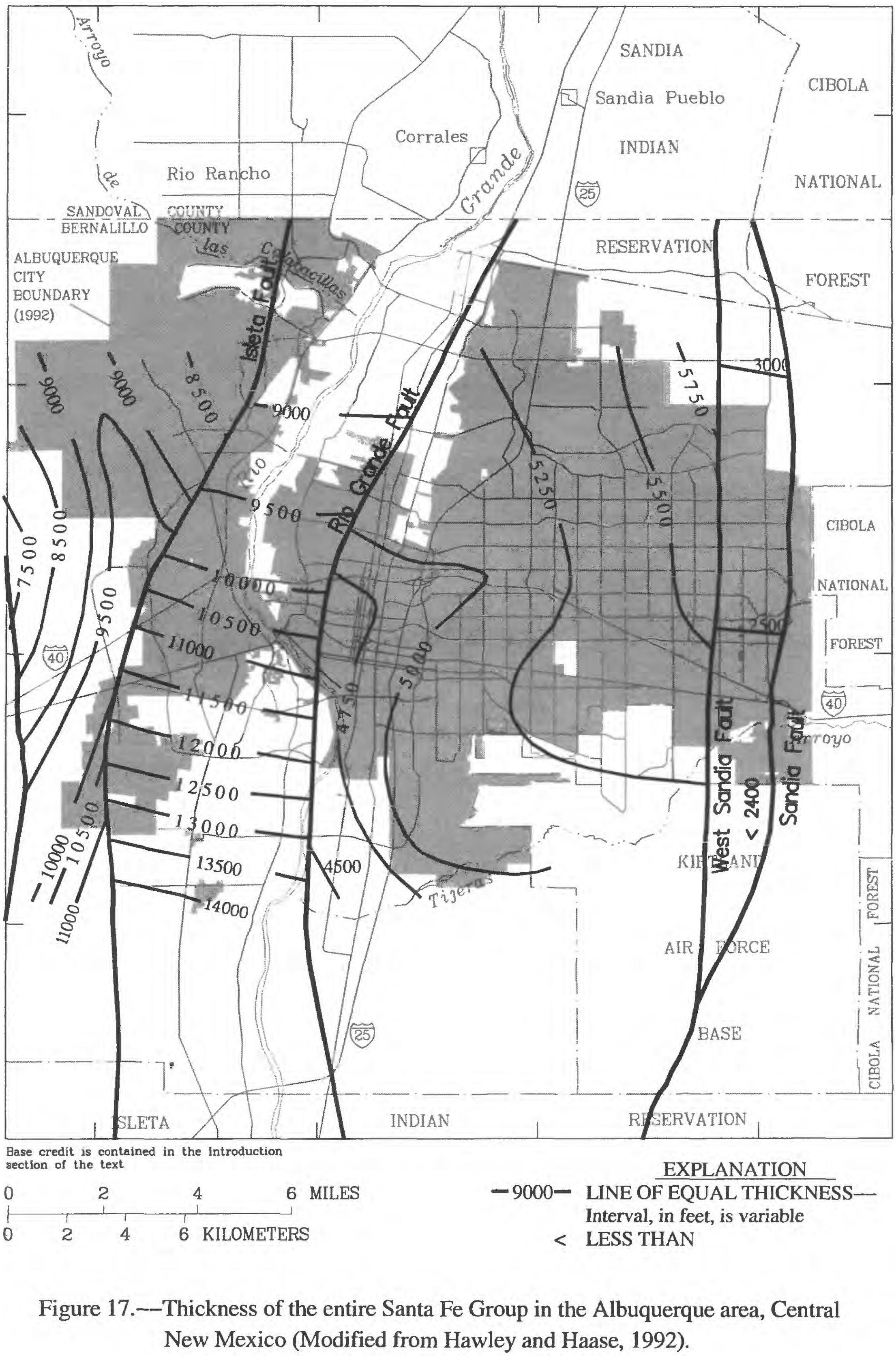
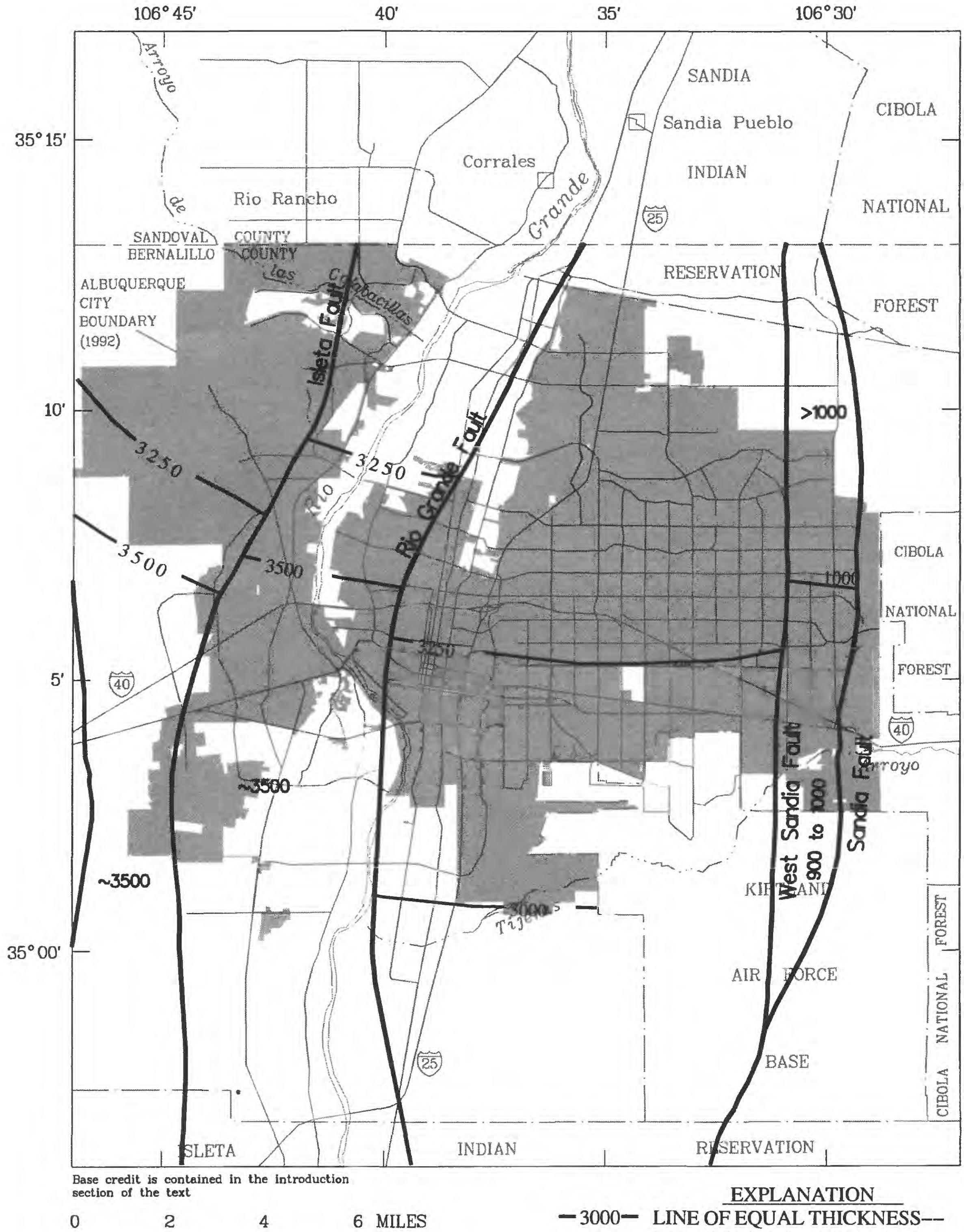


Figure 17.—Thickness of the entire Santa Fe Group in the Albuquerque area, Central New Mexico (Modified from Hawley and Haase, 1992).



EXPLANATION

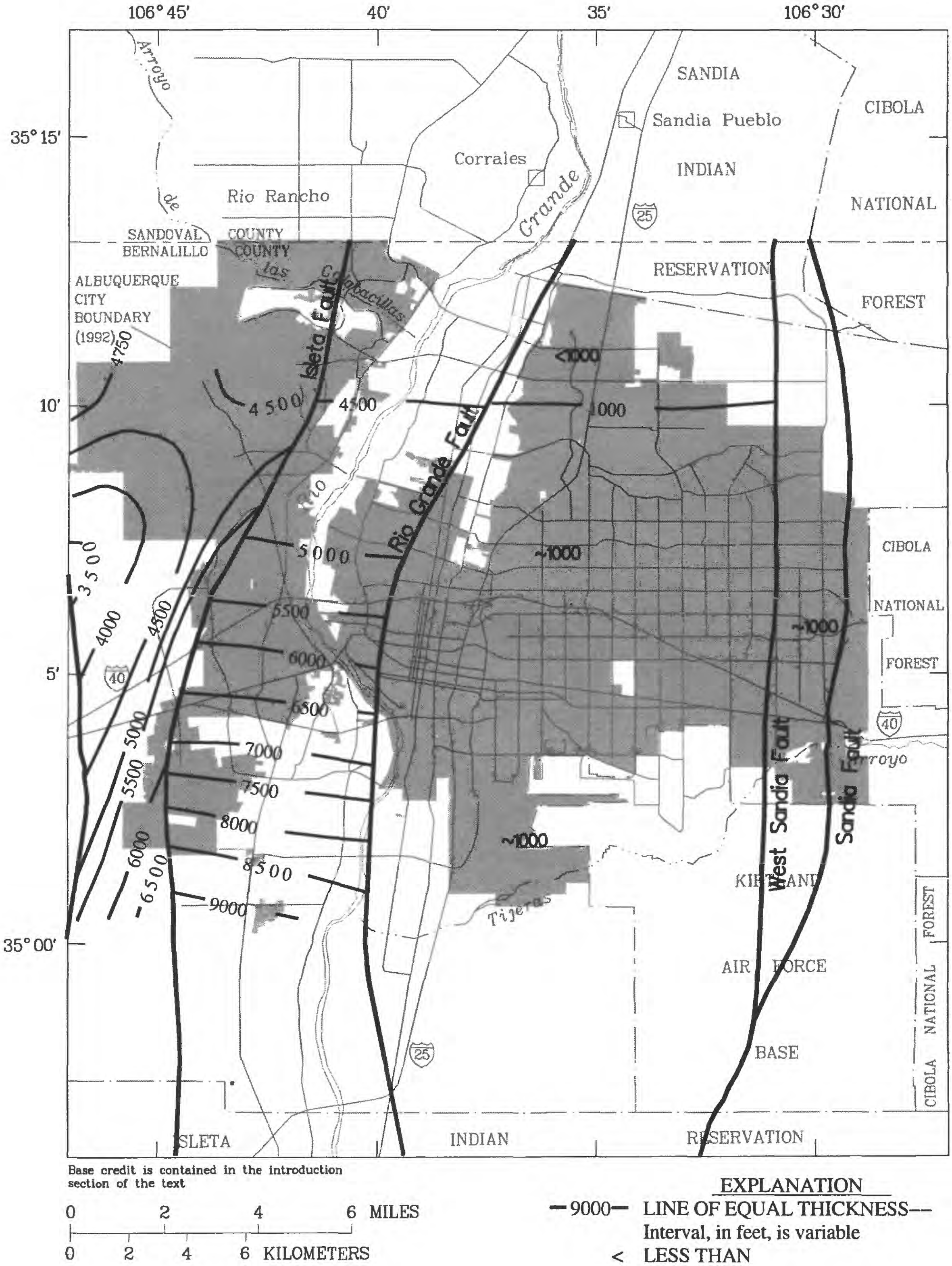
—3000— LINE OF EQUAL THICKNESS--Interval, in feet, is variable

< LESS THAN

> GREATER THAN

~ ABOUT

Figure 18.--Thickness of the lower part of the Santa Fe Group in the Albuquerque area, Central New Mexico (Modified from Hawley and Haase, 1992).



EXPLANATION

—9000— LINE OF EQUAL THICKNESS—Interval, in feet, is variable

< LESS THAN

~ ABOUT

Figure 19.—Thickness of the middle part of the Santa Fe Group in the Albuquerque area, Central New Mexico (Modified from Hawley and Haase, 1992).

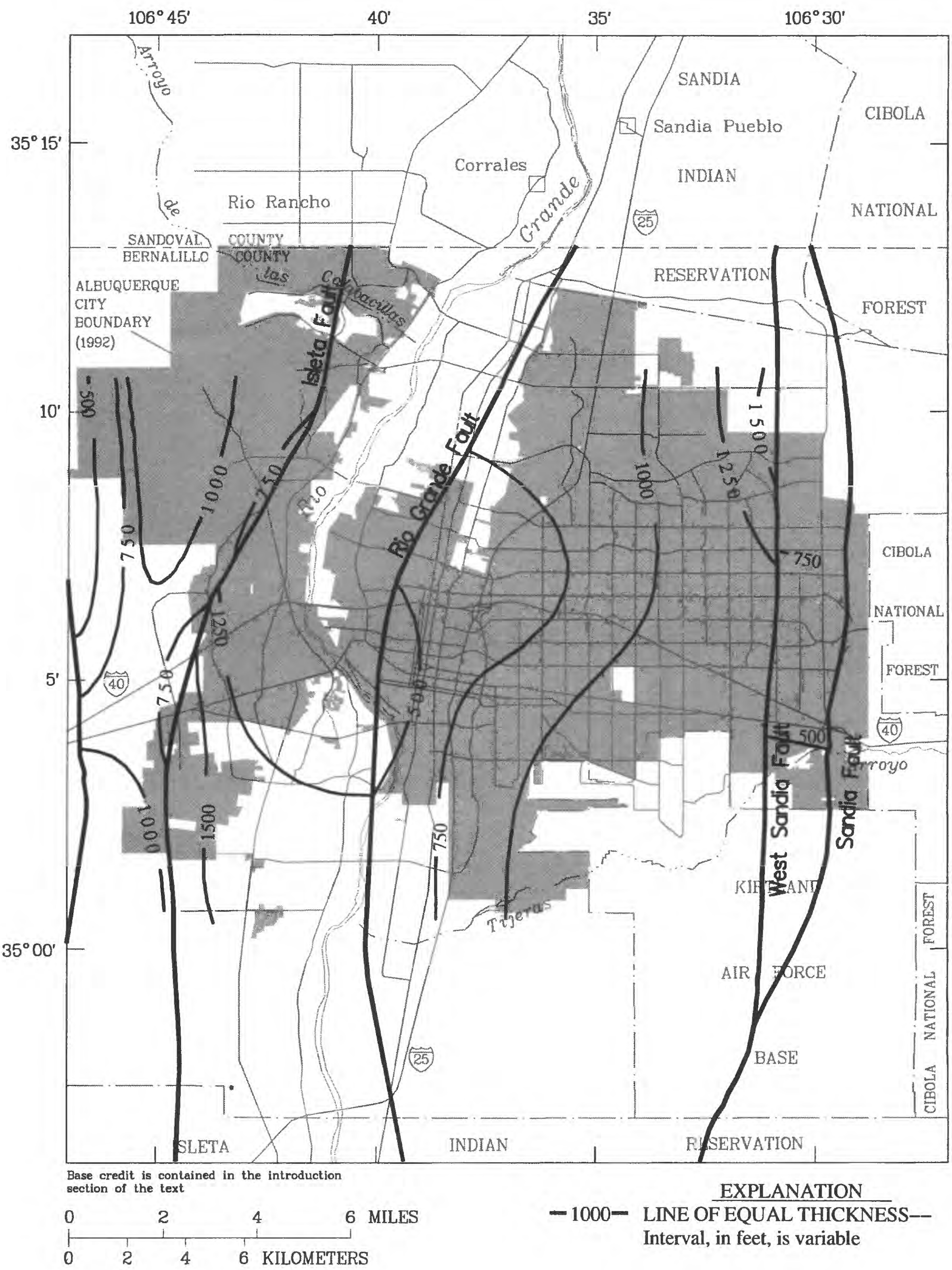


Figure 20.--Thickness of the upper part of the Santa Fe Group in the Albuquerque area, Central New Mexico (Modified from Hawley and Haase, 1992).

Aquifer material that does not display any difference in hydraulic conductivity in the Cartesian x, y, or z directions is isotropic. In most cases, however, the fabric, or internal makeup, of the aquifer material of the Santa Fe Group is such that directional properties do exist and therefore the aquifer material is anisotropic. The conditions under which the aquifer material was deposited determine the positional relation of the individual grains relative to one another, thereby determining the overall fabric of the aquifer material. For example, most of the productive aquifer material within the Albuquerque Basin was deposited in a fluvial environment. Two conditions determine the deposition of the individual grains in a fluvial environment: (1) Particles generally are not spherical and are deposited with their flat surfaces down, thereby creating an irregular packing or arrangement of the grains; (2) alluvium generally consists of layers of different particle sizes, each layer having its own hydraulic conductivity. If these layers are horizontal, any single layer that has a low hydraulic conductivity retards the vertical movement of water; however, ground water could easily move horizontally in any single layer that has a relatively high hydraulic conductivity (Todd, 1980). Therefore, alluvial deposits generally are anisotropic, having horizontal hydraulic conductivity that is greater than vertical conductivity (Hearne, 1985).

The specific storage of an aquifer, in common units, is defined as the volume of water, in cubic feet, taken in or released from storage per cubic foot of the aquifer material per 1-foot change in hydraulic head (Lohman and others, 1972). The units for specific storage in this report are per foot ($foot^{-1}$). Under confined conditions the ability of an aquifer to release water from storage, due to a decline in hydraulic head, is in part a function of the compressibility of the aquifer material and the expansion of the water being released. Likewise, an aquifer's ability to take water into storage, due to an increase in hydraulic head, is related in part to the aquifer's ability to expand and the water's ability to compress. The product of saturated thickness and specific storage is equal to the storage coefficient of a confined aquifer. The storage coefficient is dimensionless.

Specific yield is equal to the volume of water drained by gravity from a volume of aquifer material (Lohman, 1979). The percentage of water that remains within the aquifer material drained by gravity is defined as the specific retention. Specific yield also is equal to porosity (percent pore space) minus specific retention. Specific yield is dimensionless.

All aquifer material is elastic; the amount of elasticity is dependent on the composition and arrangement of the aquifer materials and the amount of water withdrawn from the aquifer. During withdrawal of water from storage, the aquifer will react elastically if the fluid (pore) pressure is not lowered beyond the point of permanent rearrangement of the aquifer materials or adjacent confining beds. Water removed from storage can be replaced with an increase in hydraulic head if the internal arrangement of aquifer materials remains elastic. However, if withdrawal of water continues beyond the point of aquifer materials maintaining their internal arrangement, the aquifer behaves inelastically, commonly referred to as permanent compaction or inelastic compaction (Terzaghi, 1936; Leake and Prudic, 1988). As water is removed from the aquifer the weight of the overlying material causes permanent compaction of aquifer material and confining beds. Water removed from storage by inelastic compaction cannot be returned to the aquifer after pumping ceases; hence this water comes from a one-time source (Leake and Prudic, 1988). Land and Armstrong (1985) and Kernodle (1992) reported interbed compaction in the Rio Grande Valley.

Numerous investigations have been undertaken to estimate some of the aquifer properties in the Albuquerque area. The aquifer tests reported in table 2 were made on wells that, in most cases, are screened over many hundreds of feet. The earliest of these investigations, by Bjorklund and Maxwell (1961), reported 20 aquifer tests that resulted in transmissivity values ranging from 4,300 to 80,000 feet squared per day and averaging about 33,000 feet squared per day. They also noted that the wells tested on the east side of the Rio Grande performed the best. Groundwater Management, Inc. reported 69 aquifer tests that resulted in transmissivity values ranging from 670 to 67,000 feet squared per day and averaging 20,000 feet squared per day (table 2; Groundwater Management, Inc., 1988a-v). Wilkins (1987) reported transmissivity values of 3.9, 3,900, and 1,300 feet squared per day for two test holes drilled on the west side of the Rio Grande (table 2). Aquifer tests conducted on three City production wells reported by Shomaker (1988, 1990, and 1991; table 2) resulted in transmissivity values of 1,184, 56,940, and 2,580 feet squared per day, respectively. The large variation of these reported transmissivity values within the Albuquerque area is in part due to the varying thickness of aquifer material penetrated by each well and the hydraulic conductivity of the aquifer materials.

An estimate of hydraulic conductivity can be obtained by dividing transmissivity values by the screen length, as shown in table 2. The areal distribution of hydraulic conductivity calculated in this manner is shown in figure 21. The localized area of greatest hydraulic conductivity shown in figure 21 corresponds with the area of axial channel deposits of the ancestral Rio Grande.

Within the Santa Fe Group, the primary water-yielding zones are within the upper part of the Santa Fe Group deposited during late Miocene to early Pleistocene (5 to 1 Ma) and to a lesser degree in the middle part of the Santa Fe Group deposited during middle to late Miocene (15 to 5 Ma). During this time the Albuquerque Basin was receiving alluvial sediments from the adjacent highlands (pediment-slope deposits) and fluvial sediments (river deposits) from northern New Mexico and southern Colorado. The resultant sedimentary sequence represents the intertonguing of basin-floor fluvial deposits and pediment-slope alluvial deposits (fig. 22). Within the Albuquerque area, the source for the pediment-slope deposits was the Sandia Mountains east of the City; they provided, for the most part, weathered granitic and limestone material to the basin. The fluvial deposits consist of a variety of material characteristic of the geology north of the Albuquerque Basin, including volcanic rock fragments from volcanic centers north and west of the Albuquerque Basin.

Hawley and Haase (1992) presented a detailed study of the hydrogeologic framework of the northern Albuquerque Basin. In that report they divided the Santa Fe Group and post-Santa Fe Group deposits into 4 hydrostratigraphic units and 10 lithofacies units (appendix). The hydrostratigraphic units consist of major valley and basin-fill mappable units that are grouped on the basis of origin and age of a stratigraphic sequence of deposits (Hawley and Haase, 1992, p. VII-1). Examples include basin-floor playa, ancestral river valley, alluvial-fan pediment, and present river valley depositional environments. Time-stratigraphic classes include units deposited during early, middle, and late stages of basin filling (lower, middle, and upper parts of the Santa Fe Group deposits, respectively). Post-Santa Fe Group valley and basin-fill deposits consist of channel and flood-plain deposits beneath the modern inner valley or preserved as alluvial terraces (Hawley and Haase, 1992, p. VII-1). The 10 lithofacies represent different depositional settings and are mappable units recognized by characteristic bedding and compositional properties having distinctive geophysical, geochemical, and hydrologic characteristics (appendix; fig. 22; Hawley and Haase, 1992, p. VII-1). Also dispersed throughout the Santa Fe Group are mafic volcanic flows and ash beds (appendix).

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico

[Latitude and longitude: location of well, in degrees, minutes, and seconds north latitude and degrees, minutes, and seconds west longitude; --, no data; GMI, Groundwater Management, Inc.; B&M, Bjorklund and Maxwell; USF, upper Santa Fe unit; MSF, middle Santa Fe unit; LSF, lower Santa Fe unit]

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Atrisco 1 350418 1064124	6,360	230	30	Recovery	--	GMI,1988a,p.15
Atrisco 3 350513 1064117	3,480	--	--	Drawdown	--	GMI,1988a,p.15
Atrisco 4 350412 1064055	3,220	--	--	Drawdown	--	GMI,1988a,p.15
Atrisco 9 350513 1064118	8,000	624	13	Recovery/drawdown	--	B&M,1961,p.71
Burton 2 350421 1063610	21,040	420	50	Recovery	--	GMI,1988b,p.15
Burton 3 350439 1063559	25,320	636	40	Drawdown	--	GMI,1988b,p.15
Candelaria 2 350710 1063813	5,490	--	--	Recovery	--	GMI,1988c,p.15
Candelaria 4 350704 1063826	3,080	--	--	Recovery	--	GMI,1988c,p.15
Charles Wells 1 350628 1063348	59,500	576	103	Drawdown	USF,USF-2; Ib,Vd,IX	GMI,1988d,p.16
Charles Wells 2 350604 1063414	56,280	564	100	Observation well	USF,USF-2; Ib,Vd,IX	GMI,1988d,p.16

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Charles Wells 3 350640 1063427	67,000	576	120	Observation well	USF,USF-2; Ib,Vd,IX	GMI,1988d,p.16
Charles Wells 4 350601 1063331	56,280	576	98	Unknown	USF,USF-2; Vd,IX	GMI,1988d,p.16
College 1 350645 1064432	6,570	990	7	Recovery	USF,MSF, MSF-2	GMI,1988e,p.15
College 2 350646 1064359	14,740	1,014	15	Recovery	USF,MSF, MSF-2	GMI,1988e,p.15
Don 1 350406 1064524	8,710	852	10	Recovery	USF,MSF-2 MSF	GMI,1988f,p.15
Duranes 1 350640 1064005	5,090	720	7	Recovery	USF,USF-2; Ib,Ib-III,IX	GMI,1988g,p.15
Duranes 1 350640 1064005	10,000	720	14	Recovery	USF,USF-2; Ib,Ib-III,IX	B&M,1961,p.72
Duranes 2 350710 1064046	12,600	624	20	Recovery	USF,USF-2; Ib,Ib-III,IX	GMI,1988g,p.15
Duranes 2 350710 1064046	4,300	624	7	Recovery	USF,USF-2; Ib,Ib-III,IX	B&M,1961,p.71
Duranes 3 350630 1064043	10,720	818	13	Recovery	USF,USF-2; Ib,Ib-III,IX	GMI,1988g,p.15
Duranes 4 350627 1064114	3,220	806	4	Recovery	USF,USF-2; Ib,Ib-III,IX	GMI,1988g,p.15

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Duranes 5 350605 1064116	4,690	802	6	Drawdown	USF, USF-2; Ib, Ib-III, IX	GMI, 1988g, p.15
Duranes 6 350652 1064029	5,490	384	14	Recovery	USF, USF-2; Ib, Ib-III, IX	GMI, 1988g, p.15
Duranes 7 350655 1064109	7,370	800	9	Recovery	USF, USF-2; Ib, Ib-III, IX	GMI, 1988g, p.15
Four Hills	38,000	--	--	Recovery/drawdown	--	B&M, 1961, p.83
Gonzales 2 350634 1064149	2,580	700	4	Step-drawdown	USF, USF-2; Ib, Ib-III, IX	Shomaker, 1991, p.22
Griegos 1 350823 1063950	10,720	570	19	Recovery	--	GMI, 1988h, p.15
Griegos 2 350748 1064007	11,790	656	18	Recovery	--	GMI, 1988h, p.15
Griegos 3 350805 1064026	3,750	656	5	Drawdown	--	GMI, 1988h, p.15
Griegos 4 350823 1063902	8,710	586	15	Recovery	--	GMI, 1988h, p.15
Griegos 5 350804 1063926	12,000	624	19	Recovery/drawdown	--	B&M, 1961, p.74
Veterans Hospital	43,000	--	--	Recovery/drawdown	--	B&M, 1961, p.79

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Kirtland 2	13,400	--	--	Recovery/drawdown	--	B&M,1961,p.78
Leavitt 1 350312 1064345	10,990	900	12	Recovery	USF,USF-2; III-IX	GMI,1988i,p.15
Leavitt 2 350248 1064339	2,550	840	3	Recovery	--	GMI,1988i,p.15
Leyendecker 1 350751 1063421	55,210	528	105	Drawdown	USF-1; Ib,Vf,IX	GMI,1988j,p.15
Leyendecker 1 350751 1063421	71,000	528	130	Recovery/drawdown	USF-1; Ib,Vf,IX	B&M,1961,p.74
Leyendecker 2 350729 1063406	40,600	528	77	Drawdown	USF-1; Vf,II,IX	GMI,1988j,p.15
Leyendecker 2 350729 1063406	54,000	528	100	Recovery	USF-1; Vf,II,IX	B&M,1961,p.72
Leyendecker 3 350815 1063438	56,010	540	100	Recovery	--	GMI,1988j,p.15
Leyendecker 3 350815 1063438	80,000	540	150	Recovery/drawdown	--	B&M,1961,p.74
Leyendecker 4 350814 1063406	49,040	516	95	Recovery	USF-1; Ib,Vf	GMI,1988j,p.15
Leyendecker 4 350814 1063406	71,000	516	140	Recovery/drawdown	--	B&M,1961,p.74

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Lomas 1 350429 1063024	17,020	600	28	Recovery	--	GMI,1988k,p.16
Lomas 2 350459 1063045	1,070	796	1	Observation well	--	GMI,1988k,p.16
Lomas 7	14,740	828	18	Observation well	--	GMI,1988k,p.16
Lomas 8	13,400	812	17	Observation well	--	GMI,1988k,p.16
Love 1 350515 1063142	6,030	500	12	Observation well	--	GMI,1988l,p.16
Love 2	10,000	564	18	Recovery/drawdown	--	B&M,1961,p.74
Love 3 350512 1063217	28,140	600	47	Observation well	--	GMI,1988l,p.16
Love 3 350512 1063217	15,000	600	25	Recovery/drawdown	--	B&M,1961,p.74
Love 4 350512 1063257	23,720	684	35	Drawdown	--	GMI,1988l,p.16
Love 4 350512 1063257	32,000	684	47	Recovery/drawdown	--	B&M,1961,p.74
Love 5 350450 1063239	14,740	588	25	Observation well	--	GMI,1988l,p.16

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Love 5 350450 1063239	24,000	588	41	Recovery/drawdown	--	B&M,1961,p.74
Love 6 350553 1063137	4,690	759	6	Unknown	--	GMI,1988l,p.16
Love 7 350608 1063213	18,760	831	23	Unknown	--	GMI,1988l,p.16
Love 8 350538 1063330	56,940	800	71	Step-drawdown	USF,USF-2,MSF; Vd,IX,V	Shomaker,1990, p.32
Miles Road 1 350306 1063747	9,650	750	13	Recovery	USF,MSF; II-Ib,II-III	GMI,1988m,p.15
Ponderosa 2 350802 1063151	7,240	768	9	Recovery	--	GMI,1988n,p.15
Ponderosa 3 350821 1063209	19,160	720	27	Recovery	--	GMI,1988n,p.15
Ponderosa 4 350821 1063148	4,820	613	8	Recovery	--	GMI,1988n,p.15
Ponderosa 6 350852 1063219	42,610	810	53	Recovery	--	GMI,1988n,p.15
Ponderosa 7	6,430	674	10	Recovery	--	GMI,1988n,p.15
Ponderosa 9	9,650	729	13	Recovery	--	GMI,1988n,p.15

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
SAF-1	1,184	102	12	Unknown	LSF; IV,VII	Shomaker, 1988, p.14
Sandia 1	60,000	--	--	Recovery/drawdown	--	B&M,1961,p.79
Santa Barbara 1 350647 1063625	22,910	672	34	Recovery	--	GMI,1988o,p.15
San Jose 1 350315 1063847	670	--	--	Recovery	--	GMI,1988p,p.15
San Jose 2 350315 1063901	6,030	732	8	Recovery	USF,MSF; II-Ib,II-III	GMI,1988p,p.15
San Jose 3 350301 1063836	6,160	--	--	Recovery	--	GMI,1988p,p.15
San Jose 7	7,000	732	10	Recovery	--	B&M,1961,p.73
Test well 1 350449 1064931	3.9	141	.03	Step-drawdown	MSF-2,LSF; III-VII,IX-VII	Wilkins,1987,p. 75
Test well 3 351051 1063953	3,900	40	97	Step-drawdown	USF; Ib	Wilkins,1987,p. 76
Test well 3 351051 1063953	1,300	100	13	Step-drawdown	USF; Ib,II	Wilkins,1987,p. 76
Thomas 1 350752 1063256	28,940	468	62	Recovery	--	GMI,1988q,p.16

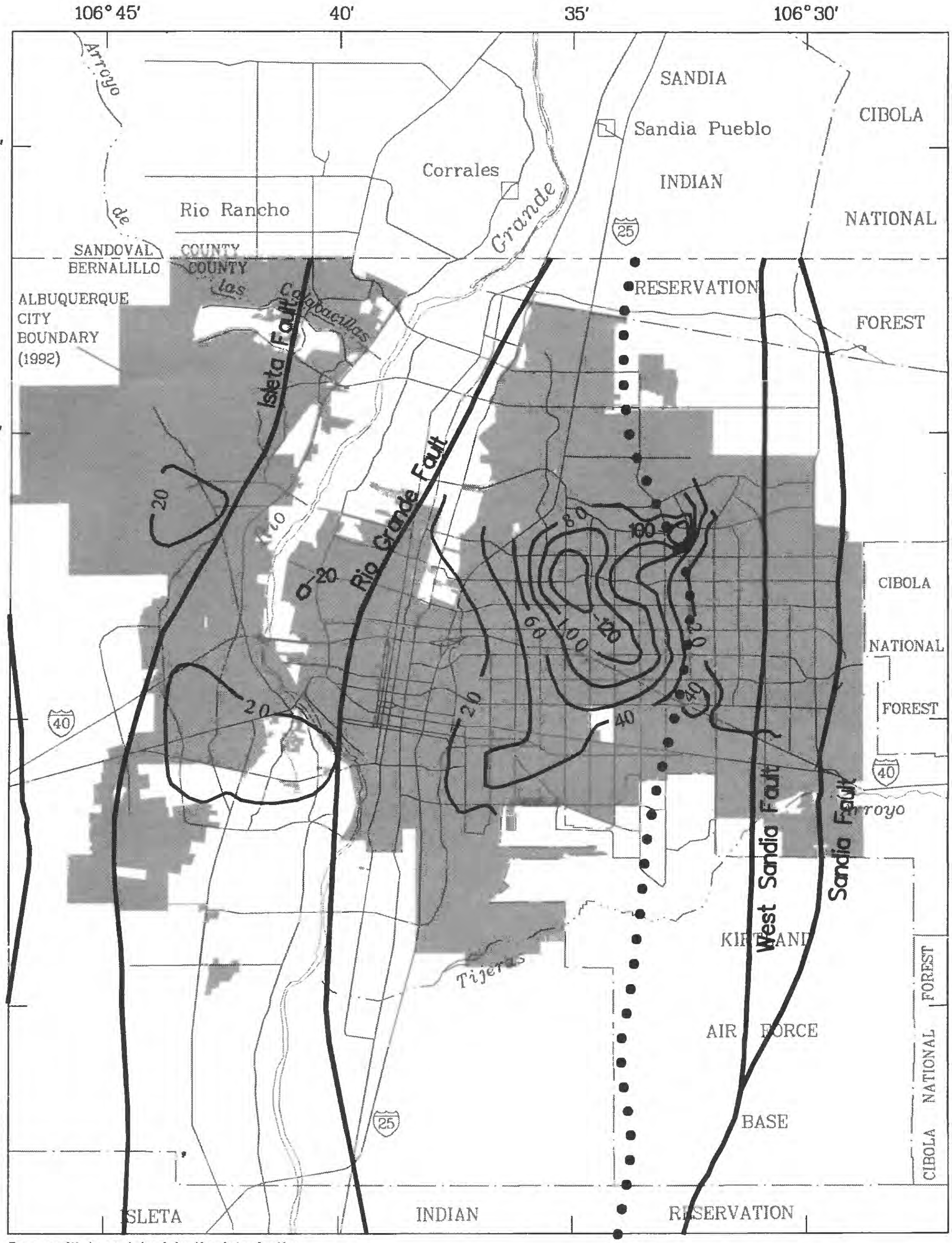
Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Continued

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Thomas 1 350752 1063256	54,000	468	112	Recovery/drawdown	--	B&M,1961,p.74
Thomas 2 350748 1063235	18,220	528	35	Recovery	--	GMI,1988q,p.16
Thomas 2 350748 1063235	13,000	528	25	Recovery	--	B&M,1961,p.74
Thomas 3 350815 1063313	43,680	528	83	Recovery	--	GMI,1988q,p.16
Thomas 4 350812 1063240	40,070	348	115	Recovery	--	GMI,1988q,p.16
Thomas 4 350812 1063240	40,000	348	110	Recovery/drawdown	--	B&M,1961,p.74
Vol Andia 1 350804 1063547	55,610	672	83	Recovery	--	GMI,1988r,p.15
Vol Andia 2 350731 1063502	65,260	492	133	Recovery	--	GMI,1988r,p.15
Vol Andia 4 350803 1063512	58,020	504	115	Recovery	--	GMI,1988r,p.15
Vol Andia 5 350804 1063609	40,470	636	64	Recovery	--	GMI,1988r,p.15
Vol Andia 6 350826 1063525	51,320	660	78	Recovery	--	GMI,1988r,p.15

Table 2.--Transmissivity values, hydrostratigraphic units, and lithofacies from selected wells in the Albuquerque area, Central New Mexico--Concluded

Well name, and latitude and longitude location	Transmissivity (feet squared per day)	Screen length (feet)	Transmissivity divided by screen length (feet per day)[1]	Aquifer-test method	Hydrostratigraphic units and lithofacies[2]	References
Volcano Cliffs 1 350934 1064343	8,980	528	17	Recovery	--	GMI,1988s,p.15
Volcano Cliffs 2 350911 1064340	8,710	348	25	Recovery	--	GMI,1988s,p.15
Walker 1 351026 1063140	4,020	--	--	Recovery	--	GMI,1988t,p.15
Webster 1 351030 1063316	42,080	725	58	Drawdown	USF,MSF; Vf,IX,I-Vf,Vf	GMI,1988u,p.15
Webster 2 351012 1063335	19,970	726	28	Recovery	USF,MSF; Vf,IX,I-Vf,Vf	GMI,1988u,p.15
Yale 1 350425 1063726	15,280	624	24	Recovery	--	GMI,1988v,p.15
Yale 2 350357 1063728	19,560	828	24	Recovery	USF,MSF; II-Ib,II-III	GMI,1988v,p.15
Yale 3 350435 1063800	8,040	672	12	Recovery	--	GMI,1988v,p.15

1. Approximate hydraulic conductivity.
2. From Hawley and Haase, 1992; see figure 22, table 3, and appendix for lithofacies composition, depositional settings, ground-water production potential, and complete description of lithofacies.



Base credit is contained in the introduction section of the text

0 2 4 6 MILES

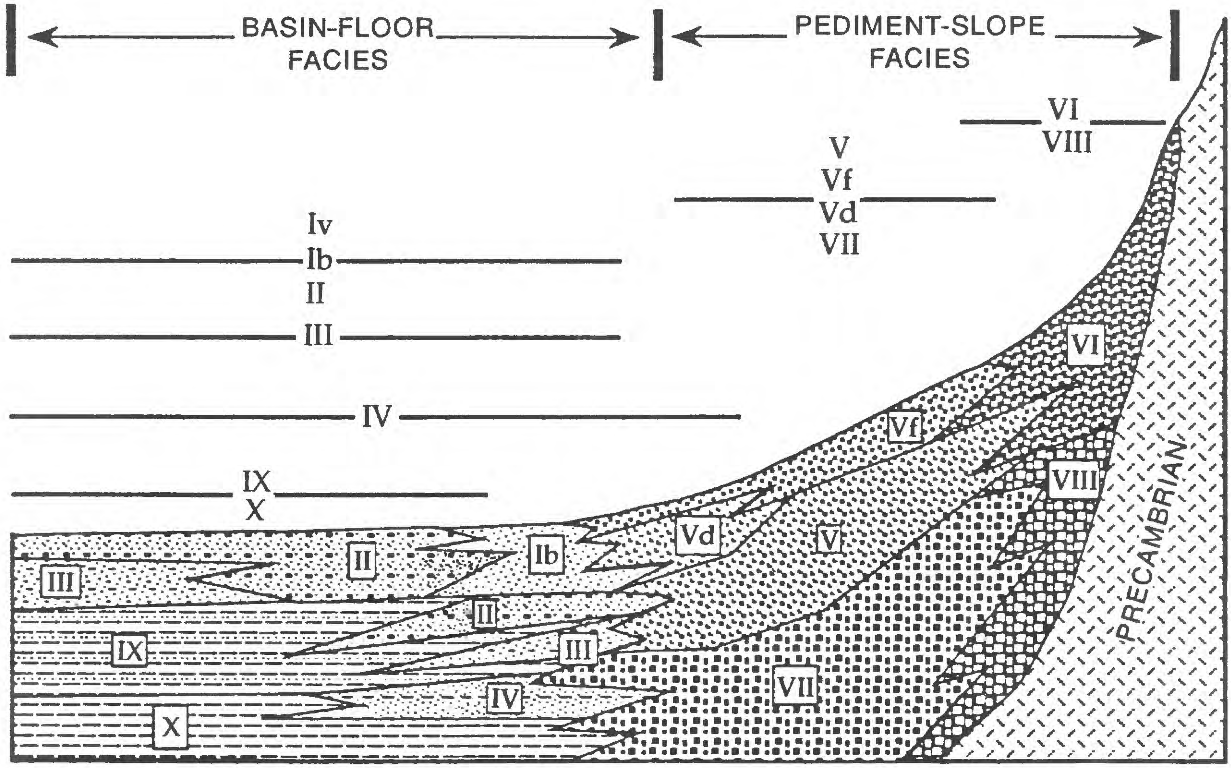
0 2 4 6 KILOMETERS

EXPLANATION

—20— LINE OF EQUAL HORIZONTAL HYDRAULIC CONDUCTIVITY--Interval 20 feet per day

• • • EASTERN LIMIT OF AXIAL CHANNEL DEPOSITS

Figure 21.--Horizontal hydraulic conductivity in the upper part of the Santa Fe Group in the Albuquerque area, Central New Mexico.



EXPLANATION

Lithofacies designation	DEPOSITIONAL SETTING	COMPOSITION
Iv	River valley and basin-floor fluvial	Sand and pebble to cobble gravel
Ib	River valley and basin-floor fluvial; braided streams	Sand and pebble gravel; lenses of sandstone and silty clay
II	Basin-floor fluvial; locally eolian	Sand; lenses of pebbly sand, silty sand, and clay
III	Basin-floor alluvial and playa lake	Interbedded sand, sandstone, and silty clay; lenses of pebbly sand
IV	Basin-floor eolian and distal pediment alluvial fan	Sand and silty sand; lenses of silty clay and clay
V	Undifferentiated distal to medial pediment-slope alluvial fan	Gravel, sand, silt, silty clay, and clay
Vf	Distal to medial pediment-slope alluvial fan associated with small watersheds; alluvial-fan distributary channel and debris flow	Gravelly sand, silt and clay; lenses of sand, gravel, and silty clay
Vd	Distal to medial pediment-slope alluvial fan associated with large watersheds; alluvial-fan distributary channel	Sand and gravel; lenses of gravelly to nongravelly sand, silt, and clay
VI	Proximal to medial pediment-slope alluvial fan; debris flow; distributary channel	Coarse gravelly sand, silt, and clay; lenses of sand and gravel; cobbles and boulders
VII	Distal to medial pediment-slope alluvial fan; alluvial-fan distributary channel and debris flow	Gravel, sand, silt, and clay; indurated Vf,Vd, and V
VIII	Proximal to medial pediment-slope alluvial fan	Coarse gravelly sandstone and silty sandstone; lenses of sand and gravel; cobbles; indurated VI
IX	Basin-floor playa lake and alluvial flat; distal-pediment alluvial	Silty clay interbedded with silty sand, and mudstone
X	Basin-floor playa lake and alluvial flat; distal-pediment alluvial	Mudstone interbedded with silty sand and sandstone; indurated IX

Figure 22.—Hypothetical distribution of lithofacies in the Albuquerque Basin, Central New Mexico (Modified from Hawley and Haase, 1992).

Thickness of the Santa Fe Group ranges from less than 2,400 to greater than 3,000 feet along the margins of the basin to 14,000 feet in the central part of the basin (fig. 17; Lozinsky, 1988; Hawley and Haase, 1992). The lower part of the Santa Fe Group was deposited from 30 to 15 Ma in an internally drained basin prior to deep subsidence of the basin and increased uplift of the marginal mountains (Hawley and Haase, 1992). Thickness of the lower part of the Santa Fe Group ranges from less than 1,000 feet along the basin margin to 3,500 feet in the central part of the basin (fig. 18). The accumulation of Santa Fe Group material was greatest during the time of deposition of the middle part of the Santa Fe (15 to 5 Ma). During this time the basin margins were supplying major pediment-slope deposits to the basin, and major fluvial systems were transporting material to the basin from the north, northeast, and southwest; these fluvial systems probably terminated in playa lakes in the southern part of the basin (Lozinsky, 1988; Hawley and Haase, 1992). The different sediment sources and high rates of sedimentation, combined with active tectonism, especially in the inner graben, allowed for this accelerated rate of deposition. Also during this time the half-grabens that made up the early Albuquerque Basin were filled to form a single topographic basin (Lozinsky, 1988; Hawley and Haase, 1992). Thickness of the middle part of the Santa Fe Group ranges from about 250 feet in the western margin of the basin (Hawley and Haase, 1992, p. III-7) to 9,000 feet in the central part of the basin (fig. 19). During the next 4 million years the upper part of the Santa Fe Group was deposited and is characterized by intertonguing pediment-slope and fluvial basin-floor deposits. Thickness of the upper part of the Santa Fe Group is locally as much as 1,500 feet but averages less than 1,000 feet (fig. 20).

Santa Fe Group deposition ceased about 1 million years ago when the Rio Grande and Rio Puerco started to cut their present valleys (Hawley and Haase, 1992). Post-Santa Fe units were deposited during a series of river incision and backfilling episodes; the latest cut and fill episode of the Rio Grande and Rio Puerco systems produced the channel and flood-plain deposits of the present inner valley (Hawley and Haase, 1992). For the last 10,000 to 15,000 years the river valleys have been aggrading due to tributary input of more sediment than the regional fluvial system can remove. This young valley fill, as much as 200 feet thick, functions as a shallow source of water and as a connection between the surface-water system and the underlying Santa Fe Group (Hawley and Haase, 1992).

Most of the City of Albuquerque's production wells are located on the east side of the Rio Grande and west of the eastern extent of the ancestral river axial channel deposits (appendix). The most productive wells are completed in the upper part of the Santa Fe Group and to some extent in the middle part of the Santa Fe Group (table 2). Lithology characteristic of the axial channel deposits and to some extent the alluvial deposits of the pediment-slope and alluvial-fan environments provides the best aquifer material in the Santa Fe Group (fig. 22 and table 3). Lithology of the lower part of the Santa Fe Group containing basin-floor playa lake deposits provides for poor aquifer material (fig. 22 and table 3).

Table 3.--Summary of properties that influence ground-water production potential of Santa Fe Group lithofacies (Modified from Hawley and Haase, 1992)

[>, greater than; <, less than]

Lithofacies	Ratio of sand plus gravel to silt plus clay[1]	Bedding thickness (feet)	Bedding configuration[2]	Bedding continuity (feet)[3]	Bedding connectivity[4]	Hydraulic conductivity	Ground-water production potential
I	High to moderate	>5	Elongate	>500	High	High to moderate	High to moderate
Iv	High to moderate	>5	Elongate	>500	High	High to moderate	High
Ib	High	>5	Elongate	>500	High	High	High
II	High to moderate	>5	Elongate	>500	Moderate to high	High to moderate	High to moderate
III	Low	1 to 5	Planar	>500	Low	Low	Low
IV	Low to moderate	1 to 5	Planar to elongate	100 to 500	Low to moderate	Moderate to low	Moderate to low
V	Moderate	1 to 5	Elongate to lobate	100 to 500	Moderate to high	Moderate	Moderate
Vf	Moderate	1 to 5	Elongate to lobate	100 to 500	Moderate	Moderate to low	Moderate to low
Vd	Moderate to high	>5	Elongate to lobate	100 to 500	High	Moderate to high	Moderate to high
VI	High	>5	Lobate	<100	Moderate	Moderate to high	Moderate
VII	Moderate	1 to 5	Elongate to lobate	100 to 500	Moderate to high	Moderate to low	Moderate to low
VIII	High	>5	Lobate	<100	Moderate	Moderate to low	Moderate to low
IX	Low	<1	Planar	>500	Low	Low	Low
X	Low	<1	Planar	>500	Low	Low	Low

[1]High >2; moderate 0.5-2; low <0.5.
[2]Elongate (length to width ratios >5); planar (length to width ratios 1-5); lobate (asymmetrical or incomplete planar beds).
[3]Measure of the lateral extent of an individual bed of given thickness and configuration.
[4]Estimation of the ease with which ground water can flow between individual beds within a particular lithofacies. Generally, high sand + gravel/silt + clay ratios, thick beds, and high bedding continuity favor high bedding connectivity. All other parameters being equal, the greater the bedding connectivity, the greater the ground-water production potential of a sedimentary unit (Hawley and Haase, 1992, p. VI).

The earliest structural development of the Rio Grande Rift set the stage for the creation of a highly productive aquifer beneath the Albuquerque East Mesa area (fig. 16). Two half-grabens developed as the rift separated. The northern half-graben subsided more to the east and the southern subsided more to the west. The zone separating the two half-grabens passes just south of Albuquerque. During the time of deposition of the lower part of the Santa Fe Group, the two half-grabens were closed basins that collected fine-grained material from the low-relief surrounding area as well as playa-lake evaporites. These deposits probably will not directly contribute to Albuquerque's water supply because of their great depth, low hydraulic conductivity, or mineralized water contained in them. Rifting accelerated during deposition of the middle and upper parts of the Santa Fe Group but, more important, a through-flowing drainage system developed from the north. Either the energy of the fluvial system was lower during deposition of the middle part of the Santa Fe Group than during the upper part of the Santa Fe Group or an influx of fine sediments into the active rift clogged the Albuquerque Basin during the deposition of the middle part of the Santa Fe Group. In either case, the deposits of the middle part of the Santa Fe Group are generally finer and less permeable than those of the upper part of the Santa Fe Group. Water will be more difficult to extract from these deposits than from the upper part of the Santa Fe Group and the water is mineralized as well. In either case, an ancestral river system was guided to the eastern side of the rift by rapid subsidence of the eastern part of the northern half-graben beneath the area that is now called the East Mesa during the time of deposition of both the middle and upper parts of the Santa Fe Group. During deposition of the upper part of the Santa Fe Group, the depositional environment for the axial channel deposits was especially energetic and the deposits were coarse and well sorted. The interface position between these deposits and more poorly sorted pediment wash from the east remained sharp and very stable for millions of years (appendix). The western edge of the axial channel deposits is less clearly defined but generally lies near the Rio Grande Fault. In the vicinity of the Rio Grande Fault the coarse sediments intertongue with finer but still fluvial sediments to the west.

The map showing contours of equal horizontal hydraulic conductivity (fig. 21) generally supports the conceptual model of a stable axial channel of the ancestral Rio Grande during deposition of the upper part of the Santa Fe Group. The high hydraulic-conductivity zone abruptly terminates at the mapped eastern limit of the axial channel deposits. However, the relation between transitional areas of lower hydraulic conductivity and depositional environment is less definitive in all other directions. The estimated hydraulic conductivity is high only in east-central Albuquerque. From there it diminishes very rapidly to the east and rapidly to the west. The decrease in hydraulic conductivity in the north and south directions is less abrupt but is still present. Several generalizations can be formulated from the map of contoured hydraulic conductivity: (1) hydraulic conductivity is low east of the eastern limit of axial channel deposits in the upper part of the Santa Fe Group; (2) hydraulic conductivity is high west of the eastern limit of the axial channel deposits and east of the Rio Grande Fault; and (3) hydraulic conductivity is uniformly low in the upper part of the Santa Fe Group everywhere west of the Rio Grande Fault.

Stratigraphic pinch-outs of productive aquifer material are barriers to ground-water flow in the Albuquerque Basin. As discussed above, the most productive aquifer material is limited to facies that were deposited in a characteristic depositional environment during the deposition of the Santa Fe Group (table 3). The width of the high-conductivity zone varies from 2 to 6 miles and is bounded on the east by the limit of the axial fluvial deposits and on the west by the Rio Grande Fault.

Faults are likewise barriers to ground-water flow in the Albuquerque Basin. As described earlier in this report, the geometry of the basin is controlled by normal faults having large displacements, in some cases as great as 15,000 to 20,000 feet (fig. 14). These faults create barriers to ground-water flow by placing nonproductive aquifer material adjacent to productive aquifer material. For example, the Menaul hydrogeologic section (appendix) indicates that displacement along the Sandia Fault has placed Precambrian granite adjacent to units of the lower, middle, and upper parts of the Santa Fe Group, thereby creating a flow barrier. Movement along the County Dump Fault has brought the units of the lower part of the Santa Fe Group (nonproductive aquifer material) in contact with units of the middle and upper parts of the Santa Fe Group. The westernmost fault shown in the Menaul hydrogeologic section, the Sand Hill Fault, brings Cretaceous units in contact with the lower part of the Santa Fe Group. Within the upper part of the Santa Fe Group, and to a lesser degree, the middle part of the Santa Fe Group, there are lithofacies of productive aquifer material. These lithofacies also can be abruptly terminated by faults, thereby placing productive lithofacies material adjacent to nonproductive lithofacies material, restricting the lateral movement of ground water.

Materials along and near fault planes generally are tightly cemented by secondary mineralization. Cemented faults are more resistant to weathering than the host material and often form linear topographic spines that facilitate their mapping. Also, some major faults are zones of weakness that have guided fissure-flow basalts to land surface; for example, the Albuquerque Volcanoes (fig. 16) that were formed along the County Dump Fault (appendix). In both cases the altered fault is a barrier to ground-water movement. All faults shown in figure 16 probably are sealed to some extent by secondary cementation or by fissure-flow basalt.

HYDROLOGIC CONDITIONS

The Rio Grande extends the length of the Albuquerque Basin and is the only perennial stream in the basin. The headwaters of the Rio Grande are in the mountains of southern Colorado. The Rio Grande has a drainage area of about 14,900 square miles where it enters the Albuquerque Basin. Tributaries to the Rio Grande in the basin include the Santa Fe River, Galisteo Creek, Jemez River, Rio Puerco, and Rio Salado. Many arroyos and washes, flood diversion channels, and water-reclamation plants are also tributary to the Rio Grande in the basin. Water is diverted from the Rio Grande into a series of canals for irrigation of land in the inner valley. Drains, which intercept ground water and receive return flow from canals, return water to the Rio Grande.

Two major reservoirs are within the basin: Cochiti Lake and Jemez Canyon Reservoir. Cochiti Lake, at the north end of the basin on the Rio Grande, has a storage capacity of about 502,300 acre-feet and began storing water in 1973, primarily for flood and sediment control. Jemez Canyon Reservoir, on the Jemez River, has a controlled storage capacity of about 102,700 acre-feet, and was completed in 1953 for sediment control. Flood-detention structures have been constructed on several of the larger arroyos in the vicinity of Albuquerque to reduce peak flows during floods.

Within the Santa Fe Group aquifer system, the alluvium of the inner Rio Grande Valley is the hydraulic connection between the Santa Fe Group and the Rio Grande, canals, and drains. In much of the inner valley, layers of clay as thick as about 15 feet in the alluvium limit the flow of water between the surface-water system and the alluvium, and thus the underlying Santa Fe Group.

Urban, Rural, Commercial, and Industrial Ground-Water Withdrawal

Ground water is the primary source of water for urban, rural, commercial, and industrial uses (other than agricultural) in the Albuquerque Basin. Early ground-water withdrawal in the basin was from shallow hand-dug wells in the alluvium of the inner Rio Grande Valley. Lee (1907, p. 34-37) reported a few deep drilled wells in the basin, ranging in depth from 291 to 893 feet below land surface. Five of those wells were outside of the inner valley. In 1905, 10 wells supplied the City of Albuquerque: one well 710 feet deep, eight wells 291 feet deep, and one hand-dug well 65 feet deep that had pipes driven through the bottom, for a total depth of 100 feet (Lee, 1907, p. 34-35). The Albuquerque wells were reported to be capable of producing a combined yield of about 3,000 acre-feet per year (3 million gallons per day). Prior to 1932, ground-water withdrawal outside the inner valley of the basin was less than 120 acre-feet per year (Kernodle and others, 1987, p. 20).

Estimates of urban, rural, commercial, and industrial ground-water withdrawal in the Albuquerque Basin for 1970, 1980, and 1990 are listed in table 4. The total withdrawal in the basin is estimated to have been 152,700 acre-feet in 1990. The increase in withdrawal from 1970 to 1980 in the "other urban" category in table 4 reflects the development of suburban communities such as Rio Rancho, Paradise Hills, and Sandia Heights. The City of Albuquerque withdraws the largest amount of ground water in the basin, about 77 percent of the total withdrawal in 1990. The amount increased from 59,200 acre-feet in 1970 to 117,000 acre-feet in 1990 (table 4).

Table 4.--Estimates of urban, rural, commercial, and industrial ground-water withdrawal in the Albuquerque Basin, Central New Mexico

Category of use	Annual withdrawal, in acre-feet			
	[1]1970	[2]1980	[3]1990	Mean 1974-92
City of Albuquerque	59,200	89,300	117,000	98,300
Other urban	19,700	30,200	21,100	[4]23,700
Rural	8,500	4,400	6,300	[4]6,400
Commercial and industrial	9,600	[5]7,100	[5]8,300	[4]8,300
Total	97,000	131,000	152,700	136,700

[1] 1970 withdrawal estimates compiled from New Mexico Interstate Stream Commission and New Mexico State Engineer Office (1974a-f) using basin population calculated from U.S. Bureau of Census digital data (1970).

[2] 1980 withdrawal estimates compiled from Sorensen (1982) using basin population calculated from U.S. Bureau of Census digital data (1980).

[3] 1990 withdrawal estimates compiled from Wilson (1992) using basin population calculated from U.S. Bureau of Census digital data (1990).

[4] Estimated by averaging values for 1970, 1980, and 1990.

[5] Estimated by multiplying industrial and commercial withdrawals in Bernalillo and Sandoval Counties (Sorensen, 1982; Wilson, 1992) by the ratio of the 1970 industrial and commercial withdrawals in the basin (New Mexico State Engineer Office files, Albuquerque) to the 1970 industrial and commercial withdrawals in Bernalillo and Sandoval Counties (New Mexico Interstate Stream Commission and New Mexico State Engineer Office (1974a, b).

Ground-water withdrawal for the City of Albuquerque from 1933 through 1992 is shown in figure 23. From 1932 to 1948 the City's water was supplied by the Main Plant well field, located within the Rio Grande inner valley (fig. 24). The growth of Albuquerque was relatively slow prior to 1945, as reflected in ground-water withdrawal. Beginning about 1945 Albuquerque experienced rapid growth and a parallel increase in water use (fig. 23). From 1948 to 1958 the City constructed seven new well fields (Bjorklund and Maxwell, 1961, table 1, p. 71-74), and most of the City's withdrawals during this time were from the inner valley. In the following years, the City continued to develop new well fields, most of which were constructed outside the inner valley. The locations of the City's current (1993) wells are shown in figure 24. In recent years, most of Albuquerque's ground-water withdrawal has been in the area east of the Rio Grande inner valley.

The "other urban" category in table 4 consists of water systems supplying urban water users in the basin other than those supplied by the City of Albuquerque. In 1990, most ground-water withdrawal in this category was for Rio Rancho (8,200 acre-feet), Kirtland Air Force Base (4,700 acre-feet), Paradise Hills (2,700 acre-feet), Belen (1,400 acre-feet), Los Lunas (1,100 acre-feet), Bernalillo (900 acre-feet), Sandia Peak Utility Company in Sandia Heights (700 acre-feet), and Rio Grande Utilities in Belen (600 acre-feet) (Wilson, 1992, table 6, p. 96-113). The remainder of 1990 withdrawal in this category was for self-supplied urban homes (Wilson, 1992, table 6, p. 96, 107).

The "rural" category of ground-water withdrawal in table 4 consists of water systems serving rural water users and self-supplied rural homes. No rural water system in the basin withdrew more than 150 acre-feet of water in 1990 (Wilson, 1992, table 6, p. 96-113). Withdrawal in this category for self-supplied rural homes was estimated by multiplying the per capita rural water use in the basin by the number of people in the basin that were neither supplied by a water system nor categorized as self-supplied urban. This calculation was done by county and summed for the basin. Values used in the calculations were reported by the New Mexico Interstate Stream Commission and New Mexico State Engineer Office (1974a-f), Sorensen (1982), and Wilson (1992). The weighted average per capita water use for self-supplied rural homes in the basin, estimated based on values cited by Wilson (1992, table 6, p. 96-113), was 0.095 acre-foot per person per year (85 gallons per person per day) in 1990.

The "commercial and industrial" category of ground-water withdrawal in table 4 includes self-supplied businesses, institutions, manufacturing plants, power generation plants, mineral extraction operations, and golf courses (Wilson, 1992, p. 54-61). Water for many of these uses is supplied by public water systems or by a combination of public water systems and self-supplied wells. Only the water that is self supplied is included in this category.

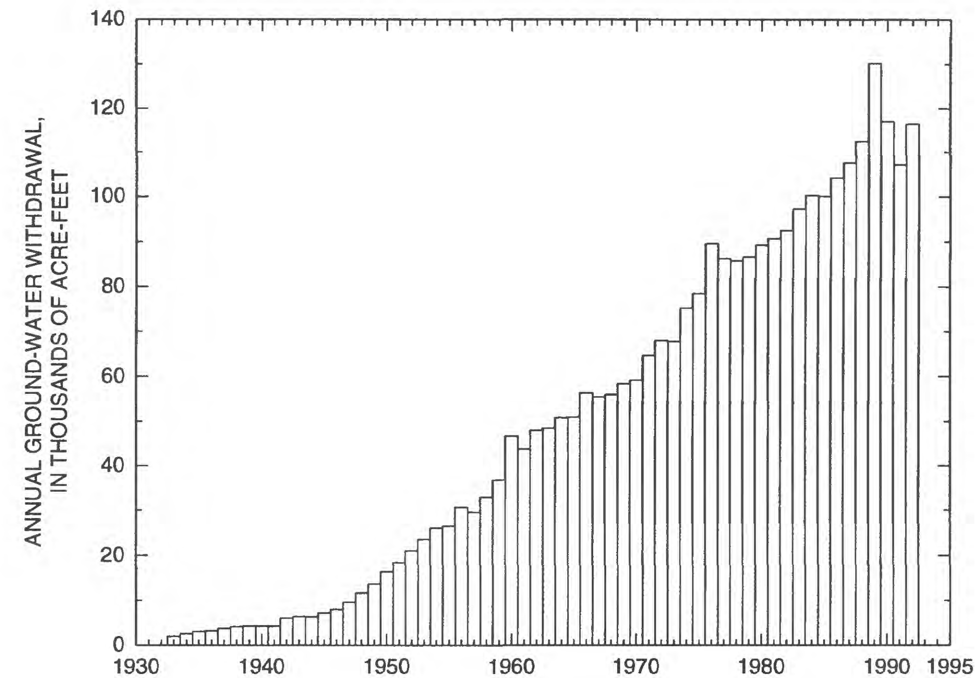


Figure 23.--Annual ground-water withdrawal for the City of Albuquerque, 1933–92 (data from Bjorklund and Maxwell, 1961; Sorensen, 1982; Wilson, 1992; and files of New Mexico State Engineer Office, Albuquerque).

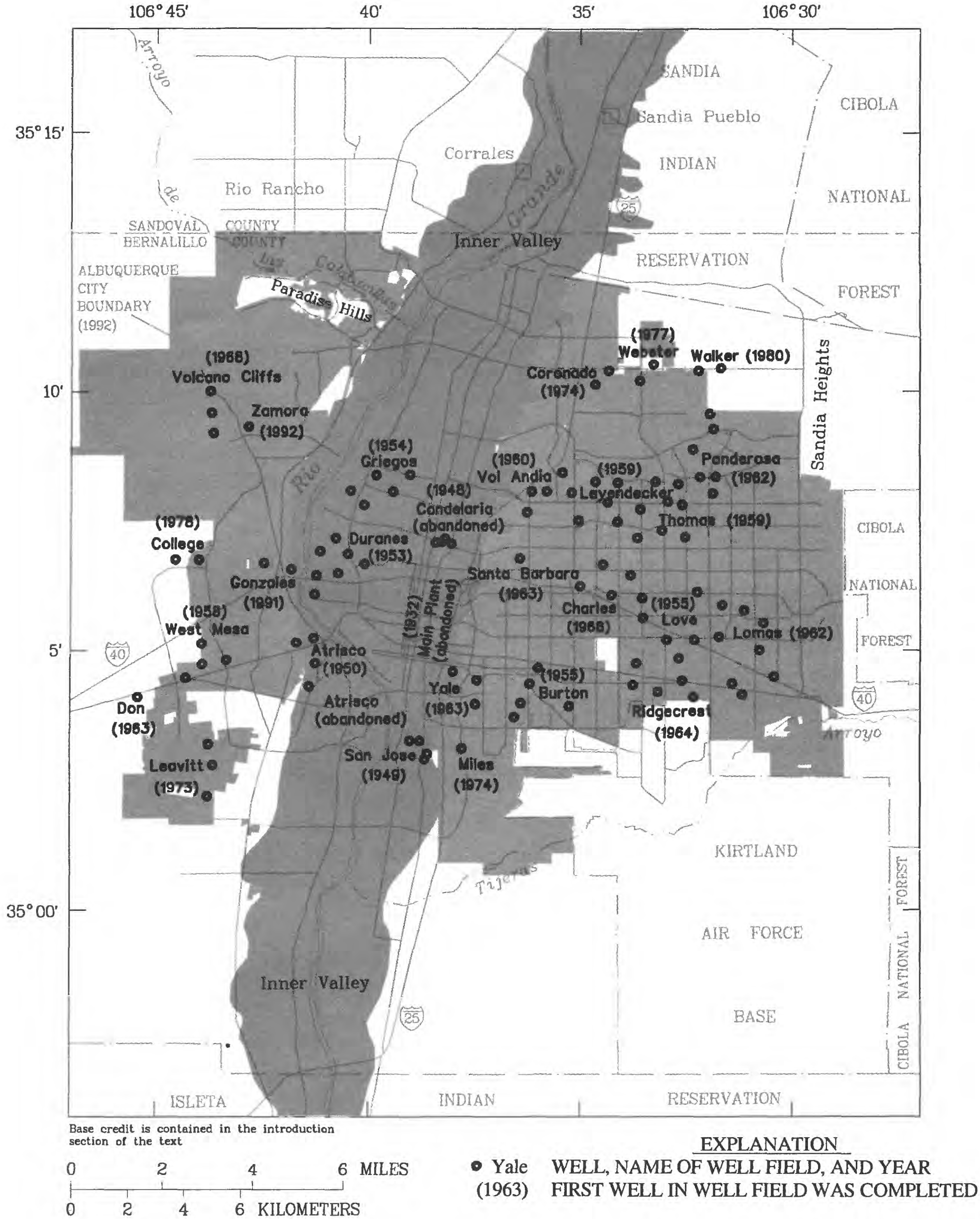


Figure 24.--Location of City of Albuquerque wells, 1993.

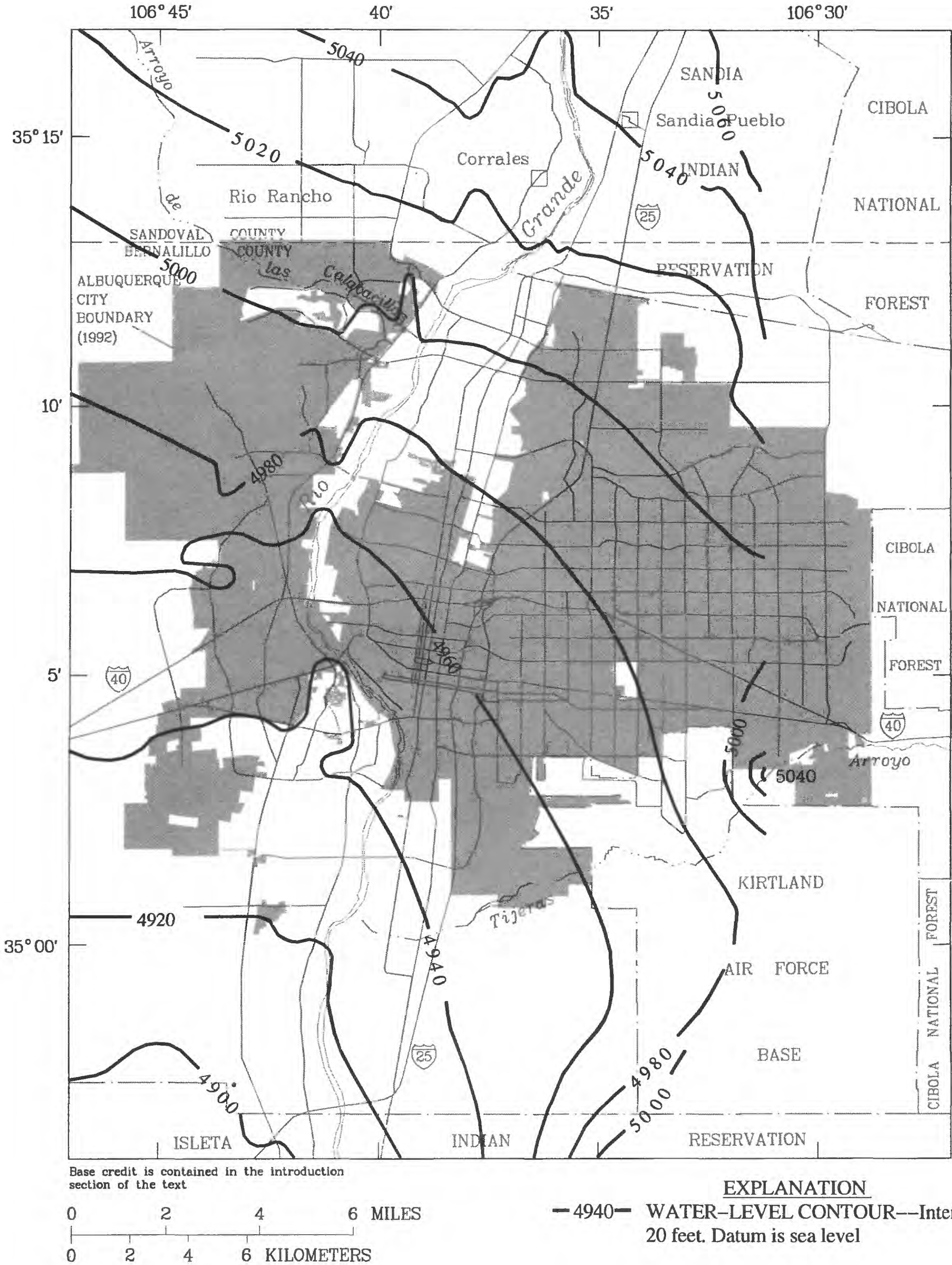
Ground-Water Levels And Water-Level Changes

Water-level contours that represent predevelopment steady-state conditions in the Albuquerque Basin were calculated using a ground-water flow model by Kernodle and Scott (1986). Those steady-state contours for the Albuquerque area are shown in figure 25. Steady state is a hypothetical condition. The existence of a steady-state potentiometric-head distribution is based on the presumption that all natural climatic stresses influencing the aquifer also are unchanging. However, climatic changes do occur (figs. 8 and 9) and the report of Kernodle and Scott (1986) showed that the Albuquerque-Belen Basin needed at least 200 years to almost completely respond to only a 10-percent change in mountain-front and tributary recharge. Because climatic variations are cyclically occurring, the potentiometric heads in the aquifer system naturally would be changing regardless of changes in ground-water withdrawals.

The model of Kernodle and Scott (1986) and Kernodle and others (1987) had an intentional oversimplification in design and construction: the water-table heads in the 150-foot-thick alluvial aquifer in the Rio Grande inner valley were simulated as being fixed at the modern altitudes of interior and riverside drains and the river. Therefore, the heads in the inner valley shown in figure 25 reflect conditions that might have existed in the mid- to late 1930's after the construction of drains but prior to large-scale ground-water development, instead of early-agricultural or pre-ground-water development (early 1600's). Outside the valley the water-table altitudes were computed as a function of the simulated values of recharge, hydraulic conductivity, and aquifer thickness. The simulated hydraulic-conductivity values and thicknesses are now known to be incorrect but, to a large extent, the errors would be offsetting for a steady-state simulation. Therefore, these contours need to be considered only an approximation of the water levels in the aquifer prior to development. The concentric contours on the southeast side of Albuquerque reflect the simulated recharge from Tijeras Arroyo.

Theis (1938) constructed water-level contour maps representing 1936 conditions in the irrigated areas of the middle Rio Grande Valley (Theis, 1938, p. 270-272, pls. 6-9). Those maps cover most of the inner Rio Grande Valley of the Albuquerque Basin from south of the Jemez River. The 1936 contours are shown in figure 26 for the Albuquerque area. Flexures in the contours reflect the interaction between ground water in the aquifer and surface water in the Rio Grande, canals, and drains. Any effects of ground-water withdrawal in Albuquerque are not identifiable from the 1936 contours of Theis (1938).

Bjorklund and Maxwell (1961) constructed water-level contours representing 1960 conditions in the Albuquerque area and Titus (1963) constructed contours representing 1961 conditions in Valencia County. These two maps are combined in figure 27 to represent 1960-61 conditions in most of the Albuquerque Basin. Bjorklund and Maxwell's 1960 contours in the Albuquerque area (fig. 28) show the effects of ground-water withdrawal. Substantial cones of depression are shown near present-day Interstate 25 and on the east side of Albuquerque.



EXPLANATION

—4940— WATER-LEVEL CONTOUR--Interval 20 feet. Datum is sea level

Figure 25.--Simulated water table that represents steady-state conditions in the Santa Fe Group aquifer system in the Albuquerque area, Central New Mexico (Modified from Kernodle and Scott, 1986).

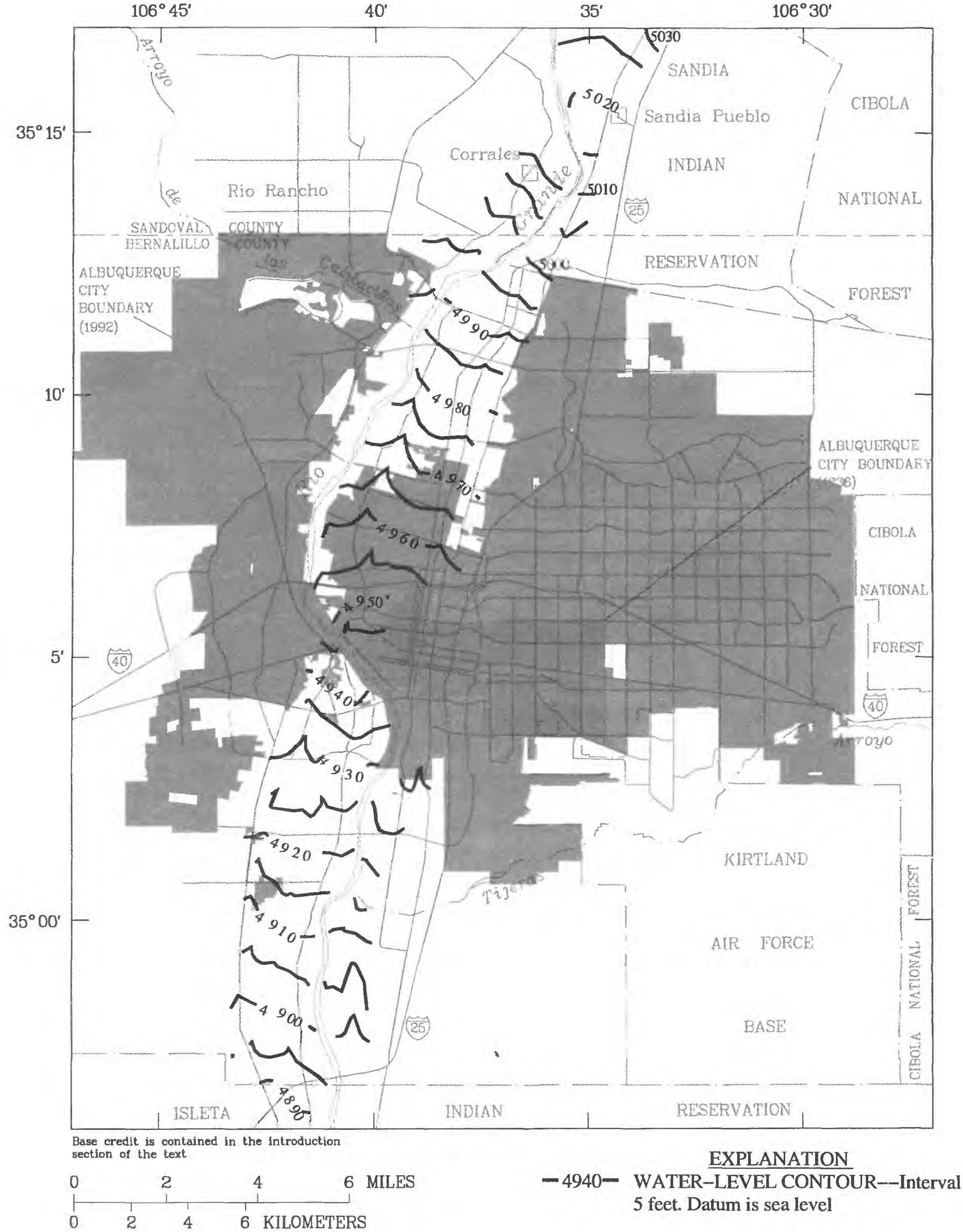
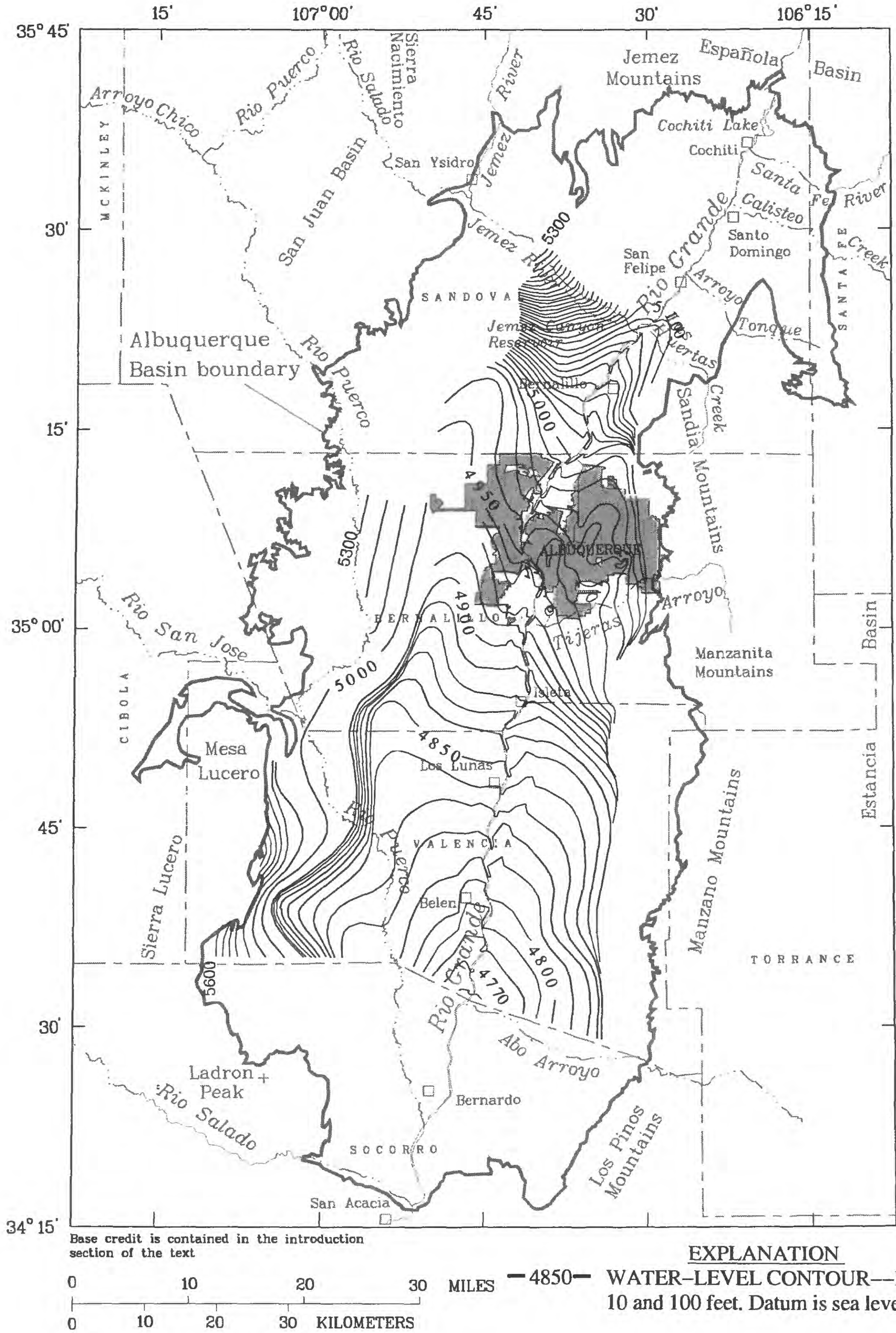


Figure 26.--Ground-water levels that represent 1936 conditions in the Santa Fe Group aquifer system in the Albuquerque area, Central New Mexico (Modified from Theis, 1938, pl. 6).



EXPLANATION

—4850— WATER-LEVEL CONTOUR—Intervals 10 and 100 feet. Datum is sea level

Figure 27.—Ground-water levels that represent 1960–61 conditions in the Santa Fe Group aquifer system in the Albuquerque Basin, Central New Mexico (Modified from Bjorklund and Maxwell, 1961; and Titus, 1963).

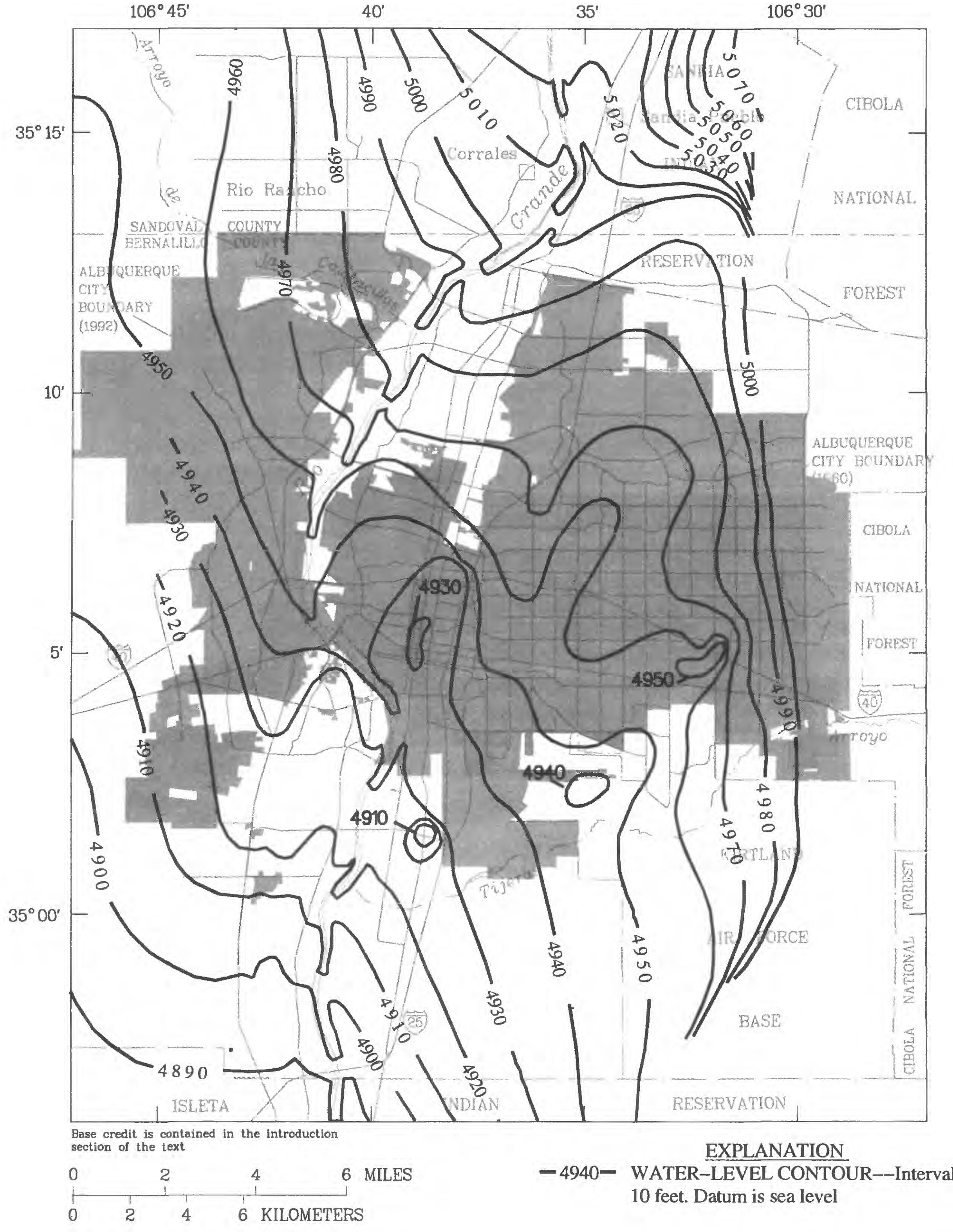


Figure 28.—Ground-water levels that represent 1960 conditions in the Santa Fe Group aquifer system in the Albuquerque area, Central New Mexico (Modified from Bjorklund and Maxwell, 1961).

Summers (1992) constructed water-level contours that represent winter 1988-89 conditions in the Albuquerque area (fig. 29). A large cone of depression had developed on the east side of Albuquerque as a result of ground-water withdrawal, as shown in figure 29. The general direction of ground-water flow in the area just north of Tijeras Arroyo and east of Interstate 25 had reversed from the conditions existing in 1960 (fig. 28). In 1960, the general direction of ground-water flow in that area was to the southwest. In 1989 it was to the northeast toward City production wells (fig. 29).

Water-level contours that represent conditions in the Albuquerque area in early 1992 are shown in figure 30. The contours show the continuing development of the large cone of depression in the eastern part of Albuquerque. Cones of depression can also be seen in the northwest part of Albuquerque near the Volcano Cliffs well field and in the south-central part of Albuquerque near the San Jose well field (figs. 24 and 30).

As discussed previously in the hydrostratigraphic units section, the most productive zones of the aquifer are in the upper part of the Santa Fe Group, east of the Rio Grande. The saturated thickness of the upper part of the Santa Fe Group in 1992 is shown in figure 31 for the Albuquerque area. The thickest part, about 1,100 to 1,400 feet, is along the Rio Grande between the Isleta and Rio Grande Faults. West of the Isleta Fault the saturated thickness ranges from 0 to about 600 feet. Between the Rio Grande and West Sandia Faults, the saturated thickness ranges from about 500 to 900 feet and averages about 600 feet. The saturated thickness between the West Sandia and Sandia Faults is generally less than 200 feet. The saturated upper part of the Santa Fe Group is discontinuous across the West Sandia Fault.

Figures 32 through 34 show lines of equal water-level decline from the calculated steady state (predevelopment; Kernodle and Scott, 1986) to 1992 (fig. 32), from 1960 to 1992 (fig. 33), and from 1989 to 1992 (fig. 34). The decline maps were constructed by computing the differences between the water-level contours shown in figures 25 and 28 through 30.

As discussed previously, the water-level contours representing the steady-state condition (fig. 25) need to be considered approximate; therefore the map of water-level decline for steady state to 1992 also needs to be considered approximate. All of the water-level decline maps show similar patterns of decline. The least amount of decline has occurred between the Isleta and Rio Grande Faults where the upper part of the Santa Fe Group has the largest saturated thickness and where ground-water withdrawal has the greatest potential for inducing recharge from the Rio Grande surface-water system. The greatest declines over the long term have occurred in the area of Albuquerque east of the limit of axial channel deposits (figs. 32 and 33) where the permeability is comparatively lower. Water-level declines of 140 feet since 1960 (fig. 33) and possibly as much as 160 feet since predevelopment (fig. 32) have occurred in that area.

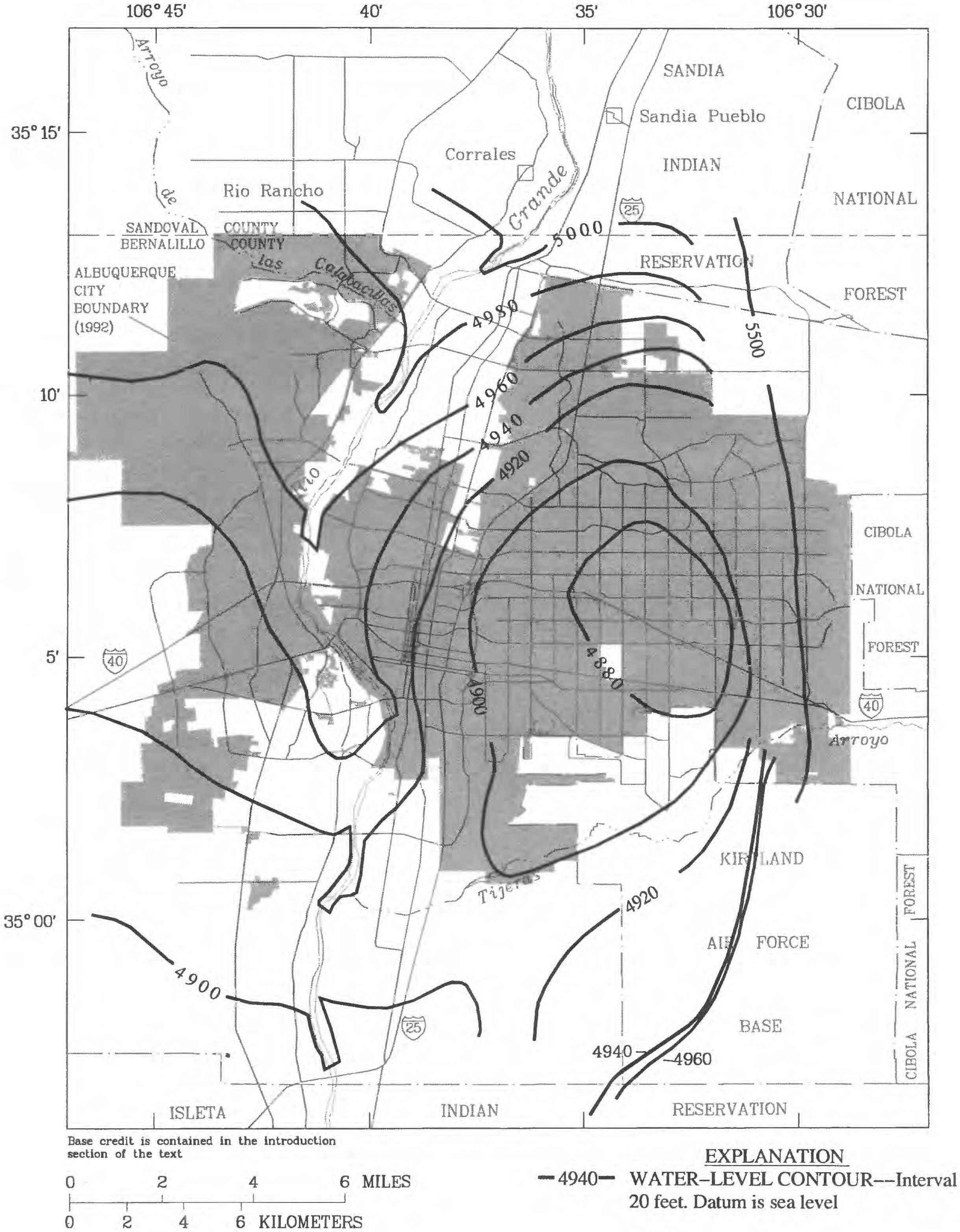


Figure 29.--Ground-water levels that represent 1988–89 conditions in the Santa Fe Group aquifer system in the Albuquerque area, Central New Mexico (Modified from Summers, 1992).

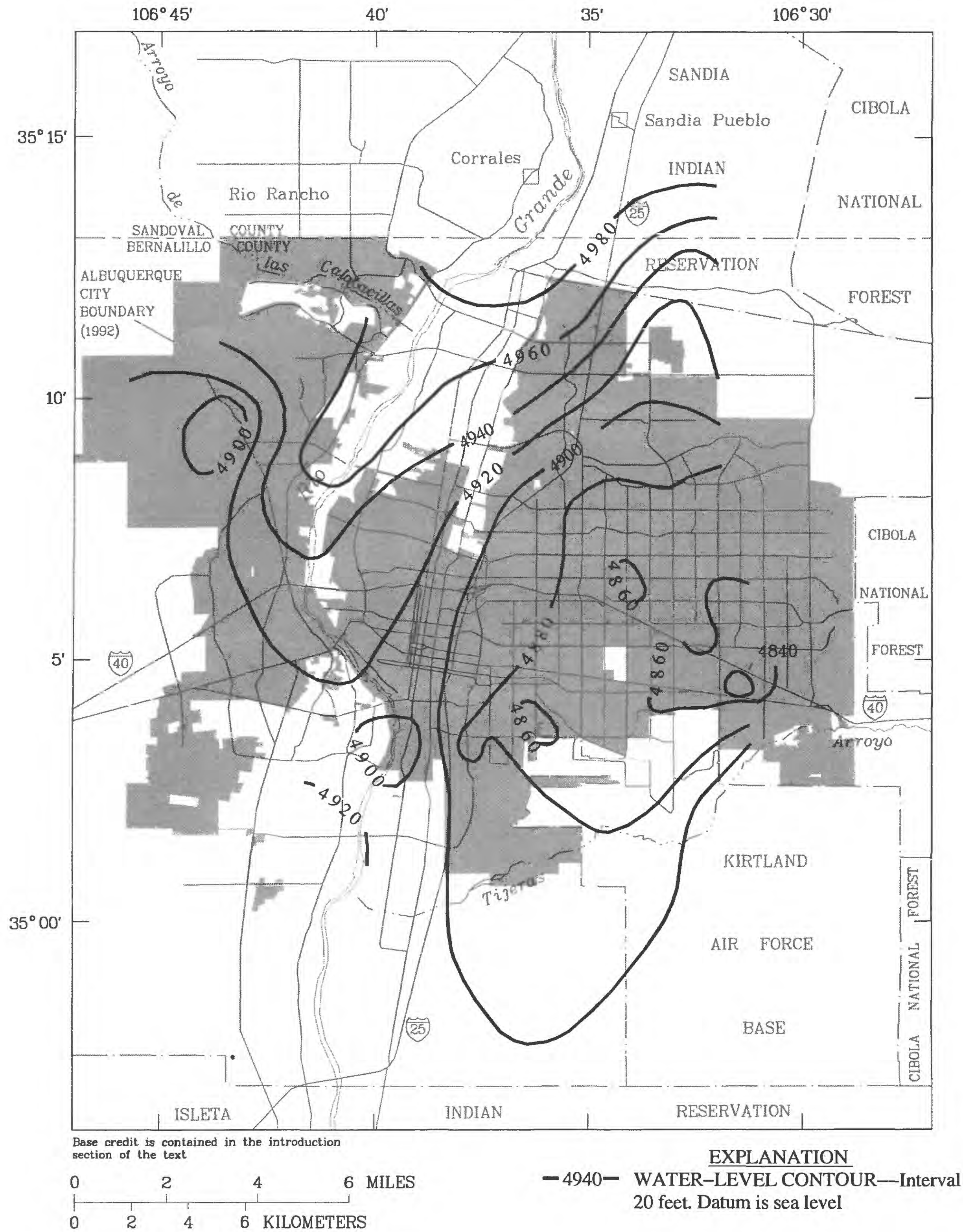


Figure 30.—Ground-water levels that represent 1992 conditions in the Santa Fe Group aquifer system in the Albuquerque area, Central New Mexico.

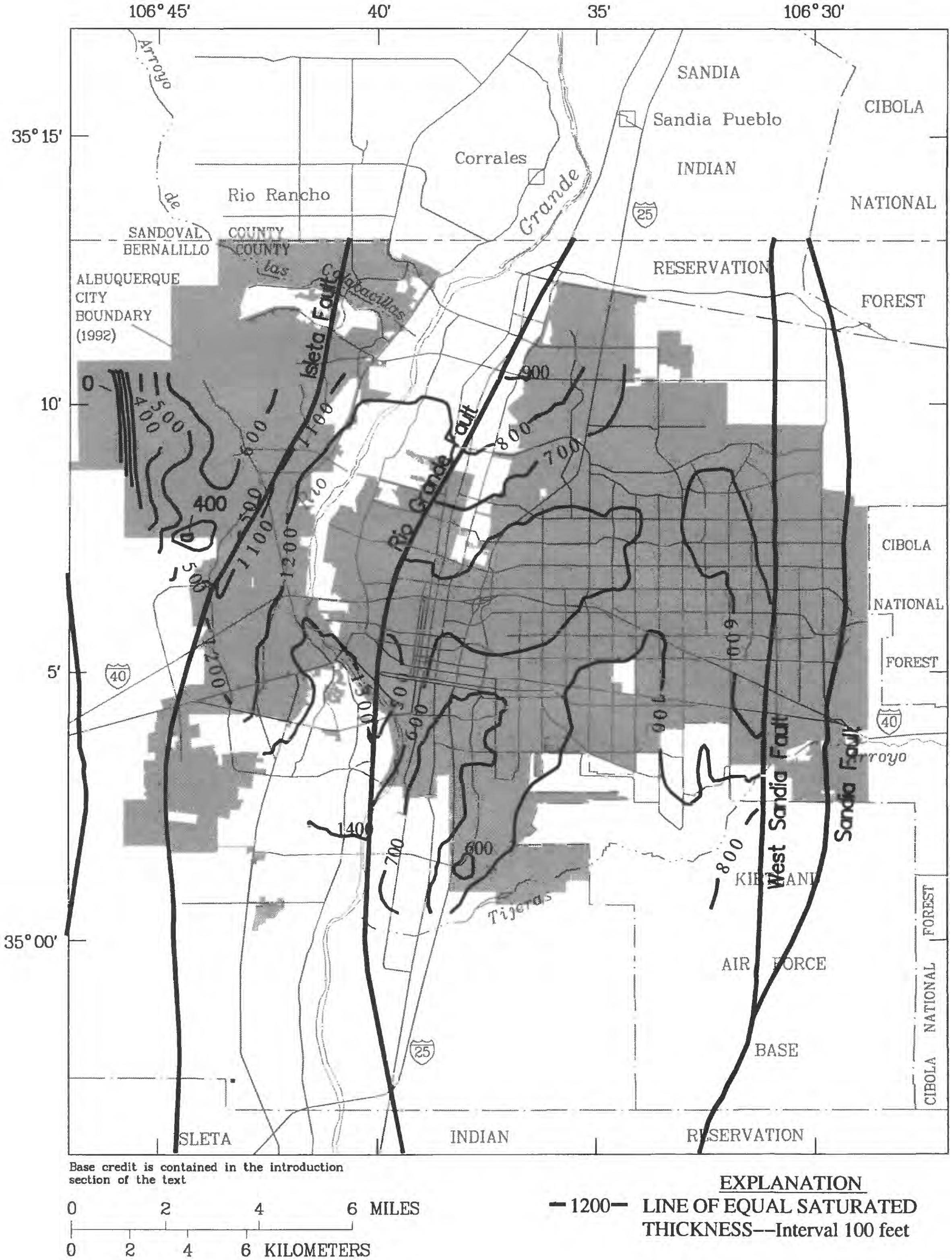
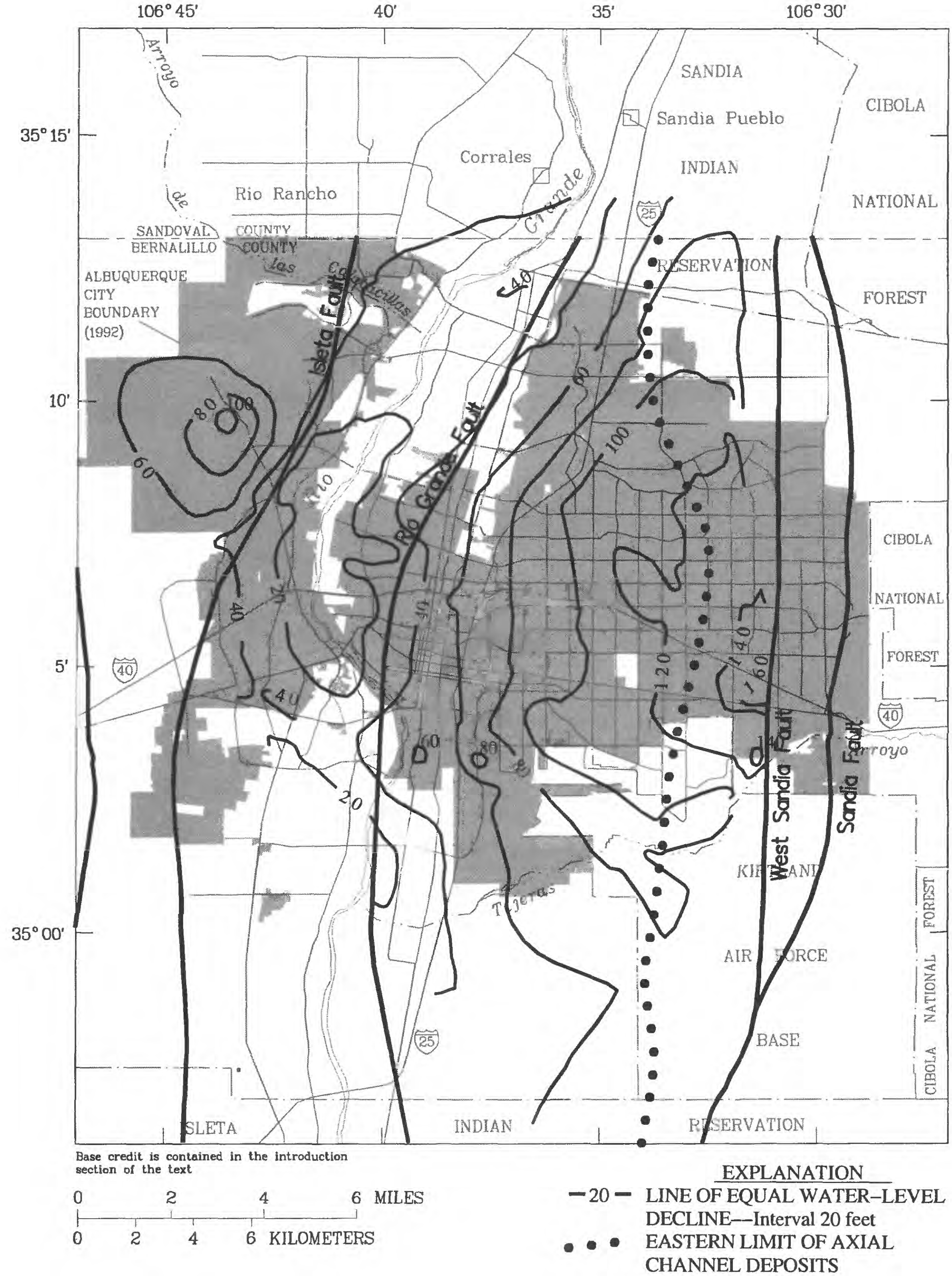


Figure 31.--Saturated thickness of the upper part of the Santa Fe Group in the Albuquerque area, Central New Mexico, 1992.



EXPLANATION

—20— LINE OF EQUAL WATER–LEVEL DECLINE––Interval 20 feet

• • • EASTERN LIMIT OF AXIAL CHANNEL DEPOSITS

Figure 32.––Water–level declines in the Santa Fe Group aquifer system that represent steady–state water levels (From Kernodle and Scott, 1986) minus 1992 water levels in the Albuquerque area, Central New Mexico.

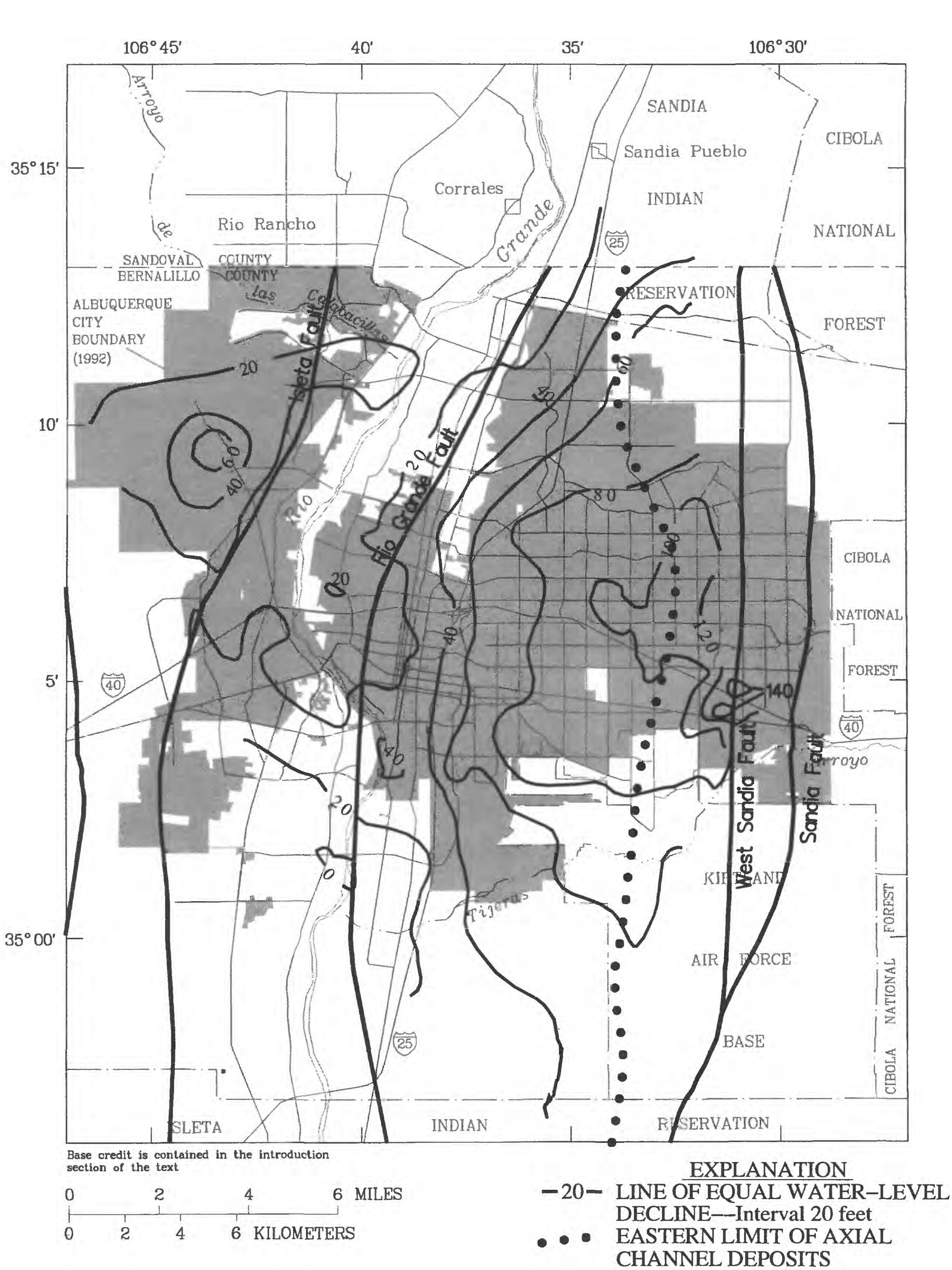


Figure 33.—Water–level declines in the Santa Fe Group aquifer system that represent 1960 (From Bjorklund and Maxwell, 1961) minus 1992 water levels in the Albuquerque area, Central New Mexico.

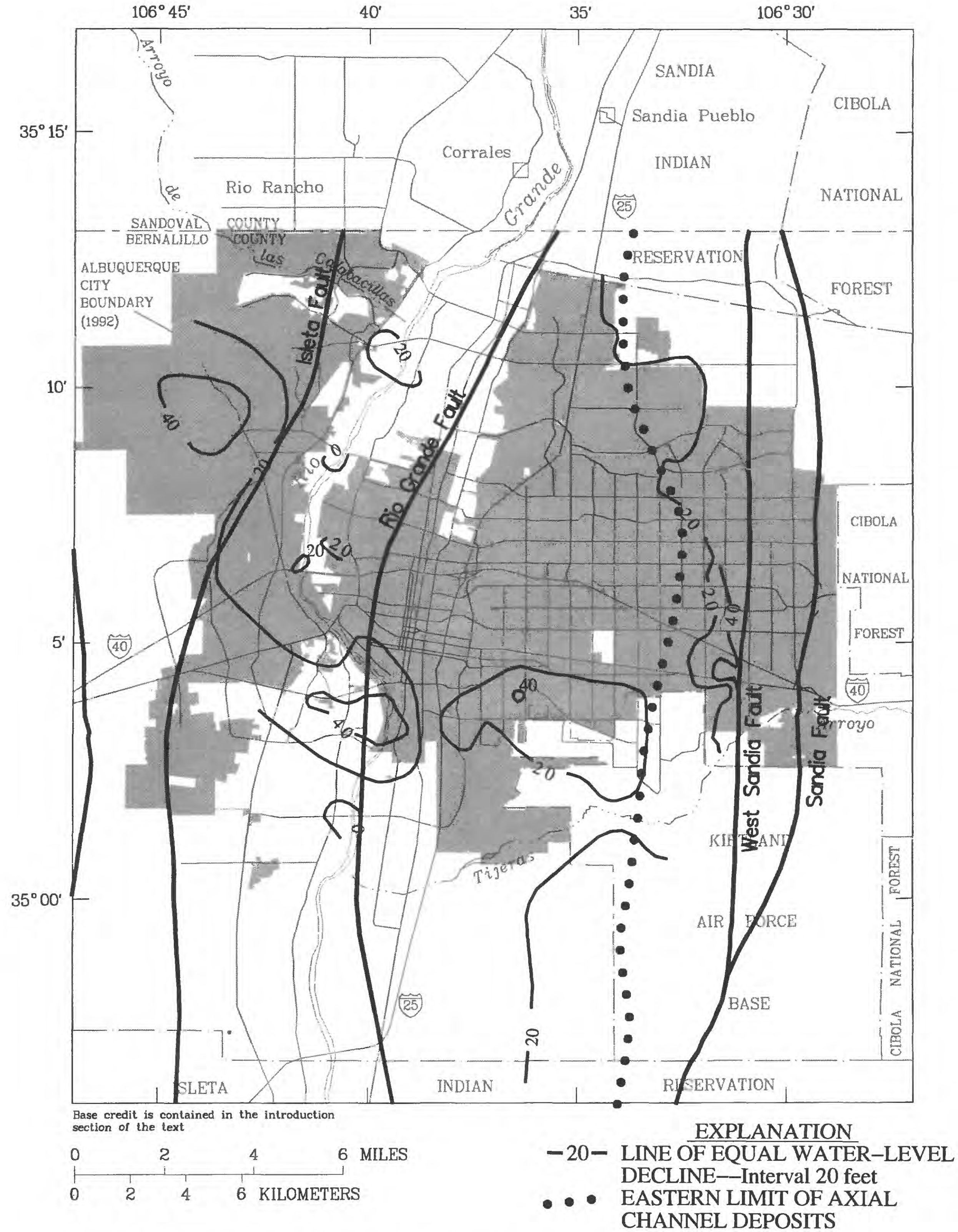


Figure 34.—Water–level declines in the Santa Fe Group aquifer system that represent 1989 (From Summers, 1992) minus 1992 water levels in the Albuquerque area, Central New Mexico.

The recent work by Hawley and Haase (1992) has added more detail in the Albuquerque area to the broader tectonic-framework descriptions of Lozinsky (1988) and Russell and Snelson (1991). Although knowledge of the details of variations in hydrostratigraphic properties is vital to a full understanding of the Santa Fe Group aquifer system, a broader understanding of the genesis of the aquifer materials and structural controls on ground-water flow is sufficient to explain most of the rapid ground-water-level declines and water-well production problems that are now being observed in the Albuquerque area. As Albuquerque grew eastward beyond the traditional confines of the valley, where an intricate system of surface-water diversions satisfied all horticultural needs and domestic water-supply needs were minimal, the City expanded into an area overlying the only presently known part of the Santa Fe Group aquifer in the Albuquerque Basin that could support rapid and intense development.

Ground water withdrawn from the Santa Fe Group in the Albuquerque area comes from three sources: depletion of aquifer storage, capture of mountain-front and tributary recharge (a constant quantity that is unaffected by withdrawals), and induced recharge from the surface-water system through or across the recent flood-plain alluvium. Local hydraulic properties of the alluvium control the degree of connection between the surface-water system and the Santa Fe aquifer. Anderholm and Bullard (1987) reported 12 to 15 feet of clay at a depth of 20 to 25 feet in the alluvium east of the Rio Grande in the southern part of the Albuquerque area. North of Interstate 40 and east of the Rio Grande they reported a similar thickness of clay and silt but at a depth beginning near land surface. Clay layers in the alluvium restrict the vertical movement of water. North of Interstate 40 the clay is shallow and the Rio Grande probably has cut through the clay and is in hydraulic connection with a sequence of high-permeability alluvium. South of Interstate 40 the clay is deeper and is not breached by the river. In this area the Santa Fe Group is not in good hydraulic connection with the surface-water system.

Figure 34, which is a map of water-level change from 1989 to 1992, shows examples of the effect of each of the ground-water controls outlined above. First, there is a tendency for contours to be aligned with the eastern limit of the axial channel deposits in the Santa Fe Group. Water-level-change contours tend to parallel the contact because of the contrast in hydraulic conductivity of the aquifer material.

Another phenomenon is occurring in the vicinity of the Volcano Cliffs well field (figs. 24 and 34), where the 20-foot line of equal water-level decline runs parallel to the Isleta Fault. The fault appears to be a barrier or partial barrier to ground-water flow even though the saturated thickness of the upper part of the Santa Fe Group increases by about 600 feet east of the fault (fig. 31).

The effect of the West Sandia Fault on water-level declines is pronounced. In addition to being a probable barrier to flow the West Sandia Fault places the middle part of the Santa Fe Group sediments on the east against the pediments-slope facies of the upper part of the Santa Fe. The low hydraulic conductivity of both of these units has caused rapid water-level declines and a reduction in the water-producing capacity of wells in the area. Several wells in the Lomas well field (fig. 24) recently have been abandoned because of marked decreases in efficiency.

Ground-water levels near the Rio Grande generally have declined 20 feet or less from 1989 to 1992 (fig. 34) except in the vicinity of the San Jose well field (fig. 24). Withdrawal from the well field is not especially great (about 3,000 acre-feet per year). However, clay in the alluvium has restricted recharge from the Rio Grande and allowed the regional water table, in the Santa Fe Group aquifer system, to separate from a shallow perched zone. The Rio Grande Fault might also function as a boundary, increasing the rate of decline near the San Jose well field.

Ground-water-level changes for the period 1960-92 (fig. 33) also show a relation to faults and hydrostratigraphic variations. Low hydraulic conductivity and the presence of the West Sandia Fault have resulted in the greatest water-level decline in the area. Likewise, the Isleta Fault is a barrier to ground-water flow westward to the Volcano Cliffs well field (fig. 24). The effect of the facies change from axial-channel to pediment-slope sediments is not as apparent as it is for the 1989-92 change map but the elongate north-south shape of the cone of depression under the East Mesa parallels the axis of the high hydraulic-conductivity zone.

Measured ground-water levels and areal water-level changes in the Albuquerque area are consistent with the conceptual hydrostratigraphic model presented by Hawley and Haase (1992). The model also provides an explanation for rapid water-level declines in individual wells and for decreases in well production capacity and efficiency.

Hydrographs of water levels in selected wells in the Albuquerque Basin are shown in figure 35. Figure 36 shows the locations of the wells for these hydrographs. The hydrographs show a range in water-level changes in the basin. As discussed in the previous paragraphs, water levels have declined the most in east Albuquerque, beyond the eastern limit of axial channel deposits (fig. 35N). The hydrographs show smaller water-level declines in other parts of the Albuquerque area (fig. 35F-M, O). Water levels have declined relatively little north (fig. 35A-E) and south (fig. 35R-V) of the Albuquerque area, and in the Rio Puerco Valley (fig. 35P).

EXPLANATION

LINES SHOWING CHANGE IN WATER LEVEL:

TIME BETWEEN MEASUREMENTS LESS THAN 2 YEARS-- + indicates time between measurements exceeds 1 percent of the period of record

- - - - - TIME BETWEEN MEASUREMENTS MORE THAN 2 YEARS

Location of wells shown in figure 36. Scales of hydrographs vary vertically and horizontally.

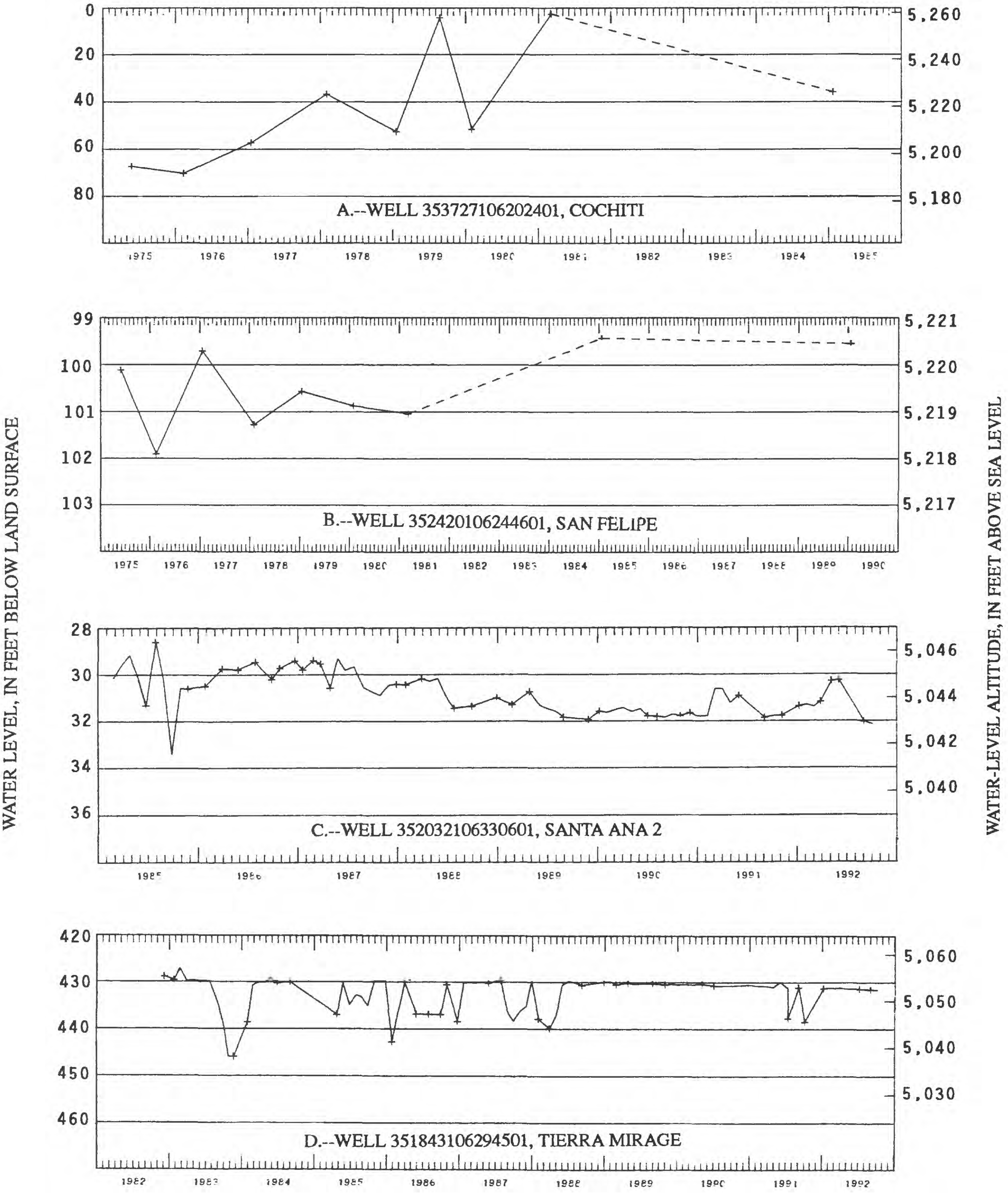


Figure 35.––Water levels in selected wells in the Albuquerque Basin, Central New Mexico.

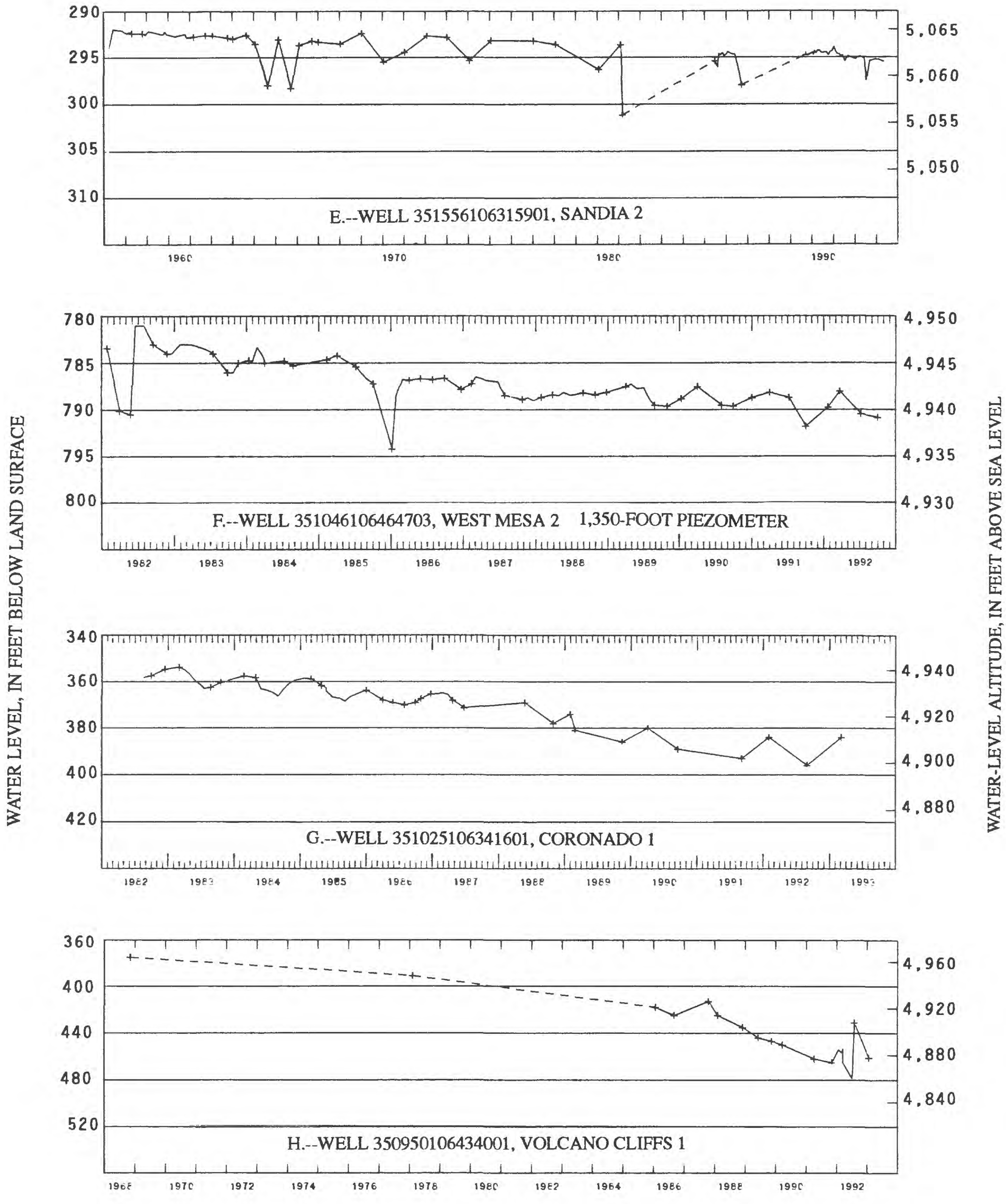


Figure 35.—Water levels in selected wells in the Albuquerque Basin, Central New Mexico—Continued.

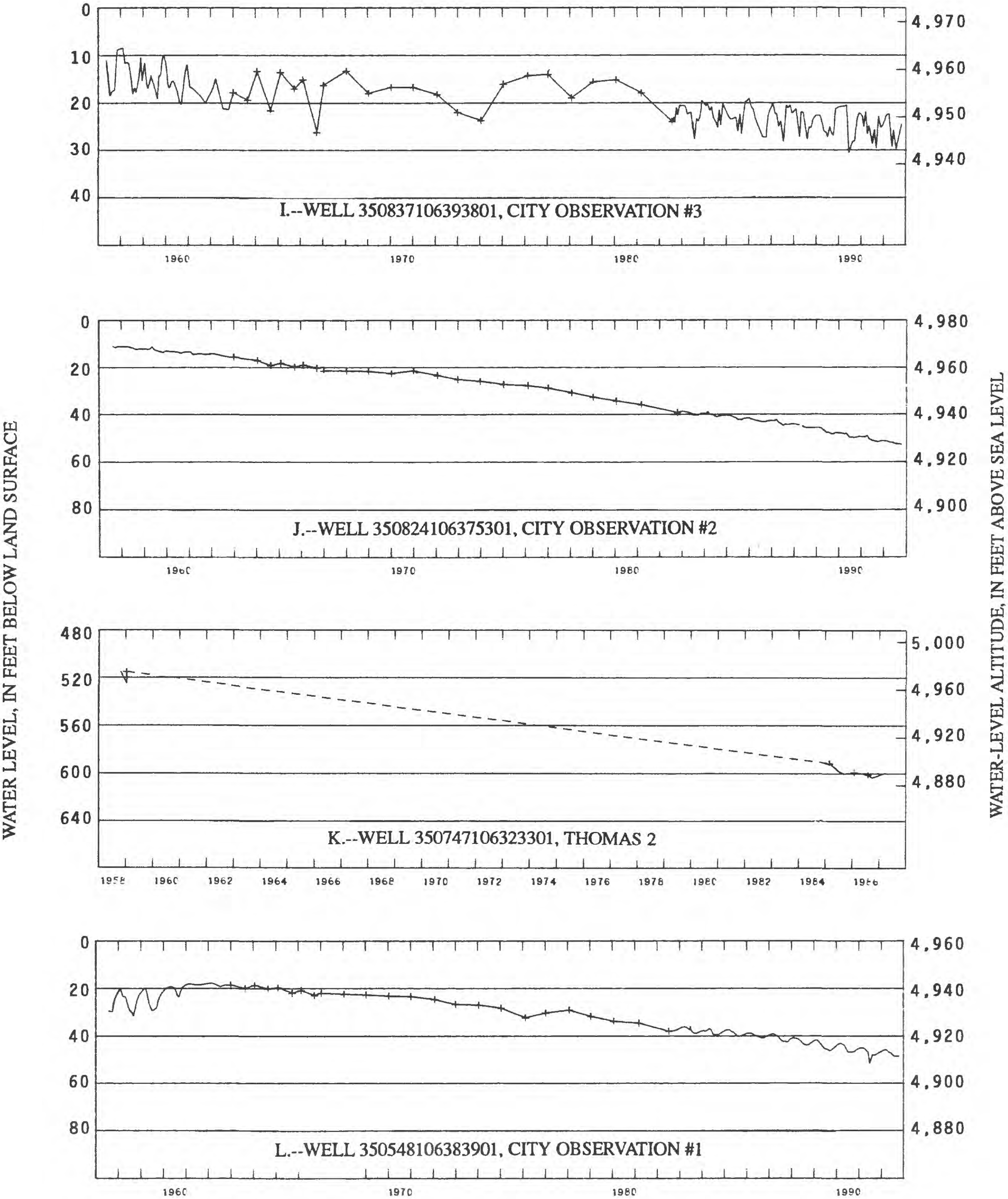


Figure 35.––Water levels in selected wells in the Albuquerque Basin, Central New Mexico––Continued.

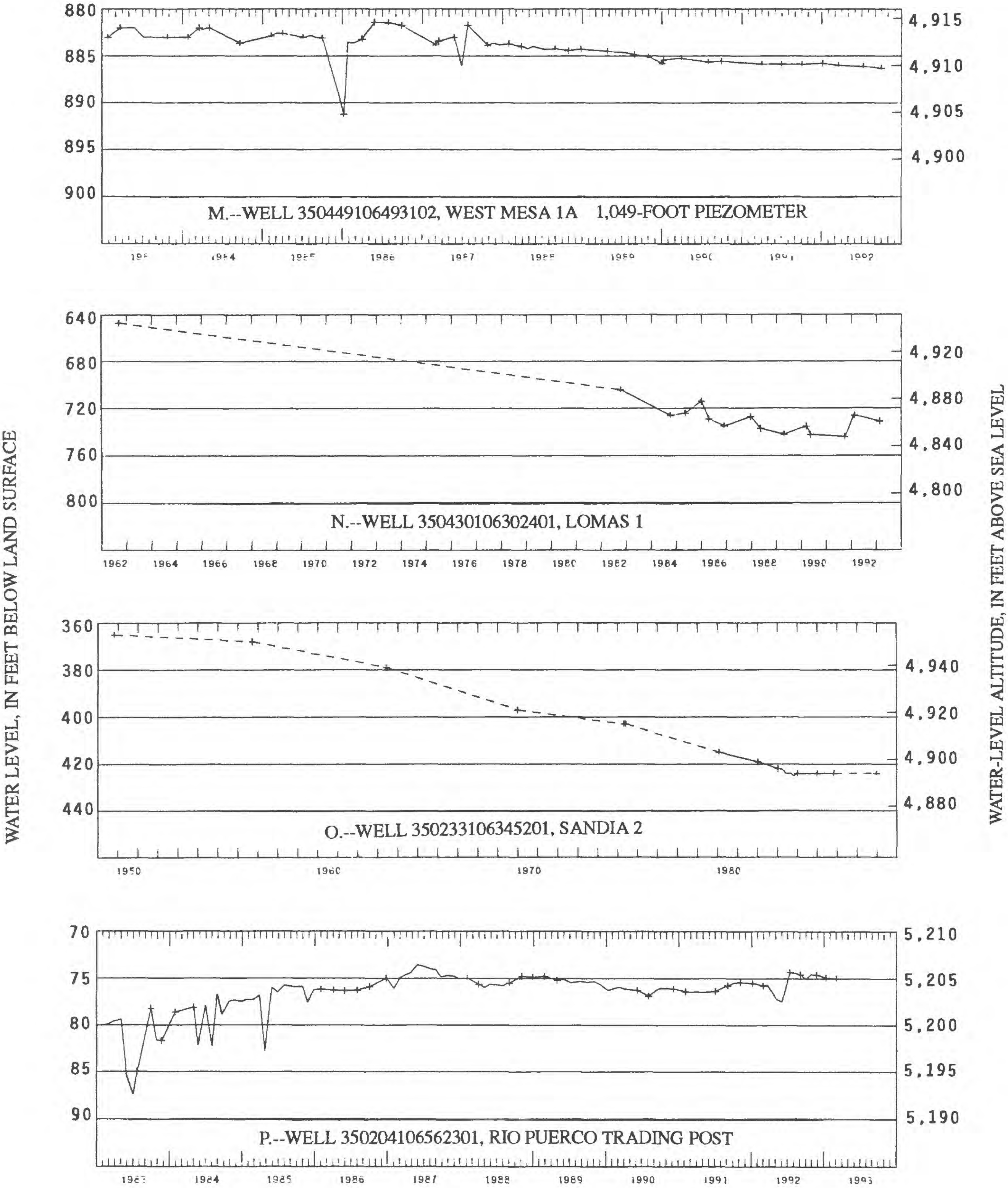


Figure 35.---Water levels in selected wells in the Albuquerque Basin, Central New Mexico---Continued.

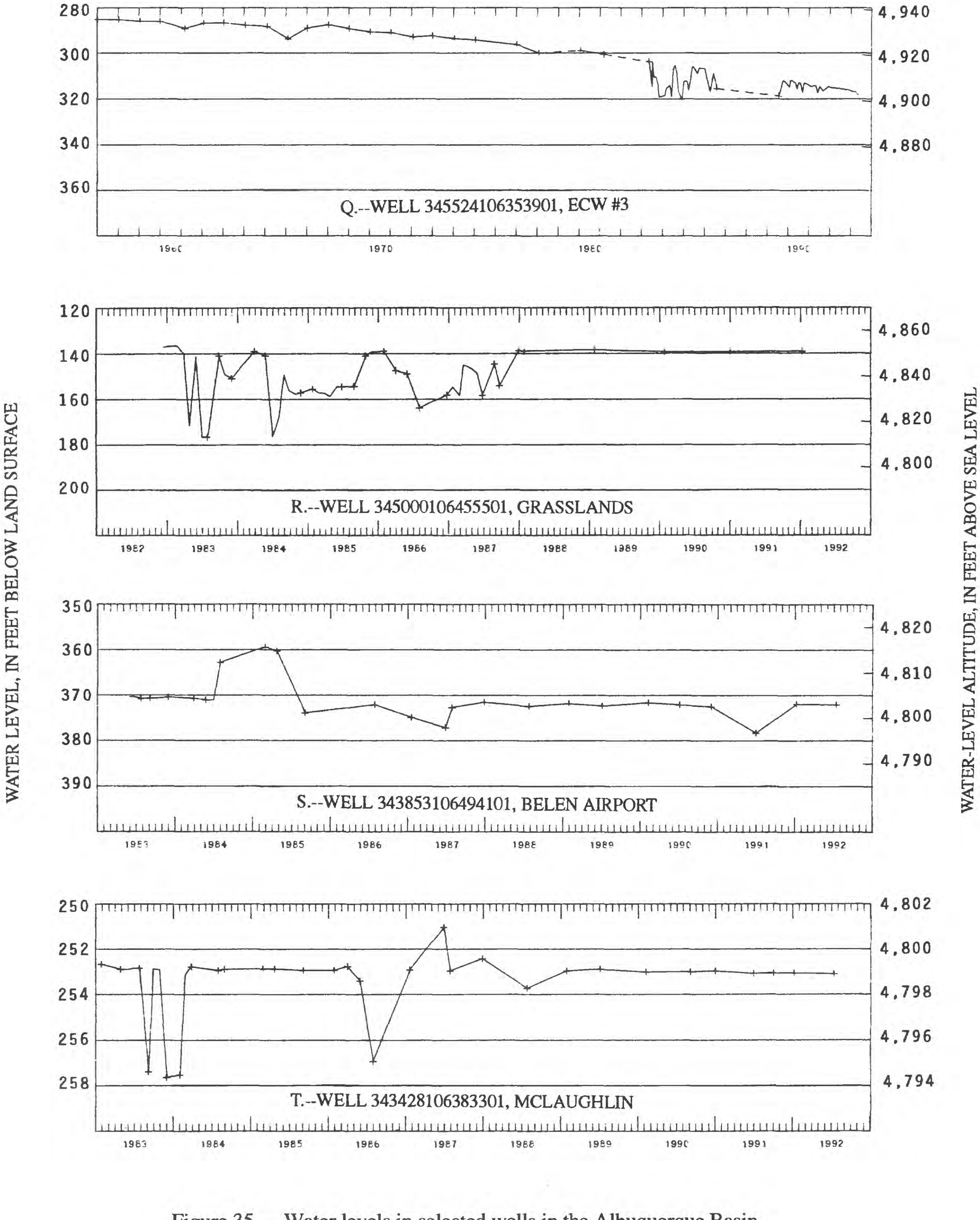


Figure 35.—–Water levels in selected wells in the Albuquerque Basin, Central New Mexico—–Continued.

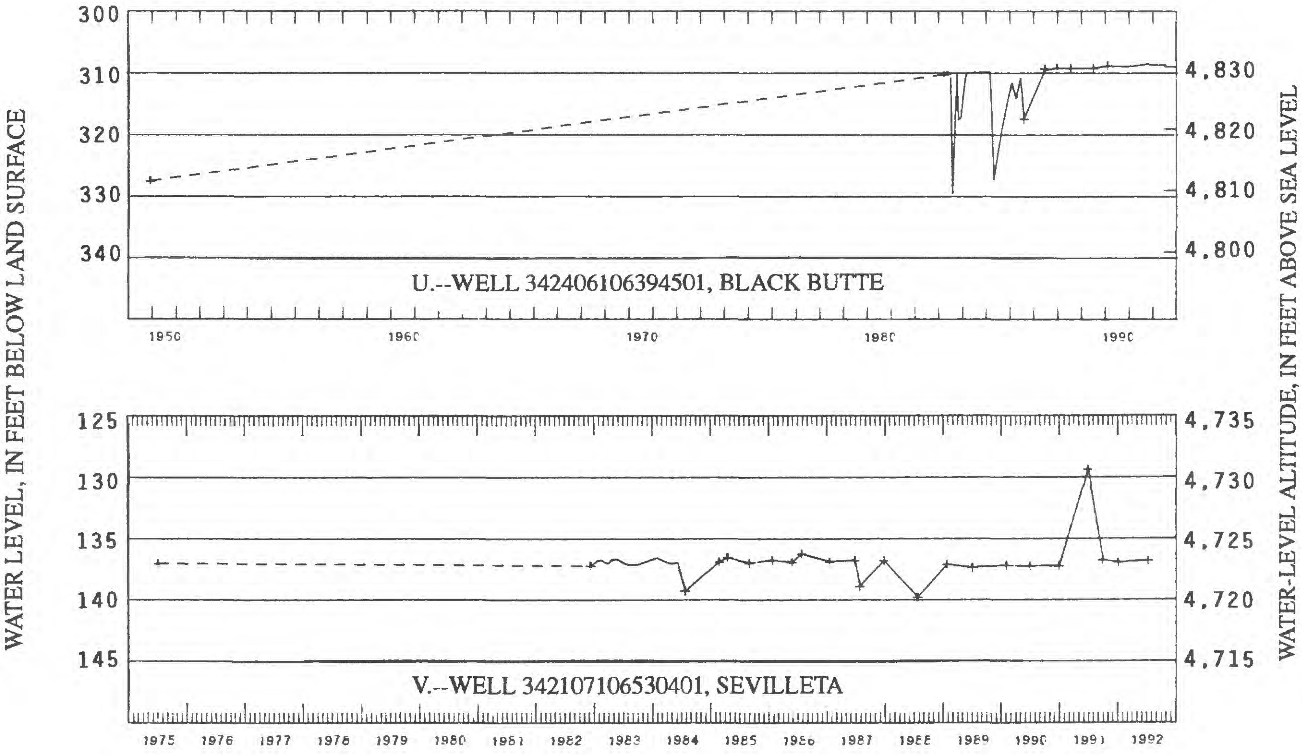
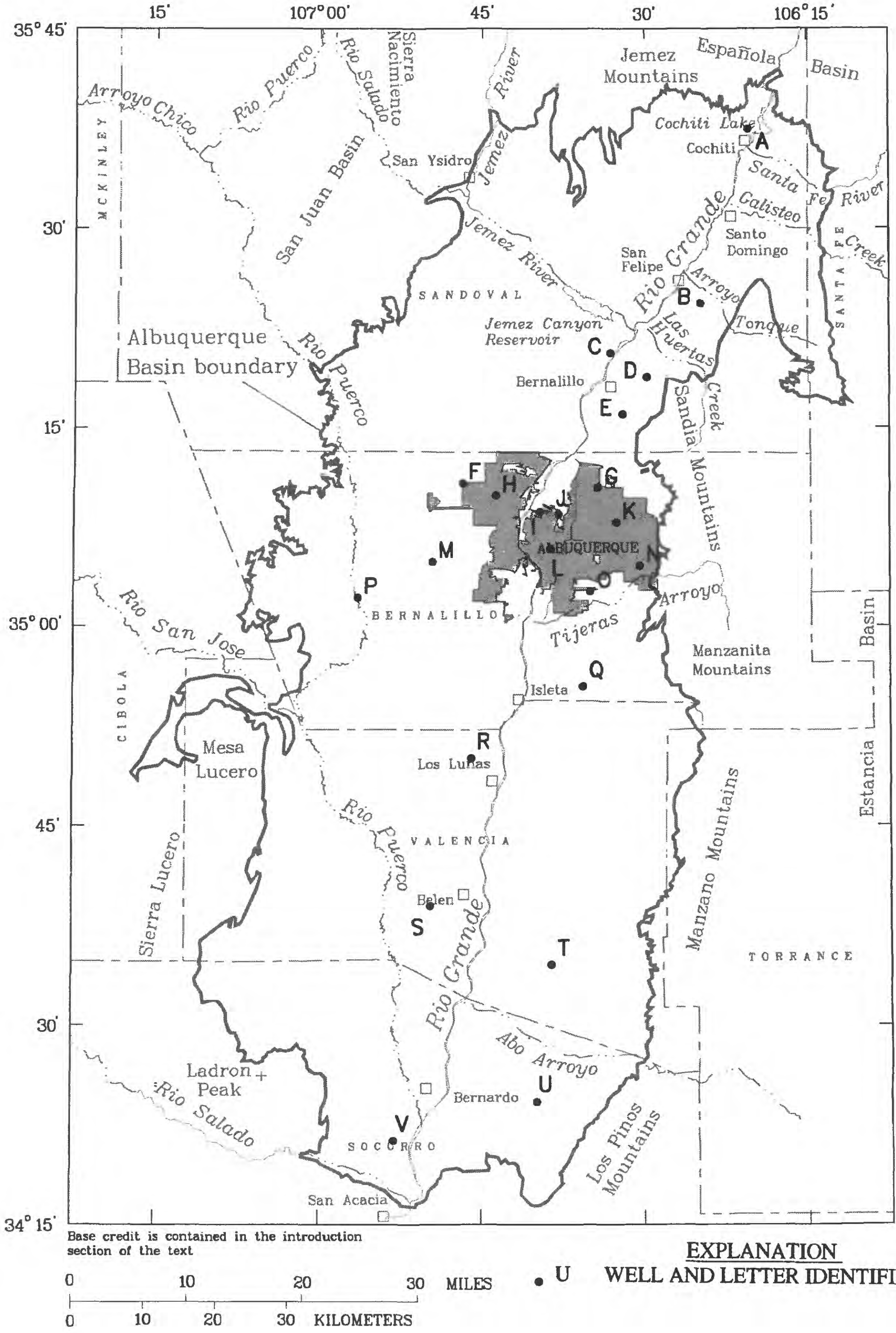


Figure 35.—–Water levels in selected wells in the Albuquerque Basin, Central New Mexico—–Concluded.



EXPLANATION

• U WELL AND LETTER IDENTIFIER

Figure 36.—Location of selected wells in the Albuquerque Basin, Central New Mexico.

Surface- and Ground-Water Inflow and Outflow

The surface-water system of the Albuquerque Basin consists of the Rio Grande and its tributaries; arroyos, washes, and flood-runoff impoundments (temporary containment of water); irrigation canals and drainage ditches; and municipal effluent. The Rio Grande is the only perennial stream in the Albuquerque Basin and is the major source of surface water. The Rio Grande flows the entire length of the basin in a general north-to-south direction, gaining about 12,900 square miles of drainage area as it flows through the basin.

The 1974 through 1992 mean annual inflow and outflow of the Rio Grande in the Albuquerque Basin is about 1,040,000 acre-feet (table 5). All mean annual flows presented in this section are from the 1974 through 1992 period of record, unless otherwise stated; 1974 marks the first full year of controlled flow by Cochiti Dam, located on the Rio Grande in the northern part of the Albuquerque Basin (fig. 37). A comparison of flow for the entire period of record compared through 1974 through 1992 is presented in table 5.

The Santa Fe River and Galisteo Creek enter the Rio Grande from the east bank at the north end of the basin (fig. 37). The Santa Fe River is diverted into Cochiti Lake by an extension of Cochiti Dam. The river channel below the dam, which receives inflow from springs, extends about 3 miles to the Rio Grande. The Santa Fe River drains an area of about 231 square miles before entering the Albuquerque Basin and has a mean annual flow to the basin of about 8,200 acre-feet (table 5); included in this flow is the return flow for the municipal supply for the City of Santa Fe. Galisteo Creek enters the Rio Grande downstream from Cochiti Lake. Galisteo Creek drains an area of about 597 square miles before entering the Albuquerque Basin and has a mean annual flow to the basin of about 3,900 acre-feet (table 5). Flow in Galisteo Creek is regulated by a flood detention dam located 0.4 mile upstream from the gage. Flow directly into the Rio Grande from the Santa Fe River or Galisteo Creek cannot be estimated because the reaches from where these two tributaries enter the Albuquerque Basin to the confluence with the Rio Grande are not gaged.

The Jemez River enters the Rio Grande from the west bank about 20 river miles upstream from Albuquerque (fig. 37). A major tributary to the Jemez River is the Rio Salado (northern Rio Salado; two Rio Salados are in the Albuquerque Basin), which has its headwaters in the San Juan Basin northwest of the Albuquerque Basin (fig. 37). The Rio Salado is not gaged. The Jemez River has a drainage area of about 470 square miles where it enters the Albuquerque Basin and about 1,038 square miles where it enters the Rio Grande. Mean annual inflow to the Albuquerque Basin from the Jemez River is about 64, 000 acre-feet, and mean annual inflow to the Rio Grande from the Jemez River is about 50,000 acre-feet (table 5). Jemez Canyon Reservoir, located on the Jemez River just upstream from the confluence of the Jemez River and the Rio Grande, was built primarily for sediment control. Current (1993) operation of the reservoir allows for a minimum amount of storage.

Table 5.--Mean annual surface-water inflow to and outflow from the Albuquerque Basin, Central New Mexico
[--, no data. Period of record is in water years unless otherwise indicated]

Station name (station number) and period of record	Period of record from 1974 through 1992		Entire period of record	
	Cubic feet per second	Acre-feet per year	Cubic feet per second	Acre-feet per year
		Inflow to the Albuquerque Basin		
Jemez River near Jemez (08324000); 1937-40, 1950, 1954-present	88	64,000	[1]77	[1]55,000
Rio Grande at Cochiti (08314500); 1924-70	--	--	[2]1,300	[2]950,000
Rio Grande below Cochiti Dam (08317400); 1970-present	1,440	1,040,000	[1]1,390	[1]1,005,000
Sili main canal (at head) at Cochiti (08314000); 1954-present	41	29,000	30	24,000
Cochiti east side main canal at Cochiti (08313500); 1954-present	77	55,000	60	43,000
Santa Fe River above Cochiti Lake (08317200); 1970-present	11	8,200	[1]9.8	[1]7,100
Galisteo Creek below Galisteo Dam (08317950); 1970-present	5	3,900	[1]6.3	[1]4,500
Rio San Jose at Correo (08351500); 1944-present	10	7,200	[1]12	[1]8,500
		Outflow from the Albuquerque Basin		
Rio Grande Floodway at San Acacia (08354900); 1959-present	[1]1,400	[1]1,040,000	1,200	870,000
		Tributary inflow to the Rio Grande		
Jemez River below Jemez Canyon Dam (08329000); 1937, 1944-present	70	50,000	[1]61	[1]44,000
City of Bernalillo water reclamation plant[3]	.7	[4]504	--	--
City of Rio Rancho water reclamation plant[5]	4.7	3,400	--	--
North Floodway Channel (08329900); 1968-present[6]	16	6,700	13	5,900
South diversion channel (08330775; 1988-present[7]	1	520	1	520

Table 5.--Mean annual surface-water inflow to and outflow from the Albuquerque Basin, Central New Mexico--Concluded

	Period of record from 1974 through 1992		Entire period of record	
Station name (station number) and period of record	Cubic feet per second	Acre-feet per year	Cubic feet per second	Acre-feet per year
Tijeras Arroyo near Albuquerque (08330600); 1983-present[7]	0.9	432	0.9	432
City of Albuquerque water reclamation plant[8]	76	55,000	--	--
City of Los Lunas water reclamation plant[9]	.6	415	--	--
City of Belen water reclamation plant[10]	--	--	--	--
Rio Puerco near Bernardo (08353000); 1941-present	32	23,000	[1]45	[1]32,000
Rio Salado near San Acacia (08354000); [11]1947-1984	[12]8	[12]5,900	14	10,400

[1]Borland and others, 1992.
[2]U.S. Geological Survey, 1971.
[3]City of Bernalillo, calendar years 1990-92, oral commun., 1993.
[4]Calendar years 1991-92.
[5]City of Rio Rancho, calendar years 1990-92, oral commun., 1993.
[6]No winter records in water years 1969-89.
[7]No winter records.
[8]City of Albuquerque, calendar years 1990-92, oral commun., 1993.
[9]City of Los Lunas, calendar years 1984-92, written commun., 1993.
[10]City of Belen, oral commun., 1993.
[11]Denis and others, 1985.
[12]Water years 1974-84.

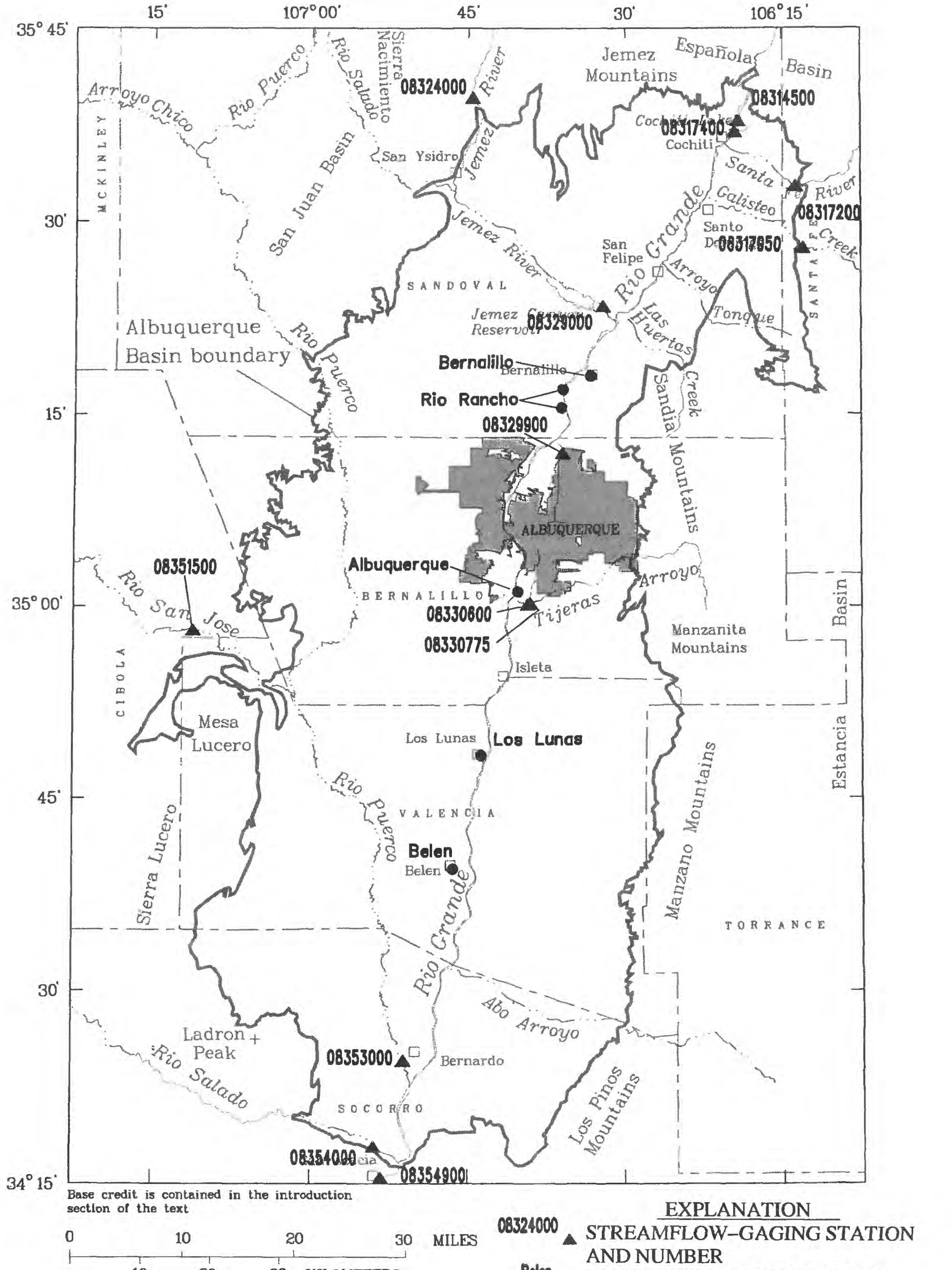


Figure 37.—Location of streamflow-gaging stations and treated-water discharge points in the Albuquerque Basin and vicinity, Central New Mexico.

The Rio Puerco enters the west bank of the Rio Grande about 50 miles south of Albuquerque and is one of the principal tributaries entering from the west (fig. 37). The Rio Puerco has its headwaters in the San Juan Basin about 110 river miles upstream from its confluence with the Rio Grande and drains an area of about 7,350 square miles, including an area of about 1,130 square miles that does not directly contribute to surface runoff. Mean annual inflow to the Rio Grande from the Rio Puerco is about 23,000 acre-feet. The Rio San Jose is a major tributary to the Rio Puerco and drains about 3,700 square miles before it enters the Albuquerque Basin (fig. 37). The mean annual flow of the Rio San Jose where it enters the Albuquerque Basin is about 7,200 acre-feet. Flow in the Rio San Jose is regulated to some extent by a dam located 79 miles upstream from the gage. Flow in both of these tributaries during the summer and fall is largely the result of runoff from thunderstorms.

The Rio Salado (southern) enters the Rio Grande from the west just downstream from the confluence of the Rio Grande and the Rio Puerco, close to the southern end of the Albuquerque Basin (fig. 37). The Rio Salado drains an area of about 1,380 square miles and receives most of its flow from storm runoff during the summer and fall months. Mean annual flow to the Rio Grande from the Rio Salado was about 5,900 acre-feet during 1974 to 1984.

Flow in arroyos and washes is another component of the surface-water system of the Albuquerque Basin. All flow in the arroyos and washes results from flood runoff from precipitation falling in the Albuquerque Basin or in the mountains bordering the basin. The three largest arroyos draining from the east are Las Huertas Creek, Tijeras Arroyo, and Abo Arroyo (fig. 37). These arroyos drain the west slopes and part of the east slopes of the Sandia, Manzanita, and Manzano Mountains. Of these three arroyos only Tijeras Arroyo, with a drainage area of 128 square miles, is gaged. The mean annual flow past the gaging station upstream from the confluence of Tijeras Arroyo with a drain paralleling the Rio Grande was about 432 acre-feet for 1983 to 1992. No arroyo draining the west side of the Albuquerque Basin is gaged.

Most arroyos do not discharge directly into the Rio Grande. They either lose their flow by infiltration or discharge into the network of drains and canals that parallel the river (Kernodle and Scott, 1986). Some recent work by Goetz and Shelton (1990) on infiltration in some arroyos in the Albuquerque area indicates an infiltration capacity of 0.05 acre-foot per mile of arroyo. Other evidence of infiltration of storm-water runoff through arroyo bottoms is the decrease of cross-sectional area and channel capacity in the downstream direction as noted by Bjorklund and Maxwell (1961).

Diversion of water from the Rio Grande into a series of irrigation canals is yet another important part of the surface-water system within the Albuquerque Basin. The major diversion of flow in the Rio Grande is from withdrawals used to irrigate lands along the Rio Grande. Surface water is diverted from the Rio Grande at Angostura (just upstream from the confluence of the Jemez River with the Rio Grande) and the Isleta Dam at Isleta. All diverted surface water is either evapotranspired, recharged to the shallow alluvium, or returned to the Rio Grande by a series of drains that parallel the river.

Drains along the Rio Grande in the Albuquerque Basin consist of two types: riverside and interior drains. The riverside drains were dug several feet below the level of the riverbed and intercept leakage from the river that normally would flood irrigated lands in the inner valley. Water in the riverside drains is transported down the valley to a point where the water level of the drain is equal to or greater than the stage of the river, thereby discharging to the river (Kernodle and Scott, 1986). Interior drains, located between the riverside drains and the outer boundary of the flood plain, intercept recharge from irrigation and leakage from canals. The interior drains discharge to the riverside drains. Both drain systems were designed to keep the water table in the flood plain at a depth favorable for irrigated crops. Riverside drains also receive treated water from some water reclamation plants to be discharged into the Rio Grande.

The communities of Bernalillo, Rio Rancho, Albuquerque, Los Lunas, and Belen discharge treated water from reclamation plants to the Rio Grande, either directly or through drains (fig. 37). Bernalillo discharges about 504 acre-feet per year, Rio Rancho discharges about 3,400 acre-feet per year, Albuquerque discharges about 55,000 acre-feet per year, and Los Lunas discharges about 415 acre-feet per year (table 5).

The major contribution to the ground-water system of the Albuquerque Basin is mountain-front and tributary recharge (fig. 38). Mountain-front recharge contributes to the ground-water system by the infiltration of runoff originating from the uplifted areas adjacent to the basin. Precipitation originating in the uplifted areas flows in a series of arroyos and tributaries that carry runoff away from the basin boundaries onto the basin floor. This runoff infiltrates both at the boundary of the basin and through the bottoms of arroyos and tributaries. Most mountain-front recharge occurs along the eastern boundary of the Albuquerque Basin. This area has the greatest topographic relief in the basin and hence the greatest amount of precipitation (figs. 2 and 5). The tributaries that contribute the most to the ground-water system are the Jemez River, Santa Fe River, and Galisteo Creek in the northern part of the basin and Abo Arroyo in the southern part of the basin (fig. 38). Total contribution to the ground-water system from mountain-front and tributary recharge is estimated to be 139,100 acre-feet per year (fig. 38).

Ground water also flows into the Albuquerque Basin from the Española and San Juan Basins to the northeast and northwest, respectively. Underflow from the Española Basin to the Albuquerque Basin is estimated to be 12,600 acre-feet per year (McAda and Wasiolek, 1988, p. 36, 49). Kernodle and Scott (1986, p. 13) estimated underflow from the San Juan Basin to be 1,300 acre-feet per year. Estimated underflow from the San Juan Basin based on values calculated by Frenzel and Lyford (1982, figs. 9, 11) is about 1,200 acre-feet per year. The estimate by Kernodle and Scott (1986) is used in the following water budget section. Another source of water contributed to the ground-water system of the Albuquerque Basin is underflow from Cochiti Dam located in the northern part of the basin. This underflow has been estimated to be 35,500 acre-feet per year (U.S. Bureau of Reclamation, oral commun., 1993).

Ground water flows out of the Albuquerque Basin along the southern boundary to the Socorro Basin. Outflow to the Socorro Basin was estimated by Kernodle and Scott (1986, p. 50) to be 15,000 acre-feet per year.

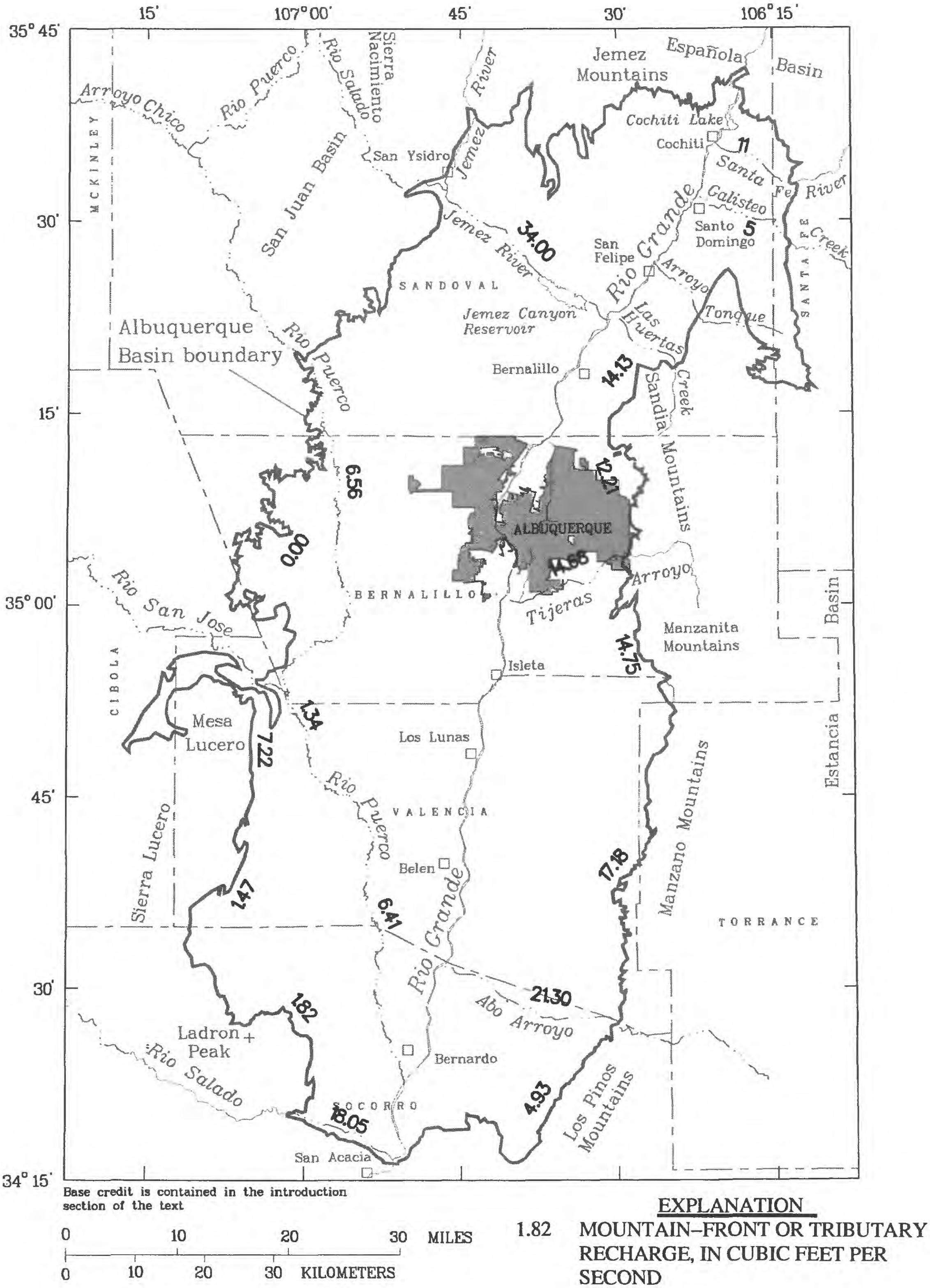


Figure 38.––Estimated mountain–front and tributary recharge to the Santa Fe Group aquifer system in the Albuquerque Basin, Central New Mexico (modified from Kernodle and Scott, 1986, fig. 5).

Effects of Land Use on Water Resources

Land uses have differing effects on the water resources of the basin. Rangeland, the most areally dominant land use in the basin, has very little effect on the available water resources in the study area. Except for severe thunderstorms that cause flash runoff, most precipitation that falls on rangeland is transpired or evaporates. Even flash runoff might not be a significant part of the water budget. The area weighted mean annual precipitation for the study area is 9.40 inches (derived from U.S. Department of Commerce data, no date), whereas the area weighted annual potential evaporation for the same area is 57.07 inches (derived from National Oceanic and Atmospheric Administration data, no date). Most of the water that is not evaporated is transpired by rangeland grasses and scrub vegetation. Medium-altitude evergreen forest land cover probably is similar to rangeland in that evapotranspiration roughly balances precipitation. The total area of these vegetation types is about 1.7 million acres in the basin. Therefore, if total water consumption equals total precipitation, the annual consumption by rangeland and medium-altitude evergreen forest is about 1.3 million acre-feet.

Urbanization and urban land use have both negative and positive effects on the water resources of the basin. The negative effects on streamflow and aquifer-storage depletion are caused by ground-water withdrawal for domestic, commercial, and industrial uses, as discussed earlier. A positive effect is that impervious areas (streets, parking lots, roofs) collect and direct runoff to the Rio Grande. This is illustrated by comparing the mean annual flows in the North Floodway Channel and Tijeras Arroyo (fig. 37; table 5). The North Floodway Channel drains 87.9 square miles of parts of eastern and northeastern Albuquerque. This area was rangeland prior to urbanization. The mean annual runoff from the drainage of the North Floodway Channel is 6,700 acre-feet. Tijeras Arroyo drains 128 square miles of a mix of rangeland inside the study area and high-altitude conifer forest outside the study area, yet the mean annual flow of Tijeras Arroyo is only 432 acre-feet.

Table 6 lists the non-urban land uses in the valleys of the Rio Grande and Jemez River and the amount of water consumed by those uses. These consumptive uses diminish the flow in the Rio Grande and reduce the net amount of available water in the study area.

Irrigated agriculture occupies about 63,000 acres in the basin and consumes about 126,300 acre-feet of water per year (table 6). Virtually all water consumed by agriculture is diverted from the Rio Grande, contributing to a net reduction in streamflow. As pointed out in the historical background section, as many as 124,800 acres in the middle Rio Grande Valley were irrigated in 1880 and as few as 31,700 acres in 1896.

Riparian deciduous forest, which occupies only 1.9 percent of the basin, consists of cottonwoods, tamarisk, russian olives, and other phreatophytes that tap shallow ground water and consume much more water than is contributed by precipitation. Field studies (U.S. Bureau of Reclamation, 1973) have indicated that an average of 3 feet of water is consumed per year by tamarisk or russian olives. The annual amount of water transpired by riparian vegetation is about 112,000 acre-feet (table 6). Although the immediate source of this water is shallow ground water the ultimate source is the Rio Grande.

Table 6.--Evaporation and transpiration from flood-plain areas of the Rio Grande and Jemez River, Central New Mexico

[GIRAS, U.S. Geological Survey's Geographic Information Retrieval and Analysis System; City, City of Albuquerque; BOR, U.S. Bureau of Reclamation; DLG, U.S. Geological Survey's Digital Line Graph, scale 1:100,000]

Land or water classification	Year; source	Acres	Rate, in feet per year	Acre-feet per year
Rio Grande agriculture	1982; GIRAS and 1992; City	59,500	2	119,000
Riparian vegetation	1989; BOR	37,300	3	112,000
Rio Grande open water	1989; BOR	4,200	5	21,000
Rio Grande wet sandbars	1989; BOR	2,700	5	13,500
Jemez River wet sandbars	1980; DLG	1,900	5	9,500
Jemez River agriculture	1982; GIRAS	2,700	2	5,400
Jemez River open water	1980; DLG	700	5	3,500
Miscellaneous agriculture	1982; GIRAS	500	2	1,000
Orchards, vineyards	1982; GIRAS	300	3	900
		----------		----------
	Total	109,800	Total	285,800

The Albuquerque Basin has about 9,500 acres of open water and wet sandbars. By assuming an annual rate of evaporation of 5 feet per year from these surfaces, the total loss is calculated to be 47,500 acre-feet per year. There are indications that historically this area was much larger (Bloodgood, 1930, p. 5).

Land use and changes in land use have an effect on the water resources of the Albuquerque Basin. Change in land use is a dynamic process that affects only a small percentage of the study area but has a very large effect on the net water budget. Three aspects of changes in land use need to be considered: urban development and growth; introduction of exotic species of plants; and refinement and specialization of agricultural techniques.

As stated earlier, comparison of 1992 data obtained from the City of Albuquerque with early 1980's GIRAS data indicates that about 14,000 acres of land in Bernalillo County have been reclassified from agricultural to urban land use. Some effects on the water resources include a reduction of at least 28,000 acre-feet of applied irrigation water, less canal leakage and irrigation return flow, a probable increase in urban runoff, a decrease in evapotranspiration, and the necessary expansion of municipal utilities.

Exotic plant species such as russian olive and tamarisk force out and replace clearings and understory native plants such as grasses and willows. Efforts to remove the exotic plants and restore native habitats have had limited success. Many exotic plants are very aggressive and difficult to eradicate. Tamarisk is especially difficult to remove and responds to most eradication efforts with a vigorous juvenile growth rate that consumes perhaps twice as much water as a mature stand (Welder, 1988). Data for 1989 from the U.S. Bureau of Reclamation (written commun., 1990) indicate that 49 percent of the bosque in the study area is infested with tamarisk and that tamarisk is the dominant species in 3 percent of the bosque.

As indicated in the historical background section, changes in agricultural practices have had a pronounced effect on the water resources in the study area. Extensive agricultural irrigation was made possible by the construction of a network of canals and diversion structures. This led to severe waterlogging and the development of saline soils. These problems were corrected by the construction of a network of riverside and interior drains.

Change in Aquifer Storage

The amount of ground water withdrawn from storage in the Albuquerque area can be estimated on the basis of water-level declines shown in figures 33 and 34. The data from which these figures were prepared were used to compute surface areas and mean water-level declines. The mean water-level decline from 1960 to 1992 was computed to be 46.04 feet over an area of 108,000 acres. The estimated amount of ground water withdrawn from storage from 1960 to 1992 was 994,000 acre-feet (46.04 feet X 108,000 acres X 0.2), assuming a storage coefficient of 0.2, or 497,000 acre-feet, assuming a storage coefficient of 0.1.

The mean water-level decline from 1989 to 1992 was computed to be 16.15 feet over an area of 94,300 acres. The estimated amount of ground water withdrawn from storage from 1989 to 1992 was 305,000 acre-feet (16.15 feet X 94,300 acres X 0.2), assuming a storage coefficient of 0.2, or 152,000 acre-feet, assuming a storage coefficient of 0.1. Table 7 lists the amounts and percentages of water derived from storage and other sources (recharge) for the periods 1960-92 and 1989-92. Recharge was computed as the difference between withdrawal and change in storage. Two storage coefficients are presented to bracket the probable true areal average although the true value might be closer to 0.2 than 0.1.

Table 7 shows that the percentage of water that came from storage during 1989-92 was about two times greater than during 1960-92 regardless of the true storage coefficient. For the period 1989-92 the percentage of water derived from storage probably was between 37 and 75 percent. The table also shows that the yearly average amount of water derived from recharge declined for a storage coefficient of 0.2 and rose slightly for a storage coefficient of 0.1. Considering the methodology used in this analysis the amount of recharge probably has remained unchanged. No distinction was made between mountain-front, tributary, or induced recharge from the Rio Grande.

Water Budget

A water budget is a useful means of establishing an understanding of the relation between the surface water and the ground water for a given area. The basic principle of a water budget is that the difference between inflow and outflow is equal to the change in storage. The numbers shown in the following calculated budget are only estimates and need to be used with caution. The quantities shown in the budget are not as important as the comparison between the different inputs to and outputs from the basin.

A water budget was made for the Albuquerque Basin for 1974 through 1992 (fig. 39). The period was begun in 1974 because that was the first full year that Cochiti Dam, located in the northern part of the Albuquerque Basin, was in operation. Data for this period are presented in preceding tables. Annual change in aquifer storage was computed from hydraulic-head data for 1960 and 1992.

A volume of aquifer was selected for which the budget was computed. The top of that volume of aquifer is the water table or the surface of water bodies in hydraulic connection with the water table. The sides of the volume are the contact between the Santa Fe Group and older rocks. The bottom is the base of the Santa Fe Group. Ground water was assumed not to cross the bottom of the volume. By defining the top to be the water table or the surface of water bodies in hydraulic connection with the water table, precipitation on and evapotranspiration from the rangeland and medium-altitude evergreen forest were excluded from the budget. Sources of water are inflow of the Rio Grande, flow of tributaries at their confluence with the Rio Grande, mountain-front and tributary recharge, point discharges of treated wastewater, and ground-water underflow from adjacent aquifer systems. Losses are outflow of the Rio Grande, evaporation from the surface of the Rio Grande and wet sandbars, transpiration by riparian vegetation and crops in the Rio Grande Valley, ground-water withdrawals, and ground-water underflow. Losses to evapotranspiration in the valleys of tributaries were excluded from the budget because of the definition of the top of the volume.

Table 7.--Sources of ground water withdrawn in the vicinity of Albuquerque, Central New Mexico

[Amounts are in thousands of acre-feet]

	1960-92		1989-92	
	Total	Yearly average	Total	Yearly average
Ground-water withdrawn				
City of Albuquerque[1]	2,508	78.4	384	128
Other major users[2]	208	6.5	22	7.3
Total withdrawn	2,716	84.9	406	135
Source of ground-water withdrawn				
Storage coefficient 0.2				
Amount from storage	994	31.1	305	102
Percentage	37		75	
Amount from recharge	1,722	53.8	101	33.7
Percentage	63		25	
Storage coefficient 0.1				
Amount from storage	497	15.5	152	50.7
Percentage	18		37	
Amount from recharge	2,219	69.3	254	84.7
Percentage	82		63	

[1]Compiled from New Mexico State Engineer Office files, Albuquerque.

[2]Compiled from Sorensen, 1982; Wilson, 1986 and 1992.

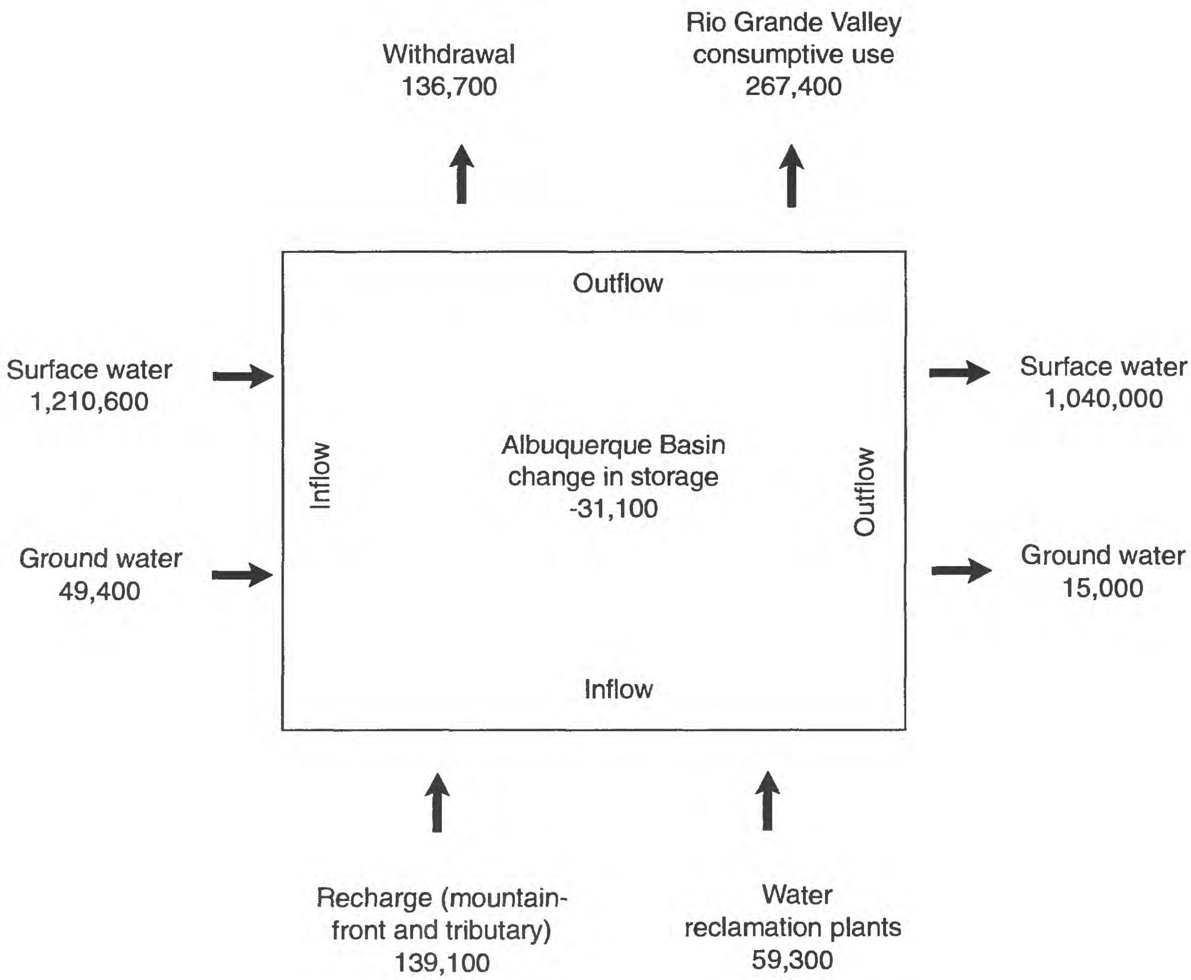


Figure 39.—Water budget for the Albuquerque Basin, Central New Mexico, 1974–92 (units are in acre–feet per year; budget does not balance because quantities were estimated from independent sources).

The surface-water inflow components of the water budget for 1974 through 1992 are the Rio Grande, the two side canals at Cochiti, and all inflows listed in table 5 under the heading of tributary flow into the Rio Grande. This includes discharges of treated municipal wastewater, which are isolated as a separate component in figure 39. The Rio Grande at San Acacia is the sole surface-water outflow.

Total mountain-front and tributary recharge is equal to the sum of the values shown in figure 38. These were computed to be the amounts that reach ground water in the Albuquerque Basin from overland flow and shallow ground-water flow from adjacent areas and from channel infiltration of tributary streams.

Consumptive use represents evapotranspiration and evaporation from the inner valley areas of the Rio Grande. Estimates of evapotranspiration were made from areas such as riparian vegetation, agricultural areas, and areas representative of orchards and vineyards (table 6; Jemez River wet sandbars, agriculture, and open water are not part of the budget volume). Evaporation was estimated from open water and wet sandbars in the Rio Grande.

Ground-water inflow used for the budget is the sum of the underflow from the Española Basin, San Juan Basin, and Cochiti Dam, presented in the section of the report on surface- and ground-water inflow and outflow. Also presented in that section is ground-water outflow, which is underflow to the Socorro Basin.

The estimate used for ground-water withdrawal is shown in table 4 for 1974 through 1992. Total mean withdrawal includes an average of annual withdrawals by the City of Albuquerque and an average of the 1970, 1980, and 1990 withdrawals for other users in the basin.

Change of aquifer storage, shown in figure 39, was calculated from the water-level change map shown in figure 33 and described in the change in aquifer storage section. The reduction in aquifer storage could range from 15,500 to 31,100 acre-feet per year, depending on the actual aquifer storage coefficient (table 7).

The average total surface- and ground-water inflow to the basin from 1974 through 1992 was estimated to be about 1,458,400 acre-feet per year, and the total outflow and consumptive loss was estimated to be about 1,459,100 acre-feet per year. Change in storage was estimated to be about minus 31,100 acre-feet per year (fig. 39). Ideally, inflow minus outflow should equal change in storage. The error in the water budget is about 30,400 acre-feet per year, or about 2 percent of total inflow. The components of inflow, outflow, and change in storage in these water budgets were estimated independently; therefore, they were not expected to balance.

SUMMARY

Recent investigations indicate that the zone of highly productive aquifer, on which the City of Albuquerque has depended for its water supply, is much less extensive and thinner than was formerly assumed. The investigation described in this report focused on gathering recent information to requantify the ground-water resources of the Albuquerque Basin in Central New Mexico. This report describes the geohydrologic framework and current (1993) hydrologic conditions in the Albuquerque Basin.

The Santa Fe Group aquifer system in the Albuquerque Basin is comprised of the Santa Fe Group (late Oligocene to middle Pleistocene) and post-Santa Fe Group valley and basin-fill deposits. The Santa Fe Group and post-Santa Fe Group deposits recently have been divided into four hydrostratigraphic units by other investigators: the lower, middle, and upper parts of the Santa Fe Group, and post-Santa Fe Group valley and basin-fill deposits. The hydrostratigraphic units were further divided into lithofacies units characterized by bedding and compositional properties that exhibit distinctive geophysical, geochemical, and hydrologic characteristics. The Santa Fe Group ranges from less than 2,400 feet in thickness near the margins of the basin to 14,000 feet in the central part of the basin.

Recent information from wells in the Albuquerque area indicate that the most productive part of the Santa Fe Group aquifer system is within the upper part of the Santa Fe Group and to some extent the middle part of the Santa Fe Group. The most productive lithologies are the fluvial axial channel deposits of the ancestral Rio Grande and, to a lesser extent, the pediment-slope and alluvial-fan deposits. This most productive part of the aquifer system is now known to be 2 to 6 miles wide and has a remaining saturated thickness of about 600 feet. The basin-floor playa lake deposits of the lower part of the Santa Fe Group produce little ground water. Faults and cemented fault planes, where present, impede ground-water flow within the Santa Fe Group aquifer system.

Water levels declined 140 feet from 1960 to 1992 in the east Albuquerque area. Water levels declined 40 feet from 1989 to 1992 in eastern, northwestern, and south-central Albuquerque. The magnitude of these declines is due in part to shifts in pumping centers, the presence of fault barriers, and the limited extent of the axial channel deposits.

On the basis of an assumed storage coefficient of 0.2, the water-level declines in the Santa Fe Group aquifer system in the Albuquerque area represent a decrease in storage due to ground-water withdrawal of an estimated 994,000 acre-feet from 1960 to 1992. The decrease in storage due to ground-water withdrawal from 1989 to 1992 is estimated to be 305,000 acre-feet.

The average total annual surface- and ground-water inflow to the basin from 1974 through 1992 was estimated to be 1,458,400 acre-feet and the total outflow and consumptive loss was estimated to be 1,459,100 acre-feet. The average annual change in storage was estimated to be minus 31,100 acre-feet. The water budget components of inflow and outflow were estimated independently from that of change in aquifer storage. As a result the water budget does not balance; the error in the water budget is 2 percent.

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