HYDROGEOLOGIC FRAMEWORK AND PRELIMINARY SIMULATION OF GROUND-WATER FLOW IN THE MIMBRES BASIN, SOUTHWESTERN NEW MEXICO

By R.T. Hanson, J.S. McLean, and R.S. Miller

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
inch	25.40	millimeter
foot	0.3048	meter
mile	1.609	kilometer
square foot	0.09290	square meter
acre	4,047	square meter
square mile	2.590	square kilometer
gallon	3.785	liter
acre-foot	1,233	cubic meter
acre-foot per year	1,233	cubic meter per year
foot per day	0.3048	meter per day
foot per year	0.3048	meter per year
cubic foot per second	28.32	liter per second
gallon per minute	0.06309	liter per second
gallon per minute per foot	0.2070	liter per second per meter
foot squared per day	0.09290	meter squared per day

Specific conductance is measured in microsiemens per centimeter at 25 degrees Celsius, referred to as microsiemens in this report.

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.

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ABSTRACT

The bolson-fill aquifer, the major water-yielding unit in the Mimbres Basin, southwestern New Mexico, ranges in thickness from 0 to about 3,700 feet. Recharge to the bolson-fill aquifer occurs by infiltration of ephemeral streams that cross the basin margin, infiltration from precipitation and streamflow, ground-water underflow from adjacent basins, and infiltration of springflow from adjacent bedrock units within the basin. Ground water generally flows southward from the northern highland areas of the basin. Ground-water discharge consists of pumpage from wells, transpiration by plants, outflow to playas and springs in the Los Muertos Basin in Mexico, discharge to the Mimbres River, and ground-water flow to the Mesilla Basin near Mason Draw. Before 1910, ground-water recharge and discharge were approximately equal; by 1975, however, about 75 percent of the 146,000 acre-feet withdrawn annually was ground water, most of it from aquifer storage.

The transmissivity of the bolson-fill aquifer determined from aquifer tests and specific-capacity data ranges from 10 to 50,000 feet squared per day. Hydraulic conductivity, calculated from saturated thickness and transmissivity, ranges from 0.03 to 800 feet per day, with median values of about 18 feet per day in the Deming area and 6 feet per day elsewhere. Reported storage-coefficient values representing confined parts of the aquifer range from 0.00036 to 0.0036, and those representing unconfined parts of the aquifer range from 0.02 to 0.24.

Water quality in the north and central parts of the Mimbres Basin is suitable for most uses. Due to its large salinity and alkalinity, some of the ground water in the south and southeastern areas of the bolson-fill aquifer may not be suitable for irrigation or domestic use.

A preliminary two-dimensional digital model was constructed to evaluate ground-water flow in the bolson-fill aquifer. The model was divided into zones of uniform hydraulic conductivity corresponding to the major structural elements of the basin. For simulation purposes, hydraulic conductivity in the central part of the basin ranged from 2.2 to 4.4 feet per day, whereas locally along the edges of the aquifer less certain values ranged from 0.003 to 62 feet per day. Analysis of the results of this predevelopment model indicated that use of the mountain-front recharge method overestimates total recharge and that evapotranspiration is substantial. The simulated total inflow was about 55 percent of that estimated in a water budget for the Mimbres Basin.

Ground-water development between 1930 and 1985 was simulated using storage-coefficient values of 0.01 and 0.02 for the Gila Conglomerate, 0.04 to 0.17 for bolson-fill deposits, and 0.001 for bolson fill capped with lacustrine clay. The simulated transient water budget indicated that most of the water pumped by 1985 came from storage, and lesser but substantial amounts came from reductions in evapotranspiration.

INTRODUCTION

Water levels in the Mimbres Basin in southwestern New Mexico have declined since the pumping of ground water for irrigation of crops began in the early 1900's. The New Mexico State Engineer Office requires information on the availability of ground water in the basin and on the effects of pumping ground water. The U.S. Geological Survey, in cooperation with the New Mexico State Engineer Office, conducted a two-part investigation of water resources in the Mimbres Basin. In the first part of the investigation well data, water levels, and chemical analyses were compiled (McLean, 1977).

Purpose and Scope

The purpose of this report is to describe the hydrogeologic framework of the Mimbres Basin, describe the water-yielding properties of the geologic units, and develop and test a conceptual model of ground-water flow in the bolson-fill aquifer. The report also describes a preliminary digital ground-water flow model that was created to test the conceptual model.

The scope of the investigation was limited to the Mimbres Basin within the United States. However, because the aquifer and ground-water flow are continuous across the international boundary, some geologic and hydrologic features in Mexico are described and simulated. Only the bolson-fill aquifer was simulated because most ground water is obtained from this aquifer, the hydraulic properties of the adjacent bedrock aquifers are little known, and nearly all of the ground-water flow in the basin is believed to take place within the bolson-fill aquifer. Model boundaries were extended into Mexico so that they would be distant from areas of simulated ground-water withdrawals in the United States.

Location and Physiographic Setting

The Mimbres Basin comprises an area of about 5,140 square miles in parts of the United States and Mexico. The study area consists of 4,410 square miles of the basin in southwestern New Mexico, including parts of Grant, Luna, Doña Ana, and Sierra Counties (fig. 1). Population centers in the study area are Deming (population 10,774; Wilson, 1986), Silver City (9,887), Bayard (3,036), Central (1,968), Hurley (1,616), and Columbus (444).

The Mimbres Basin lies within the Basin and Range physiographic province (Fenneman, 1931). The northern part of the basin is dominated by steep north- to northwest-trending mountain ranges. Isolated north-trending mountain ranges also rise from the low plains in the southern part of the basin.

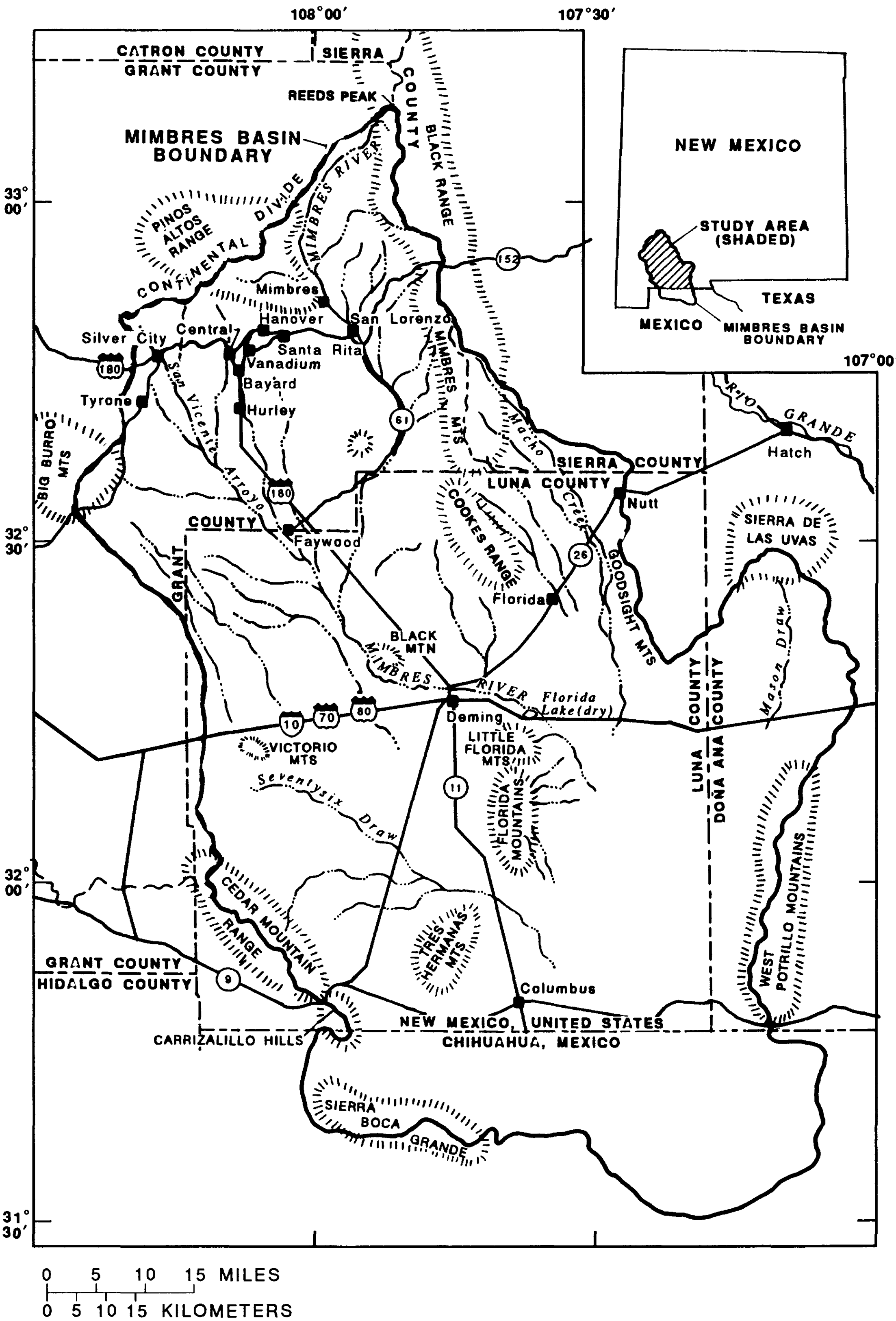


Figure 1.--Location of the study area in the Mimbres Basin.

The Mimbres Basin is a surface-water drainage basin bounded on the north by the Black Range (fig. 1). At 10,011 feet above sea level, Reeds Peak in the Black Range is the northernmost and highest point of the basin. The Black Range and Mimbres Mountains decrease in altitude southward and are separated from the Cookes Range by a broad saddle. The basin is bounded on the east by the Goodsight Mountains, the Sierra de las Uvas, and the basalt flows and ash cones of the West Potrillo Mountains. South of the United States-Mexico border, the basin is bounded by the Sierra Boca Grande. However, the boundary between the Mimbres Basin and the much larger Los Muertos Basin in Mexico (southeast of the basin boundary in Mexico) is indistinct. The lowest point in the Mimbres Basin, about 3,770 feet above sea level, is near this boundary. The northwest-trending Cedar Mountain Range and the Carrizalillo Hills form the southwest boundary of the Mimbres Basin. North of the Cedar Mountain Range, the basin boundary follows the Continental Divide up a slope of coalescing alluvial fans, across the southeast slope of the Big Burro Mountains, and northeastward through the Pinos Altos Range. The eastern slopes of the Pinos Altos Range and the western slopes of the Black Range form the headwaters of the Mimbres River.

The only major stream in the Mimbres Basin is the Mimbres River (fig. 1). From its headwaters, the Mimbres River flows south to the vicinity of Black Mountain, where it turns to the east and flows north of Deming and the Little Florida Mountains. Although it contains perennial reaches in the 25 miles upstream from the Grant County-Luna County border, the Mimbres River flows past Deming only during infrequent floods, when water flows beyond the defined channel and spreads out north and east of the Little Florida Mountains. San Vicente Arroyo drains the northwest part of the basin. This arroyo contains an intermittent stream except for a short perennial reach in Silver City that receives water from the town's water-supply and sewage systems. Other drainage channels in the basin are dry arroyos that flow only in response to intense rainstorms.

Climate

The climate of the Mimbres Basin is arid to semiarid, characterized by low humidity, large diurnal variations in temperature, and orographically controlled precipitation. The mean monthly temperature at Deming, based on 1941-70 data, ranged from 41 degrees Fahrenheit in January to 81 degrees Fahrenheit in July. At Fort Bayard, about 2 miles north of Central, the corresponding temperatures ranged from 37 to 72 degrees Fahrenheit. The average annual precipitation in the basin ranged from less than 9 inches in the south to more than 24 inches in the Black Range (fig. 2). Winter precipitation supplies from one-quarter to slightly more than one-third of the mean annual precipitation. Precipitation from May through October derives from scattered short-duration thunderstorms that may produce locally intense rainfall. Most of this rain occurs during July, August, and September (U.S. Weather Service, 1955-70).

The average growing season is 197 days in Deming (from about April 15 to October 29). The growing season is only slightly shorter in Silver City, averaging 180 days (from about April 27 to October 24).

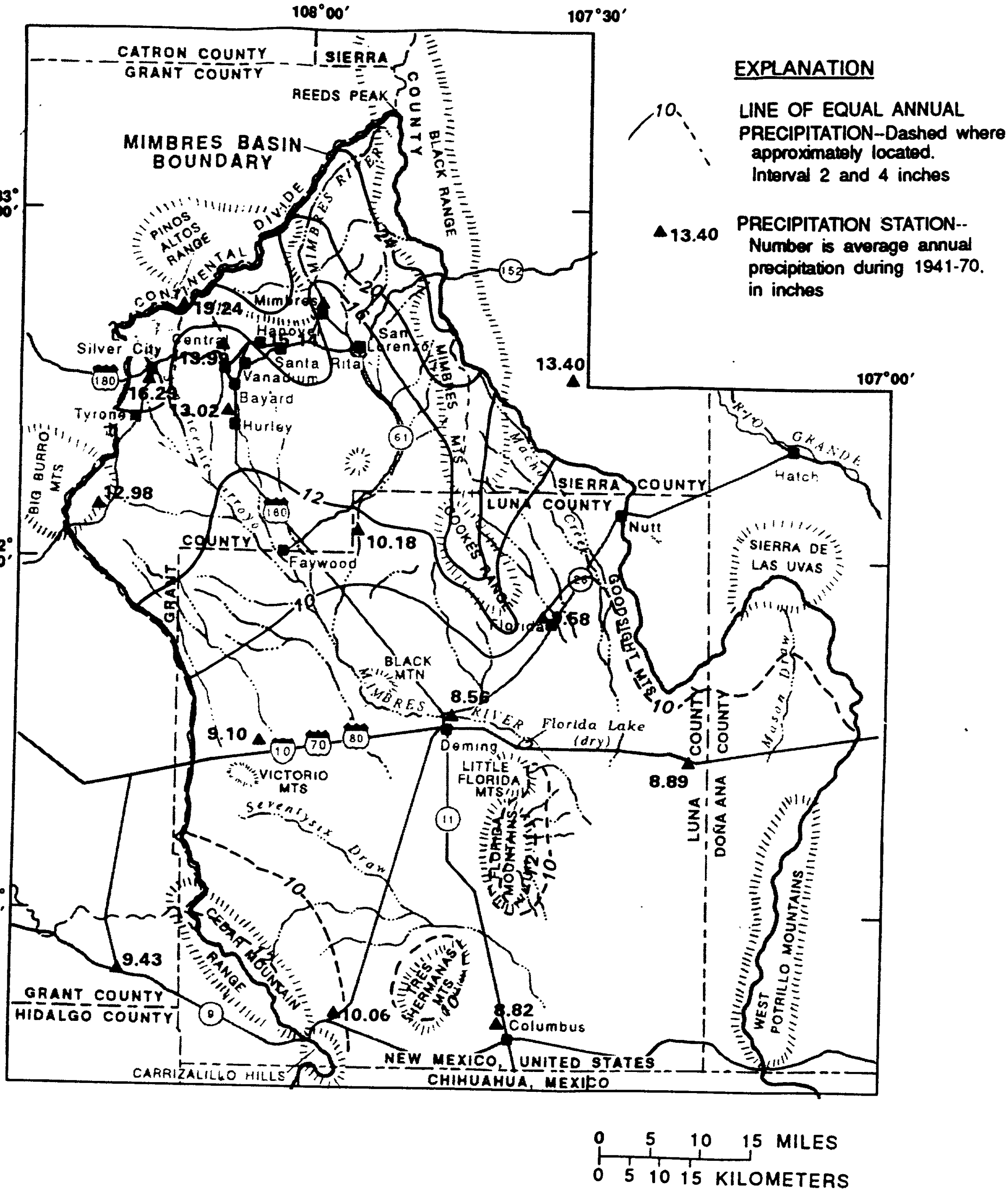


Figure 2.--Average annual precipitation in the Mimbres Basin, 1941-70.

Well- and Spring-Numbering System

Wells and springs in this report are numbered on the basis of townships, ranges, sections, and parts of sections (fig. 3). The first three parts of the well or spring number are the township, range, and section numbers. The subdivisions within a section are numbered as shown in figure 3. The first digit of the last part of the location number gives the quarter section, the second digit gives the quarter of that quarter, and so on. Locations are commonly given to three quartered subdivisions of a section; that is, to the nearest 10 acres. If the well or spring cannot be located to three divisions, the remaining digits are omitted. Where map accuracy permits, wells and springs are located to five divisions; that is, the nearest 0.6 acre. Because most sections are not exact squares, wells and springs are located on an exact 1-mile-square section and referenced to the southeast corner and eastern boundary of the mapped section. The second well or spring located within the smallest subdivision is followed by an "A," the third by "B," and so on.

Acknowledgments

Many individuals and organizations assisted in this study. In particular, Lewis Putnam, former District 3 Engineer of the New Mexico State Engineer Office, contributed data on wells, irrigated acreage, and distribution of irrigated crops. Victor Trujillo and Robert Babcock of the District 3 staff obtained many well locations and water levels used in the study. Companies that contributed information include Kennecott Copper Corporation, Public Service Company of New Mexico, and the Columbus Electric Cooperative.

STRUCTURAL SETTING

The thickness, character, and extent of the bolson-fill sediments in the Mimbres Basin are determined by its structural history. The structures that formed the basin are discussed in detail in this section to provide a basis for the maps of aquifer thickness and properties in this report and information for future modifications of maps of the aquifer thickness and hydraulic properties. The location of large-scale structural components of the basin that, in part, control the regional hydrologic system is shown in figure 4. The sections on plate 1 illustrate the relation between structure and stratigraphy through the central part of the basin.

The Mimbres Basin is superimposed upon parts of three tectonic provinces (fig. 4) Its northern part lies within the Mogollon segment of the Colorado Plateau and its southwestern part lies within the Basin and Range tectonic province (Kelley, 1955). East of the Florida Mountains, Cenozoic faulting formed a north-trending graben adjacent to the Rio Grande Rift that is considered by Chapin and others (1978) to be part of the Rio Grande Rift structure. The major structural features and tectonic provinces overlap in many areas of the basin. For the purposes of this report, therefore, the basin structures are divided according to the three tectonic provinces into Colorado Plateau structures, Basin and Range Province structures, and Rio Grande Rift structures.

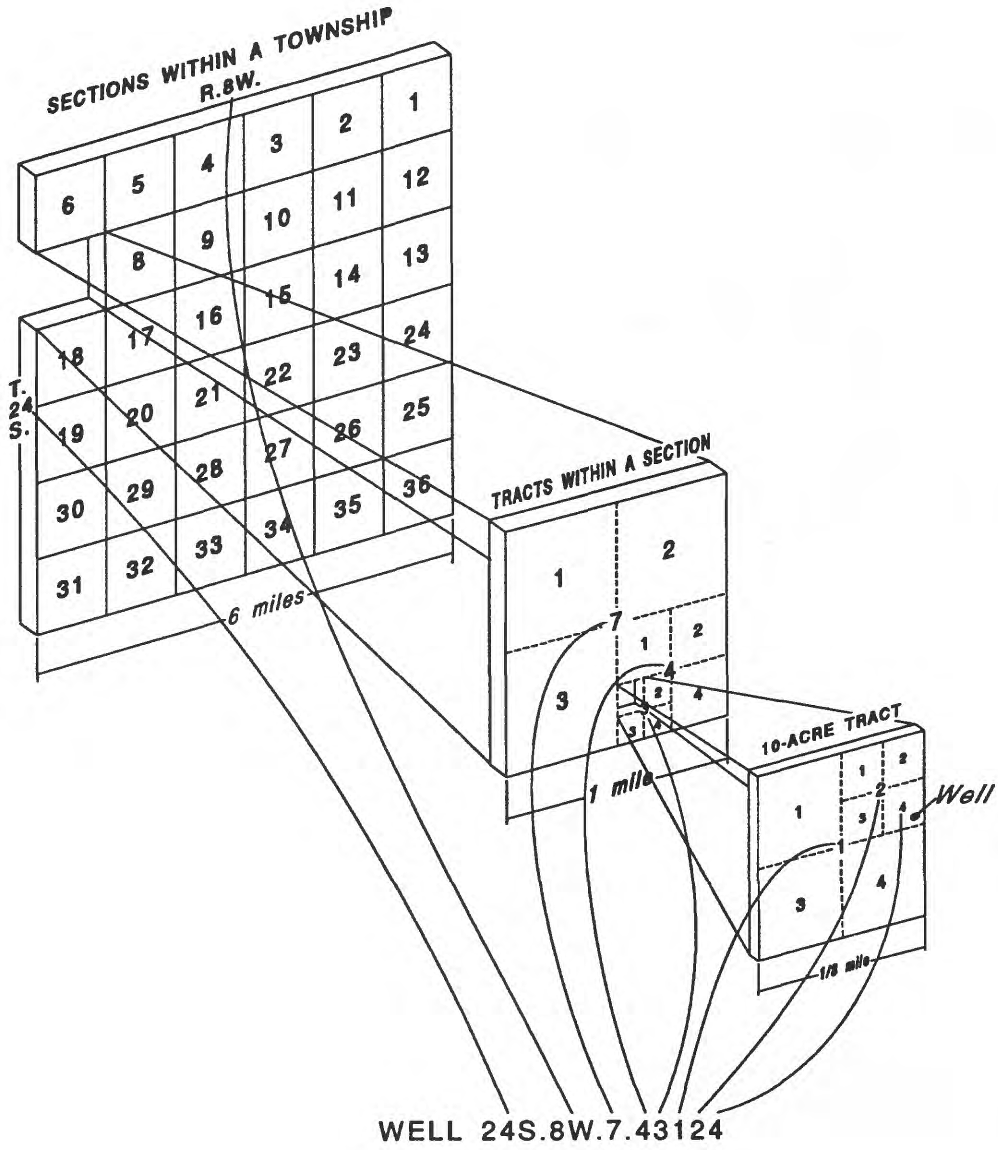
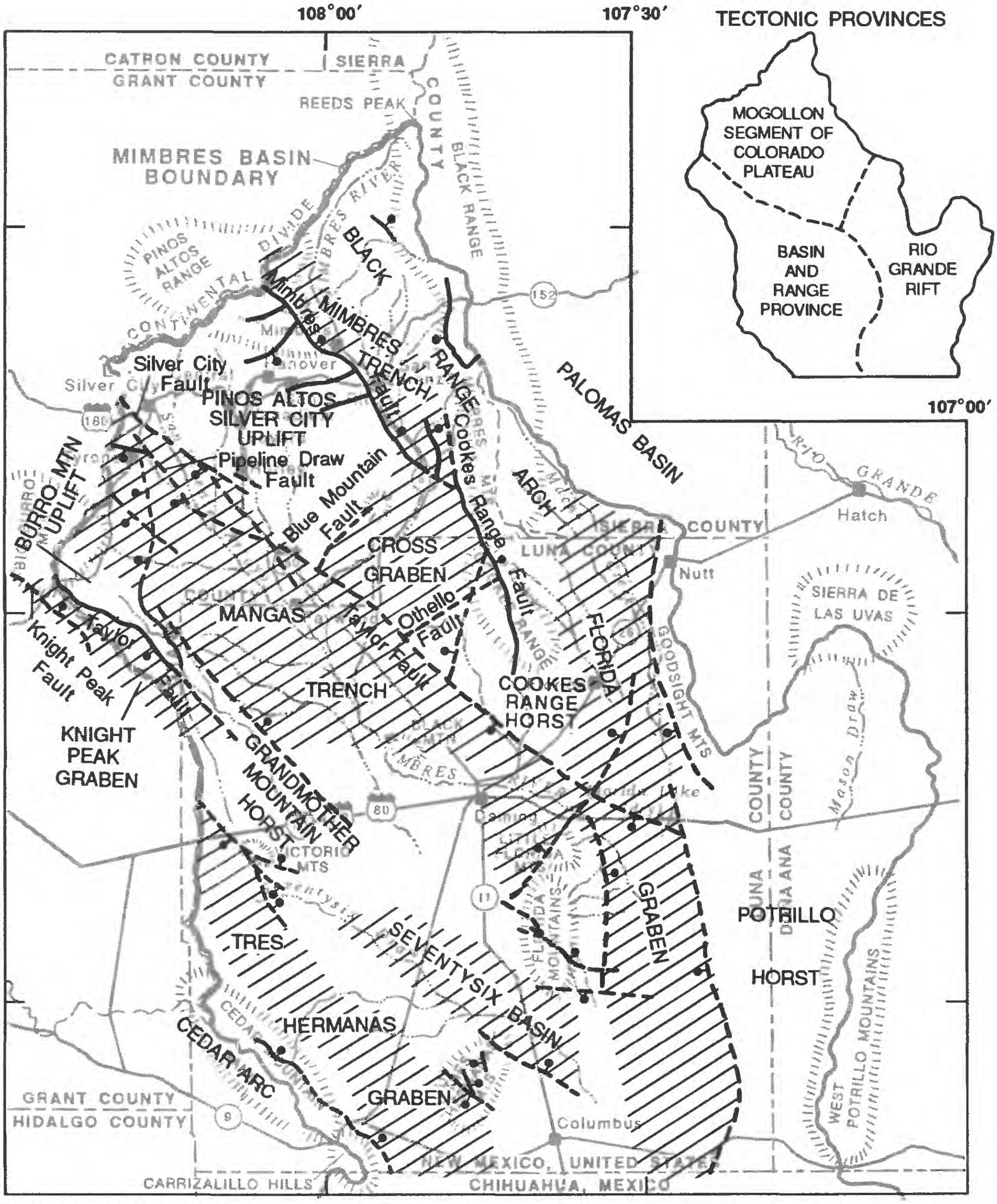


Figure 3.--System of numbering wells and springs.



Tectonic and structural features compiled and modified from Ballman (1960), Chapin and others(1978), Corbitt (1971), Decker and others (1975), Elston (1957, 1958), Hedlund (1978d,e,f), Kuellmer(1954, 1956), Seager and Morgan (1979), Trauger (1972), Woodward and others (1975)

0 5 10 15 MILES

0 5 10 15 KILOMETERS

EXPLANATION

DOWNDROPPED STRUCTURAL FEATURE

FAULT--Dashed where inferred; ball and bar on downthrown side

Figure 4.--Tectonic provinces and structural features in the Mimbres Basin.

Structures of the Colorado Plateau

The Colorado Plateau structures, which include the Black Range Arch, Mimbres Trench, Pinos Altos-Silver City Uplift, Cookes Range Horst, and part of the Mangas Trench, are present in the northern part of the basin (fig. 4). The Black Range Arch includes the Black Range and the northern part of the Mimbres Mountains. Kuellmer (1954, 1956) described the doming and uplift as occurring along normal faults that trend north to northwest near the crest of the Black Range. In most places, the normal faults that define the Black Range Arch are concealed by the Tertiary volcanic deposits that form the bedrock exposure (pl. 1).

The Mimbres Trench (Trauger, 1972) is a graben in the northern part of the study area, where it is bounded on the northeast by concealed faults that define the Black Range Arch and on the southwest by the Mimbres Fault (fig. 4). The structure is asymmetrical, being deeper on the west side, adjacent to the Mimbres Fault (Elston, 1965, fig. 3) where as much as 1,500 feet of sediments have filled the trench (Jicha, 1954). Gravity studies by Decker and others (1975) suggest that the trench extends southeast of the Mimbres Mountains, where it is truncated by the younger Rio Grande Rift.

The Pinos Altos-Silver City Uplift, bounded on the northeast by the Mimbres Fault and on the southwest by the Silver City Fault, is structurally very complex, as indicated by numerous northwest- and northeast-trending normal faults shown by Jones and others (1967). In this study, the northwest-trending uplift is considered a single structural feature.

The Cookes Range Horst and the Pinos Altos-Silver City Uplift are structurally similar. The Mimbres Fault, the northeast boundary fault of the Pinos Altos-Silver City Uplift, may be related to the Cookes Range Fault that borders part of the east edge of the Cookes Range Horst (Elston, 1957). The two uplifts are separated by a cross graben through which the Mimbres River flows. The low structural relief of the cross graben and the stratigraphic and structural similarities between the two adjacent uplifts indicate that the Cookes Range Horst may be a southeastern extension of the Pinos Altos-Silver City Uplift.

Only the north part of the Mangas Trench described by Trauger (1965, p. 186) is located in the Colorado Plateau tectonic province, but the entire structure is described in this section. Gravity studies by Decker and others (1975) indicate that the trench extends southeast into the basin until it terminates against the Florida Mountains. This northwest-trending trench is bounded on the northeast by the Pipeline Draw-Silver City Fault system. The southwestern margin is formed by the northeasterly dipping rocks of the Burro Mountain Uplift and the normal faults bounding the Burro Mountain Uplift and Grandmother Mountain Horst. The Mangas Trench, asymmetrical due to interior faulting, is deeper along the east side where it contains more than 1,400 feet of bolson fill.

Structures of the Basin and Range Province

Structures of the Basin and Range Province include the Grandmother Mountain Horst, Knight Peak Graben, Cedar Arc, Tres Hermanas Mountains, and Florida Mountains (fig. 4). The Basin and Range structures overlap the Colorado Plateau and Rio Grande Rift structures. For example, the Mangas Trench has the characteristic Basin and Range northwest orientation but is partly within the Colorado Plateau Province. The Florida Mountains have the distinction of containing structural features belonging to all three tectonic provinces.

The Grandmother Mountain Horst, believed to be a southeastern extension of the Burro Mountain Uplift, is composed of Tertiary volcanic rocks that probably overlie Precambrian crystalline rocks (Hedlund, 1978 d,e,f). Although Elston (1958) suggested that this horst block may extend into the subsurface to the Florida Mountains, seismic data and sparse well data indicate that this extension, if present, is lowered by cross faulting because the depth to bedrock along the horst increases to the southeast. The Knight Peak Graben, which overlaps part of the western boundary of the Mimbres Basin, is bounded by the Taylor Fault and the Knight Peak Fault. This structure may be deep; Ballman (1960) reported more than 5,000 feet of bolson-fill deposits exposed near the Knight Peak Graben. The gravity survey of Decker and others (1975) indicates a possible southeastern extension of the Knight Peak Graben between the Tres Hermanas Mountains and Cedar Arc (fig. 4). Drillers' logs, in the files of the U. S. Geological Survey, Albuquerque, New Mexico, indicate that more than 2,400 feet of alluvial fill, bolson deposits, and Gila Conglomerate is present. These logs appear to substantiate the existence of the southeastern extension of the Knight Peak Graben, herein called the Tres Hermanas Graben.

The southwestern boundary of the Mimbres Basin is coincident with the northwest-trending Cedar Mountain Range and Carrizalillo Hills (fig. 1). These mountains are part of the Cedar Arc (Trauger, 1972), which in turn is one of several complex Basin and Range Province fault-block systems exposed along the United States-Mexico border. The Cedar Mountain Range is composed of Tertiary volcanic rocks overlying folded and faulted rocks of Mesozoic and Paleozoic age (Corbitt and others, 1978). The northwest-trending, en echelon Basin and Range normal faults that give this range its present shape and orientation have displaced Precambrian and Paleozoic rocks against Tertiary volcanic and Quaternary alluvium (Bromfield and Wrucke, 1961; Varnell, 1976; Thorman and Drewes, 1979). The Sierra Boca Grande in Mexico (fig. 1) represents a similar en echelon fault-block system that forms part of the southern boundary of the Mimbres Basin.

The Florida Mountains and the Tres Hermanas Mountains, located in the center of the basin, are composed of Paleozoic rocks (Brookins, 1974) that were deformed by Late Cretaceous thrusting and Basin and Range faulting (Corbitt and Woodward, 1973). The location of north-trending faults on the east and west sides of the Florida Mountains has been inferred from gravity measurements (Decker and others, 1975). A small, deep basin, also inferred from gravity data, is located between the Florida and Tres Hermanas Mountains (herein named the Seventysix Basin after the Seventysix Draw that occupies the basin). The Tres Hermanas Mountains contain Tertiary volcanics intruded into Mesozoic and Paleozoic rocks (Balk, 1961; Griswold, 1961).

Structures of the Rio Grande Rift

The structures of the southern Rio Grande Rift, like those discussed previously, are superimposed on earlier structures. Formed by a composite of Late Cretaceous tectonism and middle Tertiary cauldron formation, they are the youngest structures within the Mimbres Basin (Hawley, 1978). For the purposes of this study, Rio Grande Rift structures include the Florida Graben, Potrillo Horst, and Goodsight Mountains (fig. 4).

The Florida Graben, named herein for the Florida Mountains to the west, is bordered on the east by the Potrillo Horst. The boundary fault between the two structures is inferred from gravity studies (Seager, 1975; Ramberg and others, 1978) and air-photo lineations. The Florida Graben probably is continuous with the Palomas Basin to the north (fig. 4) (Decker and others, 1975; Woodward and others, 1978, sheet 2) and the Los Muertos Basin to the south in northern Mexico (Woodward and others, 1975; Seager and Morgan, 1979).

The Potrillo Horst, which bounds the study area on the east, is one of many horsts near the margins of the Rio Grande Rift. The horst is composed of Quaternary and Tertiary volcanics and Mesozoic and Paleozoic rocks covered by a veneer of alluvium.

The structure of the Goodsight Mountains, which border the east-central edge of the Mimbres Basin, is not entirely clear. It may be a tilted fault block or the western edge of a buried intrusive (Clemons, 1979). The faults on the west side of the Goodsight Mountains were postulated from gravity studies (Seager, 1975; Ramberg and others, 1978). The Goodsight Mountains presently are included in the Goodsight-Cedar Hills volcano-tectonic depression (Woodward and others, 1978, sheet 2).

WATER USE

Estimated water use in the Mimbres Basin totaled about 146,000 acre-feet in 1975 (table 1), and ground water accounted for about 75 percent of this total. The areas from near Deming south to Columbus, north and east of the Florida Mountains, east of Columbus, and east of the Cedar Mountain Range are irrigated exclusively with ground water. Land along the Mimbres River in the northern part of the basin is irrigated with both surface water and ground water.

The major uses of water are for agriculture, mineral processing, and urban water supply. Irrigated agriculture accounted for an estimated 77 percent of total water use in 1975.[1] Mineral processing accounted for about 17 percent and urban use for only 3 percent of the water used. Data are not available for 1985 for the Mimbres Basin as a whole for categories other than irrigated agriculture. However, totals for most of the other water uses are summarized (Wilson, 1986) for Grant and Luna Counties. Withdrawals for irrigated agriculture of about 112,800 acre-feet (Wilson, 1986, p. 72-73) for only the Mimbres Basin part of Grant and Luna Counties accounted for 77 percent of the total water withdrawn in these counties. A total of 4,863 acre-feet was withdrawn for urban use (3%); 1,763 acre-feet for rural domestic and livestock use (1%); 1,178 acre-feet for livestock use (1%); 1,026 acre-feet by stock-pond evaporation (1%); 23,306 acre-feet for minerals processing (16%); and 2,026 acre-feet for combined commercial, industrial, power production, fish and wildlife, recreational and reservoir evaporation uses (1%) in all of Grant and Luna Counties (Wilson, 1986, p. 26 and 33).

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[1]The most recent water-use statistics tabulated by water-use category for the Mimbres Basin as a whole are for 1975. More recent tabulations for Grant and Luna Counties, parts of which are outside the Mimbres Basin, were used to extrapolate values for 1985 for the Mimbres Basin.

Table 1.--Estimated water use in the Mimbres Basin, 1975

[--, no data]

Water-use category	Surface-water diversions, in acre-feet	Ground-water withdrawals, in acre-feet	Combination of surface- and ground-water withdrawals, in acre-feet	Total water use, in acre-feet
Irrigation[1]	7,900	102,700	2,300	112,900
Minerals[2]	--	--	24,200	24,200
Urban	--	4,800	--	4,800
Rural	--	1,700	--	1,700
Other[3]	1,600	800	--	2,400
Total	9,500	110,000	26,500	146,000

[1]Based on a depletion of 79,010 acre-feet (Sorensen, 1977, p. 31), assuming depletion is equal to 70 percent of diversion, and 30 percent of diversions infiltrate to the aquifer.

[2]Based on U.S. Bureau of Reclamation and New Mexico Interstate Stream Commission (1976); and Sorensen (1977, p. 18).

[3]Includes manufacturing water use, livestock supply, stock-pond evaporation, and fish and wildlife use for Luna and Grant Counties.

The changes in irrigated agriculture in the Mimbres Basin from 1910 to 1985 (fig. 5) were constructed from values from Sorensen (1977), hydrographic-survey data for 1940 from the files of the New Mexico State Engineer Office, values for 1929-39 of total acres irrigated from Conover and Akin (1942, p. 250), values for 1980 from Sorensen (1982), and values for 1985 from Wilson (1986). The growth rate during the remaining periods is adapted from estimates of total irrigated acreage, in 5-year intervals, prepared by the New Mexico State Engineer Office from claims submitted by water users, field checks, ground-water permits, and licenses. "Total irrigated cropland" is all developed acreage for which irrigation systems exist to supply water to the land. "Total acres irrigated" is the area on which irrigation water was applied during the crop year. Because some of the total irrigated cropland is not actually irrigated (fallow) each year, the acres irrigated are always fewer than the total irrigated cropland. In 1940, 87 percent of the total irrigated cropland was actually irrigated and in 1975, 79 percent was irrigated (fig. 5). Between 1910 and 1940, 87 percent of the total irrigated cropland was assumed to be irrigated and between 1940 and 1975, the acres irrigated were assumed to decrease linearly from 87 percent to 79 percent of the total irrigated cropland.

From 1975 to 1980 total irrigated cropland increased from an estimated 62,000 acres to 65,830 acres, calculated from table 9 of Sorensen (1982, p. 37). Total irrigated cropland was assumed to remain constant between 1980 and 1985; total acres irrigated with ground and surface water increased slightly from about 49,000 acres in 1975 (Sorensen, 1977) to 50,100 acres in 1980 (Sorensen, 1982, p. 37), but then decreased to only 35,435 acres in 1985 (calculated from Wilson, 1986, p. 72-73). The acreage irrigated with ground water and that part of the acreage irrigated with combined ground and surface water that was attributable to ground water decreased from 40,840 acres in 1975 (Sorensen, 1977, p. 32) to 38,150 acres (assuming that half the 1,900 acres of combined irrigation represented ground-water irrigation) in 1980 and to only 23,600 acres in 1985 (Wilson, 1986, p. 72-73). This large decrease was due to the general decline of the farm economy in the early 1980's (Robert Babcock, New Mexico State Engineer Office, oral commun., 1987).

The mining industry uses both surface and ground water in mineral-processing activities (table 1). Most of the water use is associated with the mining and milling of copper, lead, zinc, gold, silver, and molybdenum near Silver City.

Urban water use in the Mimbres Basin, summarized by Randall and Dewbre (1972), is shown in table 2. The city of Deming used 2,050 acre-feet of water in 1970; this accounted for 45 percent of the total urban water use in the basin. Urban use in the basin increased from an estimated 4,800 acre-feet in 1975 to an estimated 5,590 acre-feet in 1985 (Wilson, 1986).

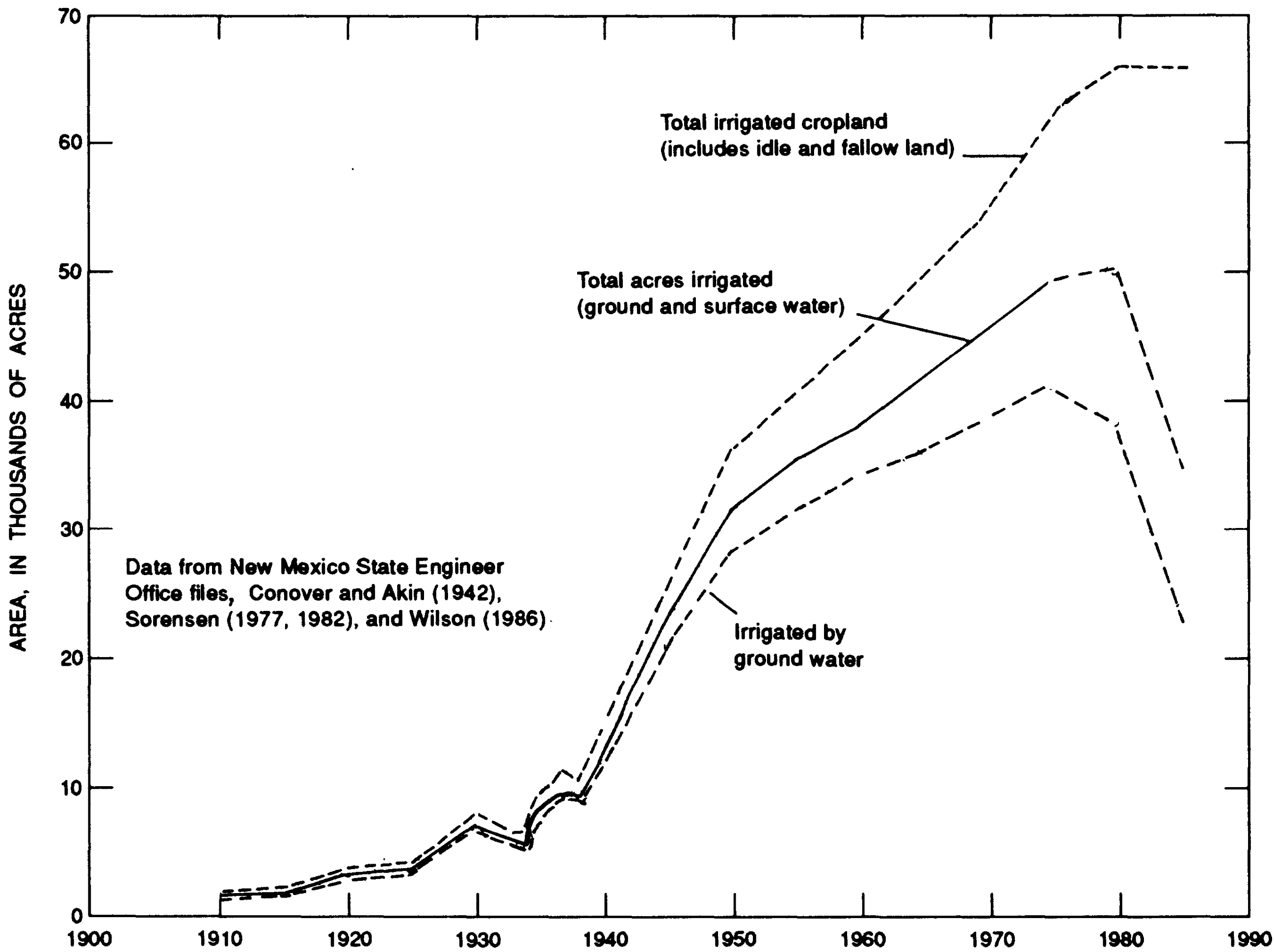

Figure 5.--Estimated total irrigated cropland and acres irrigated in the Mimbres Basin, 1910-85.

Table 2.--Summary of urban water use in the Mimbres Basin, 1970, 1985, and 1989

[Data in thousands of acre-feet per year, rounded to 0.01. Data from Randall and Dewbre, 1972; Wilson, 1986; and files of the New Mexico State Engineer Office, 1989. --, no data]

Community	1970	1985	1989
Deming	2.05	3.20	3.48
Silver City	1.49	1.33	2.56
Bayard	.29	.34	.33
Hurley	.27	[1].15	--
Central	.24	.24	.26
Santa Rita	.11	--	--
Hanover	.05	--	.17
Columbus	.03	.11	.12
Tyrone	.02	.22	--
North Hurley	.01	(1)	--
Vanadium	.01	--	--
Total	4.57	[2]5.59	[2]6.92

[1] Hurley and North Hurley combined.

[2] Partial total.

SURFACE WATER

Surface water in the study area consists mainly of the Mimbres River, ephemeral streams in arroyos, and intermittent mountain streams. The Mimbres River, flowing southward from its headwaters in the Black Range and Pinos Altos Range, is the largest stream in the Mimbres Basin (fig. 1). The channel of the Mimbres River usually contains water from about 7 miles north of the town of Mimbres to the Grant County-Luna County border (Trauger, 1972, p. 50), except during the irrigation season when irrigation diversions may cause parts of the channel to be dry in this reach. In Luna County, the flow of the Mimbres River usually does not extend past the site of Florida Lake, now dry (fig. 6). However, occasional large flows extend east of the Little Florida Mountains. Two exceptionally large flows from December 1904 through May 1905 and from January through April 1906 resulted in floodflows extending almost to the Mexican border (Darton, 1916a, p. 111).

San Vicente Arroyo, which originates on the southwest slope of the Pinos Altos Range, is the principal drainage for the northwest part of the Mimbres Basin. Throughout most of its length, San Vicente Arroyo is an ephemeral stream, although an estimated 20 to 30 gallons per minute flow in the channel downstream from the gage at Silver City (fig. 6) due to "ground-water discharge, return seepage from yard watering, and probable line losses from the city water system" (Trauger, 1972, p. 51). The sewage treatment plant located in the NW 1/4 of section 25, T. 18 S., R. 14 W. discharges approximately 1.4 cubic feet per second of treated effluent to San Vicente Arroyo. This effluent infiltrates within a half mile downstream (A.C. Lewis, New Mexico State Engineer Office, written commun., 1990).

Streamflow in the Mimbres River and San Vicente Arroyo was measured at continuous streamflow-gaging stations shown in figure 6. Flow-duration curves for these stations were plotted (fig. 7) using data from Reiland (1980). The steep slopes of the flow-duration curves and the large variation in streamflow for Mimbres River at McKnight Dam Site and San Vicente Arroyo at Silver City indicate that the flow is derived mainly from surface runoff. The curves also show the large percentage of time without flow at these locations. The flattened slope on the tail of the flow-duration curve for the Mimbres River near Mimbres and the flattened slope in the middle and lower parts of the curve for the Mimbres River near Faywood indicate that ground water contributes to the flow. The estimated ground-water contribution to the flow of the Mimbres River near Mimbres, based on streamflow recession characteristics as described by Wilder and Simmons (1978, p. 10), was about 5.7 cubic feet per second during the summer of 1966. The flow-duration curve for this site also shows that about 50 percent of the time from 1931 to 1973 the flow in the Mimbres River near Mimbres was greater than 5 cubic feet per second. Maximum, minimum, mean, and median streamflows recorded at the four streamflow-gaging stations are listed in table 3.

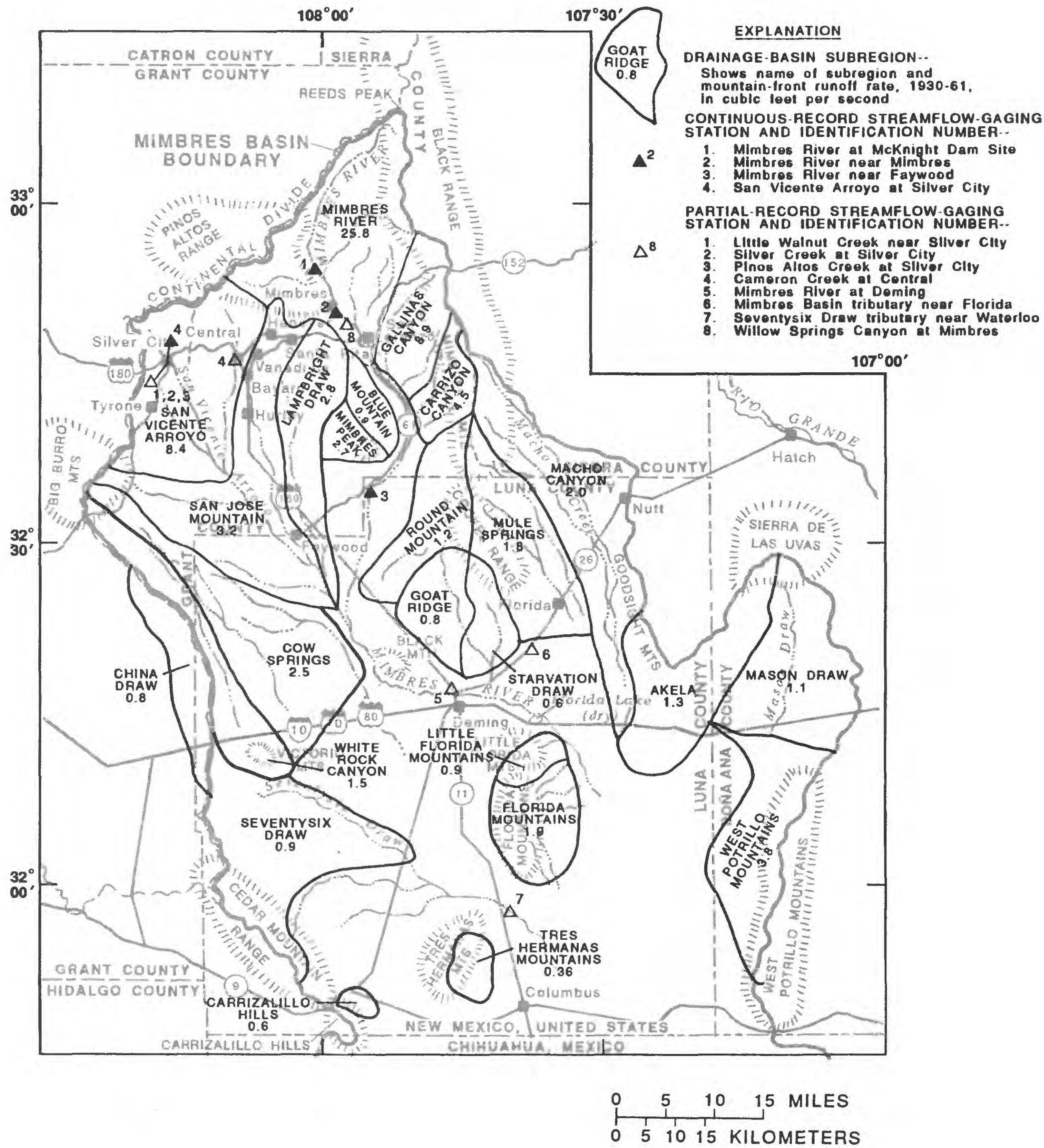

Figure 6.--Location of surface-water gaging stations and drainage-basin subregions used for mountain-front runoff estimates in the Mimbres Basin.

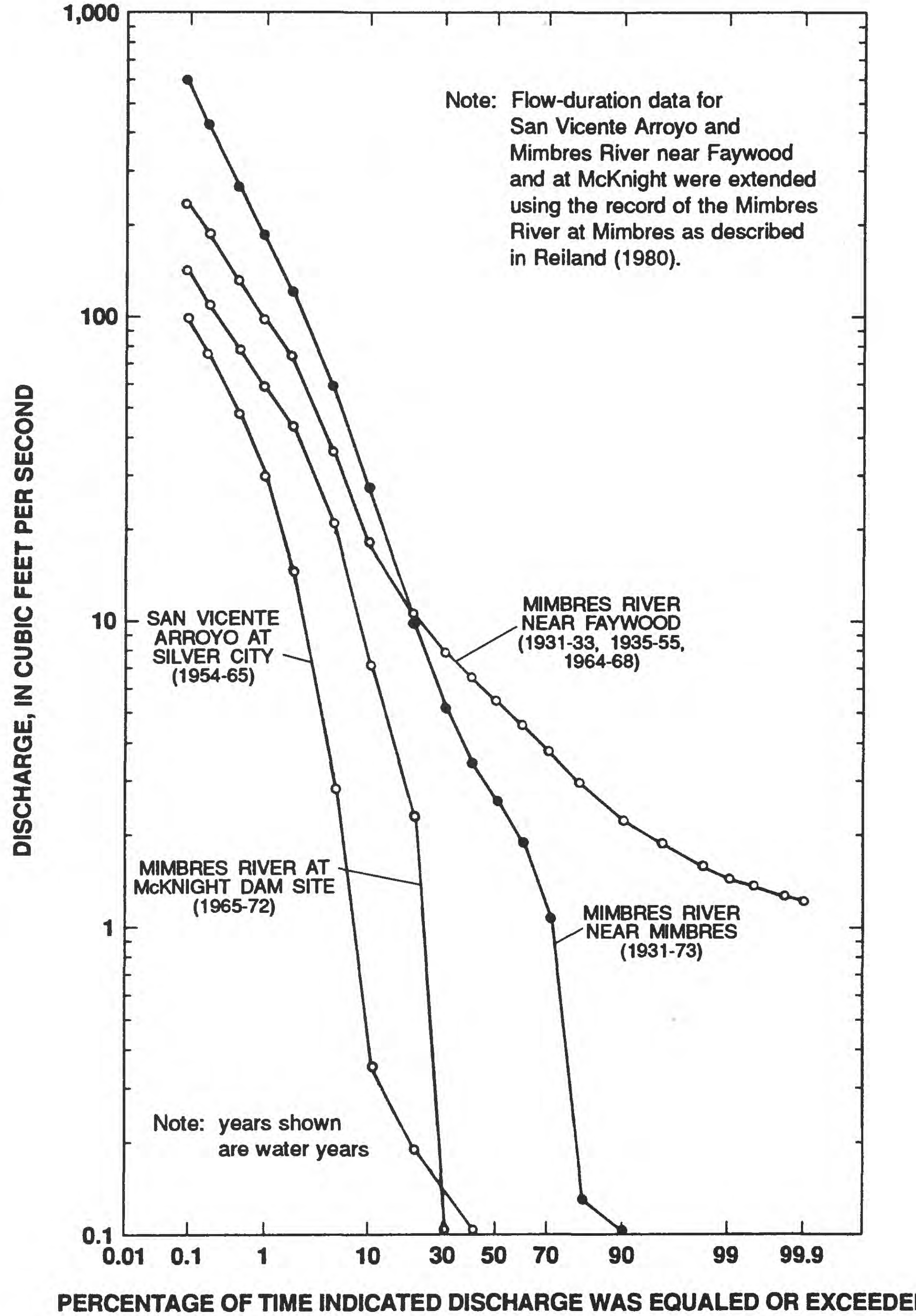

Figure 7.--Streamflow-duration curves for the Mimbres River and San Vincente Arroyo in the Mimbres Basin.

Table 3.--Summary of streamflow in the Mimbres River and San Vicente Arroyo

[Data compiled from U.S. Geological Survey, 1965, 1969, 1972, 1973; and Reiland, 1980. Station locations shown in figure 6]

Station name and number and drainage area, in square miles	Period of record used (water years)	Maximum flow, in cubic feet per second	Minimum flow, in cubic feet per second	Mean flow, in cubic feet per second	Mean yield, in cubic feet per second per square mile	Median flow, in cubic feet per second[1]
Mimbres River at McKnight Dam Site 08476300 97.2	1965-72	2,060	0.0	4.7	0.048	0.0
Mimbres River near Mimbres 08477000 152	1931-73	3,370	0.7	11.0	.072	2.9
Mimbres River near Faywood 08477500 441	1931-33, 1935-55, 1964-68	20,000	0.0	[2]14.6	.033	5.7
San Vicente Arroyo at Silver City 08477600 26.5	1954-65	[3]6,800	0.0	0.78	.029	.0

[1]Streamflow equaled or exceeded 50 percent of the time during the specified period of record.

[2]Only records for complete water years were used. Mean flow for all records was 14.4 cubic feet per second.

[3]Maximum flow determined from high-water marks found in 1956. Probably caused by flood of September 9, 1938.

Little is known about the flow-duration characteristics of ephemeral streams in the basin. In the northern part of the basin, the major ephemeral streams include San Vicente Arroyo and several tributaries of the Mimbres River and San Vicente Arroyo. Some flow data for these streams are presented in the U.S. Geological Survey's surface-water data reports (Follansbee and others, 1915; Grover and Gray, 1915; U.S. Geological Survey, 1971). In general, the early records show that these arroyos were subject to sudden, intense flooding, sometimes in excess of 1,000 cubic feet per second. For most of each year, however, the washes were dry or maintained low flow (less than 1.0 cubic foot per second) sustained by local springs and seeps.

Data from crest-stage partial-record stations maintained on Silver Creek, Little Walnut Creek, Pinos Altos Creek, Cameron Creek, a Seventysix Draw tributary, Mimbres River, Willow Springs Canyon, and a Mimbres Basin tributary (fig. 6) show that most of the discharges estimated from crest-stage gages on ephemeral streams were less than 1,000 cubic feet per second during 1980 (U.S. Geological Survey, 1981). The other major ephemeral streams in the south and central parts of the basin include Macho Creek, Mason Draw, and Seventysix Draw (previously Palomas Arroyo) (Darton, 1916a). Except for discharge estimates from the crest-stage gage at the Seventysix Draw tributary, no data exist concerning the flow characteristics of these arroyos.

Darton's (1916b) map of the Mimbres Basin shows the former perennial Florida Lake, dry since about 1910, as having a surface area of approximately 126 acres situated northwest of the Little Florida Mountains (fig. 6). This lake may have received ground-water discharge from the bolson-fill aquifer and local runoff from the Florida Mountains. Diversion of the water from Florida Lake to irrigate land east of the Florida Mountains was mentioned by Darton (1916a, p. 173) as a project being considered by local residents. If the lake had been fairly constant in surface area, approximately 670 acre-feet of water would have evaporated per year. Some water also may have discharged to the channel of the Mimbres River north of the lake.

Thirty-three springs and an unknown number of seeps are scattered throughout the Mimbres Basin. Most springs discharge from fractured bedrock in the mountainous areas of the basin, or represent underflow in alluvial channels that is forced to the surface by shallow bedrock, often volcanic dikes. Formerly, the largest spring in the basin was Apache Tejo Spring (19S.12W.19.113), which reportedly discharged 1,350 gallons per minute measured from June 1912 to August 1913 (Trauger, 1972, p. 191). The spring reportedly was destroyed in August 1913 when it was dynamited in an attempt to increase its yield. The present Apache Tejo well field produces water for mineral processing from the carbonate rocks that are believed to have supplied the springs. Warm Springs (20S.11W.18.314) was reported (Trauger, 1972) to have maintained a perennial lake covering several acres that went dry shortly after the development of the Warm Springs well field. Faywood Hot Spring (20S.11W.20.243) discharged 30 gallons per minute in 1954 from fractured volcanic rocks, and Mimbres Hot Springs (18S.10W.13.111 and 18S.10W.13.111a) discharge a total of 30 gallons per minute from volcanic rocks and related deposits (Trauger, 1972). The remaining springs in the basin are reported to yield 20 gallons per minute or less, mostly from fractured bedrock units in mountainous areas. No large springs are known to discharge from the bolson-fill deposits with the possible exception of springs shown on maps of Mexico as located south of Palomas, Chihuahua (about 7 miles south of Columbus, New Mexico), and possible playa-margin springs at Laguna de las Moscas in Mexico southwest of the Tres Hermanas Mountains. However, the source of discharge and the flow rates of these springs are unknown.

GROUND WATER

Ground water in the Mimbres Basin occupies the interstices between particles in alluvium, sandstone, and conglomerate; fractures and vugs in consolidated rocks; and solution openings in limestone, dolomite, and gypsum. Throughout most of the basin, water moves freely to wells; in only a few locations are the rocks of such small hydraulic conductivity that well yields are inadequate at least for stock or domestic use.

Occurrence in Geologic Units

Geologic units in the Mimbres Basin range in age from Quaternary to Precambrian. The occurrence of ground water is controlled in large part by the wide variety of rock types and varied hydrologic properties of these geologic units. The geologic map of the Mimbres Basin showing the surficial distribution of rock types (pl. 1) is a composite of information modified from the reports indicated on the plate inset map. Although certain bedrock units are grouped together on the geologic map, all major bolson-fill units that constitute the major aquifer in the basin are shown separately on the geologic map, with the exception of the upper and lower members of the Gila Conglomerate. Geologic sections through the center and the southern margin of the Mimbres Basin are included to show the effects of complex structural features on the geologic units (pl. 1, sections A-A′ and B-B′).

The following review of stratigraphy and occurrence of ground water is divided into discussions of ground water in Cenozoic, Mesozoic, Paleozoic, and Precambrian rocks. Characteristics discussed include the reported thickness and degree of lithification of various units, well yield, and specific capacity.

Cenozoic Rocks

Rocks of Cenozoic age include basalt flows and bolson-fill sediments of Quaternary to Tertiary age and a wide variety of silicic igneous rocks and volcaniclastic sediments of Tertiary age. Quaternary basalt flows that have a maximum thickness of about 500 feet occur within the bolson-fill deposits. Bolson-fill deposits, which are at least 3,700 feet thick locally, consist of the Gila Conglomerate of Quaternary and Tertiary age and younger Quaternary sediments. The bolson-fill deposits constitute the most extensively developed aquifer in the Mimbres Basin. Tertiary igneous rocks occur as intrusive bodies, extensive flows of differing composition, and pyroclastic deposits.

Quaternary and upper Tertiary

Quaternary and upper Tertiary sediments and interbedded basalt flows comprise the most extensive aquifer in the Mimbres Basin, which is called the bolson-fill aquifer in this report. The sediments comprising the bolson-fill aquifer are variously mapped on plate 1 as Gila Conglomerate (QTg), basalt (QTb), volcanic agglomerates (QTag), lacustrine clays (Qlc), alluvium (Qal), undifferentiated alluvium and bolson deposits (Qab), and terrace deposits (Qt).

The geologic map (pl. 1), well logs, gravity maps, and seismic profiles were used to estimate the thickness of the bolson-fill aquifer. Well logs rarely penetrate the full thickness of the aquifer, but were used to provide a minimum thickness for the bolson-fill deposits in the interior of the basin. The thickness of the bolson-fill aquifer varies greatly within the basin, from less than 50 feet in some pediment areas to about 3,700 feet east of the Florida Mountains (Clemons, 1986). Zones of equal estimated average thickness of the bolson-fill aquifer are shown in figure 8. Within each zone the aquifer thickness may differ greatly from the average values shown. The estimated thickness is more accurate in areas where the aquifer is less than 1,000 feet thick and has been developed (such as near Columbus) than it is in deep basin areas or areas where the aquifer is undeveloped (such as along the western boundary of the basin). The zones of aquifer thickness were extrapolated into Mexico, based on estimated thickness in the United States. No thickness data from Mexico were available.

The only major formal stratigraphic unit within the bolson-fill aquifer is the Gila Conglomerate of early Quaternary and late Tertiary age, which is exposed in the northern and southern parts of the basin. It is a heterogeneous unit dominated by conglomerate with lesser amounts of sandstone and shale, and in most places lies unconformably on older rocks. Two divisions of the Gila Conglomerate are recognized in exposures in the northern part of the basin.

The upper Gila Conglomerate is the principal aquifer in Silver City's Woodward well field (T. 18 S., R. 14 W., sec. 30 and 31); this well field contains wells that penetrate as much as 890 feet of Gila Conglomerate and yield 400 to 500 gallons of water per minute. Specific-capacity values of 4 and 8.8 gallons per minute per foot of drawdown are reported from these wells. The lower Gila Conglomerate, generally more consolidated than the upper Gila, contains a greater proportion of volcanic-rock clasts. The lower Gila grades into the upper Gila, except locally where they meet at an angular unconformity. In the central part of the basin, the Gila Conglomerate generally is not identifiable. In Grant County, it may underlie the bolson deposits farther south, grade laterally into the bolson deposits, or be entirely missing due to nondeposition or to early Quaternary erosion. In the southern part of the basin near the Tres Hermanas and Cedar Mountains, dissected alluvial-fan deposits were mapped as Gila Conglomerate. Because it is poorly sorted and frequently well lithified, the lower Gila Conglomerate generally yields only small quantities of water to wells.

An unusually productive section of Gila Conglomerate lies adjacent to the southeast tip of the Big Burro Mountains. Well 21S.14W.24.34134 reportedly produced 1,810 gallons per minute from 264 feet of saturated Gila Conglomerate. Another nearby well (21S.14W.25.14323) produced 1,500 gallons per minute.

A northwest-trending trough in the potentiometric surface southwest of San Vicente Arroyo may coincide with a zone of large transmissivity (Trauger, 1972, fig. 3) in either the Gila Conglomerate or the bolson deposits. Near the southeast end of this trough, the McCauley No. 8 well (21S.12W.20.221), which has a specific capacity of 22.3 gallons per minute per foot of drawdown, penetrated 630 feet of sand and gravel with very little clay. A 400-foot-deep well nearby (21S.12W.25.4414) produced 1,000 gallons per minute and had a specific capacity of 13 gallons per minute per foot. Stock wells northwest of the McCauley No. 8 well in T. 20 S., R. 13 W. and T. 19 S., R. 14 W. have low water levels and therefore may also penetrate this transmissive zone.

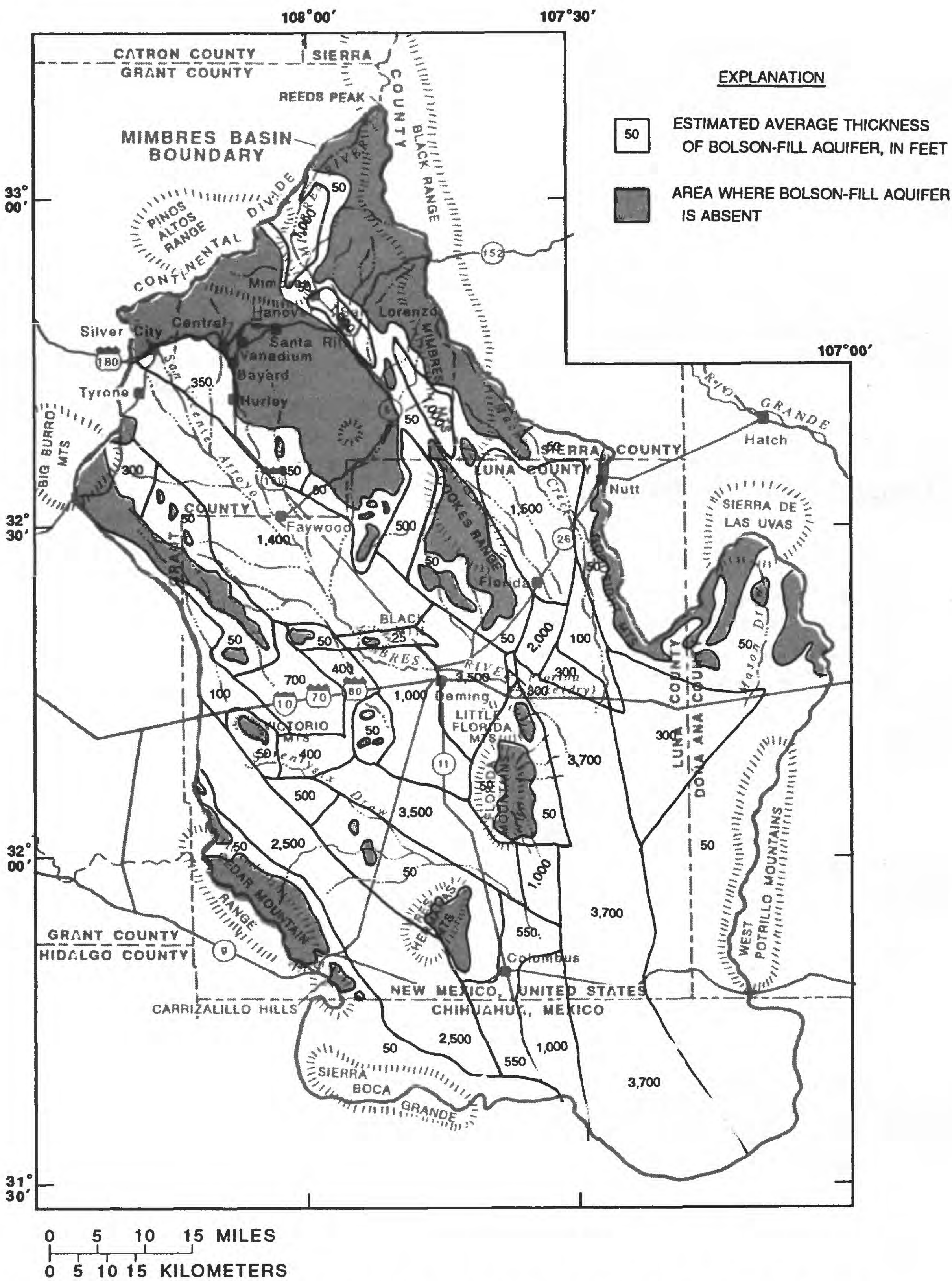

Figure 8.--Estimated average thickness of the bolson-fill aquifer in the Mimbres Basin.

Lacustrine clays (Qlc) of the bolson-fill aquifer are shown on plate 1 east and northeast of Columbus. The lacustrine deposits are described in well logs as red shale, buff or gray clay, and bentonite. The lake sediments, thin or absent west of State Highway 11, thicken eastward to more than 1,200 feet at the Watz No. 1 test well (27S.6W.10.100). The upper part of the lake sediments, which are generally overlain by a thin layer of younger bolson deposits, probably was deposited during what Reeves (1969) called La Mota level of Pleistocene Lake Palomas.

Alluvium (Qal) of the bolson-fill aquifer is shown on plate 1 only along the channels of major streams and arroyos. The alluvium, described by Trauger (1972), consists of poorly sorted and unconsolidated sand, clay, and gravel lithologically similar to, and usually derived from, the common bolson deposits. Basalt flows and associated ejecta (QTb) are minor components of the bolson-fill aquifer. The extensive basalt flows along the southeast margin of the basin, the west Potrillo basalt field, contain only a few scattered stock wells. The water table is presumed usually to be in the underlying bolson deposits. In the Columbus area, however, fractured basalt interbedded with the bolson deposits yields water to wells. Also near Columbus, several of the most productive wells having yields as great as 3,500 gallons per minute obtain water from a very transmissive layer of basalt scoria within the bolson deposits.

The alluvium and bolson deposit (Qab on pl. 1) of the bolson-fill aquifer is the most extensive unit in the Mimbres Basin, and yields the most water to wells. The extensive ground-water development in the Deming and Columbus areas depends on withdrawals from the bolson deposits. Well yields in excess of 1,000 gallons per minute and specific-capacity values greater than 20 gallons per minute per foot of drawdown are common (McLean, 1977, table 6). The bolson deposits contain a stratigraphically and lithologically undifferentiated sequence of sand, gravel, and clay, unlithified to moderately lithified. Calcite cement having subordinate silica and limonite cement is predominant.

Terrace deposits (Qt) of the bolson-fill aquifer are shown on plate 1 northeast of the Cookes Range and along the Mimbres River. These deposits of coarse sand and gravel are generally above the water table. However, where the terrace deposits are saturated, such as near San Lorenzo, they yield large quantities of water to wells. For example, well 17S.11W.24.141 produced 600 gallons per minute from terrace deposits. Well 17S.11W.25.222, which penetrated both terrace deposits and underlying Gila Conglomerate, also yielded 600 gallons per minute, with a drawdown of only 3.6 feet after it had been pumped for 30 minutes (Trauger, 1972, p. 138).

Middle and lower Tertiary

Rocks of Tertiary age and possibly Cretaceous age include intrusive igneous rocks and thick sequences of extrusive and pyroclastic igneous rocks and associated conglomerates, fanglomerates, and tuffaceous or silty sandstones. Intrusive rocks mapped as TKi on plate 1 are predominantly monzonites emplaced as stocks, dikes, and sills. These rocks, where fractured, yield as much as 20 gallons per minute to wells.

Extrusive rocks, pyroclastic rocks, and associated sediments (Tv) are widely exposed and also occur below the bolson-fill deposits under most of the Mimbres Basin. Virtually every major type of extrusive rock is represented in the basin. Where basalt and basaltic andesite (Tba) predominate, the unit is mapped separately on plate 1. Locally, sequences of overlapping volcanic flows can be very thick. In Grant County, the Rubio Peak Formation of Tertiary age alone comprises 3,200 feet of volcanic rocks and associated sedimentary rocks. Seager (1975) indicated that nearly 2,500 feet of volcanic rocks and associated sedimentary rocks are present in the northeastern part of the basin. The Skelly No. 1-A test well (28S.5W.19.431) in the southeast part of the basin penetrated more than 3,600 feet of volcanic rocks and associated sedimentary rocks underlying the bolson. The Cockrell Corporation No. 1 Victorio test well (28S.12W.29.323) just southwest of the basin penetrated almost 2,500 feet of volcanic rocks underlying the bolson-fill deposits before drilling was halted in rhyolite tuff at a depth of 4,000 feet.

The extrusive rocks of Tertiary age have not been tested extensively for water. They generally yield small quantities of water to stock and domestic wells. Notable exceptions are the "Gabby Hayes wells" (18S.14W.28.141, 18S.14W.28.143, and 18S.14W.28.121) in Grant County, which penetrated 460 feet of lithified Gila Conglomerate overlying basaltic andesite flows with interbedded sands and tuffs to a depth of at least 700 feet. The Gabby Hayes wells and the Billings well (18S.14W.21.341) are the only wells known, as of 1988, to penetrate the basaltic andesite aquifer. One of the Gabby Hayes wells produced 1,700 gallons per minute, presumably from fractures and scoria zones, with 43 feet of drawdown. The reported porosity ranges between 18 and 25 percent (Trauger and Lavery, 1976, p. 13). Although the lateral extent of the basaltic andesite aquifer is still not well known, the aquifer reportedly is small (less than 25 square miles) and is located in an intensely faulted part of the basin. In 1983, Silver City drilled an exploratory hole about 1 1/2 miles southwest of the Gabby Hayes wells. The well was reported to have penetrated 1,010 feet of upper Gila Conglomerate and 1,140 feet of lower Gila Conglomerate before entering the Kneeling Nun Tuff at a depth of 2,150 feet. The well was drilled to a total depth of 3,305 feet without penetrating the basaltic andesite aquifer (F.D. Trauger and L.M. Coons, written commun., 1984), indicating that the aquifer is of limited areal extent. The productivity of the basaltic andesite suggests that similar local aquifers may be found in the Tertiary extrusive rocks elsewhere in the basin.

Volcanic-derived sedimentary rocks within the extrusive sequence (Tv) rarely are developed for ground-water production. An exception is a sequence of gravel, sand, and tuff (Ts) shown by Trauger (1972, fig. 2) near Hurley, believed to be the principal aquifer in the Boulton well field, a municipal well field, in sections 8 and 17, T. 19 S., R. 12 W. The volcaniclastic sedimentary rocks elsewhere appear to be unsuited to ground-water production, although small quantities of water may be available from fractures and interbedded conglomerates.

Mesozoic Rocks

Rocks of Mesozoic age, represented in the Mimbres Basin only by rocks of Cretaceous age, are overlain by sediments and volcanic rocks of Quaternary and Tertiary age and rest unconformably on rocks of Permian age. Cretaceous rocks include the Beartooth Quartzite, Sarten Sandstone, and Colorado Formation in Grant County (Trauger, 1972); and as much as 1,000 feet of unnamed limestone, limestone pebble conglomerate, sandstone, and siltstone of Lower Cretaceous age in the Tres Hermanas and Victorio Mountains. The Lobo Formation (Griswold, 1961) of Cretaceous (?) or Tertiary (?) age is present in the Florida Mountains.

The Beartooth Quartzite and Sarten Sandstone are not known to be water yielding. The Colorado Formation, a heterogeneous sequence of shales with lesser amounts of sandstone and limestone, usually yields less than 5 gallons per minute to stock and domestic wells. Wells have been developed in Lower Cretaceous units in only the northern half of the basin.

Several wells in the central part of the basin penetrate more than 4,000 feet of red to brown siltstone and shale with minor sandstone. This thick, uniform unit is tentatively identified as Upper Cretaceous possibly equivalent to the Mojado Formation west of the basin in southern Grant and Hidalgo Counties. This unit is not recognized in surface exposures within the Mimbres Basin. On the basis of its lithology, the unit probably has a small hydraulic conductivity and may act as a confining unit. These rocks may be the poorly permeable "red clay" reported in logs from the Red Mountain area (pl. 1), which locally may be the base of the bolson-fill aquifer.

Paleozoic Rocks

Rocks of Paleozoic age in the Mimbres Basin include shales, clastic sedimentary rocks, and carbonate rocks. The Mimbres Basin contains formations from all systems of Paleozoic age.

Permian

Rocks of Permian age in the Mimbres Basin consist of the Abo Formation and Hueco Limestone. The red siltstone and silty limestone of the Abo Formation in the northern part of the Mimbres Basin intertongue to the south with the limestone and calcareous shale of the Hueco Limestone. Erosion during the Mesozoic Era removed the Permian units from most of the western half of the basin. The Permian section is 500 to more than 1,000 feet thick in the remainder of the basin. These units are not known to yield water to wells in the Mimbres Basin.

Pennsylvanian, Mississippian, and Devonian

Rocks of Pennsylvanian, Mississippian, and Devonian age are represented on plate 1 as a single unit. Rocks exposed in the Mimbres Basin are the Pennsylvanian Syrena Formation and Oswaldo Formation; Mississippian Kelly Limestone, Lake Valley Limestone, Paradise Formation, and Escabrosa Limestone; and the Devonian Percha Shale.

Rocks of Pennsylvanian age consist mostly of nodular, silty limestones that locally contain limy shales and siltstones. Pennsylvanian rocks are missing throughout much of central Grant and Luna Counties because of erosion or nondeposition, but thicken to as much as 2,000 feet near the southwest corner of the basin. Limestones of Pennsylvanian age grade upward into the siltstones and silty limestones of the Abo Formation, except locally where they are unconformably overlain by sediments and volcanic rocks of Tertiary through Permian age.

Rocks of Mississippian age, consisting predominantly of cherty, sandy limestone with minor calcareous sandstone and shale, are unconformably overlain by Pennsylvanian rocks in the Mimbres Basin. Mississippian rocks unconformably overlie the Percha Shale. The thickness of the Mississippian System ranges from 300 feet in the northeast part of the basin to more than 1,000 feet in the southwest (Kottlowski, 1963, fig. 8).

The Percha Shale of Devonian age unconformably overlies the Fusselman Dolomite. The Percha Shale consists of approximately 150 to 300 feet of black, fissile shale and minor sandstone and sandy limestone.

Trauger (1972) reported that a well completed in limestones of Pennsylvanian and Mississippian age in the Apache Tejo well field (19S.12W.19.134) yielded 500 gallons per minute and had a drawdown of 26 inches. Presumably the water was derived from solution-enlarged fractures or bedding-plane solution channels. A nearby well (19S.12W.8.242), drilled to 1,542 feet, reportedly yielded 1,150 gallons per minute from Tertiary sediments and Pennsylvanian and Mississippian limestones. When the well collapsed near the base of the Tertiary section, the yield was reduced to 230 gallons per minute, implying that prior to the collapse the limestones yielded about 920 gallons per minute.

The City Services Oil Company Corralitos No. 1 Federal test well (22S.2W.6.132) reportedly penetrated a cavity 3 feet high in limestone at a depth of 3,000 feet. When the casing in this well was later perforated at 3,000 feet for use as a stock well, the well yielded 7 gallons per minute of slightly saline water (specific conductance 1,930 microsiemens) and had no measurable drawdown. The occurrence of water of usable quality at such depth implies that, locally, substantial quantities of water may be moving through the limestones beneath the volcanic rocks and bolson-fill deposits in the basin.

Silurian, Ordovician, and Cambrian

Rocks of Silurian, Ordovician, and Cambrian age are grouped together on plate 1 as a single unit. The Fusselman Dolomite (Silurian), Montoya Dolomite (Ordovician), El Paso Limestone (Ordovician), and Bliss Formation (Cambrian) are exposed in the Mimbres Basin.

The Fusselman Dolomite consists of massive, crystalline dolomite and minor amounts of chert. Less than 100 feet thick in northern Grant County, it thickens southward to possibly 1,000 feet or more in Luna County. The Fusselman Dolomite unconformably overlies the Montoya Dolomite.

The Montoya Dolomite is predominantly dolomite and dolomitic limestone with a basal calcareous sandstone. It is generally 300 to 400 feet thick throughout the basin. The Montoya Dolomite unconformably overlies the El Paso Limestone.

The El Paso Limestone is 520 feet thick near Silver City and thickens southward to more than 1,100 feet near the southeast corner of Luna County (Kottlowski, 1963, fig. 4). It is irregularly dolomitized, silty, and locally contains chert nodules and beds of sandstone. The El Paso Limestone conformably overlies the Bliss Formation.

The Bliss Formation consists of 50 to 280 feet of glauconitic sandstone and shale and lesser amounts of orthoquartzite, limestone, dolomite, and conglomerate. The Bliss Formation, the basal sandstone of the Paleozoic sequence, overlies a uniform erosion surface on the Precambrian granite and metamorphic rocks.

Rocks of Silurian, Ordovician, and Cambrian age are not extensively used for ground-water production in the Mimbres Basin. The Fusselman and Montoya Dolomites have not been developed, but some evidence indicates that they may be capable of yielding water to wells. The evidence includes a report that secondary porosity is locally well developed in the Fusselman Dolomite (Kottlowski, 1963), and an oil-test well near Hatchita (pl. 1) that reportedly lost circulation in the Montoya Dolomite. Wells within the El Paso Limestone yield as much as

200 gallons per minute (Trauger, 1972). The Bliss Formation, not a productive aquifer, probably could yield small quantities of water from fractures. Carbonate units locally contain secondary porosity and increased hydraulic conductivity due to fractures and solution channels.

Precambrian Rocks

Precambrian rocks, which consist primarily of granite and minor amounts of metamorphic rocks, are exposed in some of the mountains in the Mimbres Basin (pl. 1). Fractures and weathered zones in the granitic rocks yield small quantities of water to stock and domestic wells in the northern part of the basin. No wells are known to produce water from the metamorphic rocks.

Hydraulic Properties of the Bolson-Fill Aquifer

The ability of an aquifer to transmit and store water can be described by the hydraulic properties transmissivity, horizontal hydraulic conductivity, and storage coefficient. These properties were evaluated for the bolson-fill aquifer within the Mimbres Basin.

Transmissivity

The transmissivity[1] of the bolson-fill aquifer was estimated using values determined from aquifer tests, specific capacities[2] of wells, and lithologic logs of wells. Transmissivity values determined from aquifer tests at wells completed in the bolson-fill aquifer range from 54 to 50,000 feet squared per day (table 4). Most of these tests were single-well tests of short duration in wells that penetrated only a small part of the total thickness of the bolson-fill aquifer. The wide range in transmissivity values may be caused partly by limitations in the testing methods and by the heterogeneity of sediments that comprise the bolson-fill aquifer.

Transmissivity of the bolson-fill aquifer also was estimated from the specific capacity of selected wells. Specific capacity is a function of transmissivity of the aquifer, length of time the well has been pumped, the effective well radius, the storage coefficient, and hydraulic-head losses within the well. If well construction techniques are similar throughout an area, an empirical relation between specific capacity and transmissivity can be established.

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[1]The transmissivity of an aquifer is "the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer under a unit hydraulic gradient" (Lohman, 1972).

[2]The specific capacity of a well is the rate at which water is withdrawn from the well divided by the drawdown in the well.

Table 4.--Summary of aquifer-test results at wells completed within the bolson-fill aquifer in the Mimbres Basin

EXPLANATION

Location of pumped well: Location number explained in text

Well depth: Refers to depth of observation well. If no observation well is listed in remarks, pumped well was used as observation well, and well depth refers to pumped well

Method of analysis: Semilog rec = Transmissivity calculated using Theis recovery method (Ferris and others, 1962, p. 100)

Semilog dd = Transmissivity calculated using modified nonequilibrium formula (Ferris and others, 1962, p. 98)

Harrill = Transmissivity calculated using method of Harrill (1970, p. C212)

Theis = Transmissivity calculated using Theis nonequilibrium method (Ferris and others, 1962, p. 98)

Cooper = Transmissivity calculated using leaky aquifer method of Cooper (1963, p. C48)

Source of data/remarks: NMSEO = New Mexico State Engineer Office

L = Lithologic log available for well

OB = Transmissivity determined from drawdown or recovery data in observation well

C&A (1942) = Test reported by Conover and Akin (1942)

W&G (1951) = Test reported by White and Guyton (1951)

M (1942) = Test reported by Murray (1942)

C (1952) = Test reported by Conover (1952)

S (1956) = Test reported by Spiegel (1956)

S = Storage coefficient

--, data not available

Table 4.--Summary of aquifer-test results at wells completed within the bolson-fill aquifer--Continued

Location number of pumped well	Well depth, in feet	Date test began	Average discharge, in gallons per minute	Duration of test, in hours	Trans-missivity, in feet squared per day	Method of analysis	Source of data/remarks
16S.12W.36.444	789	//78	60	44	54	Semilog rec	NMSEO
17S.11W.24.141	--	5/26/79	580	4	14,000	Semilog dd	NMSEO
18S.14W.31.21324	1,030	1/13/72	520	8	1,900	do.	L
18S.14W.32.32413	950	10/26/83	240	124	220	do.	NMSEO
19S.10W.27.234B	--	5/20/79	140	19	9,000	do.	NMSEO
19S.14W.6.414	900	9/28/76	300	96	2,200	do.	NMSEO
19S.14W.35.332	589	10/02/79	616	48	5,900	do.	NMSEO
20S.11W.29.321	400	3/18/68	800	24	17,000	Semilog rec	Kennecott Copper Co.
20S.11W.30.11313	350	12/12/69	400	24	2,000	Semilog rec	Do.
20S.11W.30.224	350	1/11/70	405	24	5,500	Semilog rec	Do.
20S.11W.32.130	400	6/30/68	620	24	4,000	Semilog dd	Do.
20S.11W.33.410	600	10/27/68	500	24	23,000	Semilog rec	Do.
20S.12W.26.322	400	1/09/70	295	24	250	Semilog dd	Do.
20S.12W.27.312	400	12/15/69	200	24	1,400	Semilog rec	Do.
20S.12W.29.130	400	12/04/68	500	24	5,000	Semilog dd	Do.
20S.12W.29.443	400	8/16/69	298	24	220	Semilog dd	Do.
20S.12W.33.141	400	1/06/69	400	24	450	Semilog dd	Do.
20S.12W.33.414	--	10/05/69	305	24	360	Semilog dd	Do.
20S.14W.1.111	1,020	10/02/80	700	24	9,000	Semilog rec	NMSEO
21S.12W.4.14241	400	8/20/69	600	24	2,100	do.	Kennecott Copper Co.
21S.12W.4.421	400	9/24/69	752	24	800	do.	Do.
21S.12W.11.242	400	7/28/69	500	24	2,300	do.	Do.
21S.12W.12.121	400	7/31/69	500	24	4,000	do.	Do.
21S.12W.13.111	400	12/08/69	400	24	1,700	do.	Do.
21S.12W.13.141	400	12/06/69	500	24	900	do.	Do.
21S.12W.13.412	400	10/03/69	400	24	1,600	do.	Do.
21S.12W.13.424	400	9/27/69	500	24	5,800	do.	Do.
21S.12W.20.221	630	1/22/70	1,650	24	26,000	do.	Do.
21S.12W.25.22213	600	8/24/69	699	24	1,100	do.	Do.
21S.12W.25.241	600	8/13/69	800	24	9,000	do.	Do.
21S.12W.25.4414	400	5/22/68	1,000	24	18,000	do.	Do.
22S.7W.22.224	780	1/27/72	529	26	930	Harrill	L; step test; NMSEO
23S.9W.35.34333	485	4/11/71	865	4	1,500	Semilog dd	--
23S11W.34.34442	430	3/07/74	118.5	31	160	Semilog rec	--
24S.5W.18.33334	298	3/05/74	104	48	1,570	Semilog rec	--

Table 4.--Summary of aquifer-test results at wells completed within the bolson-fill aquifer--Continued

Location number of pumped well	Well depth, in feet	Date test began	Average discharge, in gallons per minute	Duration of test, in hours	Trans-missivity, in feet squared per day	Method of analysis	Source of data/remarks
24S.5W.18.33334	302	3/05/74	104	48	1,700	Semilog rec	OB 24S.5W.18.33344
24S.6W.3.111	–	8//36	225	–	4,800	Semilog rec	C&A (1942)
24S.7W.4.42112	398	2/18/51	470	4	940	Semilog rec	W&G (1951)
24S.7W.8.21223	–	9//36	145	–	3,400	Semilog rec	C&A (1942)
24S.7W.9.24112A	375	2/18/51	797	–	1,700	Semilog rec	L; W&G (1951)
24S.7W.9.24112A	398	2/18/51	797	–	3,100	Theis	L; OB 24S.7W.4.42112; S=0.0006; W&G (1951)
24S.7W.10.11111	803	1//40	400	–	2,100	Semilog rec	L; C&A (1942)
24S.7W.13.22111	109	8//36	200	–	2,300	do.	C&A (1942)
24S.8W.6.110	235	–	450	24	14,000	do.	L; C&A (1942)
24S.9W.1.21134	235	–	400	24	16,000	do.	L; C&A (1942)
24S.9W.1.22232	235	–	365	24	2,000	do.	L; C&A (1942)
24S.9W.6.431	1,000	5/21/41	465	14	2,900	do.	L; M (1942)
24S.9W.7.211	575	3//42	450	–	5,300	do.	C&A (1942)
24S.9W.17.12114	258	7//36	265	–	2,700	do.	C&A (1942)
24S.9W.21.131A	–	2//40	400+	–	2,300	do.	OB 24S.9W.21.131; C&A (1942)
24S.10W.2.21114	102	8//36	575	–	20,000	do.	C&A (1942)
24S.10W.12.41111	450	3//40	350+	–	7,800	do.	C&A (1942)
24S.10W.12.43111	172	3/13/40	300	37	1,900	do.	C&A (1942)
24S.11W.11.21131	–	11/29/40	280	48	670	do.	C (1952)
24S.11W.11.21131	–	11/29/51	280	48	5,500	Cooper	OB 24S.11W.2.344; C (1952); S=0.0036
24S.11W.12.32431	200	12/02/51	374	48	4,300	Semilog dd	C (1952)
24S.11W.12.32431	200	12/04/51	374	48	4,400	Semilog rec	C (1952)
24S.11W.12.32431	–	12/02/51	374	48	16,000	Theis	OB 24S.11W.12.412; C (1952); S=0.0014
24S.12W.34.43132	597	3/05/71	485	–	5,400	Harrill	L; pumping rate fluctuated during test
24S.12W.34.43133	–	3/05/71	485	–	5,400	Harrill	L; OB 24S.12W.34.43334; S=0.0005

Table 4.--Summary of aquifer-test results at wells completed within the bolson-fill aquifer--Concluded

Location number of pumped well	Well depth, in feet	Date test began	Average discharge, in gallons per minute	Duration of test, in hours	Trans-missivity, in feet squared per day	Method of analysis	Source of data/remarks
25S.6W.3.121A	505	2/04/64	561	48	2,900	Semilog rec	L
25S.6W.3.121A	230	2/04/64	561	48	3,400	Semilog dd	OB 25S.6W.3.121; S=0.0006
25S.6W.3.121A	232	2/04/64	561	48	3,200	Semilog dd	OB 25S.6W.3.1111; S=0.00036
25S.6W.3.121A	--	2/04/64	561	48	2,800	Semilog dd	OB 25S.6W.3.233; S=0.00065
25S.6W.3.121A	234	2/04/64	561	48	3,100	Semilog dd	OB 25S.6W.2.111A
25S.6W.5.311	230	2/05/53	540	--	1,900	Semilog rec	S (1956)
25S.6W.8.112	340	1/18/54	650	--	1,100	do.	S (1956)
25S.9W.7.21213	146	7//36	240	--	9,000	do.	C&A (1942)
25S.9W.15.21111	--	7//36	385	--	6,700	do.	
25S.9W.28.21113	--	7//36	390	--	8,700	do.	Do.
25S.9W.30.111	--	8//36	210	--	7,000	do.	Do.
25S.10W.36.222(?)	--	1/10/40	400	25	5,200	do.	Do.
26S.9W.3.411	--	8//36	315	--	10,000	do.	Do.
26S.10W.11.11211	--	7//36	390	--	8,700	do.	Do.
27S.8W.8.31111	413	10/25/55	800	--	7,900	do.	L
28S.7W.21.21113	488	10/25/55	1,500	--	50,000	do.	L
28S.8W.25.31111	605	2/25/60	2,500	24	22,000	do.	L
28S.SW.25.31111	529	2/25/60	2,500	--	4,500	Theis	OB 28S.8W.25.21211
28S.8W.25.31111	696	2/25/60	2,500	--	8,900	Theis	OB 28S.8W.26.24224
28S.8W.2S.31111	594	2/25/60	2,500	--	6,400	Theis	OB 28S.8W.26.32222

Transmissivity values determined from aquifer tests were compared to specific-capacity values for selected wells completed in the bolson-fill aquifer. An approximate relation[1] between specific capacity and transmissivity was determined such that:

$$T = SC \times 260 \qquad (1)$$

where T = transmissivity, in feet squared per day; and
SC = specific capacity of the well, in gallons per minute per foot of drawdown.

This linear relation was used to estimate transmissivity values for wells where only specific-capacity tests were performed. The 278 transmissivity values for the bolson-fill aquifer determined from aquifer tests (table 4) and specific-capacity data (McLean, 1977, table 6) range from 10 to 50,000 feet squared per day with a mean of 4,050 feet squared per day.

Estimating transmissivity in areas where aquifer tests and specific-capacity data were sparse also relied on lithologic information about the aquifer. Lithologic logs of wells made by drillers and geologists have been used to estimate aquifer properties in other areas. Transmissivity is estimated by assigning typical hydraulic-conductivity values to the individual lithologies described in the well log (Gutentag and Weeks, 1981). Transmissivity values determined from lithologic logs were compared to values determined from aquifer tests and specific-capacity data for the same wells. Comparison of the technique in the vicinity of Deming and the central Florida Graben is shown below:

		Average transmissivity, in feet squared per day	
Location	Number of wells	Determined from aquifer tests and specific-capacity data	Determined from lithologic logs
Deming area	13	4,320	5,330
Florida graben	19	1,790	2,960

[1]Based on transmissivity values from table 4 and specific-capacity values from McLean (1977) ($n=32$, $r^2=0.7$). This relation between transmissivity and specific capacity is also a common "rule of thumb" that can be deduced from the semilog form of the Theis equation.

In addition to the lateral variability of transmissivity within the bolson-fill aquifer, hydraulic-conductivity variation with depth is also a probability, as suggested in figure 9, which indicates a general decrease in the specific capacity of wells completed in progressively deeper zones within the bolson-fill aquifer. Although this decrease may reflect only the need to drill deeper to obtain adequate well yields in areas with smaller transmissivity, it also could indicate an actual decrease in hydraulic conductivity with depth. If so, the flow system may be more restricted in depth than the thicknesses shown in figure 8.

Horizontal Hydraulic Conductivity

The average horizontal hydraulic conductivity of the aquifer (equal to its transmissivity divided by its saturated thickness) was calculated from estimates of transmissivity divided by the saturated thickness opposite the screened interval of the well. Average horizontal hydraulic conductivity of the bolson-fill aquifer computed from transmissivity values obtained from aquifer tests and specific-capacity measurements ranges from 0.03 to 800 feet per day (fig. 10). The distribution of hydraulic conductivity is skewed toward smaller values; therefore, the median was used as the measure of the hydraulic conductivity of each area. The median hydraulic conductivity in the Deming area, 18 feet per day, is significantly larger than in the rest of the basin, whereas the median values of hydraulic conductivity of the Mangas Trench, Florida Graben, Tres Hermanas Graben, and Columbus area do not differ significantly. The median hydraulic conductivity for the bolson-fill aquifer exclusive of the Deming area is about 6 feet per day. However, all hydraulic-conductivity values may be biased toward large values because most tests were performed on productive irrigation wells, and most wells were completed only in the upper, presumably more permeable, parts of the bolson-fill aquifer. The true median hydraulic-conductivity values may be less than these values.

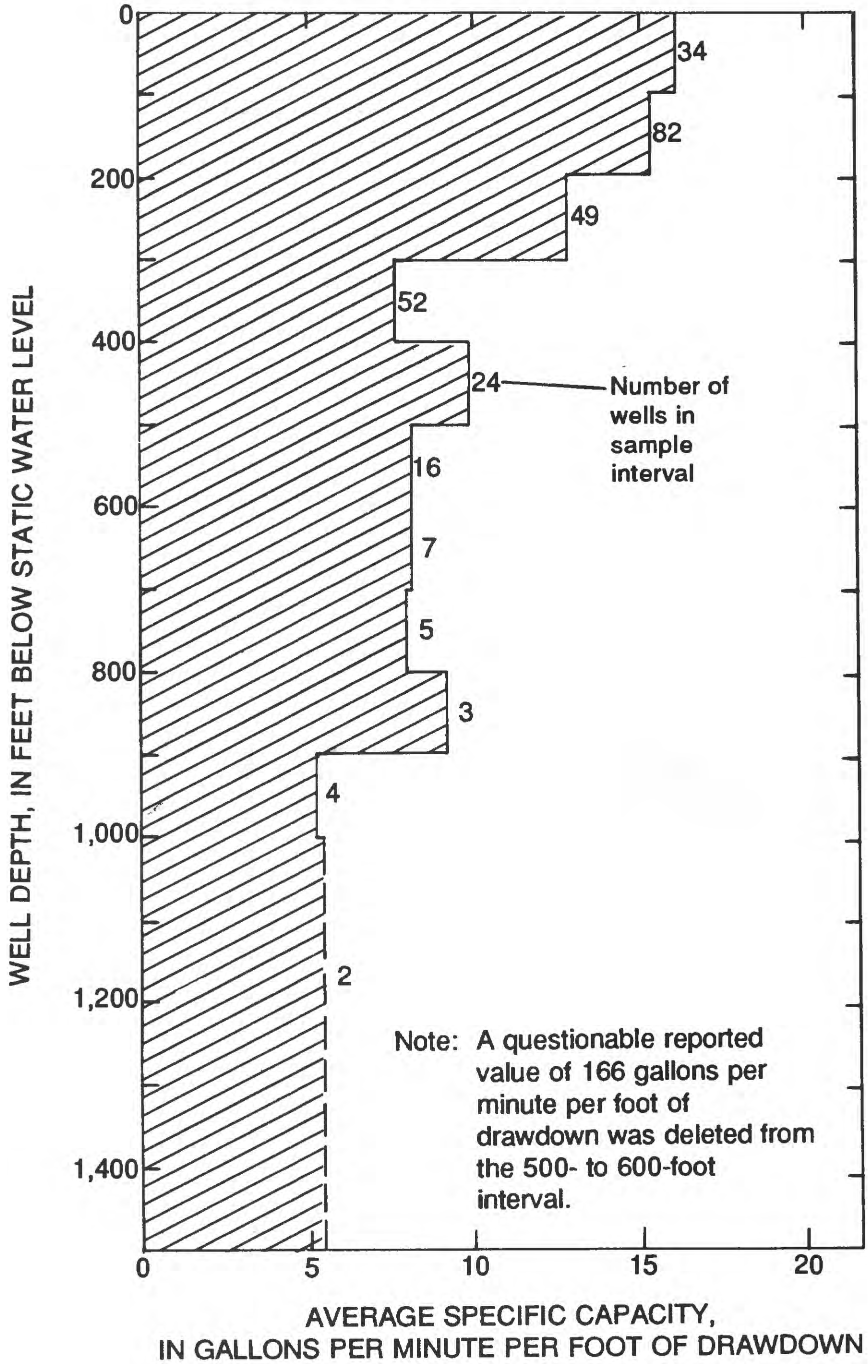

Figure 9.--Variation in specific capacity with depth of wells completed in the bolson-fill aquifer in the Mimbres Basin.

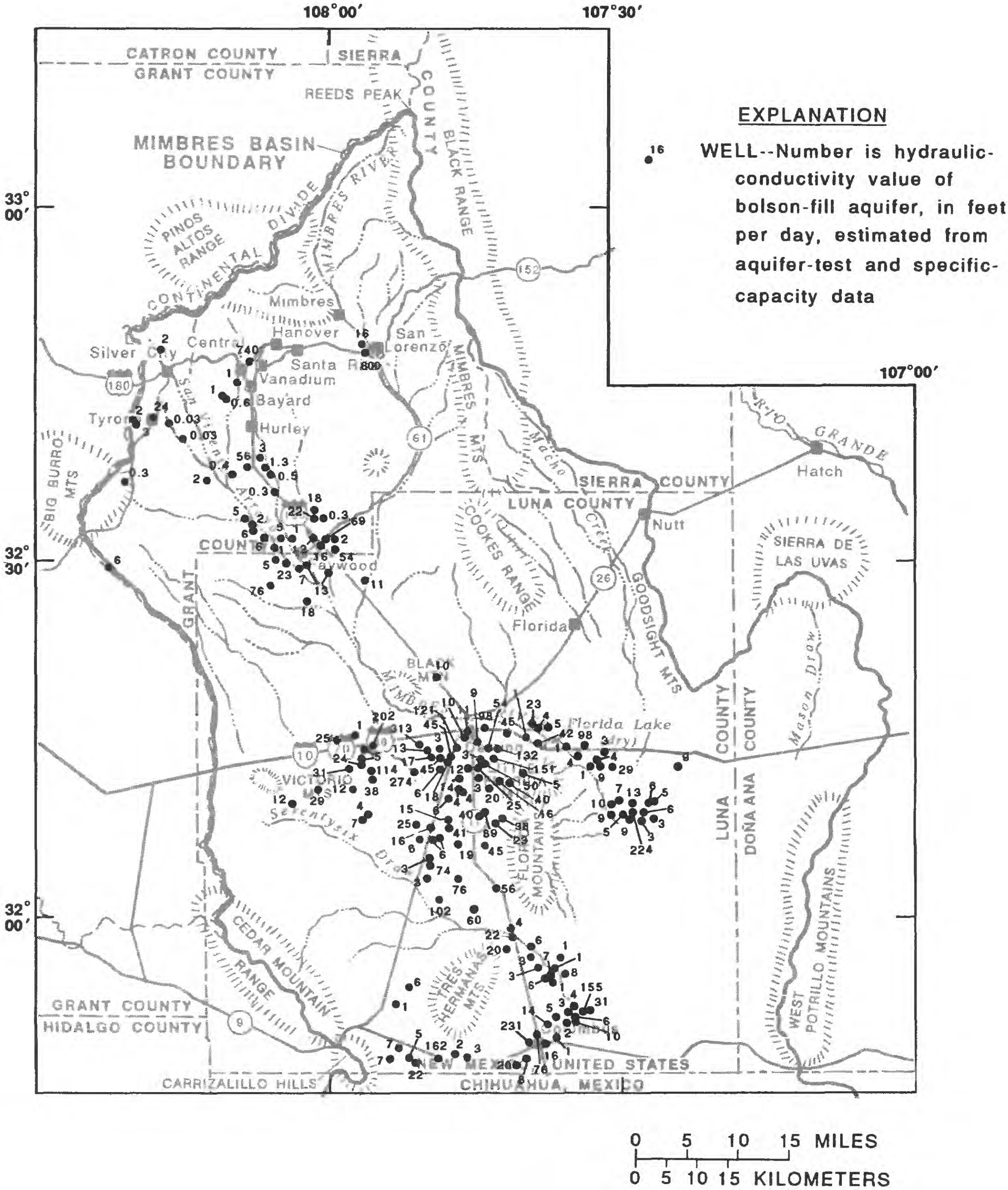

Figure 10.--Hydraulic-conductivity values of the bolson-fill aquifer in the Mimbres Basin.

Storage Coefficient

The storage coefficient of an aquifer is a measure of its ability to store water. In unconfined aquifers the storage coefficient is essentially equal to the specific yield. The storage coefficient is the volume of water an aquifer takes into or releases from storage per unit aquifer surface area per unit change in head (Lohman, 1972, p. 8). The specific yield of an unconfined aquifer is the volume of water drained by gravity per total volume of aquifer drained (Lohman, 1972, p. 6). Water pumped from wells in the Mimbres Basin is initially derived from expansion of water and compression of the aquifer material in the confined and semiconfined parts of the aquifer near the pumped well, and later from drainage of water from near the water table. Some of the aquifer material is elastic and will expand when water levels recover, whereas some is inelastic and could be permanently compressed, resulting in a lowering of the land surface. Storage coefficients or specific yields of the bolson-fill aquifer estimated from aquifer tests and other methods are compiled in table 5. Storage coefficients determined from aquifer tests range between 0.00036 and 0.0036 and represent the release of water from expansion of water and compression of the bolson-fill aquifer early in the aquifer test. Specific-yield values determined from the volume of sediments dewatered or estimated from lithologic logs range from 0.02 to 0.24. The volume of the bolson-fill aquifer dewatered between 1910 and 1970 was estimated by summing the volumes represented by the water-level declines shown in figures 3-7 in McLean (1977). This volume was divided by the estimated consumptive use of ground water withdrawn by pumpage for the period 1910 through 1970 to give an average specific yield of 0.14. This estimate has several sources of error: the volumes of dewatered bolson fill outside the 20-foot contours (McLean, 1977, figs. 3-7) are poorly defined; the estimate of consumptive use does not account for salvaged evapotranspiration; and the water-level changes are assumed to represent the dewatered bolson-fill aquifer, thus neglecting water derived from compaction of interbedded clays and local perched-water zones derived from infiltration of applied irrigation water. Nevertheless, because the estimate integrates water-level changes over a long time period, it may be the best estimate of specific yield.

Recharge

The total basinwide ground-water recharge contributed by precipitation is much less than the total precipitation falling on the basin. Annual precipitation in the study area from 1930 to 1961 averaged 3,160,000 acre-feet, or an area-weighted average of about 13 inches.

Recharge was analyzed for four parts of the basin: that segment of the Mimbres River Valley upstream from the gaging station Mimbres River near Faywood; the remainder of the basin north of section A-A' shown on plate 2, including the Mimbres River Valley downstream from Faywood; the part of the basin between section A-A' and the Mexico-United States border; and the part of the basin in Mexico. The recharge to the four parts was estimated by analyzing mountain-front runoff, infiltration from streams and springs, and underflow. Estimates are summarized in table 6 and discussed below.

Table 5.--Estimated storage-coefficient values for the bolson-fill aquifer in the Mimbres Basin

[--, no data]

Method of analysis	Storage coefficient or specific yield	Well location number	Reference
Volume of bolson-fill aquifer dewatered[1]:			
1910-30	0.11	--	This study
1931-40	0.16	--	Do.
1941-50	0.22	--	Do.
1951-60	0.13	--	Do.
1961-70	0.09	--	Do.
Average 1910-70	0.14	--	Do.
Lithologic logs for wells completed in bolson-fill aquifer	0.06-0.20	--	--
Areal estimates:			
Red Mountain area	0.09	--	Galloway (1953, p. 21)
Basin average	0.24	--	Galloway (1953, p. 21)
Woodward Ranch well field	0.04	--	Trauger (1972)
Franks Ranch well field	0.02-0.15	--	Koopman and others (1969)
Aquifer-test estimates:			
Red Mountain area	0.0036	24S.11W.11.21131	Conover (1952)
	0.0014	24S.11W.12.32431	Do.
	0.0005	24S.12W.34.43133	Do.
Florida Graben area	0.00065	25S.6W.3.121A	Do.
	0.0006	25S.6W.3.121A	Do.
	0.0005	25S.6W.3.121A	Do.
	0.00036	25S.6W.3.121A	Do.

[1]The volume of aquifer dewatered was measured on maps of water-level decline (McLean, 1977). This volume was divided by the total ground water pumped for the period to obtain an estimate of specific yield. This method does not account for water derived from salvaged evapotranspiration or other induced recharge or decreased discharge, and thus overestimates specific yield.

Table 6.--Estimated predevelopment ground-water budget for the bolson-fill aquifer in the Mimbres Basin

EXPLANATION

Q_r = Recharge to the bolson-fill aquifer from surface water

Q_c = Ground-water discharge to the soil zone, consisting of evaporation (E) plus transpiration by crops or natural vegetation (T) minus precipitation (P)

Q_d = Ground-water discharge to surface water

Q_{bi} = Inflow from bedrock aquifers to the bolson-fill aquifer

Q_{gi} = Ground-water underflow from another ground-water basin

Q_{go} = Ground-water underflow to another ground-water basin

Location	Water-budget component	Inflow, in acre-feet per year	Outflow, in acre-feet per year	Error
Mimbres River Valley upstream from Faywood	Mountain-front recharge (Q_r)	25,200		
	Evapotranspiration upstream from Faywood (Q_c)		3,400	
	Ground-water discharge to base flow of Mimbres River (Q_d)		4,800	
	Flow through valley alluvium and cross graben		5,800	
Subtotals		[1]25,000	[1]14,000	[1]11,000
Mimbres Basin in the United States downstream from Faywood, north of section A-A′ on plate 2	Flow through valley alluvium and cross graben	5,800		
	Infiltration of Mimbres River downstream from Faywood (Q_r)	10,100		
	Mountain-front recharge (Q_r)	20,000		
	Infiltration from Apache Tejo Spring, Lindauer Spring, and Faywood Hot Spring (Q_{bi})	2,200		
	Underflow from Mangas Trench and Palomas Basin (Q_{gi})	8,400		
	Flow across section A-A′		46,000	
Subtotals		[1]46,000	46,000	0

Table 6.--Estimated predevelopment ground-water budget for the bolson-fill aquifer in the Mimbres Basin--Concluded

Location	Water-budget component	Inflow, in acre-feet per year	Outflow, in acre-feet per year	Error
Mimbres Basin in the United States south of section A-A′ on plate 2	Flow across section A-A′	46,000		
	Mountain-front recharge (Q_r)	6,100		
	Transpiration from alluvial flats near Deming (Q_c)		42,000	
	Underflow near Mason Draw (Q_{go})		500	
	Net evaporation from Florida Lake (E-P)		[1]700	
	Flow across the Mexico-United States border		6,500	
Subtotals		[1]52,000	[1]50,000	[1]2,000
Mimbres Basin south of the Mexico-United States border	Flow across the Mexico-United States border	6,500		
	Mountain-front recharge (Q_r)	4,000		
	Evapotranspiration at playa lakes (Q_c)		28,000	
Subtotals		[1]11,000	28,000	[1]-17,000
Totals[2]		76,000	79,400	[1]-4,000

[1]Rounded.
[2]Excludes within-basin flow through the valley alluvium and cross graben, across section A-A′, and across the Mexico-United States border.

Mountain-Front Runoff

Calculations of mountain-front runoff provided an initial estimate of recharge to the bolson-fill aquifer in the basin. Runoff from mountainous regions is estimated by developing a regression equation between mean annual runoff for streamflow stations in mountainous areas of New Mexico and the physical characteristics of the basins: drainage area, channel slope, winter precipitation, and latitude. Runoff calculated by this method usually is assumed to infiltrate the bolson-fill aquifer as recharge. The long-term (1930-61) average mountain-front recharge to the entire basin was estimated to be 61,100 acre-feet per year, or about 84 cubic feet per second, from runoff estimated for 24 drainage-basin subregions within the Mimbres Basin (fig. 6). Hearne and Dewey (1988) described the theory, application, and sources of error in the mountain-front-runoff method, a method that does not account for evapotranspiration and that, therefore, overestimates recharge from runoff. Also, the method neither determines the distribution of recharge between ephemeral stream channels that contribute recharge within the same subregion nor accounts for changes in recharge rate through time. The use of the mountain-front-runoff method alone ignores direct infiltration from precipitation on the lower parts of the basin. Such infiltration is assumed to be negligible compared to recharge from mountain-front runoff.

The analysis of recharge was divided at the gaging station near Faywood because a bedrock constriction there forces much of the ground water that infiltrates upstream to discharge to the Mimbres River, allowing it to be measured. For the Mimbres River drainage upstream from Faywood, the sum of the mountain-front-runoff values is 31,000 acre-feet per year. Thus, if all this runoff were to recharge the aquifer, about half the mountain-front recharge for the entire basin would originate upstream from Faywood. However, the estimate of mountain-front runoff upstream from Faywood, 31,000 acre-feet per year, needs to be reduced by that part of the runoff that passes the Faywood gage without having infiltrated to the ground-water system. That part is assumed to be the average discharge at the Faywood gaging station of 10,600 acre-feet per year (14.6 cubic feet per second, table 3) minus the base flow at the station (assumed to be contributed from ground-water discharge) of 4,800 acre-feet per year (6.6 cubic feet per second), or 5,800 acre-feet per year (8.0 cubic feet per second). The resultant mountain-front recharge is therefore 31,000 minus 5,800, or 25,200 acre-feet per year (table 6). Mountain-front recharge that infiltrates upstream from the gaging station near Faywood either discharges to the Mimbres River to provide the base flow at the station, is transpired by vegetation, bypasses the gaging station as flow in the alluvium of the river valley, or bypasses the gaging station as flow in the bolson fill south of the river (cross graben in fig. 4). All of the 30,100 acre-feet per year of mountain-front runoff calculated for the remainder of the basin (table 6) was assumed to recharge the bolson-fill aquifer and to be distributed according to the locations of the subregions shown in figure 6. Because there is virtually no information on actual recharge rates, these mountain-front runoff estimates are more important for showing the relative distribution of recharge than for actual rates.

Infiltration from Streams and Springs

In addition to the ground-water inflow to the bolson-fill aquifer from the Mimbres River Valley near Faywood, the surface-water discharge itself needs to be considered. Downstream from the gaging station near Faywood, the Mimbres River is a losing stream. The annual streamflow near Faywood for 29 years between 1931 and 1968 (table 3) ranged from 0.8 to 21.8 cubic feet per second and averaged 14.6 cubic feet per second, or about 10,600 acre-feet per year. This streamflow nearly always infiltrates between the Faywood gage and Deming, although occasionally flow has passed the north end of the Little Florida Mountains. Not all of the streamflow that passes the gage near Faywood recharges the bolson-fill aquifer. Some is evaporated directly from the water surface, some is evaporated from wet sand in the channel, and some is diverted in the Wamel Canal for irrigation. During 1963-68, flow was measured at Spaulding, 10 miles downstream from the Faywood gaging station, and at the Wamel Canal, 24 miles downstream from the Faywood gaging station (U.S. Geological Survey, 1969; 1974). Flow was measured in both the Mimbres River and Wamel Canal. The average loss for all measurements for which there was flow at the downstream station was 2.4 cubic feet per second per mile between the Faywood and Spaulding gaging stations and 3.8 cubic feet per second per mile between the Spaulding and Wamel gaging stations. The channel averages 50 feet wide upstream from Spaulding and 80 feet downstream. By using these average rates of infiltration, the length of channel containing flowing water can be estimated. Assuming that the streamflow duration is that shown for the Mimbres River near Faywood in figure 7 and that the average pan evaporation rate of 9 feet per year (as will be discussed in the "Evapotranspiration" section) applies to the entire width of the channel throughout the reach containing flow, the average evaporation from all flow past Faywood is about 500 acre-feet per year. The remaining 10,100 acre-feet per year is assumed to infiltrate between Faywood and Deming (table 6).

Numerous wells are present adjacent to the river north of San Lorenzo and between San Lorenzo and the gaging station near Faywood. Pumping these wells likely induces additional infiltration from perennial reaches of the Mimbres River, so that infiltration is not constant but varies with both stream stage and pumpage. These withdrawals presumably reduce the flow of the Mimbres River at the Faywood gaging station.

Most springs in the Mimbres Basin discharge from bedrock in the mountainous areas of the basin. The largest of these are shown on plate 2. The water from these springs either is consumed or flows into and infiltrates ephemeral stream channels. Thus, most springs in the basin represent points of recharge to the bolson-fill aquifer. Thirty-three springs and an unknown number of seeps are scattered throughout the Mimbres Basin. Before its destruction, Apache Tejo Spring discharged 1,350 gallons per minute. The 2,200 acre-feet per year of springflow from Apache Tejo Spring, Lindauer Spring, and Faywood Hot Spring is assumed to have infiltrated to the bolson-fill aquifer near those springs (table 6). Each of the remaining springs discharges less than 30 gallons per minute (less than 50 acre-feet per year). The discharge of these minor springs does not represent a large source of recharge to the bolson-fill aquifer, and the recharge they represent is assumed to be included in the mountain-front recharge values (Trauger, 1972; McLean, 1977).

Underflow

A bedrock constriction of the Mimbres River Valley near Faywood forces much of the underflow in the valley to discharge to the Mimbres River, creating a perennial reach and allowing the flow to be gaged. The flow at Faywood infiltrates downstream from the constriction, providing the largest component of inflow to the downstream part of the Mimbres Basin and providing an independent estimate of one component of the water budget for use in model simulations. The ground-water inflow to the bolson-fill aquifer downstream from Faywood includes ground-water flow components bypassing the gaging station near Faywood, which consist of flow through the valley alluvium near the gage and flow through the cross graben south of the river. White (1930), using salt as a ground-water tracer, estimated underflow through the valley alluvium adjacent to the gaging station to be 850 acre-feet per year. On the basis of Darcy's law, flow through the cross graben can be estimated, using a width of 18,000 feet, an average thickness of 500 feet, a hydraulic gradient of 0.011, and a median hydraulic conductivity of 6 feet per day, to be equal to about 5,000 acre-feet per year. Therefore the ground-water inflow to the bolson-fill aquifer as underflow near Faywood is about 5,800 acre-feet per year (table 6).

Ground water may enter the Mimbres Basin from the north through the Mangas Trench near T. 18 S., R. 14 W. and R. 15 W., and from the Palomas Basin near T. 19 S., R. 6 W. as underflow from surrounding areas outside the Mimbres Basin watershed. By using Darcy's law, the total underflow into the basin at these locations was initially estimated to be about 8,400 acre-feet per year (tables 6 and 7).

Movement

Ground water in the Mimbres Basin generally moves from the northern highlands to the interior basins and southward toward the Mexican border. Isolated interior mountains locally modify the regional flow pattern by adding minor amounts of recharge and by altering the width and depth of the bolson-fill aquifer. The horizontal direction of ground-water movement in the bolson-fill aquifer prior to most ground-water development can be inferred from plate 2. Ground water moves at approximately right angles to the contours in the direction of decreasing water-level altitude. This map of predevelopment water levels in the bolson-fill aquifer was constructed using reported values for the depth to water in 1910 and 1911 from Darton (1916a) listed in McLean (1977). Land-surface altitudes at these wells, most of which have been destroyed, were obtained by plotting the sites on 1:24,000-scale topographic maps and estimating the altitudes for the sites. Because the wells in Darton (1916a) are located only to the nearest 1/4 of 1/4 of a section, the error in estimating the land-surface altitude may be large in areas with steep slopes. These water-level altitudes were supplemented with altitudes measured before 1931 reported in McLean (1977). Where necessary, these data were supplemented in areas distant from current intensive ground-water development with the earliest measurement in the area. The dates of these water-level measurements, between 1931 and 1958 (McLean, 1977), are shown on plate 2. Water-level contours in these areas should be interpreted with caution because some may have been affected by distant development.

Table 7.--Calculations of ground-water flow across various sections in the Mimbres Basin

[All values rounded]

Description of section across which flow was estimated	Location of section where flow was estimated	Approximate cross-sectional area, in square feet	Estimated predevelopment hydraulic gradient, in feet per foot	Estimated hydraulic conductivity, in feet per day	Calculated flow across section, in acre-feet per year
Underflow across Mimbres Basin boundary from areas outside of Mimbres Basin	Mangas Trench (T. 18 S., R. 14 W. and R. 15 W.)	12,700,000	0.013	6	8,300
	Palomas Basin T. 19 S., R. 6 W.)	1,100,000	0.0015	6	80
Total inflow in bolson fill across Mimbres Basin boundary					[1]8,400
Flow in bolson-fill aquifer across section A-A′ on plate 2	Mangas Trench part of section A-A′	45,000,000	0.0045	18	30,500
	Mangas Trench and Florida Graben part of section A-A′	110,000,000	0.0022	6	12,000
	Potrillo Horst part of section A-A′	34,000,000	0.002	6	3,400
Total flow in bolson fill across section A-A′					[1]46,000
Flow in bolson-fill aquifer across the Mexico-United States border	Tres Hermanas Graben along Mexican border	150,000,000	0.0003	6	2,300
	Florida Graben along Mexican border	270,000,000	0.0003	6	4,100
	Potrillo Horst along Mexican border	9,200,000	0.0003	6	140
Total flow in bolson fill across Mexican border					[1]6,500

[1]Rounded.

The predevelopment water-level map was constructed only for areas having a significant thickness of the bolson-fill aquifer. Water levels in bolson-fill and bedrock areas were contoured by McLean (1977, fig. 8). Although McLean's map shows water levels as of 1973, water levels in undeveloped areas probably are approximately representative of predevelopment conditions.

Ground-water flow through the bolson-fill aquifer south of the major recharge areas of the basin was estimated across section A-A', plate 2, for comparison with the net recharge estimates for the northern part of the basin. For predevelopment conditions, the flow should be equal to the amount of recharge to the bolson-fill aquifer upgradient from the section minus the discharge from the bolson fill upgradient. For predevelopment calculations, the system is assumed to be in dynamic equilibrium; that is, on the average, changes in ground-water storage are negligible and inflow is equal to outflow (also called steady state). Along section A-A', the aquifer was divided into three sections. The gradients are uniform, and only the component of the gradient perpendicular to the sections was used to calculate flow across the sections. The total flow through the section, which is the sum of the three segments, is 46,000 acre-feet per year (tables 6 and 7).

Ground-water flow in the bolson-fill aquifer across the United States-Mexico border also was estimated. Although the estimate is uncertain due to uncertainties in the hydraulic gradient, aquifer thickness, and hydraulic conductivity, the predevelopment flow across the border was probably only about 6,500 acre-feet per year (tables 6 and 7). Development has altered the directions of ground-water flow in the bolson-fill aquifer. Comparing water levels in the bolson-fill aquifer, estimated for conditions before development (pl. 2), with 1973 water levels from McLean (1977, fig. 8) shows a decline in water levels and a change in direction of ground-water movement near Deming and Columbus. Extensive ground-water development in these areas has altered flow directions toward local pumping centers.

Vertical movement of ground water occurs throughout the Mimbres Basin; however, estimating the direction and rate of this movement is difficult because the change in hydraulic head with depth is unknown. In general, downward movement of ground water is presumed to occur mainly in recharge areas in the northern part of the basin. Upward movement is likely where the aquifer becomes thinner, such as near Black Mountain and north of the Little Florida Mountains, as indicated by anomalously high ground-water temperatures in shallow wells. Upward movement also is likely in the Mexican part of the basin where ground water discharges to playas; throughout most of the basin, however, the principal component of flow is horizontal.

Discharge

Prior to development that began in the early 1900's, ground water was discharged from the Mimbres Basin by evaporation from lakes and playas, transpiration from vegetation, and underflow across parts of the basin boundary. Estimates of predevelopment ground-water discharge from these sources are summarized in table 6 and discussed below.

Evapotranspiration

The warm, arid climate of the Mimbres Basin causes a high rate of evaporation from water surfaces and a large potential evapotranspiration rate. The class A evaporation pan at Florida, about 12 miles northeast of Deming on State Highway 26, had an average evaporation rate of almost 108 inches per year for 1929-75 (Gabin and Lesperance, 1977, p. 202). A nonstandard pan at Santa Rita, about 3 miles northeast of Bayard, had an evaporation rate of 94 inches per year for 1912-52 (Gabin and Lesperance, 1977, p. 140).

Playas and Lakes

Evaporation from playas in Mexico, which have a total surface area of 23,600 acres, has the potential to account for large amounts of discharge. However, the highest rate of evaporation could have occurred only during the wettest periods, when the playas contained water. Therefore, actual discharge of water from the playas probably was much less than this maximum rate. Most of the time the water levels probably are below the surface of the playas. The rate of ground-water evaporation from bare ground in the playas is difficult to estimate; however, Culler and others (1982) estimated 25 inches per year of evaporation from areas of Gila River alluvium (Arizona) with no phreatophytes. If the rate of evaporation is similar at the playas, and if all rainfall evaporates, the annual ground-water evaporation would be about 25 inches minus 10 inches (the amount supplied by rainfall). This rate is a very rough approximation, indicating only that evaporation would be adequate to discharge all the ground water flowing into Mexico. If a rate of evaporation from the bare ground in the playas of 1.2 feet per year is assumed, about 28,000 acre-feet per year would have evaporated (table 6).

Prior to development of ground water in the Deming area, a small amount of water probably discharged through evaporation at Florida Lake in Luna County. With an area of about 126 acres and an annual pan evaporation of almost 9 feet, an assumed pan coefficient of 0.7, and rainfall accounted for on the lake surface, probably about 670 acre-feet of ground water per year evaporated (table 6).

Vegetation

Prior to 1930, vegetation may have been well enough established to extract ground water from depths below land surface of 50 feet or more. Darton's (1916b) hydrologic map identifies areas near Deming in which the depth to water was less than 50 feet (fig. 11). White (1930, p. 149) cited the occurrence of mesquite roots at a depth of 41 feet in a well drilled 1.5 miles southeast of Deming; the water table at that site was at a depth of 48.5 feet.

Evapotranspiration from ground water was assumed to occur in the regions outlined by Darton as having a depth to water of less than 50 feet. Based on the mesquite consumptive-use coefficient of 0.65 for the Deming area (Blaney and Hanson, 1965, table 22) multiplied by the ratio of consumptive use for sparse to dense vegetation (Blaney and Hanson, 1965, table 21), the consumptive-use coefficient for the Mimbres Basin is 0.38. Based on a consumptive use of 42.37 inches per year (Blaney and Hanson, 1965, table 11), multiplied by 0.38, the maximum evapotranspiration rate is about 1.3 feet per year.

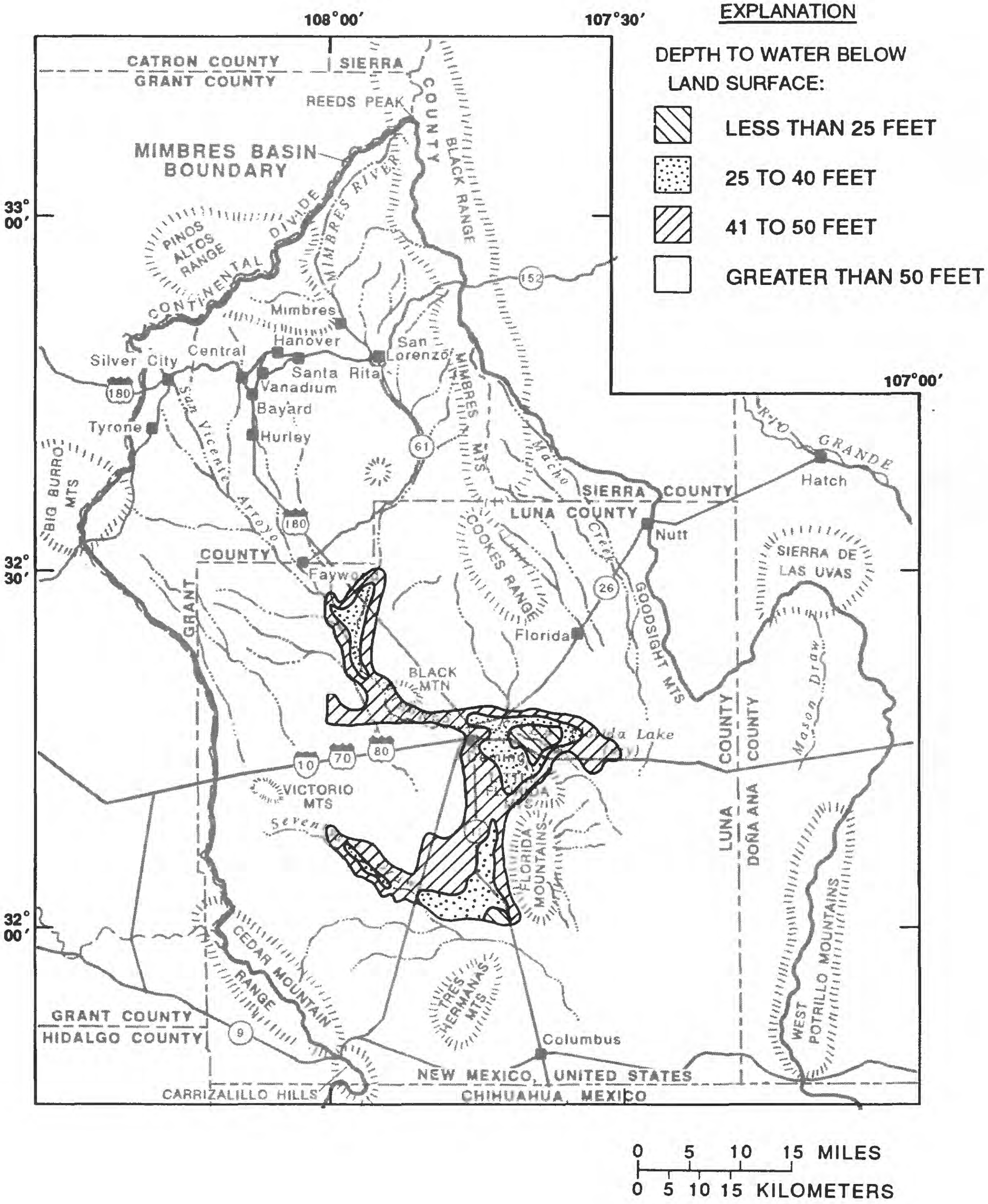

Figure 11.--Depth to water in the central Mimbres Basin during 1910-13 (depths to water from Darton, 1916b).

No information is available for the rate of decrease of transpiration with depth to the water table in the Mimbres Basin. A maximum rate of transpiration for mesquite of 3.0 feet per year, at 100-percent vegetation density, and a depth to water of 5 to 8 feet were estimated by Mower and others (1964, p. 65-66) for the Roswell Basin. Adjusted for vegetation density, as above, the transpiration rate could be as much as 1.7 feet per year. Therefore, a maximum rate of evapotranspiration of about 1.7 feet per year and a maximum depth of evapotranspiration of about 50 feet could be possible in the Mimbres Basin.

Based on a linear reduction in the evapotranspiration rate with depth of 1.7 feet per year at land surface to zero at 50 feet and the depth-to-water regions outlined by Darton (1916b) shown in figure 11, the estimated evapotranspiration rate could have been as much as 42,000 acre-feet per year (table 6). This value, however, does not include areas of shallow water east of the Florida Mountains, for which few early water-level data are available.

In addition to evapotranspiration in the area outlined by Darton (1916b), predevelopment evapotranspiration from willows, cottonweeds, mesquite, and other vegetation along the Mimbres River flood plain is estimated to have been 3,400 acre-feet per year (J. D. Dewey, U.S. Geological Survey, oral commun., 1980). Most of this evapotranspiration occurred upstream from the Faywood gaging station.

Underflow

The only underflow leaving the Mimbres Basin, except flow to Mexico, may be in the Mason Draw area where water-level data are questionable. Several of the water levels in this area were measured near pumped wells or in recently pumped wells (McLean, 1977, table 5) and thus do not correctly represent predevelopment conditions. By assuming a hydraulic conductivity of 6 feet per day and a hydraulic gradient of 0.011 foot per foot, underflow of about 500 acre-feet per year (table 6) may be leaving the basin through a 972,000-square-foot section east of Mason Draw (pl. 2).

Water-Level Fluctuations

Water levels in the bolson-fill aquifer fluctuate due to changes in natural recharge rate, natural discharge rate, and ground-water withdrawals. Generally, changes in natural recharge and discharge rates produce small and erratic water-level fluctuations, as shown in well 21S.10W.6.112 (fig. 12). This well is located west of the Cookes Range in an area of little ground-water development.

Wells located in areas of extensive ground-water development show larger changes in water level. Annual fluctuations in water level caused by the variation in the quantity of water pumped between summer and winter months are shown in well 24S.10W.12.431 (fig. 12). Long-term declines in water levels also may be caused by ground-water withdrawals. Well 24S.8W.5.111, located near Deming, showed a fairly steady water-level decline of about 40 feet from 1930 to 1980. Water levels in wells 29S.8W.12.244 and 28S.8W.24.111 near Columbus illustrate the declines that occurred after major ground-water withdrawals began in that area in the early 1950's.

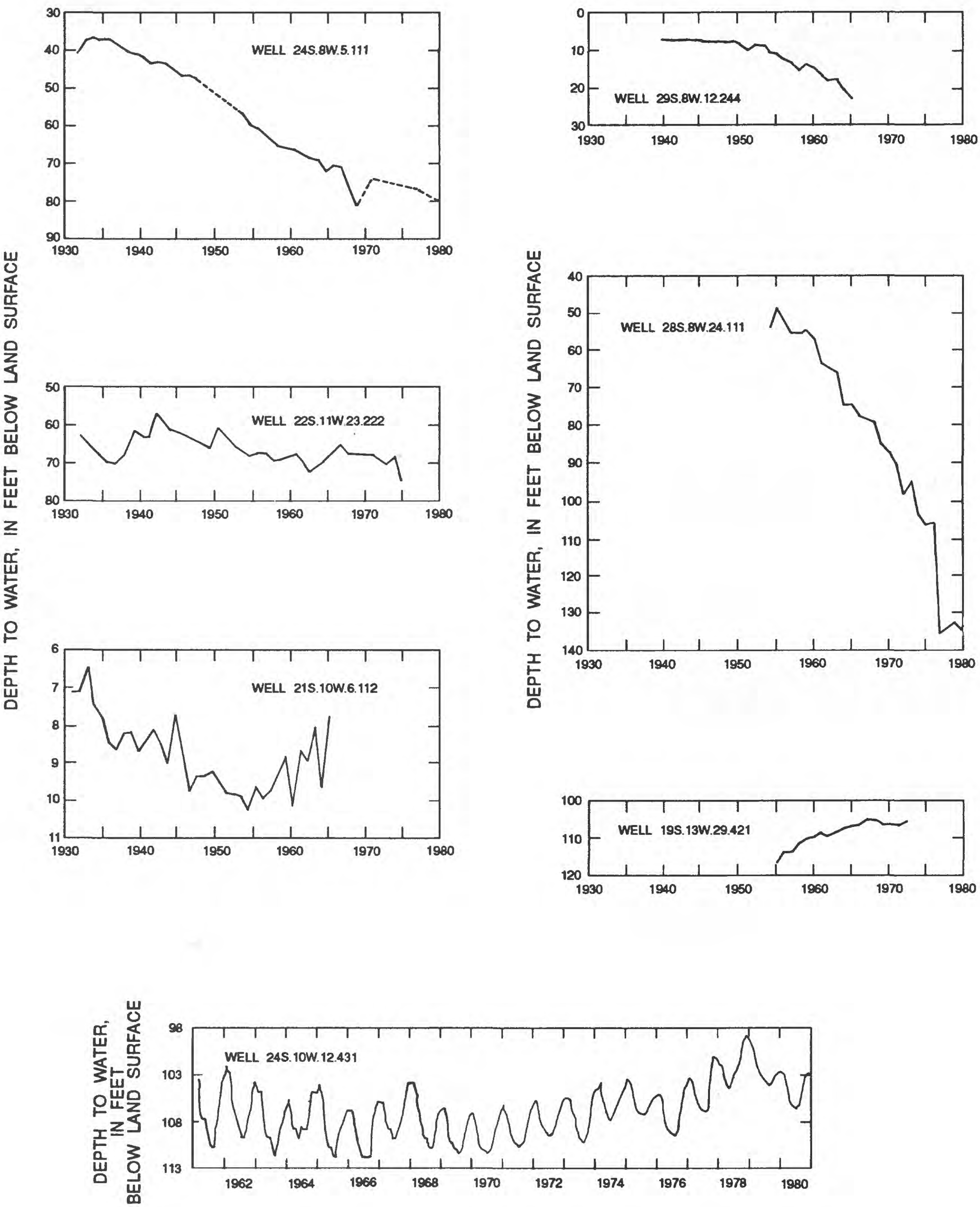

Figure 12.--Water-level fluctuations in the bolson-fill aquifer in the Mimbres Basin.

Records of wells 24S.8W.5.111, 29S.8W.12.244, and 28S.8W.24.111 indicate a gradual and largely consistent decline of water levels since development of the basin. Many other wells, however, have histories of intermittent decline and recovery. Well 22S.11W.23.222, completed in the bolson-fill aquifer northwest of Deming, shows an initial water-level decline between 1930 and 1936, followed by 6 years of general water-level recovery (fig. 12). The water-level decline since 1942 has been marked by occasional periods of recovery. Well 19S.13W.29.421 has a history opposite that of the normal trend in the basin; water levels have risen almost 9 feet since 1957 (fig. 12). This stock well, shallower than nearby irrigation wells, may be responding to infiltration of applied irrigation water or to recovery from earlier periods of drawdown (McLean, 1977, p. 12). Average water-level declines throughout the Mimbres Basin were mapped for various time periods (McLean, 1977, figs. 3-7). These data were used to compute the approximate net water-level decline in the basin from 1910 to 1970 (fig. 13). Water levels declined nearly 100 feet south of Deming and nearly 140 feet east of Columbus.

Ground-Water Quality

Quality of ground water in the Mimbres Basin was evaluated using selected chemical analyses from the U.S. Geological Survey's WATSTORE data file (table 8, at back of report). Ground-water samples thought to be contaminated, analyses from wells deeper than 2,000 feet, and some analyses from areas having uniform chemistry and a large density of samples were not selected from the data base. Also, analyses were not used unless a complete determination of calcium, magnesium, sodium, potassium (or sodium plus potassium), bicarbonate, chloride, and sulfate was reported and the milliequivalent weights of cations and anions balanced within 5 percent. Analyses that did not meet the selection criteria included waters containing large sulfate concentrations in the Hanover-Fierro Mining District (about 5 miles north of Bayard) and water containing large concentrations of chloride and sulfate from deep oil wells drilled in the Florida Graben along the Mexican border.

Water-chemistry data are sparse along the Potrillo Horst, the Cedar Arc-Knight Peak Graben region, along the Silver City-Pipeline Draw Fault system, and in bolson-fill deposits along the Mimbres Trench. Incomplete analyses in U.S. Geological Survey data files and a lack of supporting well specifications and stratigraphic data were the major reasons for not using analyses from these areas.

The selected water analyses in table 8 were used to define water quality of the bolson-fill aquifer within the Mimbres Basin. The relative percentage of cations and anions in waters of the bolson-fill aquifer is shown in figure 14. The chemical composition changes along flow paths as the ground water moves from the northern highlands to the Mexican border. In general, water in the bolson-fill aquifer adjacent to bedrock exposures in the northern part of the basin is composed mainly of calcium, magnesium, bicarbonate, and sulfate (fig. 14, base of arrow shaft). The composition of this water is controlled partly by the bedrock through which it flowed before recharging the bolson fill. As the ground water flows south, it mixes with bicarbonate-rich water recharged from streams such as the Mimbres River that flow across the bolson fill. Because clays within the bolson-fill aquifer exchange two sodium atoms from their crystal structure for each calcium atom in ground water, the water changes from calcium bicarbonate water to sodium bicarbonate water (fig. 14); this characterizes most water in the aquifer. Farther along the flow path, the ground water increases in sulfate and to a lesser extent, chloride content. Possible sources of sulfate include solution of gypsum from playa deposits interbedded in the bolson fill, oxidation of sulfide minerals in adjacent bedrock units, and infiltration of wastewater in streams from the milling of sulfide ores in a few local areas.

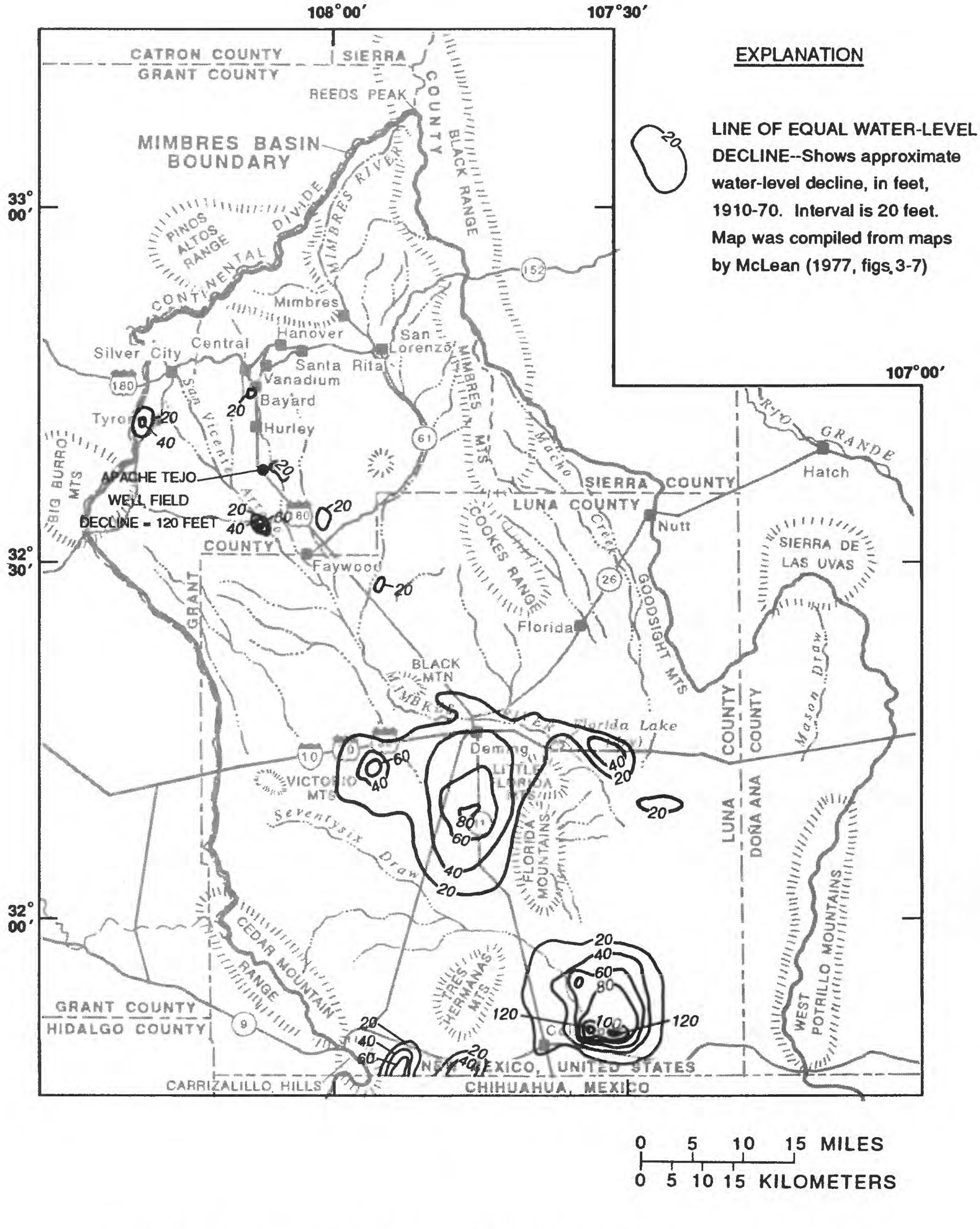

Figure 13.--Approximate water-level decline in the Mimbres Basin, 1910-70.

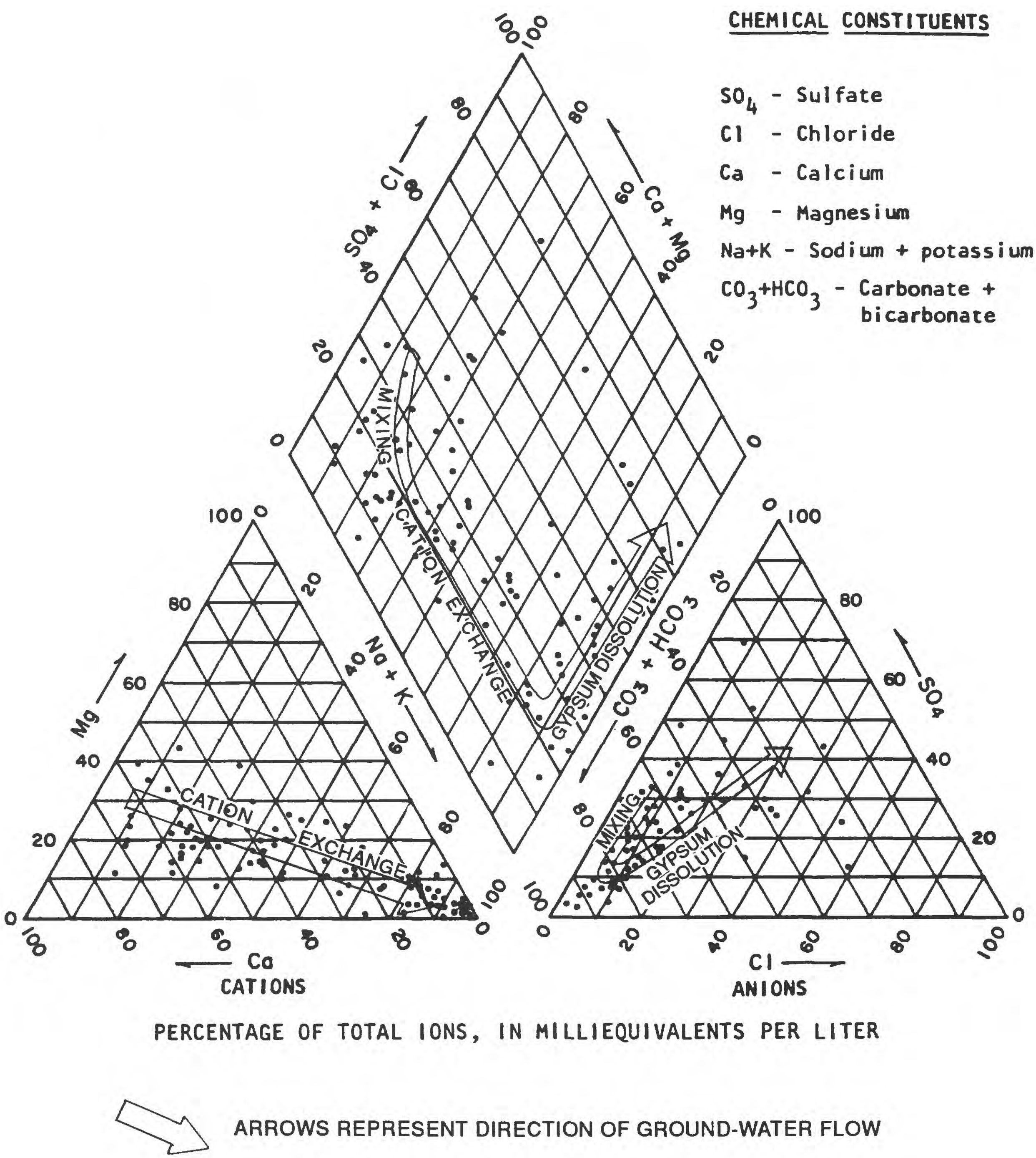

Figure 14.--Generalized evolution of chemical composition of ground water in the bolson-fill aquifer in the Mimbres Basin.

Specific conductance (fig. 15) provides an estimate of dissolved-solids concentration in the bolson-fill aquifer. Dissolved-solids concentration of a water sample can generally be approximated by multiplying its specific conductance times a constant between 0.55 and 0.75 (Hem, 1970, p. 99). In the bolson-fill aquifer, specific conductance is greater in the southern part of the basin.

The effects of human activities locally are superimposed on the pre-existing water quality in the basin. These effects include infiltration of municipal and industrial wastewater and infiltration of agricultural chemicals. These activities have created local anomalies in the water quality.

Water-quality criteria usually depend on categories of water use such as public drinking supplies, industrial use, stock use, and the irrigation of fruit, vegetable, forage, or field crops. Except for the deeper water in the Mimbres Basin, most ground water is acceptable for most industrial use (Hem, 1970, p. 334). All analyses in table 8 show dissolved-solids concentrations that are less than the limit for livestock drinking water (Hem, 1970, p. 324).

The largest water use in the Mimbres Basin is for agriculture. Crops are sensitive, in varying degrees, to the salinity, alkalinity, and temperature of irrigation waters. Figure 15 shows salinity-hazard categories (U.S. Department of Agriculture, 1954) for ground water from the bolson-fill aquifer. A large salinity hazard is present in the southern part of the basin. The alkali (sodium) hazard is based on the ratio of sodium to other major cations, called the sodium adsorption ratio (Hem, 1970, p. 228). The alkali hazard for irrigation that uses water from the bolson-fill aquifer also is shown in figure 15. Only water samples from the southeast part of the basin have sodium adsorption ratios that create a large alkali hazard. Examination of the salinity- and alkali-hazard map (fig. 15) provides a guide to the general suitability of water in the bolson-fill aquifer for irrigation.

On the basis of salinity tolerances established by the U.S. Department of Agriculture (1954), ground water in the Mimbres Basin is usually suitable for the irrigation of field crops and most vegetable and forage crops. Green beans, celery, radishes, and some types of clover forage may be difficult to grow using water from the south-central part of the Florida Graben. Because most fruit crops can tolerate only small to medium salinity and alkalinity, most of the southern third of the basin contains water that may be too saline and too alkaline for irrigation of fruit orchards. As shown by the numerous orchards along the Mimbres River upstream from Faywood, the northern two-thirds of the basin is suitable for the irrigation of fruit crops.

The temperature distribution of ground water in the bolson-fill aquifer is shown in figure 16. As would be expected, the ground-water temperatures, with a few notable exceptions, increase with a decrease in land-surface altitude. Above-normal temperatures are found in wells located in the southern part of the Florida and Tres Hermanas Grabens, north of the Little Florida Mountains, and within the northern extension of the Florida Graben east of the Cookes Range.

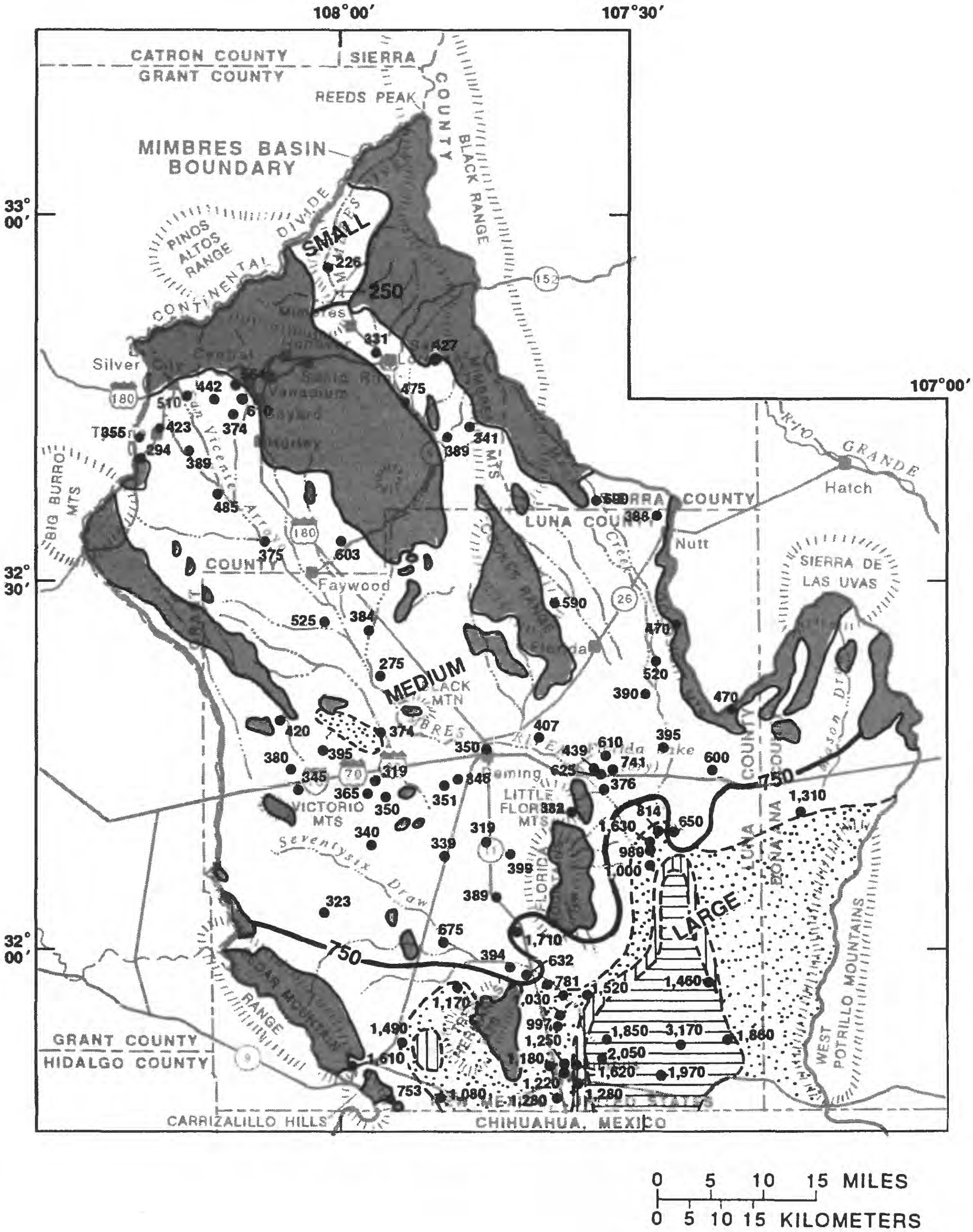

Figure 15.--Salinity and alkali hazard for irrigation using ground water from the bolson-fill aquifer in the Mimbres Basin.

EXPLANATION

AREA WHERE BOLSON-FILL AQUIFER IS ABSENT

ALKALI HAZARD OF GROUND WATER IN THE BOLSON-FILL AQUIFER--Determined from the sodium adsorption ratio (SAR) (Hem,1970):

SMALL ALKALI HAZARD (SAR less than 10)

MEDIUM ALKALI HAZARD (SAR between 10 and 18)

LARGE ALKALI HAZARD (SAR between 19 and 26)

VERY LARGE ALKALI HAZARD (SAR greater than 26)

MEDIUM SALINITY HAZARD--Shows salinity hazard based on specific-conductance categories (Hem, 1970):
Small--less than 250 microsiemens per centimeter
Medium--251-750 microsiemens per centimeter
Large--greater than 750 microsiemens per centimeter

—750— LINE OF EQUAL SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS--Interval is 500 microsiemens per centimeter

1,610 ● WELL--Number is specific conductance of well water, in microsiemens per centimeter at 25 degrees Celsius

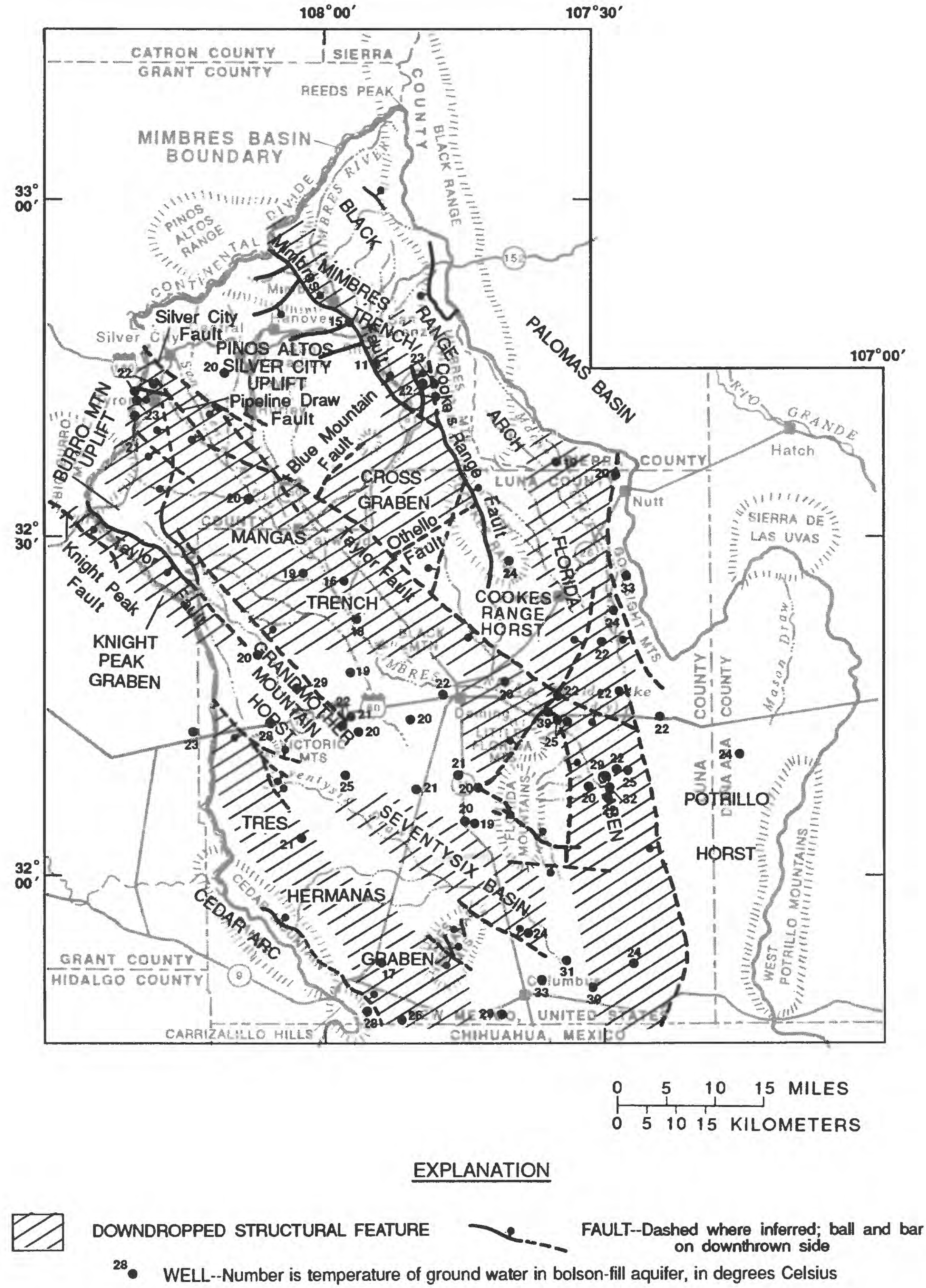

Figure 16.--Temperature of ground water in the bolson-fill aquifer in the Mimbres Basin.

Large heat-flow rates also were measured within the Mimbres Graben and the Palomas Basin, both of which are included in the Rio Grande Rift region of elevated heat-flow rates (Reiter and others, 1978, p. 234). The wells that yield water of above-normal temperature usually are located within regions in which the ground water has relatively large salinity or alkalinity. This warm, saline, or alkaline well water is useful for space heating of homes and greenhouse crops and sometimes is used for frost prevention in orchards.

In summary, ground water in the bolson-fill aquifer in the northern and central parts of the basin generally is suitable for the major uses discussed previously. In contrast, ground-water quality deteriorates to the south and southeast (down the hydraulic gradient) and may be unsuitable for irrigation of fruits, some vegetables, and some forage crops. Some water samples from the international border region of the Florida Graben also exceed recommended dissolved-solids content for public drinking water supplies. Locally, water from the Mimbres Hot Spring contains too much fluorine for public drinking water, and oil tests of rocks of Cretaceous age in the southeastern part of the basin found water that was too saline for public drinking water or the irrigation of most crops.

SIMULATION OF GROUND-WATER FLOW IN THE BOLSON-FILL AQUIFER

The bolson-fill aquifer is the most widely developed ground-water resource in the Mimbres Basin. This section describes a preliminary digital model of ground-water flow in the bolson-fill aquifer. The main purpose of the digital model is to establish a quantitative understanding of ground-water flow in the aquifer. To develop such an understanding, conditions prior to development (steady state) and the historical response of the aquifer to ground-water development (transient state) were simulated.

Conceptual Model

The quantitative basis for a conceptual model of the Mimbres Basin has been presented in previous sections of this report. The nature of the ground-water flow system in the bolson-fill aquifer and its relation to surface water and adjacent aquifers are described below.

Infiltration of precipitation, infiltration of runoff in stream channels and along bedrock mountain fronts, and underflow from adjacent alluvial aquifers recharge the bolson-fill aquifer. Ground water flows from the Mimbres and Mangas Trenches and Knight Peak Graben in the northern recharge areas to the Florida Graben, Tres Hermanas Graben, and Seventysix Basin in the south and discharges as transpiration, discharge to playas in Mexico, and evapotranspiration. The bolson-fill aquifer is bounded laterally by faults in some places that place bedrock units that have smaller hydraulic-conductivity values adjacent to the alluvial deposits. The bottom of the aquifer is bounded by Tertiary or older rocks that are assumed to be of such small hydraulic conductivity that movement of water to or from these rocks may be neglected.

A ground-water budget can be written for the bolson-fill aquifer using equations that describe the sources, sinks, and movement of water within the aquifer as described earlier. The most general form of the mass-balance equation is:

$$I - O = \Delta S, \qquad (2)$$

where I = inflow during a time period;

O = outflow during the same time period; and

ΔS = net change in the amount of ground-water storage in that time period.

The budget equation is useful when evaluating which components are directly measurable, which can be calculated through indirect information, and which components are unknown. These water-budget components can then be evaluated in a digital model of the ground-water system.

Expansion of the inflow and outflow budget terms for the bolson-fill aquifer from equation 2 results in two expressions of the form:

$$I = Q_{di} + Q_r + Q_{gi} + Q_{bi}; \qquad (3)$$

and

$$O = W + Q_{go} + Q_{bo} + Q_d + Q_c + \Delta S; \qquad (4)$$

where Q_{di} = precipitation that infiltrates directly to the bolson-fill aquifer;

Q_r = recharge to the bolson-fill aquifer from surface water;

Q_{gi} = underflow from another ground-water basin;

Q_{bi} = inflow from bedrock aquifers to the bolson-fill aquifer;

W = ground-water withdrawals by pumping;

Q_{go} = underflow to another ground-water basin;

Q_{bo} = outflow to bedrock aquifers from the bolson-fill aquifer;

Q_d = ground-water discharge to surface water; and

Q_c = ground-water discharge to the soil zone, consisting of evaporation (E) plus transpiration by crops or natural vegetation (T) minus precipitation (P).

The predevelopment budget is based on the assumptions that the Mimbres Basin was in a state of dynamic equilibrium (steady state) and that the change of water in storage over a long period was equal to zero. Hydraulic heads in the bedrock aquifers prior to development are not well known, but were assumed to have been equal to or greater than heads in the bolson-fill aquifer, so that flow from bolson-fill to bedrock aquifers (Q_{bo}) was negligible. By neglecting the change in storage (ΔS) and the withdrawals by pumping (W), a simplified balance between equations 3 and 4 becomes:

$$Q_{di} + Q_r + Q_{gi} + Q_{bi} = Q_{go} + Q_c + Q_d . \qquad (5)$$

In these equations, ground-water discharge to the soil zone represents a net loss from the ground-water system rather than a gross value, which includes loss from precipitation or soil-moisture storage. Budget estimates using equation 5 were made by evaluating different combinations of recharge and discharge values previously discussed in the text and table 7. The resulting budget for the four parts of the bolson-fill aquifer is shown in table 6. In preparing this water budget, the direct infiltration from precipitation, Q_{di}, is assumed to be negligible. Recharge from Apache Tejo Spring is assumed to represent inflow from bedrock, Q_{bi}, even though the flow was discharged to the land surface before infiltrating to the bolson-fill aquifer. The budget for the Mimbres River Valley upstream from Faywood shows that recharge estimates based on mountain-front runoff are larger than the estimated evapotranspiration, ground-water discharge, and underflow, implying that the mountain-front-runoff method overestimates recharge. The inflow and outflow components for the two central segments of the basin appear to be approximately equal, but the budget for the segment south of the United States-Mexico border indicates that estimated discharge may be too large.

This budget shows inflows to be 76,000 acre-feet per year, about 2 percent of the average annual precipitation on the basin, but estimated outflow from the basin is 4,000 acre-feet per year more than estimated inflow. This disparity indicates that all budget terms have not been accurately determined. In fact, the errors in some of the individual components could be much larger than indicated by the imbalance of 4,000 acre-feet per year. The ground-water flow model was used to evaluate the budget components within the constraint of known water levels and estimated hydraulic properties of the bolson-fill aquifer. The magnitude of the adjustments in the budget components indicates which properties and components need additional study.

Model Construction

Construction of the digital computer model involved four steps: (1) selecting the appropriate computer code, (2) assigning a finite-difference grid to the area of the aquifer, (3) assigning boundary conditions, and (4) assigning initial estimates of hydraulic properties to each block in the grid. These steps translate the conceptual model of ground-water movement in the bolson-fill aquifer to a quantitative digital model.

Computer Code

The bolson-fill aquifer of the Mimbres Basin, viewed on a regional scale, is a relatively thin, nearly horizontal sheet. Because ground-water flow within the sheet, although locally complex, is largely constrained to a two-dimensional, horizontal plane, a two-dimensional flow model was used to simulate ground-water flow. Thus, the model does not simulate vertical differences in hydraulic head and contains the implicit assumption that aquifer properties in each block are uniform with depth. The model was initially prepared using the two-dimensional, blockcentered, finite-difference computer code of Trescott and others (1976) and later modified for use with the modular model developed by McDonald and Harbaugh (1988).

Finite-Difference Grid

The flow model was restricted to the contiguous areas of the bolson-fill aquifer.[1] Several bedrock areas adjacent to the bolson-fill aquifer were included to allow recharge and discharge areas to be located at some distance from areas used for comparisons of simulated and measured heads and from areas of large ground-water withdrawals. These include the Tertiary rhyolites west of the Mimbres River in the San Lorenzo-Faywood area, the basalt flows in Mexico south of the Carrizalillo Hills, and isolated exposures of Cretaceous sediments on the Potrillo Horst.

The finite-difference grid used for the Mimbres model consists of 56 rows and 46 columns (fig. 17). The active part of the model consists of 1,513 blocks, each of which has a row and column designation; thus, the block situated at the intersection of row 21 and column 18 is called block 21-18. The dimensions of the active blocks range from 6,101 feet by 6,101 feet (about 1.3 square miles) to 20,592 feet by 20,592 feet (about 15.2 square miles). The grid columns are oriented N. 33° W., roughly parallel to the reach of the Mimbres River adjacent to the Mimbres fault and at nearly the orientation of stream channels and fault lineations in the basin. The smallest blocks are located in the areas of most intensive pumping to provide better resolution of water levels there, and the largest blocks are located near the margins of the basin, where there is little pumping.

Boundary Conditions

Boundary conditions define the physical extent of the system to be simulated and how the flow of water into and out of the aquifer will be simulated in the model. All blocks outside the boundary of the bolson-fill aquifer (fig. 17) are no-flow blocks. In addition to the no-flow blocks, flow boundaries used in the model include constant-flow, constant-head, and head-dependent boundaries.

Constant-flow boundaries

All recharge was simulated as a constant flow by using the recharge option in the model code (McDonald and Harbaugh, 1988, p. 7-1 to 7-22). Most recharge in the model is simulated at the periphery of the bolson-fill aquifer adjacent to no-flow boundaries. The initial estimate of about 55,000 acre-feet per year (table 6) of mountain-front recharge was divided among blocks at the upstream reaches of ephemeral streams within the subregions outlined in figure 6. The total recharge available from each subregion was applied uniformly to blocks representing the upstream reaches of streams that provide recharge from that subregion. During model calibration, mountain-front recharge was reduced to the rates shown in table 9 (at back of report).

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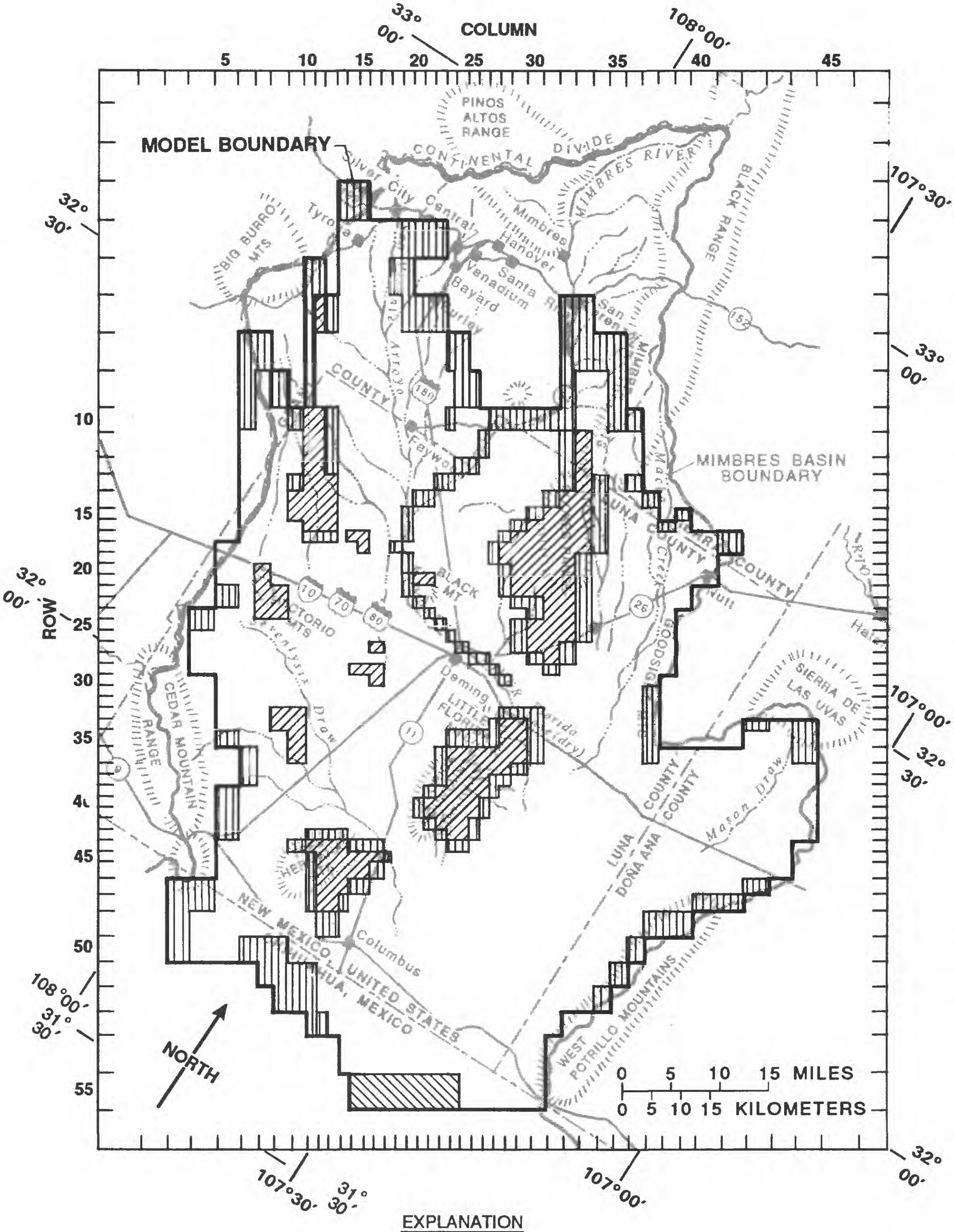
[1]The part of the bolson-fill aquifer north of San Lorenzo was not included in the model because the aquifer is narrow and no water levels are available except those immediately adjacent to, and in the same model mode with, the Mimbres River. Thus, at this scale, the model is not sensitive to hydraulic properties in the area and all pumpage represents diversions from the stream.



EXPLANATION

NO-FLOW BLOCKS — CONSTANT-FLOW BLOCKS — CONSTANT-HEAD BLOCKS

ALL BLOCKS OUTSIDE THE MODEL BOUNDARY ARE NO-FLOW BLOCKS

Figure 17.--Grid and boundary conditions used in the model of the bolson-fill aquifer in the Mimbres Basin.

Recharge along the Mimbres River was estimated using mountain-front runoff and infiltration from the river. Recharge upstream from the Faywood gaging station initially was applied using the net mountain-front recharge value of 25,200 acre-feet per year (table 6) from the Mimbres River, Blue Mountain, and Mimbres Peak subregions (fig. 6). Recharge from the Mimbres River subregion was distributed among model blocks representing the reach from San Lorenzo to the streamflow-gaging station near Faywood. Additional recharge from the Blue Mountain and Mimbres Peak subregions was added to recharge from the Mimbres River subregion in blocks representing the reach of the Mimbres River within the appropriate subregion. The infiltration from the Mimbres River immediately downstream from the gaging station near Faywood represents recharge to the model blocks along the river at and downstream from the gaging station at Faywood (table 9).

Recharge of 13.7 cubic feet per second to the bolson-fill aquifer along the Mimbres River downstream from the Faywood gaging station was based on the 14.6 cubic feet per second of average annual flow of the river (table 3) minus losses due to evaporation. Almost all of the flow infiltrates between the gage and a bridge 6 miles east of Deming on Highway 70. This flow is distributed among model blocks along the river as shown in table 9.

Initially, ground-water underflow from adjacent basins, primarily the Gila River Basin along the northwest-trending Mangas Trench (fig. 4), was estimated to be 11.6 cubic feet per second, which is the second largest component of recharge to the bolson-fill aquifer (table 6). However, because reinterpretation of water-level data in the Mangas Trench area indicated a ground-water divide near the basin boundary, recharge in the Mangas Trench area (blocks 4-13, 4-14, and 4-15) was reduced to the mountain-front recharge value. Recharge of 0.15 cubic foot per second in blocks 17-41 and 18-41 was used to simulate flow to the Mimbres Basin where it adjoins the Palomas Basin in the northern extension of the Florida Graben.

The smallest and least defined component of recharge enters the bolson-fill aquifer directly from adjacent bedrock aquifers in the subsurface along the Silver City-Pipeline Draw Fault system. The two components of bedrock-aquifer recharge used in the model were the Apache Tejo Warm Spring and the Lindauer Cold Spring-Faywood Hot Springs (combined as Apache Tejo Spring in table 6), which, on the basis of reported springflow, are believed to have contributed 3 cubic feet per second to the bolson-fill aquifer from the adjacent bedrock aquifers that are juxtaposed along the fault system. Most of this water was recharged near the Silver City-Pipeline Draw Fault system in the vicinity of the Apache Tejo Warm Springs.

Discharge of 0.546 cubic foot per second of ground-water outflow was initially simulated at the Mason Draw boundary as constant discharges of 0.273 cubic foot per second at blocks 45-43 and 46-43; however, this discharge was eliminated during subsequent model adjustment without significantly affecting the model. A net evaporation rate of 0.92 cubic foot per second from Florida Lake was simulated as a constant discharge at block 33-29 in the predevelopment simulation.

Constant-head boundaries

Discharge from the bolson-fill aquifer through ground-water outflow from the Florida and Tres Hermanas Grabens to springs and playas in Mexico was simulated using constant-head blocks (fig. 17). The altitudes of the constant-head blocks were set to be equal to the land surface at playa lakes in Mexico. The implicit assumption is that the water level remains near land surface at these discharging playas. These outflow blocks are just northwest of alkali flats and just east of the Casas Grandes malpais (basalt flows south of the Carrizalillo Hills) area where the flow of ground water is probably complex and where water-level data are not available. The assigned constant-head altitudes decline to the northeast, resulting in increased discharge at the northeast part of this boundary.

Head-dependent flow boundaries

Head-dependent flow boundaries were used to simulate evapotranspiration throughout the basin. Discharge from vegetation in the central part of the Mimbres Basin was estimated to be as much as 58 cubic feet per second for the area covered by Darton's (1916b) Deming folio (table 6) and about 5 cubic feet per second for the streamside vegetation along the Mimbres River upstream from Faywood. The model was used to test the effects of distributed evapotranspiration in the basin. Head-dependent flow was allowed throughout the model on the assumption that vegetation would become established wherever the water level was sufficiently shallow. The predevelopment model was constructed using the average land-surface altitude at each block. The depth of transpiration was limited to 55 feet below the land surface, and the maximum rate of evapotranspiration was established during model calibration.

Aquifer Thickness

The altitude of the base of the aquifer was calculated by subtracting average values of aquifer thickness shown in figure 8 from the altitude of predevelopment water levels. In areas having steep water-level gradients near the margin of the basin it was necessary to use a greater thickness than average in some nodes and to reduce the hydraulic conductivity in those nodes proportionately to prevent water levels in adjacent blocks from falling below the base of the block.

Steady-State Simulation

The model parameters of hydraulic conductivity, recharge, maximum rate of evapotranspiration, and maximum depth of evapotranspiration were adjusted in the simulation of predevelopment conditions. Hydraulic conductivity and storage coefficient were adjusted in the transient simulation. Predevelopment and transient conditions were simulated alternately until simulated predevelopment water levels and transient water-level changes approached the measured values. Model-derived locations and rates of evapotranspiration were compared with estimates from table 6 and figure 11. More importance was assigned to water-level changes than to predevelopment water levels in this process.

A steady-state simulation was conducted to represent predevelopment conditions. Water levels measured during 1910-30 were used for model calibration in the central part of the basin. McLean (1977, fig. 3) showed some small water-level declines during this period, but large-scale ground-water development did not begin until after 1930. The northern and southern parts of the basin were largely undeveloped until after 1960; therefore, water levels measured as recently as 1958 were included in the northern part of the basin and in the Columbus and Tres Hermanas areas. This section reviews the criteria, methods, results of calibration, and sensitivity of the predevelopment model.

Calibration

Calibration criteria and methods

The steady-state model was modified on the basis of comparisons between measured and simulated water-level altitudes (heads), ground-water outflow, and total ground-water budget. Water-level altitudes at the 206 wells (table 10, at back of report) used to contour the predevelopment water-level map (pl. 2) were compared with simulated water levels. Ground-water outflows simulated by the model at head-dependent blocks (representing evapotranspiration) and constant-head blocks (ground-water discharge in Mexico) were compared with outflow estimates described in previous sections.

The differences between the measured and simulated water levels and locations and rates of ground-water discharge indicated necessary changes in model parameters. Recharge rates and hydraulic-conductivity values were adjusted within what were judged to be the limits of error of the measurement of these values. The fit of the predevelopment model was accepted when the average absolute difference between the simulated and measured water-level altitudes (referred to as the average absolute error between the simulated and measured heads) could not be substantially improved by adjusting hydrologic parameters within preset limits. This resulted in a "best-fit" predevelopment model.

Calibration results

Recharge rates.--In the course of calibration, the initial mountain-front recharge was changed. Necessary changes included additional recharge in the southern part of the model, reducing recharge in the Mimbres Valley, followed by an overall reduction in recharge to 70 percent of the initial values in the remainder of the model and further reduction in recharge at blocks with unreasonably large evapotranspiration.

Mountain-front recharge from the Florida and Little Florida Mountains was redistributed. Because the Little Florida Mountains are smaller and lower than the Florida Mountains, blocks bordering the Little Florida Mountains were assigned 33 percent of the total recharge caused by runoff from both ranges; blocks bordering the Florida Mountains were assigned the remaining 67 percent.

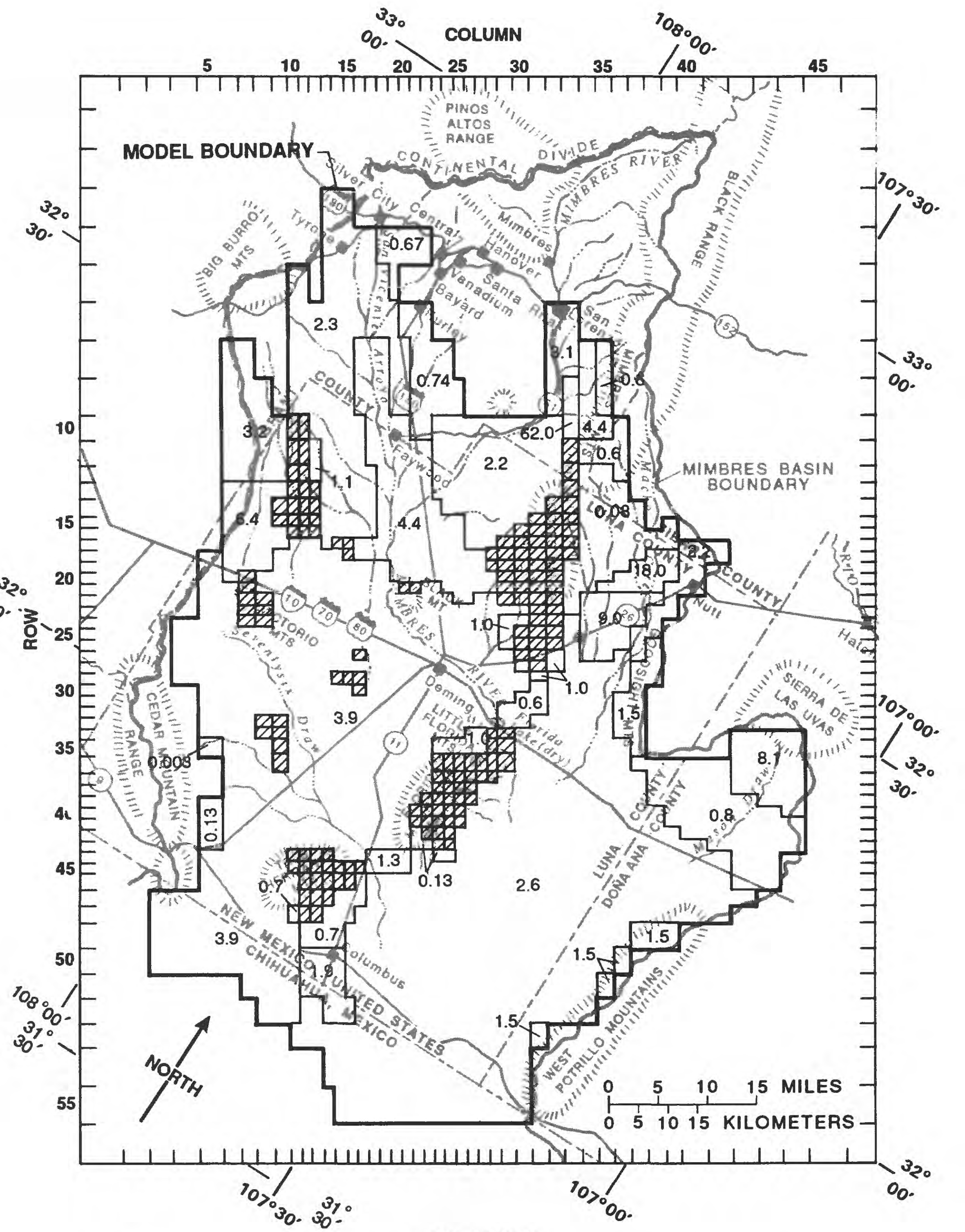
The first simulations showed excessively high water levels and large rates of evapotranspiration in the Mimbres Valley upstream from the Faywood gaging station, requiring that the recharge in this area be reduced from 20,400 to 8,000 acre-feet per year. During sensitivity analysis, the agreement between measured and simulated water levels was improved by uniformly reducing the remaining mountain-front recharge values to 70 percent of the previous values. This reduction is consistent with the previous conclusion, implied in table 6, that the mountain-front recharge method had overestimated recharge in the area upstream from Faywood and therefore probably had overestimated recharge throughout the basin.

Along the model boundary, the model simulated evapotranspiration in a few blocks with no known concentrations of phreatophytes and for which hydraulic conductivity was not well known. This was assumed to represent local excessive rates of recharge, thus recharge at these nodes was further reduced to eliminate the spurious evapotranspiration. The resulting estimated and simulated recharge rates are compared in table 11 (at back of report). The recharge values used in the best-fit predevelopment model are listed in table 9. This resulted in a total reduction in recharge of 55 percent.

Hydraulic conductivity.--The initial hydraulic-conductivity distribution consisted of seven zones based on the tectonic zones in the basin, and each zone was assigned the median of the hydraulic-conductivity values from aquifer tests or specific-capacity tests within that zone. The differences between measured and simulated water levels at the upgradient and downgradient ends of individual zones were inconsistent with differences in the middle of the same zone, a pattern that prompted subdivision of the original zones along the boundaries of the structural areas (fig. 8). Most of the changes involved specifying zones of relatively small hydraulic conductivity along the margin of the basin boundary and the isolated interior no-flow zones.

The final distribution of hydraulic conductivity in the best-fit predevelopment model is shown in figure 18. The specified hydraulic-conductivity values range from 0.003 foot per day along the basin margin to 62 feet per day in the upper Mimbres River Valley near San Lorenzo. Most of the central part of the basin was assigned hydraulic-conductivity values ranging from 2.2 to 4.4 feet per day. The large hydraulic conductivity in the upper Mimbres River Valley was required to reduce heads and evapotranspiration near San Lorenzo by increasing flow through the cross graben, but may not represent actual hydraulic conductivity in the area. Hydraulic-conductivity values in areas having few wells such as the northern Florida Graben, along Mason Draw, and west of the Grandmother and Victorio Mountains are poorly known, thus the values shown in figure 18 need to be considered approximations.

Water levels.--The average absolute difference between measured and simulated predevelopment water levels was 21.5 feet. Values for individual blocks are given in table 10. A correlation diagram showing the simulated and measured predevelopment water-level altitudes is shown in figure 19. A histogram of the differences is shown in figure 20. The average difference between measured and simulated water levels was 0.3 foot; the standard deviation of the error was 27.3 feet over a range of measured water-level altitudes from 3,901 to 5,893 feet. The errors ranged from -68.4 feet at block 9-13 to 70.5 feet at block 47-30.



EXPLANATION

NO-FLOW BLOCKS (ALL BLOCKS OUTSIDE MODEL BOUNDARY ARE NO-FLOW BLOCKS)

3.9 HYDRAULIC CONDUCTIVITY, IN FEET PER DAY

Figure 18.--Hydraulic-conductivity values assigned to the model of the bolson-fill aquifer in the Mimbres Basin.

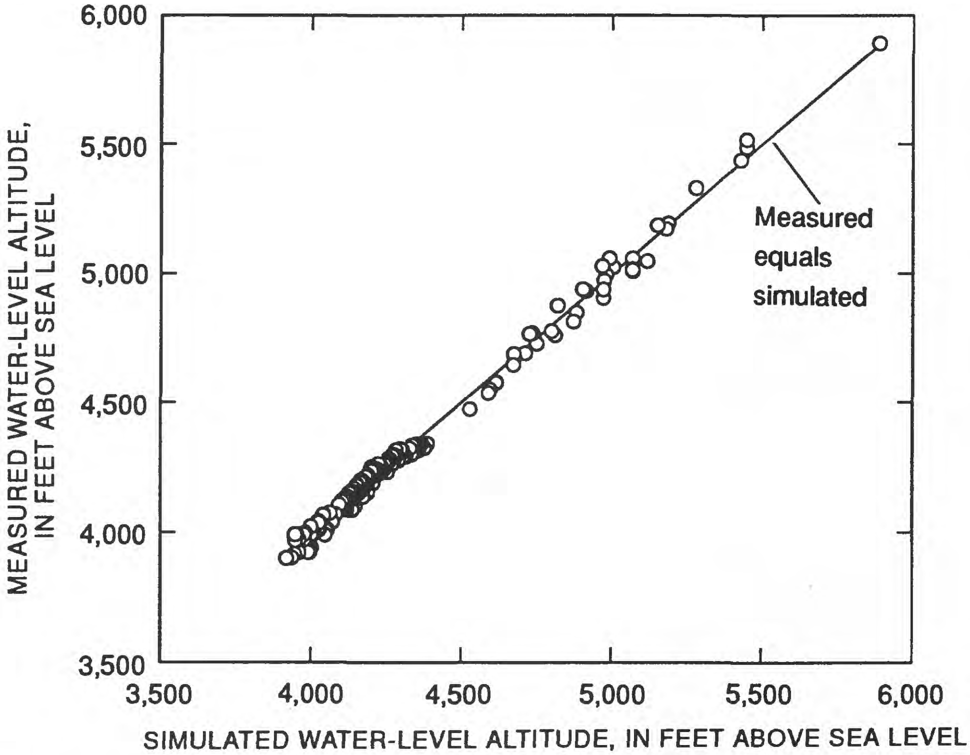


Figure 19.--Relation of simulated to measured predevelopment water-level altitudes in the Mimbres Basin.

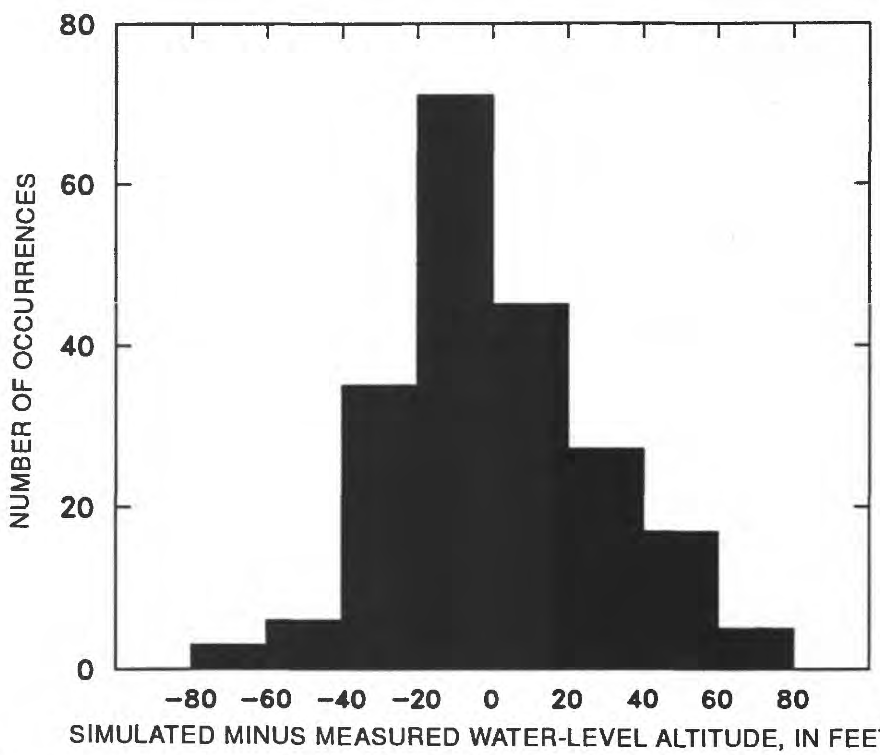


Figure 20.--Difference between simulated and measured predevelopment water-level altitudes in the Mimbres Basin.

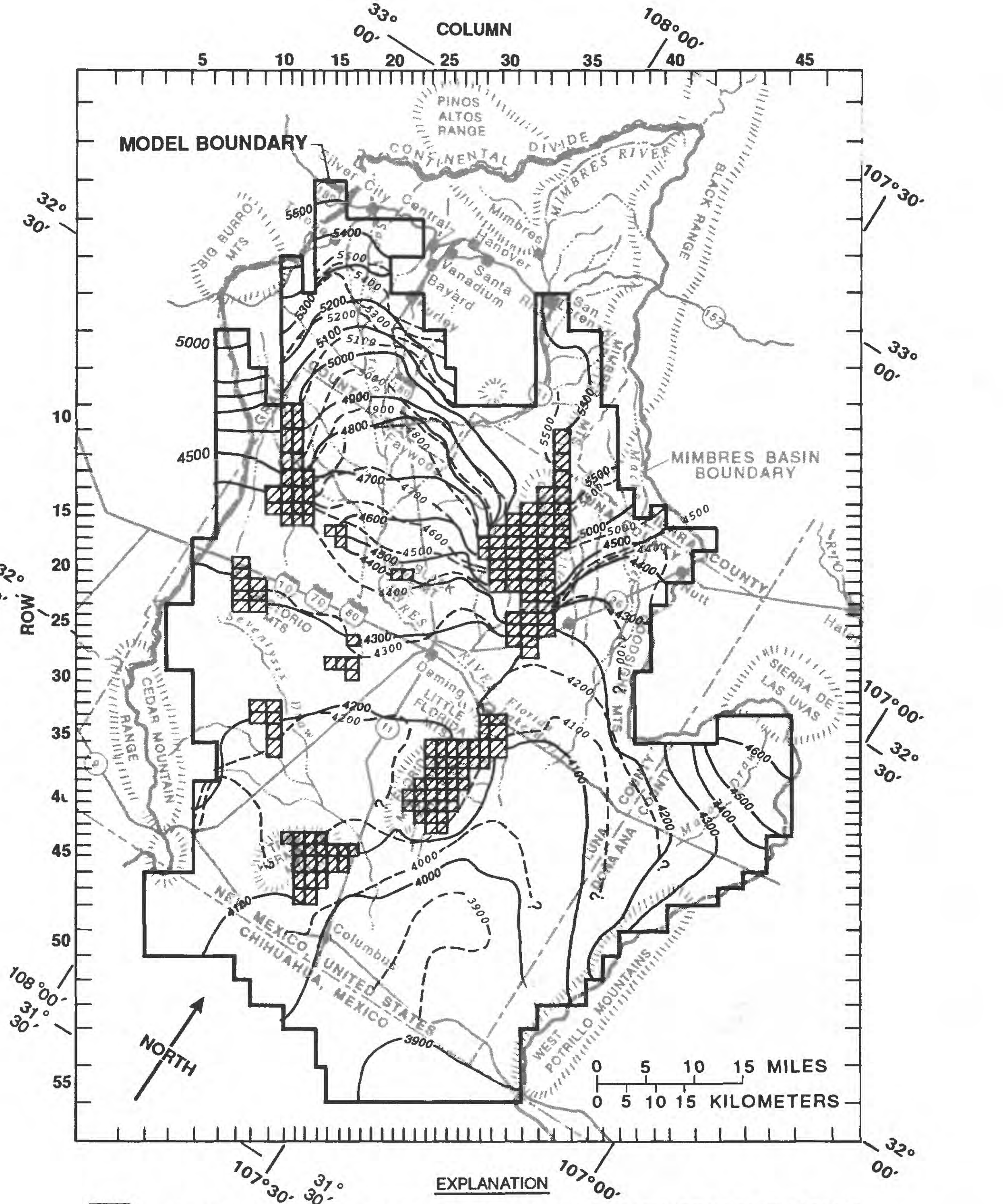
The simulated water-level altitudes were contoured (fig. 21) for comparison with the predevelopment surface (fig. 21; pl. 2). Due to a combination of factors, including poorly defined recharge rates, distributions, and predevelopment water-level altitudes, differences still exist between the measured and simulated water-level altitudes along some parts of the basin boundary. However, the simulated and measured water-level altitudes are generally comparable through the central part of the basin.

Sources of error in comparing measured and simulated water levels include errors in assigning land-surface altitudes to approximately located, destroyed wells (almost all wells shown in Darton, 1916, pl. 1, have been destroyed or replaced); the difference in water-level altitude between the well selected to represent a block and a well located at the center of the block; and measurement errors at a well. Of the 206 blocks used to compare measured and simulated water levels, 21 contain two wells. In a comparison of these 21 pairs, the absolute difference in measured water levels within a block ranged from 1 to 50 feet and averaged 13.3 feet. If this represents the typical variation within a block, it accounts for more than half of the absolute error in the model.

Ground-water budget.--The ground-water budget for the best-fit predevelopment model is shown in table 11 for comparison with the previously estimated ground-water budget. The relative differences between the terms in this table indicate the degree of uncertainty in the ground-water budget. In the simulated budget, the specified recharge of about 40,000 acre-feet per year was balanced by discharge from evapotranspiration and ground-water underflow. The largest component of discharge was evapotranspiration from phreatophytes in the basin near Deming. The second largest discharge component was discharge to playas in Mexico, simulated in the model as net discharge of 1,300 acre-feet per year at the constant-head blocks and at nearby blocks simulating evapotranspiration.

The maximum simulated rate of evapotranspiration, which is used when the water level is at land surface, that gave the best agreement between measured and simulated water levels was 0.63 foot per year, about half the initial estimate of 1.2 foot per year. The total simulated loss due to evapotranspiration (not including evaporation from Florida Lake or playas in Mexico) was about 38,200 acre-feet per year (table 11), which is 95 percent of the total simulated discharge from the aquifer. Along the Mimbres River between San Lorenzo and the streamflow-gaging station near Faywood, 4,200 acre-feet per year of evapotranspiration was simulated. Even after recharge has been reduced, this is still more than the previously estimated 3,400 acre-feet per year (table 11).

The pattern of evapotranspiration generated by the model at head-dependent boundaries is shown in figure 22. Compare this figure with Darton's subregions having less than 50 feet of depth to water (fig. 11). The patterns are similar, and the greatest rates occur between Deming and Florida Lake and along Seventysix Arroyo. This similarity suggests that widespread evapotranspiration at low rates was a significant component of discharge prior to development of the basin. Additional areas of evapotranspiration simulated in the model include lower San Vicente Arroyo, an area northeast of Columbus, playa lakes in Mexico, and the Mason Draw pond area. The depths to water in these areas were not mapped by Darton, so they cannot be compared with figure 11.



NO-FLOW BLOCKS (ALL BLOCKS OUTSIDE MODEL BOUNDARY ARE NO-FLOW BLOCKS)

--3900-- WATER-LEVEL CONTOUR--Shows altitude of measured predevelopment water levels. Contour interval is 500 feet with supplemental 100-foot intervals. Datum is sea level

—3900— WATER-LEVEL CONTOUR--Shows altitude of simulated predevelopment (steady state) water levels. Contour interval is 500 feet with supplemental 100-foot intervals. Datum is sea level

Figure 21.--Simulated and measured predevelopment water-level altitudes in the Mimbres Basin.

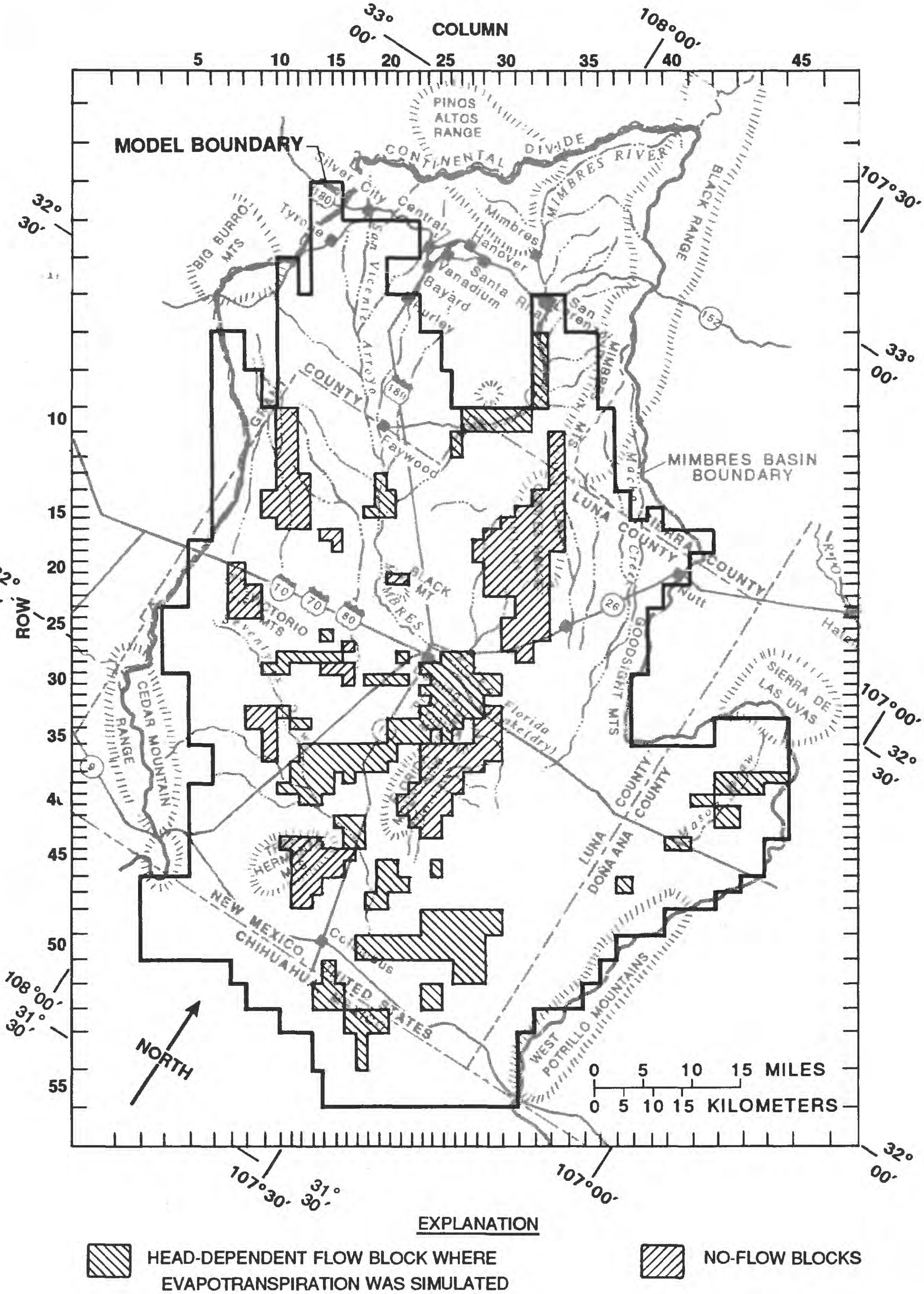


Figure 22.--Areas in which the model simulated evapotranspiration in the Mimbres Basin.

Sensitivity Analysis

The same comparison techniques and comparison points used in calibration were used in determining the sensitivity of the model. The sensitivity of the predevelopment model was assessed by independently varying the hydraulic conductivities, recharge rates, maximum rate of evapotranspiration, and maximum depth of evapotranspiration. In each case, the distribution of the property was not changed, but each value or matrix was multiplied by a constant.

The average absolute difference between simulated and measured water levels (average absolute error) for variations in hydraulic conductivity, recharge rates, maximum evapotranspiration rate, and maximum evapotranspiration depth is shown in figure 23. The average absolute error was most sensitive to decreases in recharge, increases in hydraulic conductivity, and increases in maximum depth of evapotranspiration. The average absolute error was least sensitive to changes in the maximum rate of evapotranspiration, although the sensitivity increased rapidly at values less than half the selected (best-fit) value. The model is much less sensitive to simultaneous changes in parameters, such as a decrease in recharge with a decrease in hydraulic conductivity, than it is to separate changes in either quantity.

During calibration, the hydraulic-conductivity values for each of five zones within the model were adjusted one at a time to produce the minimum average absolute error for the model. These zones included the southern Mangas Trench, the east and west Deming zones, the Seventysix Basin, and the Tres Hermanas Graben. Of these adjustments, only that for the southern Mangas Trench produced large changes in the absolute error because it is located in a recharge area containing steep hydraulic gradients. The model was slightly more sensitive to variations in the values of hydraulic conductivity of the Tres Hermanas Graben than to variations in the remainder of the zones, probably because of its proximity to the discharge areas represented as constant-head blocks. Small fractional changes in the values of hydraulic conductivity for the remainder of the zones that are located in areas of shallow gradients in the interior of the model had little effect on the absolute error. An optimum hydraulic conductivity for one zone, the southern Florida Graben, could not be found. Hydraulic-conductivity values that exceed a reasonable range of values were required to produce a minimum absolute error in this zone. This probably is because the zone contains the discharge area represented by constant-head blocks and because the altitude, extent, and hydraulic characteristics of the discharge area are poorly known.

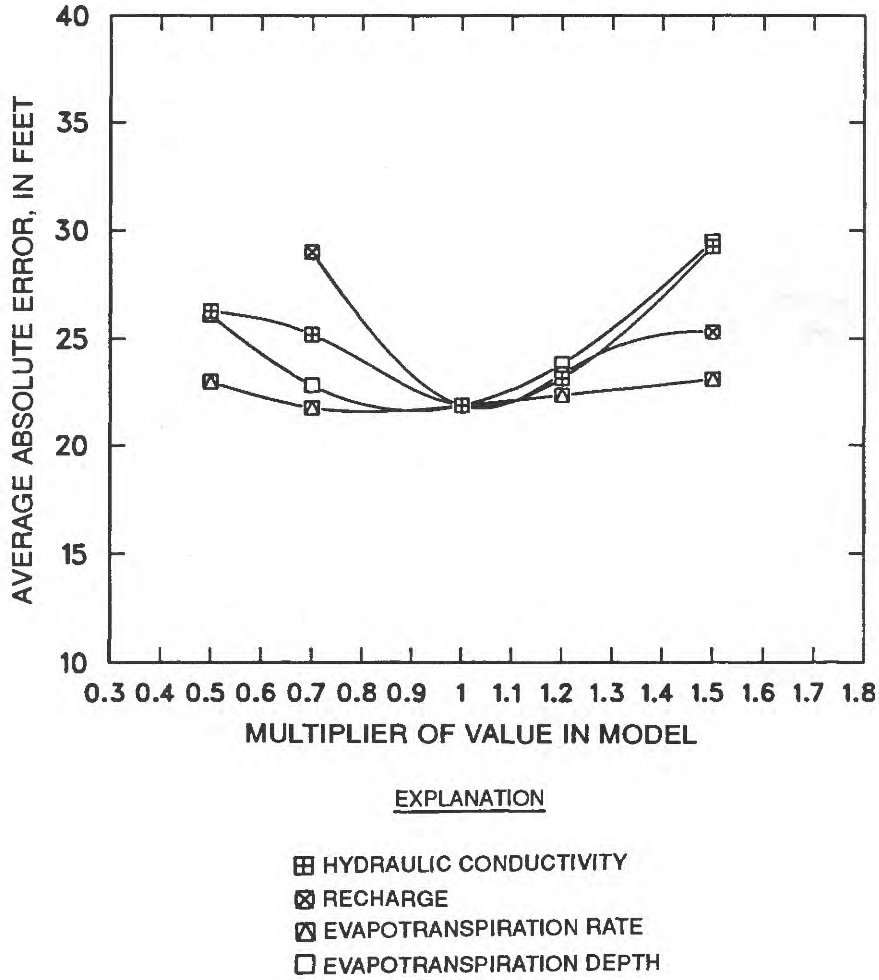


Figure 23.--Sensitivity of the steady-state simulation of ground-water flow in the Mimbres Basin to changes in hydraulic conductivity, recharge, evapotranspiration rate, and maximum depth of evapotranspiration.

Limitations of the Model

Simulated water levels at several blocks are in error by more than 50 feet. These blocks generally are located near the margins of the basin, in areas of steep gradient and unknown hydraulic conductivity. Although the model fit could be improved by additional adjustments, it was thought that such manipulation would do little to improve the understanding of the flow system. Some of the errors near the basin margins probably are due to the relatively large model blocks in areas of locally complex hydrology.

The steady-state model served as a test of the distribution and values of recharge derived by the mountain-front-recharge method. The inability of the model to simulate the recharge in the Mimbres River Valley upstream from Faywood implies that the method overestimates recharge. A few large errors in the model near the margin of the basin may imply that the assumption that all mountain-front runoff infiltrates adjacent to the mountains is in error. The errors in simulating recharge may imply that the assumption of no infiltration from direct precipitation likewise is in error.

Values of hydraulic conductivity used in the model are much less than those previously estimated from aquifer tests, specific-capacity tests, and well logs. This may be a bias in the aquifer-test data (wells with low yields are not completed as irrigation wells and those that are completed are screened only in the most productive zones). The difference also may be due to simulating the full thickness of the bolson-fill deposits in the model whereas the most productive part of the bolson fill may be the upper part (fig. 9).

The model does not represent a unique solution to ground-water flow in the bolson-fill aquifer. The model is relatively insensitive to simultaneous variations in recharge and hydraulic conductivity and is insensitive to the maximum rate of evapotranspiration within certain limits. Furthermore, recharge and discharge are widely distributed throughout the area simulated. The interdependence of the recharge, transmissivity, and evapotranspiration implies that, with various combinations of model input parameters, a wide range of water budgets could be simulated with about the same average absolute error in the water levels. The distribution and rates of these parameters, particularly recharge, need to be better known before large improvements in the steady-state simulation can be made.

The model was relatively insensitive to a wide range of values for maximum rate of evapotranspiration; however, when rates were reduced to less than one-half the best-fit value, the average absolute error increased greatly. The system could not be simulated using reasonable ranges of hydraulic conductivity unless evapotranspiration was included. This implies that the conceptual model of the basin needs to include some evapotranspiration and that part of the evapotranspiration in the basin may have been salvaged as ground-water levels were lowered by pumping. In the Mimbres Valley upstream from Faywood, the greatest simulated rate of evapotranspiration, at block 9-32, is 3.77 cubic feet per second, equivalent to a rate of 0.63 foot per year over the area of the block, which is the maximum rate allowed in the model. Evapotranspiration in blocks 32-28 and 33-28 also are equivalent to the maximum rate. In the remainder of the basin, rates are less than the maximum.

Transient Simulation

Transient simulations require values for ground-water withdrawals and storage coefficients in addition to the properties used for the steady-state simulation. Water-level changes in the basin were simulated using estimates, supplied by the New Mexico State Engineer Office, of ground-water withdrawals based on consumptive use by crops grown in the basin and reported pumpage by municipalities and industries. Storage coefficients in the model were based initially on the estimates in table 5. Measured water-level changes at selected wells were compared with simulated changes at the corresponding blocks. The agreement between measured and simulated water-level changes was improved by adjusting hydraulic-conductivity, recharge, and storage-coefficient values while alternating between steady-state and transient simulations throughout the calibration. The resulting steady-state simulation has been described in the previous section, and the final transient simulation, using the same values of recharge and hydraulic conductivity, is described in this section.

Ground-Water Withdrawals

The Mimbres Basin was extensively developed between 1930 and 1975; it is now a declared ground-water basin and additional development is regulated by the New Mexico State Engineer Office. As discussed previously, ground-water development throughout the basin occurred at different times and rates. Prior to 1960, most of the development was in the central part of the basin. Development of ground-water pumpage in the northern and southern parts of the basin occurred largely after 1960.

The estimates of ground-water depletions (net ground-water withdrawals, pumpage minus deep percolation of applied irrigation water) used in the transient model are based on the water-right files maintained by the New Mexico State Engineer Office. The estimates of ground-water depletions were developed by determining the total irrigated cropland in each four-section administrative block. Hydrographic survey data were used to determine the percentage of the total irrigated cropland to which water was applied, and this percentage was prorated as described in the previous section on water use. The method of Blaney and Hanson (1965) was used to estimate consumptive use on the basis of figures for the fraction of the total acres of each crop type harvested, as supplied by the U.S. Department of Agriculture; consumptive irrigation requirements for each crop type; and meteorological data from the U.S. Weather Bureau station at Deming.

For simulation purposes, the depletion data were aggregated into 5-year intervals. The data for 1935 through 1975 originally were coded for a two-dimensional model used by the New Mexico State Engineer Office. Because this model employed a different finite-difference grid, data from the New Mexico State Engineer were adapted to the grid used for this simulation by a computer program that redistributed the depletion data from blocks in the original model grid to blocks in the corresponding areas of the present model grid. Depletions in the area upstream from San Lorenzo were not included in the model. Several adjustments made to the depletion data for 1971 through 1975 provided withdrawals for the periods 1976 through 1980 and 1981 through 1985. During 1971 through 1975 an area of 686 acres in the lower San Vicente Arroyo area was taken out of production for irrigated agriculture and had not been converted for use in mineral processing. Depletions in this area therefore were reduced by 2 cubic feet per second. As described in the section on water use, the total acres irrigated with ground water decreased from 40,840 in 1975 to 38,150 in 1980 and to 23,600 in 1985. The locations of the wells that ceased pumping in this period were not known, so after adjusting for the 686 acres described above, the irrigation depletions were uniformly decreased 5 percent from 1975 to 1980 and an additional 38 percent from 1980 to 1985 in the remaining acreage. Urban depletions were increased by approximately the ratio of values shown in table 2.

The transient simulations were conducted with 5-year pumping periods beginning in 1930 and ending in 1985. Pumpage was simulated at 214 blocks during 1930-35 and at 530 blocks during 1980-85. Table 12 summarizes the ground-water depletion rates used in the original model, the rates used in this model, and the difference in depletion rates between the two models for each pumping period. The program that converted depletions from the administrative blocks to the model grid caused the simulated depletions to be distributed over a larger area in the model. A small fraction of the depletions near the basin boundaries was assigned to inactive blocks in the process. The redistribution also resulted in errors in the spatial distribution of depletion, particularly in the Columbus area. The simulated cone of depression is similar in volume to the measured cone of depression, but shallower, wider, and offset to the east. Because the model is preliminary, reevaluating the depletions in the basin was considered to be beyond the scope of this study. The decrease in simulated depletions ranged from 3.5 percent for the period 1971-75 to 7.6 percent of the much smaller estimated depletions for the period 1931-35. Because the error is much smaller than the uncertainty in the original figures, no adjustments were made to the model to compensate for the difference. No data were available for ground-water depletions in Mexico; therefore, the transient model includes no depletions south of the international border. Darton (1916a, pl. VIII) noted that "at Palomas Lakes and Florida Lake the water plane reaches the surface of the ground," thus discharge by evaporation was simulated in the predevelopment model. Because the lake was dry by 1930, and has remained dry since, discharge from Florida Lake was omitted from the transient simulations.

Calibration

Calibration criteria and methods

Transient calibration of the model was conducted by adjusting the hydraulic-conductivity, recharge, and storage-coefficient values to improve the agreement between measured and simulated hydrographs for selected wells. Wells having long periods of water-level record and wells that are widely distributed in the basin were selected. When an observation well was destroyed or abandoned and measurements were continued on a nearby well, a composite hydrograph was used for comparisons. Water levels were selected that represent a January 1 measurement for the year beginning each of the pumping periods. When no measurement was available or when the water level was affected by local pumping, linear interpolation between measurements was used to obtain a value. Although no hydrographs spanned the entire period of the simulation, water-level changes could be calculated for 683 individual 5-year intervals from a total of 107 wells. The number of wells used ranged from 0 for the 1930-35 interval, to 16 for the 1935-40 interval, to a maximum of 102 for the 1960-65 interval, decreasing to 74 for the 1980-85 interval.

The measured and simulated water-level changes were compared by calculating the measured (M) minus the simulated (S) water-level change (error, M-S=E), the average absolute value of the measured minus the simulated change (average absolute error, $|E|$), and the average cumulative value of the differences between the measured and simulated changes (average cumulative error). Thus, at each well, the cumulative error (CE) is the sum of all the differences between measured and simulated declines for all pumping periods for which data were available divided by the number (NP) of these pumping periods ($\Sigma[(M-S)/NP]=CE$). The average cumulative error (ACE) is the average cumulative error per well ($\Sigma[CE/NW]=ACE$, where NW is the number of measured wells). During calibration, the hydraulic-conductivity, recharge, and storage-coefficient values were adjusted by iterating between the steady-state and transient simulations to minimize the error in the steady-state model and to maintain the average cumulative error for the transient model within 1.0 foot.

Although selected wells were measured in 1985 and subsequent years, the measurements were not widespread enough to provide a detailed map of water-level altitudes in 1985. Therefore, a map of water-level changes from 1930 to 1985 could not be prepared by subtracting the 1985 water-level altitudes from the map of predevelopment (1930) water levels. For the purposes of this preliminary model, only hydrographs were used for calibration.

Calibration results

Hydraulic-conductivity, recharge, and storage-coefficient values were adjusted during calibration. Initial simulations had less drawdown in the pumping centers and greater drawdown away from the pumping centers, compared with measured data, indicating that initial thickness or hydraulic-conductivity estimates, or both, were too large. Hydraulic conductivity in the steady-state simulation was reduced, which required reducing the mountain-front recharge values as described previously. Recharge also was reduced because the initial values for recharge resulted in simulated discharges at Faywood that exceeded the actual baseflow in the upper Mimbres Valley area; other investigators (O'Brien and Stone, 1983) likewise have had to reduce simulated recharge based on mountain-front recharge estimates to obtain an adequate ground-water flow simulation in the Animas Valley, Hidalgo County, New Mexico. The steady-state simulation also was improved by the simultaneous reduction in recharge and hydraulic conductivity.

The possible reduction in hydraulic conductivity with depth, as discussed previously, may limit the effective thickness of the aquifer to values less than those shown in figure 8. Differences between the initial estimates of hydraulic conductivity and those required to calibrate the model may be due to the uncertainty of the change in hydraulic conductivity with depth. If hydraulic conductivities are larger in the upper part of the bolson deposits, hydraulic conductivities derived from aquifer tests and specific-capacity tests would tend to overestimate the average hydraulic conductivity of the bolson deposits when compared with the model, which, because it is two-dimensional, contains the implicit assumption that the aquifer properties are uniform with depth.

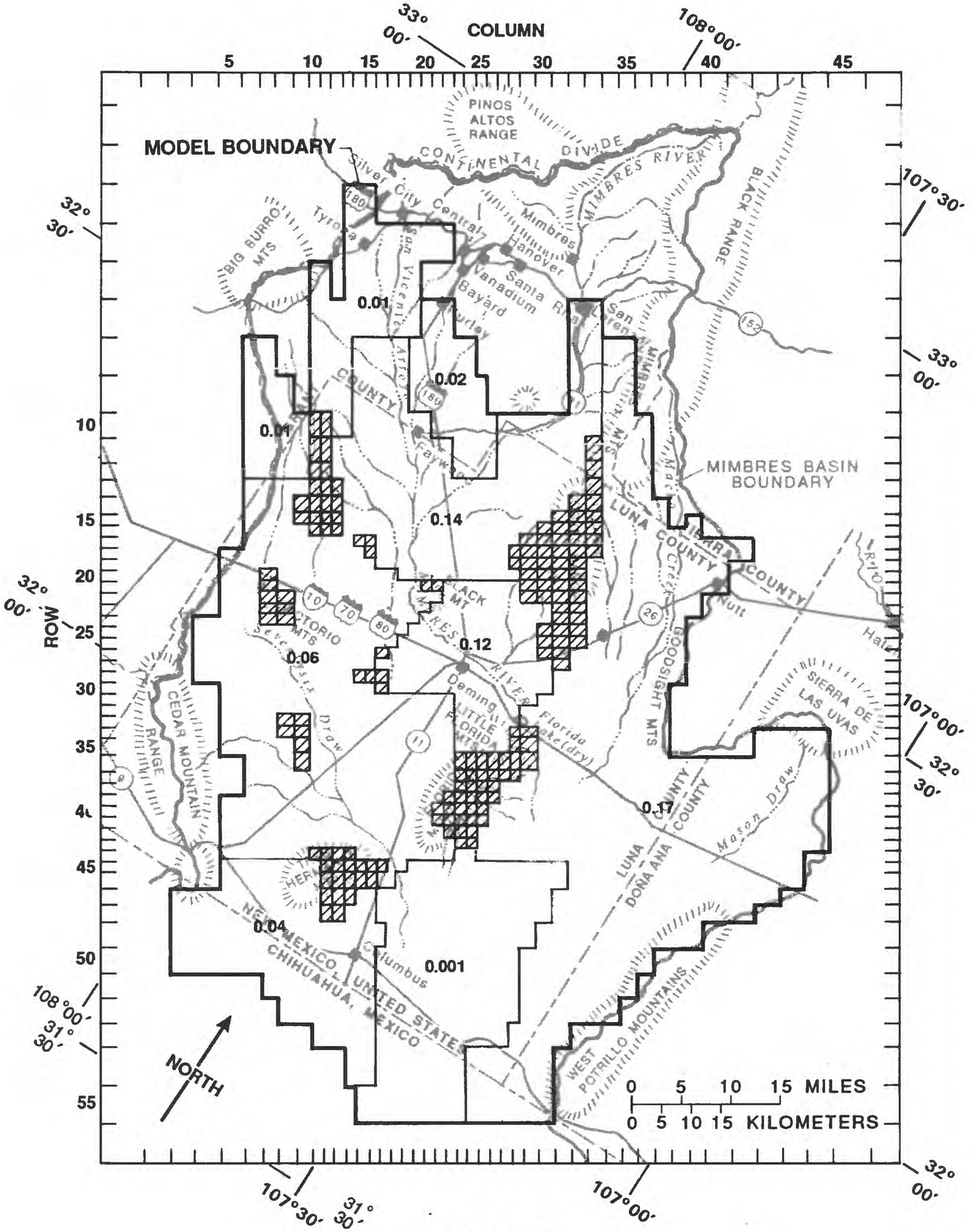
Initial estimates of storage coefficient were based on the values in table 5. An initial storage coefficient of 0.05 was assigned to the area representing Gila Conglomerate in the northwest part of the basin, and a storage coefficient of 0.0001 was assigned to the bolson-fill aquifer where it is confined by lake sediments from ancient Lake Palomas east of Columbus. A storage coefficient (specific yield) of 0.14 was assigned to the remainder of the model. These estimates were adjusted individually for each of the principal irrigation areas to minimize the cumulative error. The resulting distribution of storage-coefficient values is shown in figure 24.

The measured cumulative declines for the basin as a whole averaged 22.6 feet per well, and the average cumulative error was 0.1 foot. However, the average absolute error was 4.5 feet, as shown in table 13. The largest absolute error for any part of the basin, 13.0 feet, out of a cumulative measured decline of 44.7 feet, was in the Columbus area. Simulated declines exceeded measured declines in the western part of the Columbus area and were less than measured declines in the eastern part of the area. The center of pumpage appears to be offset from the center of water-level declines, suggesting that the locations of depletions may be in error. Consequently, no combination of changes in hydraulic conductivity and storage coefficient produced a large reduction in the error in this area. Many local areas near the margin of the basin showed poor agreement between measured and simulated hydrographs. These problems may be due to the large size of the blocks near the basin margins and the consequent inability of the model to simulate boundaries and hydraulic-property differences in sufficient detail near individual well fields such as the Woodward well field near Silver City and the Apache Tejo and Warm Springs well fields near Hurley. The simulated and measured heads agree best in the part of the basin near Deming, with an absolute error of 3.0 feet in a cumulative measured decline of 20.8 feet (table 13).

The measures of model error generally increased as ground-water withdrawals increased through time, as shown in figure 25. The average absolute error reached a maximum of 7.3 feet in the periods 1970-75 and 1980-85.

Selected hydrographs of cumulative simulated and measured water-level declines are shown in figure 26. Some of the hydrographs diverge during the last two pumping periods, indicating that the assumption of pumpage decreasing uniformly over the basin after 1975 may not be accurate. Decreases in irrigation probably were localized, but no irrigated-land surveys exist that would allow a more accurate distribution of pumpage.

The simulated drawdown from 1930 to 1970, shown in figure 27, can be compared with the approximate water-level declines from 1910 to 1970 (fig. 13). The declines are similar, although the simulated declines are slightly less in the center of the pumping areas and greater at the margins than the approximate measured declines.



EXPLANATION

NO-FLOW BLOCKS (ALL BLOCKS OUTSIDE MODEL BOUNDARY ARE NO-FLOW BLOCKS)

0.04 STORAGE COEFFICIENT ASSIGNED TO MODEL AT SPECIFIED BLOCKS

Figure 24.--Storage-coefficient values assigned to the model in the Mimbres Basin.

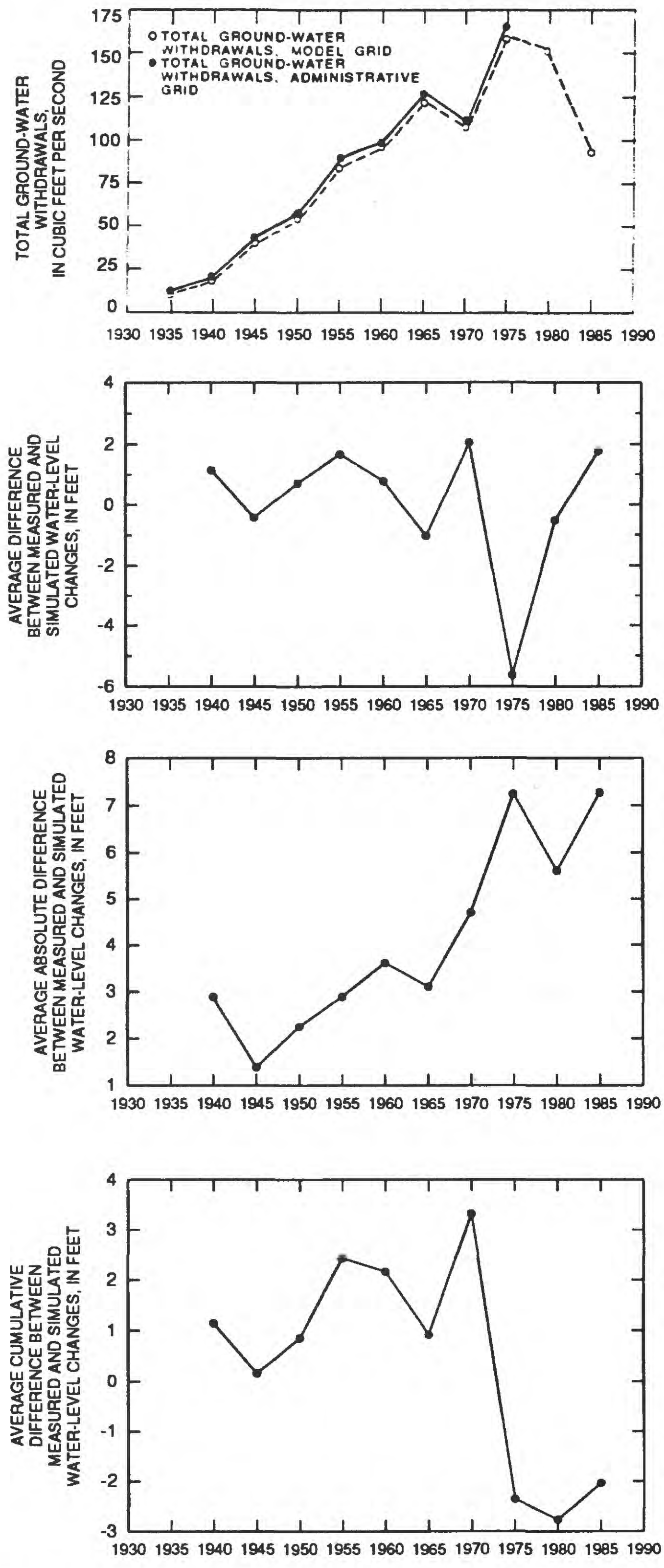


Figure 25.--Simulated ground-water withdrawal rates and difference between measured and simulated water-level changes in the Mimbres Basin, 1935-85.

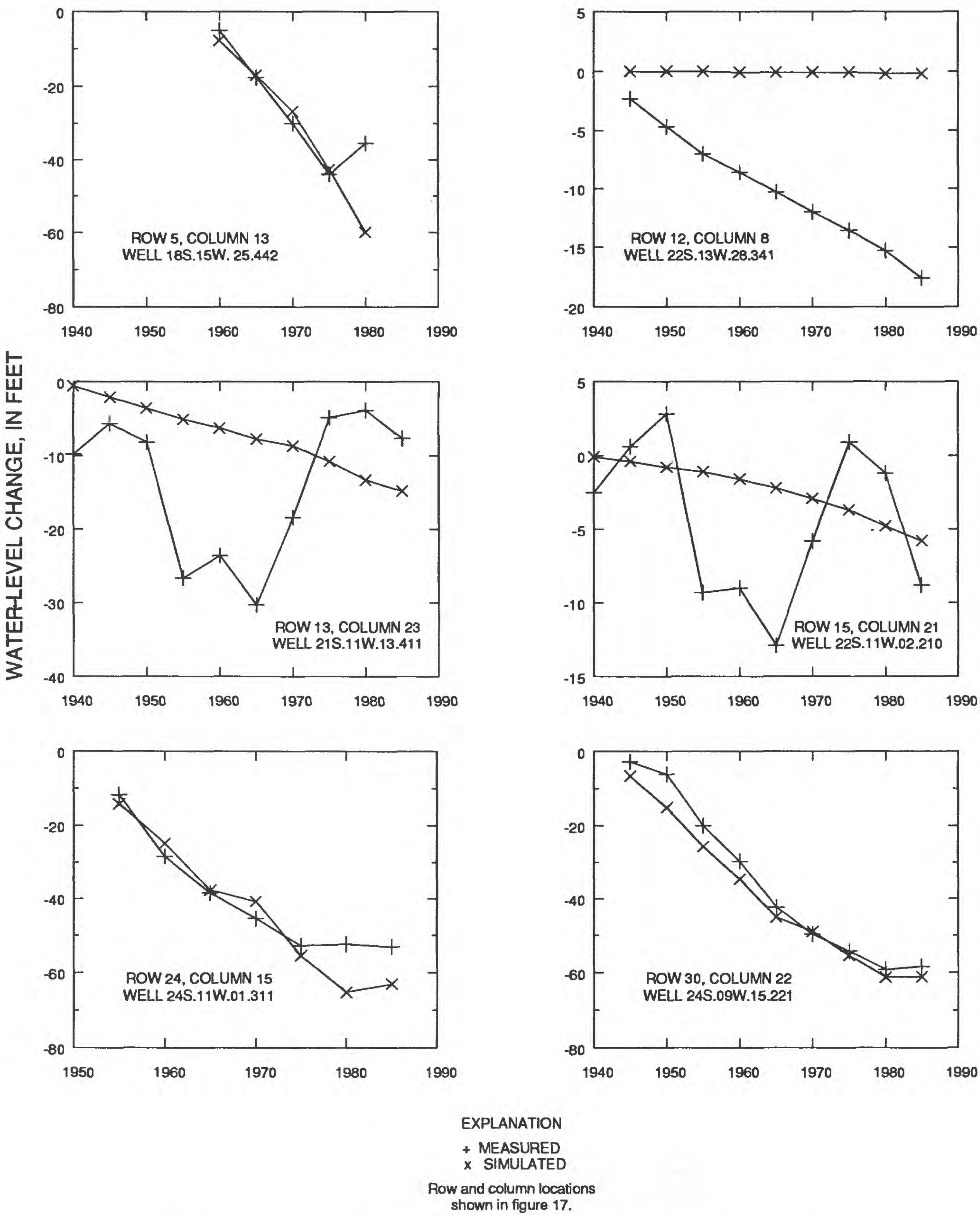
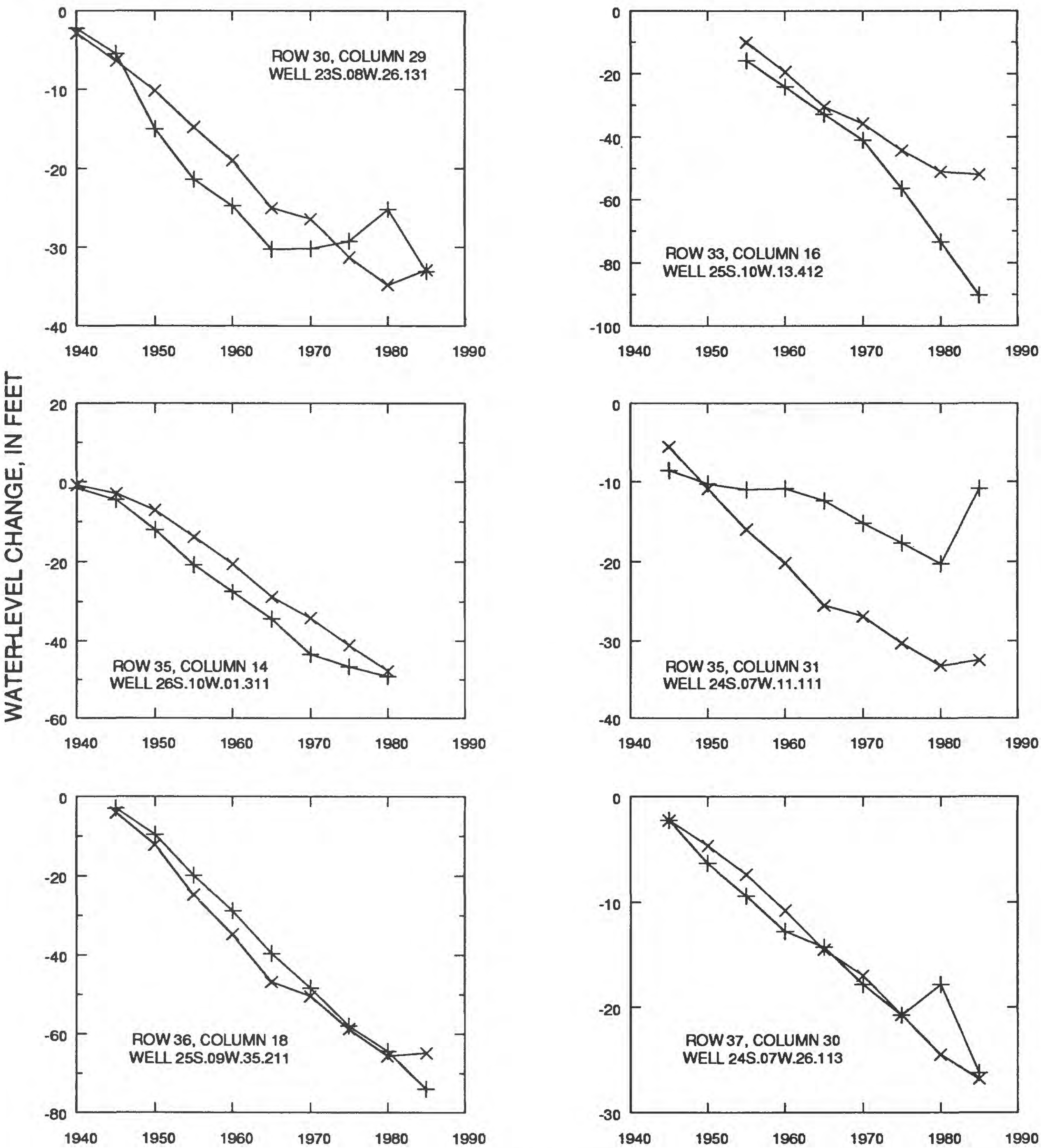


Figure 26.--Measured and simulated water-level changes in the Mimbres Basin.



EXPLANATION
+ MEASURED
x SIMULATED

Row and column locations shown in figure 17.

Figure 26.--Measured and simulated water-level changes in the Mimbres Basin--Continued.

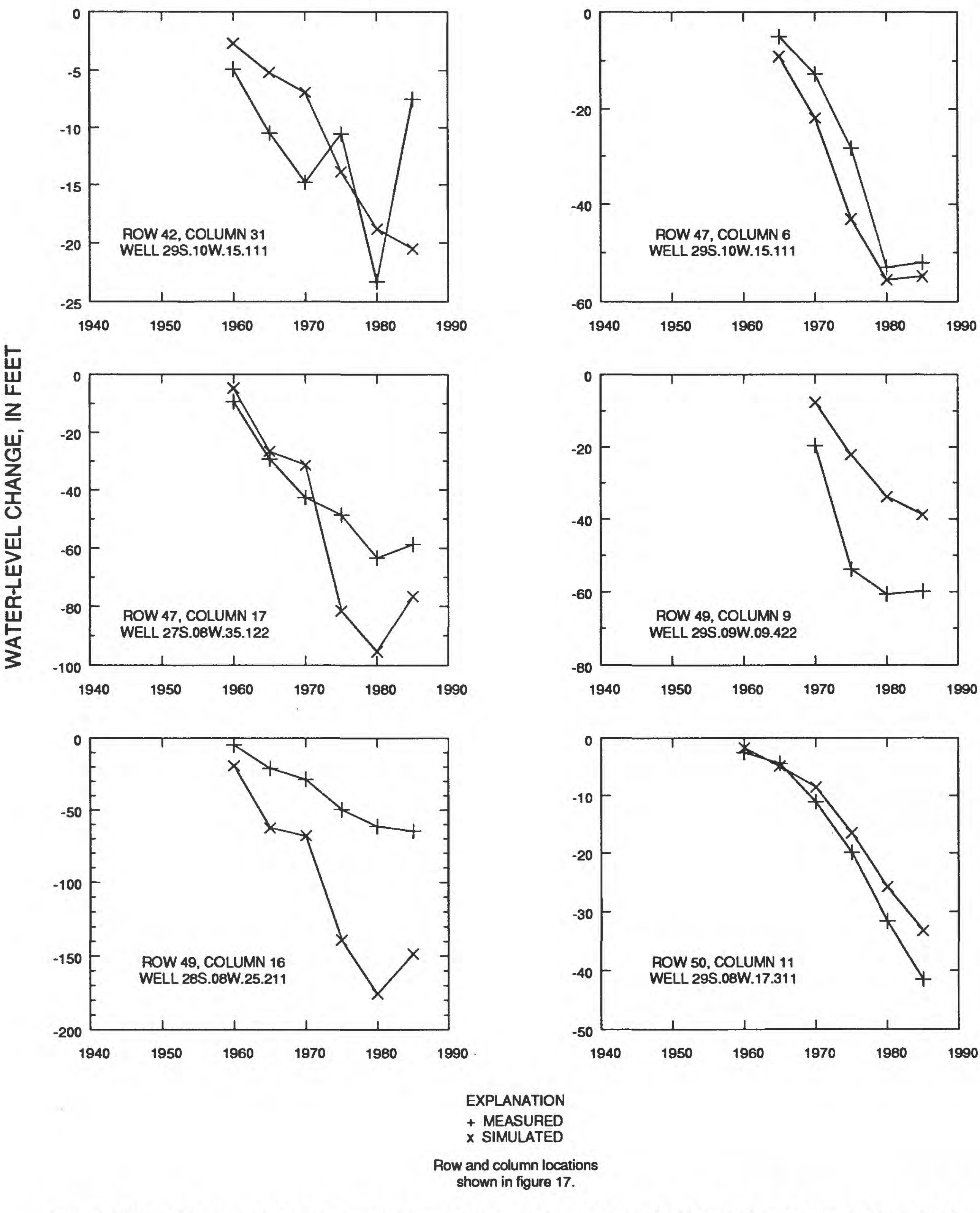
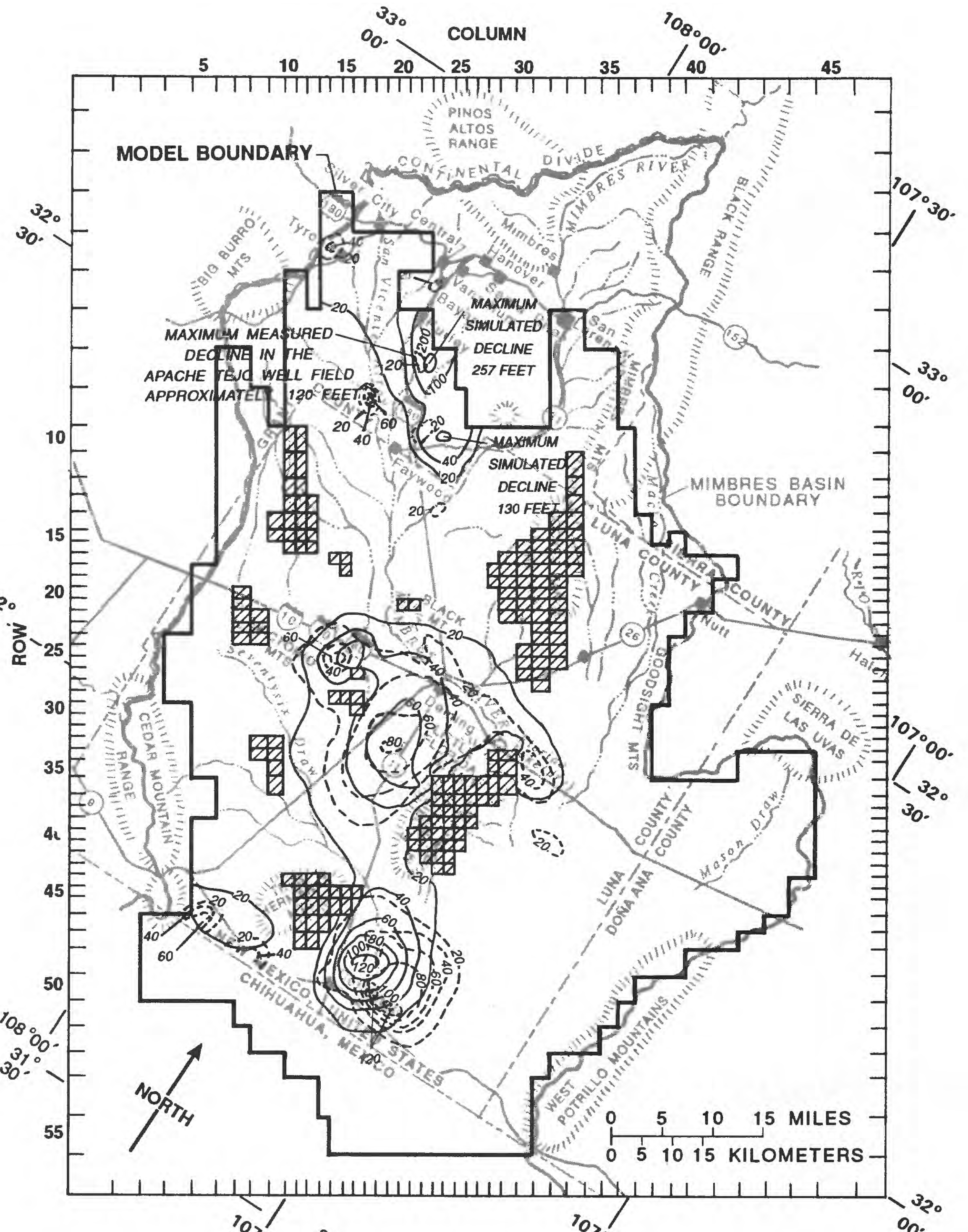


Figure 26.--Measured and simulated water-level changes in the Mimbres Basin--Concluded.



EXPLANATION

NO-FLOW BLOCKS (ALL BLOCKS OUTSIDE MODEL BOUNDARY ARE NO-FLOW BLOCKS)

— — 20 — LINE OF EQUAL MEASURED WATER-LEVEL DECLINE (APPROXIMATE), IN FEET, 1910-70--Interval is variable

——20—— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE, IN FEET, 1930-70--Interval is variable

Figure 27.--Simulated water-level declines, 1930-70, and approximated measured declines, 1910-70.

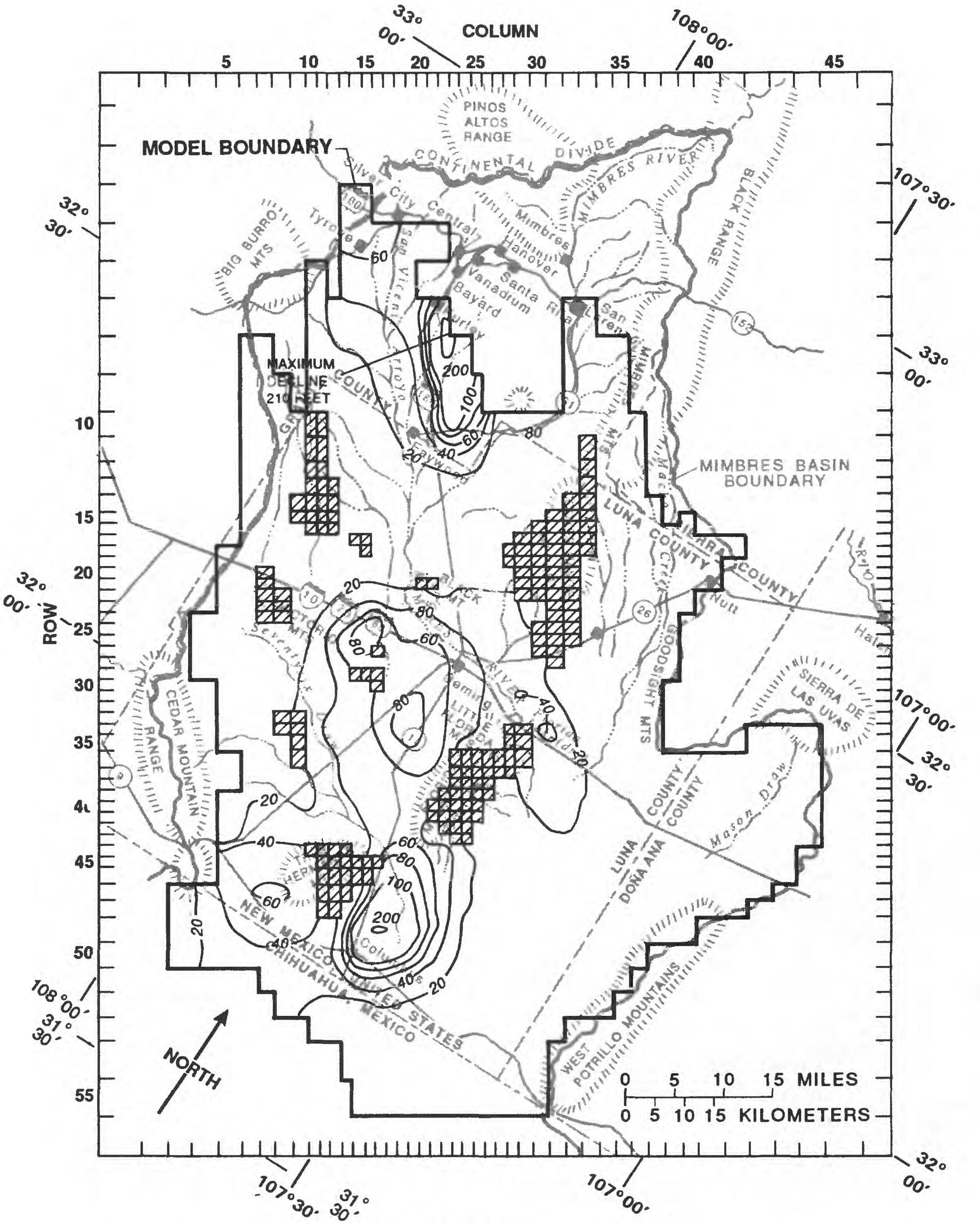
Pumpage decreased between 1975 and 1985, causing water-level recoveries in some areas, as shown by hydrographs of wells 24S.11W.01.311, 24S.09W.15.221, 29S.10W.15.111, and 27S.08W.35.122 (fig. 26). These recoveries generally occurred within pumping centers due to the local decrease in pumping, whereas water levels continued to decline outside the pumping centers as a result of previous years' pumping. The water-level declines for the entire simulation (1930-85) are shown in figure 28. Total declines of about 80 feet south of Deming and west of Red Mountain, about 60 feet southwest of the Tres Hermanas Mountains, and about 200 feet east of Columbus were simulated. The drawdowns shown in figure 28 for the Silver City, Bayard, Hurley, and Warm Springs well field areas should be considered only approximations because few blocks were used in the model to represent these areas of complex and poorly understood hydrology.

Sensitivity Analysis

The transient model was tested for sensitivity to variations in the storage coefficients and ground-water withdrawals. The model previously had been tested for sensitivity to changes in hydraulic conductivity, recharge, evapotranspiration rate, and maximum depth of evapotranspiration (fig. 23). Storage coefficients were varied as a fraction of the selected values shown in figure 24, and ground-water withdrawals were varied as a fraction of the values shown in table 14. The model was most sensitive to changes in withdrawals and large decreases in storage (fig. 29), implying that withdrawals probably are not overestimated and that values of storage coefficient are not substantially less than those shown in figure 24 for most of the bolson-fill aquifer.

Limitations of the Model

The water budget simulated by the model (table 15) indicates that during the entire 1930-85 period a total of about 3.4 million acre-feet of water was withdrawn from the bolson-fill aquifer. Of this, about 77 percent was derived from storage in the aquifer (reflected in the water-level declines) and about 22 percent was provided by a reduction in ground-water evapotranspiration in the United States and Mexico. The remaining 1 percent represented a net reduction in discharge at the constant-head blocks that represent discharge from springs and playas in Mexico.



EXPLANATION

NO-FLOW BLOCKS (ALL BLOCKS OUTSIDE MODEL BOUNDARY ARE NO-FLOW BLOCKS)

—— 20 —— LINE OF EQUAL SIMULATED WATER-LEVEL DECLINE, IN FEET--Interval is variable

Figure 28.--Simulated water-level declines, 1930-85, in the Mimbres Basin.

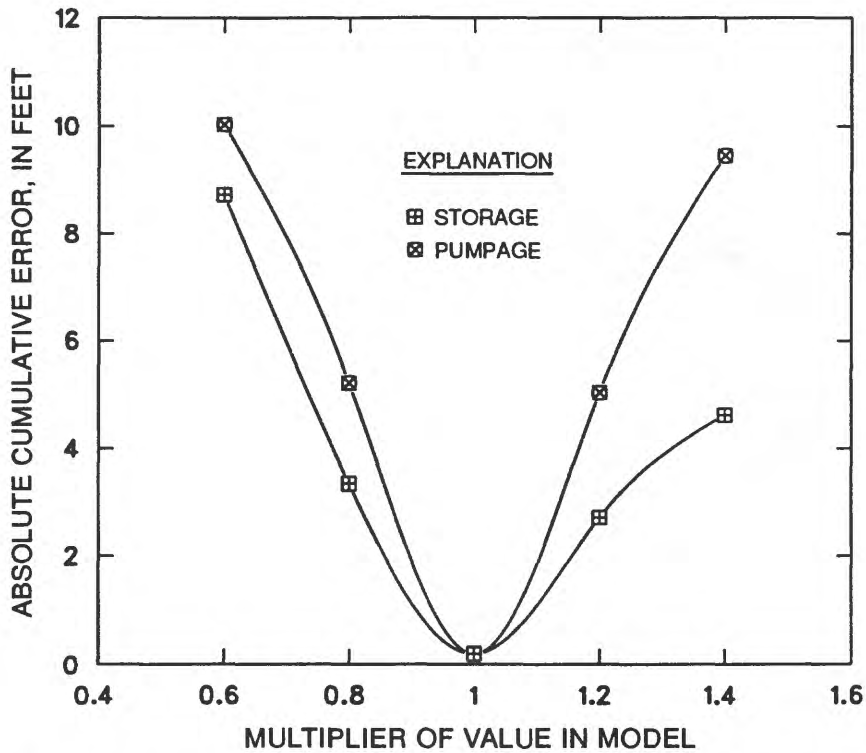


Figure 29.--Sensitivity of the transient simulation of ground-water flow in the Mimbres Basin to changes in storage coefficient and ground-water withdrawals.

This preliminary model, as with all ground-water models, is only an approximate representation of the ground-water system. Furthermore, the model is not unique in that other combinations of aquifer properties and boundary conditions would result in similar errors. Areas in which the model grid is large, such as near Silver City, were simulated with less precision than areas in which the model grid is small, such as near Deming. The thickness of the bolson-fill deposits is poorly known in the interior of the basin. The limits of saturation on pediments, where the zone of saturation is thin, are not always well known, so the responses of individual wells near mountain fronts may not be simulated accurately. Because the bolson-fill aquifer contains interbedded clay layers that may supply water by inelastic compaction, the storage-coefficient values used in the model may underestimate both the quantity of water that can be derived by long-term pumping and the rate of water-level recovery when pumping rates are reduced. The potential effects of land subsidence may be appropriate to include in future simulations to account for this additional source of water. An additional source of uncertainty is in the rate and distribution of ground-water withdrawals, particularly during the reduction in pumpage after 1975. Infiltration from the Mimbres River was simulated using constant-flow blocks. This may induce errors in the distribution of simulated water-level declines and evapotranspiration along the river, and provide an incorrect distribution of infiltration because infiltration cannot increase in response to withdrawals by wells. Simulation of water-level variations near the river might be improved by using the river-routing package for the modular model, rather than simulating the long-term average recharge rates. Some error may have been introduced in converting the pumpage from the original estimates to the transient model, causing the pumpage to be slightly more widespread from pumping centers.

Refinements to this preliminary simulation of the bolson-fill aquifer will require additional information on recharge, aquifer properties, historical depletion of ground water, irrigation-return flow, evapotranspiration, land subsidence, and boundary conditions. Results of sensitivity analyses can help evaluate the relative importance of collecting additional types of data. The Mimbres River is an important source of recharge to the bolson-fill aquifer; the rate and timing of recharge from this source might be estimated more accurately using precipitation-snowmelt runoff and streamflow infiltration models. Direct infiltration from precipitation on the bolson fill may not be negligible during wet climatic periods.

SUMMARY AND CONCLUSIONS

The Mimbres Basin, a closed topographic basin in southwestern New Mexico comprising about 5,140 square miles within the Basin and Range physiographic province of the United States and Mexico, contains high mountains and broad alluvial flats. Land-surface altitudes range from 10,011 feet in the Black Range to about 3,770 feet near the boundary between the Mimbres and Los Muertos Basins in Mexico. The major stream in the Mimbres Basin, the Mimbres River, has an average annual flow of 14.6 cubic feet per second near Faywood, and infrequently flows as far south as Deming. Although flow-duration curves for three gaging stations on the Mimbres River indicate that streamflow in the upper reaches is derived from surface runoff and ground-water discharge, little is known about the flow duration or recharge characteristics of other ephemeral streams in the basin, such as San Vicente Arroyo, an ephemeral stream (except for a short reach in Silver City) that drains the northwest part of the basin. The channels of the ephemeral streams converge on dry lakes and alkali flats at the southern end of the basin. Precipitation, temperature, and potential evaporation are orographically controlled. Annual precipitation ranges from less than 9 inches in the southern part of the basin to greater than 24 inches in the Black Range.

Because the Mimbres Basin is structurally complex and lithologically diverse (rocks exposed in the basin range in age from Quaternary to Precambrian), the water-yielding properties of its aquifers vary. Sufficient ground water can be obtained for stock or domestic supply almost anywhere in the basin. In addition, larger supplies can sometimes be obtained from consolidated rocks in the basin that contain several locally significant aquifers, the extent and properties of which are not well known. The Tertiary basaltic andesites are major components of a productive aquifer composed of interbedded sand and volcanic rocks located between the Silver City Range and the Little Burro Mountains. Reported well yields from limestones of Pennsylvanian and Mississippian age are as large as 920 gallons per minute, whereas the El Paso Limestone of Ordovician age has yielded as much as 200 gallons per minute to wells.

Although aquifers in consolidated rocks are locally important, the principal aquifer in the Mimbres Basin is the combined Quaternary and late Tertiary sediments mapped as the Gila Conglomerate and Quaternary terrace gravels, lacustrine clays, alluvium, undifferentiated alluvium, volcanic agglomerates, basalt flows, and bolson deposits. These sediments form the bolson-fill aquifer, the most extensive and productive water-yielding unit in the Mimbres Basin. The thickness of the bolson-fill aquifer varies greatly, ranging from 0 to 3,700 feet; the thicker parts within the grabens and basins presumably are bounded by faults.

The transmissivity of the bolson-fill aquifer determined from aquifer tests and specific-capacity data ranges from 10 to 50,000 feet squared per day. Transmissivity and hydraulic-conductivity values estimated from lithologic logs were comparable to values determined from aquifer tests and specific-capacity data. The horizontal hydraulic-conductivity values range from 0.03 to 800 feet per day; with the exception of the Deming area, however, the median hydraulic conductivity is not significantly different among the basin subareas. The median hydraulic conductivity estimated from aquifer tests is about 18 feet per day in the Deming area and about 6 feet per day elsewhere, whereas the simulated values of hydraulic conductivity were 3.9 feet per day in the Deming area and ranged from 2.2 to 4.4 feet per day in other large areas with extensive ground-water pumpage in the basin. Storage coefficients from aquifer tests representing confined conditions range from 0.00036 to 0.0036; estimates of storage coefficient representing unconfined conditions range from 0.02 to 0.24.

The general movement of water in the bolson-fill aquifer is from the high mountains at the north end of the basin to the broad alluvial flats at the junction of the Mimbres Graben and the Los Muertos Basin. About 70 percent of all recharge is estimated to originate as mountain-front runoff. The Mimbres River Valley supplies about 40 percent of all recharge, either as infiltration of mountain-front runoff upstream from Faywood or as infiltration of flow in the Mimbres River downstream from Faywood. Prior to development, water was discharged from the bolson-fill aquifer in the Mimbres Basin entirely through transpiration by phreatophytes, evaporation from Florida Lake, discharge from springs, and discharge to playas and springs in Mexico.

In about 1910, ground water began to be pumped for agriculture, mining, and municipal uses, and by 1975, ground water supplied about 75 percent of the 146,000 acre-feet withdrawn annually. Agricultural withdrawals for ground and surface water in the Mimbres Basin totaled approximately 112,900 acre-feet in 1975. Minerals processing accounted for approximately 24,200 acre-feet (17 percent of total water use), whereas urban water use accounted for about 4,800 acre-feet per year (3 percent of total water use). Locally, pumping has altered the rate and direction of ground-water movement and caused water-level declines. As long as withdrawal rates exceed the possible increased recharge or decreased discharge from the aquifer, water will be derived from storage in the aquifer and water levels will continue to decline.

The water throughout most of the northern parts of the basin is a calcium bicarbonate or calcium magnesium bicarbonate water. The water in the central part of the basin is a sodium bicarbonate water. Generally, the water quality is acceptable for a public drinking supply, and the salinity and alkalinity hazard is small, except for the central and southern parts of the Florida Graben, the southern Seventysix Basin, and the southern Tres Hermanas Graben. In most of the southern one-third of the basin, ground water may be too alkaline for irrigation of fruit orchards, some vegetables, and some forage crops.

A preliminary ground-water model was developed to test concepts of the ground-water flow system. The model was calibrated to the earliest available water-level measurements in each area of the basin. These predevelopment water levels were assumed to represent steady-state conditions. The model also was calibrated to transient conditions representing 11 pumping periods, each 5 years long, from 1931 through 1985.

The mountain-front runoff method overestimated recharge: more recharge to the bolson-fill aquifer north of Faywood was calculated initially than could be accounted for by the discharge of the Mimbres River near Faywood and underflow in the adjacent aquifer. Furthermore, using the larger values of recharge in the model required hydraulic-conductivity values in the steady-state simulations that were too large to produce an acceptable transient simulation. The total recharge therefore was reduced to 55 percent of the initial estimates.

Although the model was not sensitive to evapotranspiration over a range of values near the best-fit value, the steady-state simulation indicated that it was not possible to calibrate the model without including substantial evapotranspiration. The locations of simulated evapotranspiration generally agreed with the sites of known concentrations of mesquite and cottonwood trees and with areas in which the depth to water was less than 50 feet. The transient simulation indicated that about 22 percent of the water pumped in the Mimbres Basin was derived from reduction in evapotranspiration, compared with 77 percent derived from reduction in storage in the aquifer, and less than 1 percent from reduced discharge to playas in Mexico.

The transient simulation error was least in the Deming area and greatest in the Columbus area. Transient simulations in the model are limited by uncertainties in hydraulic conductivity, aquifer thickness, depletions, and storage coefficient. Improvements in the model will require additional information on recharge, aquifer properties, historical depletions, irrigation-return flow, evapotranspiration, and boundary conditions. Thus, the model presented here needs to be viewed as a preliminary analysis to guide future studies.

Future studies could include a reanalysis of the distribution of aquifer depletions, particularly in the period since 1970. Existing maps of irrigated acreage in the basin in 1930, 1940, and 1973 could be used with more recent areal photographs and crop records to provide improved estimates of consumptive use by crops and native vegetation. Areal photographs might also be used to estimate the history of irrigation in Mexico. Differences in water indicate that it may be necessary to estimate pumpage and irrigation-return flows, and use a layered, three-dimensional model to adequately account for these differences in water levels between deep and shallow wells in irrigated areas.

Improved estimates of recharge might be provided by a reanalysis of mountain-front runoff, combined with a precipitation-runoff model of the Mimbres River. An improved ground-water flow model could incorporate a streamflow-routing package, rather than distributing recharge uniformly. The assumption that all mountain-front recharge occurs in the uppermost parts of the alluvial fans needs to be evaluated, as does possible infiltration directly from precipitation on the bolson deposits by examining chloride concentrations in the unsaturated zone and at the water table in the bolson deposits. Current geophysical analysis of the basin could be used as the basis for an improved map of aquifer thickness, when combined with the geologic-structure analysis in this report and recent logs of wells in the basin. Land subsidence caused by withdrawal of ground water and compaction of fine-grained sediments also could be simulated in an improved model.

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Table 8.--Chemical analyses of selected ground-water samples within the Mimbres Basin

[Location number: see text for explanation. Geologic unit: Qal, Quaternary alluvium; Qab, Quaternary alluvium and bolson deposits; QTg, Quaternary and Tertiary Gila Conglomerate; Tv, Tertiary volcanic and associated sedimentary rocks; PMD, Pennsylvanian, Mississippian, and Devonian rocks, undivided; p€, Precambrian rocks, undivided. All analyses in milligrams per liter unless otherwise noted. --, no data]

Well location number	Date of collection	Geologic unit	Well depth, in feet below land surface	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	pH (standard units)	Temperature, in degrees Celsius	Calcium	Magnesium	Sodium	Potassium	Sodium plus potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride
16S.11W.7.214	4-29-55	Qab	--	226	7.3	--	26	10	--	--	5.0	120	--	7.7	2.5	0.1
17S.10W.19.332	4-28-55	Qab	28	427	7.3	--	58	14	--	--	10	230	--	12	7.2	.2
17S.11W.24.14132	4-28-55	Qab	310	331	7.2	14.5	46	10	--	--	9.0	190	--	8.6	3.5	.1
17S.12W.32.444	9-22-54	Tv	2,200	754	--	32	86	19	--	--	53	240	--	190	11	1.6
18S.9W.21.300	6-10-52	--	--	341	--	22.5	53	4.8	--	--	11	150	6.0	23	12	.0
18S.9W.28.11412	6-10-52	QTg	182	341	--	22	53	4.8	--	--	11	150	6.0	23	12	.0
18S.9W.30.3431	6-10-52	QTg	173	389	--	21.5	45	4.4	--	--	36	150	17	26	13	.0
18S.10W.8.443A	6-12-52	QTg	37	475	--	11	74	12	--	--	16	240	10	33	9.0	3.0
18S.13W.2.321	4-11-54	Qal	26	564	--	--	68	29	--	--	6.0	260	--	68	8.0	.8
18S.13W.8.13312	5-17-54	QTg	270	442	--	--	21	5.8	--	--	72	190	--	19	38	1.4
18S.13W.14.22111	3-21-54	QTg	--	640	7.8	--	73	28	--	--	23	270	--	68	31	.3
18S.13W.22.22212	8-30-54	Qab	700	374	--	19.5	42	13	--	--	18	200	--	13	10	.4
18S.14W.11.233	5-19-54	Qab	137	510	--	--	58	16	--	--	26	210	--	38	29	.6
18S.14W.28.141	8-28-74	QTg	700	423	--	22.5	48	9.7	--	--	28	220	--	15	14	.8
18S.14W.30.343	6-20-58	QTg	489	369	7.9	22.0	46	7.6	22	3.0	--	210	--	7.5	14	.7
18S.14W.31.21324	1-13-72	--	1,030	335	7.4	22.5	38	6.1	23	2.3	--	170	--	11	14	.4
19S.7W.28.3431	8-12-80	Qab	--	690	7.4	18.5	78	18	48	3.5	--	310	--	100	21	.7
19S.12W.19.11342	1-10-52	PMD	405	0	--	--	54	17	--	--	78	330	--	70	23	.0
19S.13W.29.421	6-04-54	QTg	221	495	--	--	57	15	--	--	26	200	--	55	16	.6
19S.14W.1.311	3-09-54	QTg	168	389	--	--	38	22	--	--	12	190	--	17	16	.4
19S.14W.6.414	10-02-76	QTg	900	294	6.9	21	37	5.5	15	2.2	--	160	--	7.5	5.5	.4
19S.15W.10.324	3-15-54	QTg	1,200	392	--	--	56	9.8	--	--	12	150	--	64	8.0	1.2
20S.6W.5.42111	1-04-72	--	--	388	7.8	28	14	3.9	65	3.8	--	190	--	27	11	1.4
20S.6W.24.332	9-09-71	Qab	--	393	8.0	26	16	7.7	50	10	--	150	--	34	17	1.1
20S.11W.20.243	12-05-74	Tv	--	603	7.1	53.5	34	7.4	79	7.6	--	280	--	49	17	5.9

Table 8.--Chemical analyses of selected ground-water samples within the Mimbres Basin--Continued

Well location number	Date of collection	Geologic unit	Well depth, in feet below land surface	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	pH (standard units)	Temperature, in degrees Celsius	Calcium	Magnesium	Sodium	Potassium	Sodium plus potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride
20S.12W.19.123	2-11-55	Qab	400	375	7.7	19.5	28	14	--	--	31	140	--	47	11	0.3
20S.14W.33.334	8-21-80	Qab	96	430	7.6	21.5	51	9.0	25	1.4	--	140	--	71	12	1.2
20S.15W.20.33122	3-23-55	p€	150	667	7.5	16.5	89	16	--	--	34	310	--	56	24	1.2
20S.15W.23.14212	8-21-80	Qab	--	810	7.3	19.5	110	25	45	1.5	--	230	--	200	52	1.0
21S.5W.8.444	8-09-65	Qab	435	489	8.0	25.5	22	6.6	--	--	77	230	--	30	12	1.6
21S.5W.29.224	7-30-80	Qab	620	470	7.7	27	20	7.0	65	10	--	210	--	22	10	1.5
21S.5W.34.444	9-09-71	Qab	298	508	7.9	24	28	15	51	6.4	--	210	--	31	15	1.5
21S.6W.27.432	8-13-80	Tv	172	470	7.6	23	32	11	47	6.4	--	200	--	27	18	1.4
21S.8W.14.33223	8-13-80	--	--	590	7.5	24	64	17	32	3.7	--	250	--	37	26	.8
21S.9W.24.14242	12-18-71	--	--	734	7.2	20	55	20	81	.4	--	310	--	100	14	1.1
21S.11W.35.310	1-04-72	--	179	384	7.2	16	45	12	19	2.0	--	200	--	19	7.8	.6
21S.12W.25.421	8-21-80	--	--	525	7.6	19	53	19	25	4.5	--	260	--	46	17	.8
21S.16W.24.411	4-10-56	Qab	76	328	6.9	16	39	9.5	--	--	20	160	--	26	11	1.0
22S.6W.16.332	8-13-80	Qab	--	520	7.7	24	42	14	42	4.3	--	200	--	41	28	.7
22S.6W.32.14424	8-14-80	Qab	--	390	7.8	22	31	5.4	45	2.4	--	170	--	28	13	.9
22S.11W.24.133	1-04-72	--	--	275	8.3	17.5	27	8.7	17	1.8	--	150	--	14	7.7	.6
22S.14W.36.223	6-08-55	--	545	291	7.8	--	28	5.2	--	--	31	160	--	13	10	.6
22S.15W.13.232	6-17-55	Qab	23	643	7.4	16	54	19	--	--	65	310	--	67	15	1.2
23S.5W.3.313	8-14-80	Tv	--	470	7.4	26	23	7.0	65	9.7	--	180	--	37	24	1.7
23S.6W.28.244	8-14-80	Qab	--	395	7.9	22	23	6.3	55	2.3	--	170	--	38	14	1.3
23S.7W.33.211	9-15-71	--	--	610	7.9	22	15	7.4	120	1.2	--	340	--	45	11	.4
23S.8W.21.222	10-18-71	--	--	407	8.2	20.0	11	5.5	73	1.2	--	210	--	22	9.2	1.9
23S.9W.28.400	11-17-54	Qab	400	350	8.1	21.5	30	5.8	37	3.0	--	180	--	17	9.5	.6
23S.11W.14.24411	2-10-72	--	--	374	7.9	19	40	8.7	26	2.8	--	200	--	21	9.1	.7
23S.12W.8.114	8-22-80	--	300	420	8.1	26	35	5.6	51	3.0	--	240	--	19	10	.8
23S.12W.25.1111	8-22-80	--	340	395	8.4	28.5	2.9	.6	89	1.0	--	180	1.00	31	11	.8
24S.4W.12.224	8-19-80	Qab	180	1,310	8.1	23.5	19	11	240	2.3	--	300	--	190	110	2.0
24S.5W.5.323	5-14-52	Qab	137	601	--	22	21	13	--	--	92	240	--	48	30	2.0
24S.7W.3.113	7-18-45	--	130	741	--	--	18	7.8	--	--	150	350	--	57	21	5.2
24S.7W.5.133	8-04-69	--	1,110	439	9.6	39	4.0	.6	--	--	100	120	46	34	9.0	1.7

Table 8.--Chemical analyses of selected ground-water samples within the Mimbres Basin--Continued

Well location number	Date of collec-tion	Geo-logic unit	Well depth, in feet below land surface	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	pH (standard units)	Temper-ature, in degrees Celsius	Cal-cium	Mag-nesium	Sod-ium	Potas-sium	Sodium plus potas-sium	Bicar-bonate	Car-bonate	Sul-fate	Chlo-ride	Fluo-ride
24S.7W.9.11113	9-15-71	--	--	623	7.9	24.5	15	2.9	120	2.0	--	250	--	69	24	3.7
24S.7W.9.24112A	7-20-44	Qab	375	376	8.5	24.5	22	3.0	57	3.0	--	160	--	40	8.8	4.4
24S.7W.16.142	7-10-73	Qab	--	382	8.1	--	20	.5	67	2.1	--	120	--	55	15	6.0
24S.8W.20.300	10-07-29	--	74	--	--	--	30	12	41	4.0	--	200	5.0	26	16	--
24S.8W.20.411	10-07-29	--	1,665	--	--	--	9.2	1.4	61	3.0	--	160	3.0	22	8.2	--
24S.9W.6.431	9-12-44	--	1,000	346	--	--	29	7.7	--	--	37	180	--	19	9.0	.6
24S.9W.12.100	10-08-29	--	80	--	--	--	57	13	42	4.0	--	200	4.0	49	49	--
24S.9W.13.111	10-08-29	--	700	--	--	--	6.8	1.3	72	4.0	--	170	5	27	10	--
24S.9W.15.433	10-07-29	--	146	--	--	--	30	5.9	35	4.0	--	180	4.0	18	7.0	--
24S.10W.12.111	9-03-52	--	274	351	--	20	42	8.2	--	--	21	190	--	15	6.0	.6
24S.11W.11.211	7-17-52	--	200	319	--	21	36	8.1	--	--	21	180	--	11	4.0	.4
24S.11W.13.411	8-09-52	--	190	350	--	20	37	9.3	--	--	31	190	--	20	7.0	4.0
24S.11W.14.11132	9-15-71	--	--	365	7.9	22	20	4.5	55	2.8	--	200	--	33	7.1	.8
24S.12W.4.112	8-21-80	--	--	380	7.8	25	32	9.5	34	2.0	--	170	--	34	10	.5
24S.12W.9.341	8-21-80	Qab	--	345	7.9	28	34	5.5	31	3.4	--	160	--	25	15	.5
24S.13W.19.141	8-21-80	Qab	300	470	8.1	23	7.1	.1	94	2.4	--	180	--	42	16	1.1
25S.6W.2.111A	8-01-52	--	--	650	--	--	2.0	12	--	--	150	270	21	58	50	--
25S.6W.3.121	2-06-64	Qab	230	723	9.2	24.5	4.6	.4	--	--	170	200	45	50	52	3.4
25S.6W.4.111	5-15-52	--	231	814	--	22	10	6.6	--	--	170	330	8.0	97	27	1.8
25S.6W.8.112	1-05-54	--	340	824	--	31.5	6.5	3.5	--	--	180	210	23	77	53	18
25S.6W.8.411	5-19-52	Qab	1,020	988	--	28.5	2.0	.9	--	--	240	360	43	67	36	18
25S.6W.20.111	9-15-71	--	--	1,000	8.5	22	3.2	.5	230	2.9	--	380	19	120	31	4.9
25S.7W.12.122	5-12-52	Qab	230	1,630	--	20	54	17	--	--	280	270	--	240	230	3.6
25S.8W.18.111A	7-25-46	Qab	160	399	--	20.5	36	8.7	--	--	41	200	--	24	16	1.0
25S.9W.11.11144	9-15-71	QTg	220	319	7.8	20.5	26	8.2	30	2.5	--	170	--	15	7.4	.8
25S.10W.13.41212	9-15-71	--	325	339	7.9	21	19	6.1	45	2.6	--	160	--	38	7.1	1.8
25S.11W.11.11223	8-15-66	--	--	340	8.0	24.5	35	4.0	--	--	33	180	--	15	9.6	.9
26S.8W.19.14123	9-15-71	--	--	1,710	7.7	21	120	83	110	3.9	--	210	--	380	250	1.1
26S.9W.2.221	9-15-71	--	225	427	7.9	20	30	11	45	2.4	--	190	--	51	16	.7
26S.10W.25.32122	9-16-71	--	--	675	7.9	19.5	26	20	95	2.5	--	300	--	80	26	3.7

Table 8.--Chemical analyses of selected ground-water samples within the Mimbres Basin--Concluded

Well location number	Date of collection	Geologic unit	Well depth, in feet below land surface	Specific conductance, in microsiemens per centimeter at 25 degrees Celsius	pH (standard units)	Temperature, in degrees Celsius	Calcium	Magnesium	Sodium	Potassium	Sodium plus potassium	Bicarbonate	Carbonate	Sulfate	Chloride	Fluoride
26S.12W.11.420	5-20-58	--	--	323	7.9	20.5	11	0.7	--	--	68	200	--	4.3	5.0	1.0
27S.5W.7.444	5-22-58	--	--	1,460	8.0	--	31	17	--	--	250	240	-	83	290	1.4
27S.7W.19.200	1-15-50	Qab	--	1,520	--	--	9.2	4.6	--	--	380	780	49	61	46	4.9
27S.8W.8.311	8-08-52	--	413	632	--	21	12	5.0	--	--	120	200	5.0	90	27	5.0
27S.8W.15.131	8-08-52	--	510	781	--	24	12	4.8	--	--	160	200	5.0	130	50	5.0
27S.8W.23.100	1-15-50	--	--	836	--	--	16	9.5	--	--	170	390	14	64	27	2.9
27S.8W.35.12213	9-16-71	--	550	1,030	8.0	23.5	9.1	4.1	220	6.3	--	360	--	150	45	5.7
27S.9W.1.431	7-19-54	Qab	62	394	--	--	24	13	--	--	42	210	--	17	10	1.2
27S.10W.14.131	9-21-58	--	--	1,170	7.9	20.5	21	4.0	--	--	260	390	--	220	36	12
28S.5W.8.224	5-22-58	--	90	1,860	8.0	--	8.3	3.6	--	--	420	570	--	140	230	4.4
28S.6W.10.31143	5-22-58	--	300	3,170	7.9	23.5	11	2.4	--	--	710	460	--	360	570	4.4
28S.7W.9.41114	8-08-52	Qab	720	1,850	--	31	4.0	2.3	--	--	420	390	37	240	200	11
28S.7W.20.42222	8-13-52	--	532	2,050	--	--	2.0	6.0	--	--	450	400	30	250	260	--
28S.7W.26.244	5-15-52	Qab	700	1,970	--	29.5	3.2	1.2	--	--	450	390	30	250	230	10
28S.8W.02.111	7-17-68	Qab	503	997	7.7	--	11	6.0	--	--	210	340	--	140	50	7.1
28S.8W.25.211	8-08-52	Qab	529	1,620	--	33	5.2	3.6	--	--	370	420	28	230	130	9.0
28S.8W.26.222	5-15-52	--	700	1,250	--	--	5.2	2.1	--	--	290	400	13	190	55	8.0
28S.8W.27.120	5-11-65	Qab	310	1,180	8.2	--	9.0	3.0	--	--	270	420	--	170	51	7.0
28S.8W.36.133	7-17-68	Qab	608	1,280	8.3	--	5.8	4.3	--	--	280	410	6.0	180	64	8.1
28S.10W.17.111	5-14-58	--	1,156	1,490	8.5	19	13	2.8	--	--	320	250	6.0	370	94	3.6
28S.11W.29.234	5-21-58	--	60	1,610	7.5	19	140	57	--	--	120	360	--	220	170	.8
29S.8W.11.11313	1-15-50	--	--	1,280	--	--	6.8	2.1	--	--	290	430	--	180	65	8.9
29S.8W.12.144	1-15-50	--	150	1,280	--	--	6.8	2.1	--	--	290	370	31	180	65	8.9
29S.8W.17.231	5-21-58	--	325	977	8.1	29	13	3.1	--	--	210	330	--	120	62	4.0
29S.10W.11.222	5-20-55	--	510	1,080	7.9	--	9.5	14	--	--	220	330	--	180	57	4.4
29S.10W.15.111	5-19-55	--	440	627	8.0	25.5	10	9.0	--	--	120	230	--	64	38	1.4
29S.11W.12.224	5-21-58	--	--	753	7.6	28	39	8.8	--	--	120	230	--	110	48	2.2

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin

EXPLANATION

Location of block: Row and column location of block in model grid shown in figure 17.

Geographic location of recharge: Location names correspond to watersheds used for mountain-front runoff estimates (fig. 6) and other recharge estimates (table 6), with the exception of the following:

Upper Mimbres River - This recharge area is located between Faywood at block 11-26 and the confluence of San Vicente Arroyo to the Mimbres River at block 14-20. Total recharge for this reach is 4.0 cubic feet per second.

Middle Mimbres River - This recharge area is along the Mimbres River downstream from the confluence at block 15-19 to the Wamel Canal gaging station at block 22-19. Total recharge for this reach is 3.4 cubic feet per second.

Lower Mimbres River - This recharge area is along the Mimbres River downstream from the Wamel Canal at block 22-19 to the bridge across the Mimbres River 6 miles east of Deming at block 30-28. Total recharge for this reach is 3.5 cubic feet per second.

Source of recharge:
BB - Underflow from adjacent basins.
BAR - Recharge from bedrock aquifers.
MFR - Recharge from mountain-front runoff.

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block: Row	Location of block: Column	Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
4	13	Mangas Trench	MFR	0.660
4	14	Mangas Trench	MFR	.660
4	15	Mangas Trench	MFR	.660
5	19	San Vicente Arroyo	MFR	.660
5	20	do.	MFR	.660
5	21	do.	MFR	.660
5	22	do.	MFR	1.319
6	10	do.	MFR	.660
6	11	do.	MFR	.660
6	18	do.	MFR	.660
6	19	do.	MFR	.660
7	10	San Jose Mountain	MFR	.325
7	12	San Jose Mountain	MFR	.325
7	19	Apache Tejo Spring	BAR	.528
7	20	San Jose Mountain and Apache Tejo Spring	MFR/BAR	.853
7	21	San Jose Mountain and Apache Tejo Spring	MFR/BAR	.853
7	22	San Jose Mountain and Apache Tejo Spring	MFR/BAR	.853
7	32	Mimbres River	MFR	.343
7	33	Mimbres River	MFR	.343
8	6	China Draw	MFR	.211
8	7	White Rock Canyon	MFR	.396
8	10	San Jose Mountain	MFR	.325
8	23	Lampbright Draw	MFR	.484
8	24	Lampbright Draw	MFR	.484
8	32	Mimbres River	MFR	.343
8	33	Gallinas Canyon	MFR	.818
8	34	Gallinas Canyon	MFR	.818
8	35	Gallinas Canyon	MFR	.818
9	6	China Draw	MFR	.211
9	8	White Rock Canyon	MFR	.396

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block: Row	Location of block: Column	Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
9	10	San Jose Mountain	MFR	0.325
9	24	Lampbright Draw	MFR	.484
9	25	Lampbright Draw	MFR	.484
9	32	Mimbres River and Blue Mountain	MFR	.996
9	35	Carrizo Canyon	MFR	1.346
10	6	China Draw	MFR	.141
10	9	White Rock Canyon	MFR	.264
10	12	Cow Springs	MFR	.305
10	23	Lindauer Spring and Faywood Hot Spring	BAR	.117
10	27	Mimbres River and Mimbres Peak	MFR	.498
10	28	Mimbres River and Mimbres Peak	MFR	.498
10	29	Mimbres River and Mimbres Peak	MFR	.501
10	30	Mimbres River and Blue Mountain	MFR	.660
10	31	Mimbres River and Blue Mountain	MFR	.660
10	32	Mimbres River and Blue Mountain	MFR	.660
10	35	Carrizo Canyon	MFR	.897
10	36	Carrizo Canyon	MFR	.897
11	12	Cow Springs	MFR	.305
11	26	Upper Mimbres River	MFR	.680
11	32	Round Mountain	MFR	.281
12	12	Cow Springs	MFR	.203
12	24	Upper Mimbres River	MFR	.681
12	25	Upper Mimbres River	MFR	.681
12	32	Round Mountain	MFR	.188
13	9	Cow Springs	MFR	.305

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block		Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
Row	Column			
13	22	Upper Mimbres River	MFR	0.681
13	23	Upper Mimbres River	MFR	.681
13	32	Round Mountain	MFR	.188
13	34	Mule Spring	MFR	.123
13	36	Macho Creek	MFR	.059
14	20	Upper Mimbres River	MFR	.681
14	21	Upper Mimbres River	MFR	.681
14	31	Round Mountain	MFR	.188
14	34	Mule Springs	MFR	.070
14	37	Macho Creek	MFR	.070
15	19	Middle Mimbres River	MFR	.554
15	30	Goat Ridge	MFR	.102
15	34	Mule Spring	MFR	.082
15	39	Macho Creek	MFR	.149
16	9	Cow Springs	MFR	.203
16	19	Middle Mimbres River	MFR	.554
16	29	Goat Ridge	MFR	.102
16	34	Mule Spring	MFR	.082
16	38	Macho Creek	MFR	.278
17	10	Cow Springs	MFR	.135
17	11	Cow Springs	MFR	.135
17	12	Cow Springs	MFR	.135
17	19	Middle Mimbres River	MFR	.554
17	28	Goat Ridge	MFR	.068
17	34	Mule Spring	MFR	.074
17	41	Palomas underflow	BB	.076
18	18	Middle Mimbres River	MFR	.554
18	27	Goat Ridge	MFR	.068
18	34	Mule Spring	MFR	.027
18	41	Palomas underflow	BB	.076
19	19	Middle Mimbres River	MFR	.554
19	27	Goat Ridge	MFR	.068
19	33	Mule Spring	MFR	.082
20	19	Middle Mimbres River	MFR	.554
20	28	Goat Ridge	MFR	.047

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block		Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
Row	Column			
20	33	Mule Spring	MFR	0.082
21	19	Middle Mimbres River	MFR	.554
21	28	Goat Ridge	MFR	.068
21	33	Mule Spring	MFR	.082
22	5	Seventysix Draw	MFR	.152
22	19	Middle Mimbres River (Wamel Canal)	MFR	.554
22	28	Starvation Draw	MFR	.029
22	33	Mule Spring	MFR	.082
23	5	Seventysix Draw	MFR	.152
23	20	Lower Mimbres River	MFR	.495
23	29	Starvation Draw	MFR	.043
23	30	Starvation Draw	MFR	.043
23	33	Mule Spring	MFR	.082
24	4	Seventysix Draw	MFR	.152
24	21	Lower Mimbres River	MFR	.495
24	30	Starvation Draw	MFR	.018
24	33	Mule Spring	MFR	.082
25	4	Seventysix Draw	MFR	.152
25	22	Lower Mimbres River	MFR	.495
25	29	Starvation Draw	MFR	.043
25	33	Mule Spring	MFR	.082
26	23	Lower Mimbres River	MFR	.495
26	29	Starvation Draw	MFR	.043
26	33	Mule Spring	MFR	.082
27	24	Lower Mimbres River	MFR	.495
27	29	Starvation Draw	MFR	.043
27	32	Starvation Draw	MFR	.043
28	25	Lower Mimbres River	MFR	.495
28	26	Lower Mimbres River	MFR	.495
28	30	Starvation Draw	MFR	.043

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block Row	Location of block Column	Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
28	32	Starvation Draw	MFR	0.043
29	27	Lower Mimbres River	MFR	.495
29	31	Starvation Draw	MFR	.043
30	28	Lower Mimbres River	MFR	.495
31	37	Akela	MFR	.129
32	37	Akela	MFR	.129
33	28	Little Florida Mts.	MFR	.031
33	29	Little Florida Mts.	MFR	.047
33	30	Little Florida Mts.	MFR	.047
33	37	Akela	MFR	.129
34	27	Little Florida Mts.	MFR	.031
34	30	Little Florida Mts.	MFR	.047
34	37	Akela	MFR	.129
34	42	Akela	MFR	.111
34	44	Mason Draw	MFR	.188
35	5	Carrizalillo Hills	MFR	.009
35	23	Little Florida Mts.	MFR	.047
35	24	Little Florida Mts.	MFR	.047
36	37	Akela	MFR	.193
36	44	Mason Draw	MFR	.281
37	6	Carrizalillo Hills	MFR	.004
37	22	Florida Mountains	MFR	.076
37	29	Florida Mountains	MFR	.113
38	6	Carrizalillo Hills	MFR	.004
38	22	Florida Mountains	MFR	.076
38	27	Florida Mountains	MFR	.031
38	28	Florida Mountains	MFR	.031
39	5	Carrizalillo Hills	MFR	.006
39	21	Florida Mountains	MFR	.076
39	27	Florida Mountains	MFR	.060
40	5	Carrizalillo Hills	MFR	.006
40	20	Florida Mountains	MFR	.076
40	26	Florida Mountains	MFR	.063
41	5	Carrizalillo Hills	MFR	.006
41	20	Florida Mountains	MFR	.076

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block: Row	Location of block: Column	Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
41	26	Florida Mountains	MFR	0.047
42	5	Carrizalillo Hills	MFR	.006
42	21	Florida Mountains	MFR	.076
42	25	Florida Mountains	MFR	.063
43	5	Carrizalillo Hills	MFR	.006
43	10	Tres Hermanas Mts.	MFR	.010
43	11	do.	MFR	.010
43	12	do.	MFR	.010
35	25	do.	MFR	.047
35	26	do.	MFR	.047
35	27	do.	MFR	.047
35	30	do.	MFR	.070
35	37	Akela	MFR	.193
35	44	Mason Draw	MFR	.281
36	6	Carrizalillo Hills	MFR	.006
36	22	Florida Mountains	MFR	.047
36	30	Little Florida Mts.	MFR	.070
43	13	Little Florida Mts.	MFR	.010
43	22	Florida Mountains	MFR	.076
43	25	Florida Mountains	MFR	.008
44	9	Tres Hermanas Mts.	MFR	.016
44	14	Tres Hermanas Mts.	MFR	.010
44	15	Tres Hermanas Mts.	MFR	.010
44	16	Tres Hermanas Mts.	MFR	.010
44	23	Florida Mountains	MFR	.073
44	24	Florida Mountains	MFR	.021
45	10	Tres Hermanas Mts.	MFR	.010
45	17	Tres Hermanas Mts.	MFR	.010
46	10	Tres Hermanas Mts.	MFR	.016
46	16	Tres Hermanas Mts.	MFR	.016
47	3	Mexico	MFR	.220
47	4	Mexico	MFR	.501
47	10	Tres Hermanas Mts.	MFR	.016
47	14	Tres Hermanas Mts.	MFR	.016
47	15	Tres Hermanas Mts.	MFR	.016

Table 9.--Summary of constant-flow blocks simulating recharge to the bolson-fill aquifer in the Mimbres Basin--Concluded

Location of block		Geographic location of recharge	Source of recharge	Simulated recharge rate, in cubic feet per second
Row	Column			
47	42	West Potrillo Mts.	MFR	0.299
48	3	Mexico	MFR	.501
48	4	Mexico	MFR	.220
48	10	Tres Hermanas Mts.	MFR	.016
48	13	Tres Hermanas Mts.	MFR	.016
48	40	West Potrillo Mts.	MFR	.299
48	41	West Potrillo Mts.	MFR	.299
49	3	Mexico	MFR	.211
49	11	Tres Hermanas Mts.	MFR	.023
49	12	Tres Hermanas Mts.	MFR	.023
49	37	West Potrillo Mts.	MFR	.299
49	38	West Potrillo Mts.	MFR	.237
49	39	West Potrillo Mts.	MFR	.123
50	3	Mexico	MFR	.211
50	6	Mexico	MFR	.035
50	7	Mexico	MFR	.035
50	8	Mexico	MFR	.035
50	36	West Potrillo Mts.	MFR	.299
51	7	Mexico	MFR	.035
51	8	Mexico	MFR	.035
51	9	Mexico	MFR	.035
51	10	Mexico	MFR	.023
51	35	West Potrillo Mts.	MFR	.299
52	8	Mexico	MFR	.035
52	9	Mexico	MFR	.035
52	10	Mexico	MFR	.023
52	34	West Potrillo Mts.	MFR	.299
53	10	Mexico	MFR	.023
53	11	Mexico	MFR	.023

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin

(Heads are in feet above sea level; errors are in feet. See figure 3 for the well-numbering system. Data are from Darton (1916a, pl. 1) and McLean (1977)

Location of block						
Row	Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
5	21	5,886.1	5,893	-6.90039	6.90039	18S.13W.9.22441
6	16	5,278.5	5,330	-51.50000	51.50000	19S.13W.18.14142
7	16	5,179.3	5,173	6.29980	6.29980	19S.13W.29.42133
7	18	5,186.4	5,194	-7.60059	7.60059	19S.13W.22.43243
7	21	5,428.1	5,437	-8.90039	8.90039	19S.12W.17.12332
8	17	5,067.9	5,060	7.89941	7.89941	20S.13W.2.21424
8	17	5,067.9	5,010	57.89941	57.89941	20S.13W.13.21124
8	18	5,067.7	5,015	52.69922	52.69922	20S.12W.7.31134A
8	18	5,067.7	5,018	49.69922	49.69922	20S.13W.1.44444
8	21	5,116.3	5,049	67.29980	67.29980	19S.12W.34.43332
8	32	5,447.3	5,516	-68.70020	68.70020	18S.10W.17.22421
8	32	5,447.3	5,487	-39.70020	39.70020	18S.10W.23.11121
9	13	4,991.5	5,060	-68.50000	68.50000	20S.13W.33.32442
9	15	4,981.1	4,996	-14.90039	14.90039	20S.13W.26.22241
9	17	4,973.8	4,974	-0.20020	0.20020	20S.12W.19.12313
9	18	4,970.8	4,939	31.79980	31.79980	20S.12W.21.41133
9	18	4,970.8	4,906	64.79980	64.79980	20S.12W.28.24223
9	19	4,967.7	5,030	-62.30078	62.30078	20S.12W.9.13333
10	14	4,903.6	4,940	-36.40039	36.40039	21S.13W.24.44442
10	18	4,881.9	4,849	32.89941	32.89941	20S.12W.34.43414
10	20	4,871.8	4,814	57.79980	57.79980	20S.12W.36.11134
10	24	4,914.1	4,933	-18.90039	18.90039	20S.11W.22.12411
10	27	5,004.0	5,026	-22.00000	22.00000	20S.10W.7.12112
10	30	5,151.1	5,187	-35.90039	35.90039	19S.10W.27.22212
11	19	4,810.9	4,761	49.89941	49.89941	21S.12W.12.44231
11	21	4,799.6	4,777	22.59961	22.59961	21S.11W.5.11222
12	21	4,750.4	4,728	22.39941	22.39941	21S.11W.15.42241
12	25	4,820.2	4,876	-55.80078	55.80078	21S.10W.6.000
13	20	4,712.2	4,691	21.19922	21.19922	21S.11W.28.11422
13	23	4,726.9	4,766	-39.10059	39.10059	21S.11W.13.411

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block Row	Location of block Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
13	24	4,736.1	4,769	-32.90039	32.90039	21S.10W.7.12233
14	19	4,672.9	4,646	26.89941	26.89941	21S.11W.33.44222
14	20	4,674.6	4,688	-13.40039	13.40039	21S.11W.35.133
14	22	4,676.2	4,676	0.19922	0.19922	21S.10W.30.33332
16	20	4,614.9	4,576	38.89941	38.89941	22S.11W.13.12221
16	20	4,614.9	4,579	35.89941	35.89941	22S.11W.14.222
17	19	4,594.6	4,550	44.59961	44.59961	22S.11W.23.22222
17	20	4,589.8	4,536	53.79980	53.79980	22S.11W.24.21111
19	22	4,529.0	4,473	56.00000	56.00000	22S.10W.22.31422
22	25	4,385.8	4,338	47.79980	47.79980	22S.9W.29.41244
23	13	4,376.1	4,320	56.09961	56.09961	24S.11W.3.440
23	23	4,366.4	4,337	29.39941	29.39941	23S.9W.7.21143
24	11	4,334.4	4,299	35.39941	35.39941	24S.11W.21.110
24	13	4,349.9	4,310	39.89941	39.89941	24S.11W.10.420
24	14	4,356.6	4,331	25.59961	25.59961	24S.11W.2.340
24	14	4,356.6	4,311	45.59961	45.59961	24S.11W.11.240
24	23	4,353.1	4,332	21.09961	21.09961	23S.9W.8.140
24	23	4,353.1	4,335	18.09961	18.09961	23S.9W.17.100
24	26	4,335.5	4,299	36.50000	36.50000	22S.9W.35.31133
25	14	4,333.2	4,295	38.19922	38.19922	24S.11W.13.210
25	16	4,348.0	4,325	23.00000	23.00000	24S.10W.7.210
25	17	4,350.2	4,336	14.19922	14.19922	24S.10W.5.410
25	22	4,341.1	4,324	17.09961	17.09961	23S.9W.19.132
25	23	4,336.2	4,331	5.19922	5.19922	23S.9W.18.41224
25	28	4,314.6	4,288	26.59961	26.59961	22S.8W.31.310
25	33	4,253.4	4,228	25.39941	25.39941	22S.7W.9.11124
26	18	4,327.5	4,319	8.50000	8.50000	24S.10W.3.411
26	24	4,311.0	4,292	-10.00000	10.00000	23S.9W.22.220
26	26	4,304.8	4,285	19.79980	19.79980	23S.9W.12.440
27	11	4,268.3	4,258	10.29980	10.29980	24S.11W.34.200
27	17	4,303.9	4,312	-8.10059	8.10059	24S.10W.15.310
27	17	4,303.9	4,305	-1.10059	1.10059	24S.10W.15.410
27	19	4,303.8	4,309	-5.20020	5.20020	24S.10W.1.340
27	21	4,298.8	4,308	-9.20020	9.20020	23S.9W.31.42222
27	22	4,296.7	4,317	-20.30078	20.30078	23S.9W.29.210

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block Row	Location of block Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
27	26	4,289.0	4,272	17.00000	17.00000	23S.8W.18.130
27	29	4,270.2	4,290	-19.80078	19.80078	23S.8W.3.340
27	36	4,248.7	4,262	-13.30078	13.30078	22S.6W.6.123
28	18	4,283.0	4,312	-29.00000	29.00000	24S.10W.14.110
28	19	4,282.8	4,291	-8.20020	8.20020	24S.10W.13.410
28	20	4,280.7	4,289	-8.30078	8.30078	24S.9W.7.331
28	21	4,275.5	4,295	-19.50000	19.50000	24S.9W.5.420
28	24	4,275.6	4,278	-2.40039	2.40039	23S.9W.26.410
28	25	4,275.1	4,280	-4.90039	4.90039	23S.9W.25.330A
28	26	4,273.4	4,266	7.39941	7.39941	23S.8W.19.440
29	18	4,262.7	4,276	-13.30078	13.30078	24S.10W.23.110
29	22	4,259.0	4,279	-20.00000	20.00000	24S.9W.10.110
29	27	4,257.2	4,267	-9.80078	9.80078	23S.8W.20.120
30	9	4,224.2	4,235	-10.80078	10.80078	25S.11W.22.440
30	9	4,224.2	4,240	-15.80078	15.80078	25S.11W.27.310
30	12	4,200.3	4,232	-31.70020	31.70020	25S.10W.18.110
30	13	4,201.2	4,246	-44.80078	44.80078	25S.10W.17.110
30	13	4,201.2	4,236	-34.80078	34.80078	25S.10W.8.310
30	22	4,245.7	4,245	0.69922	0.69922	24S.9W.15.221
30	23	4,245.0	4,257	-12.00000	12.00000	24S.9W.12.410
30	24	4,245.4	4,249	-3.60059	3.60059	24S.8W.7.110
30	25	4,246.0	4,258	-12.00000	12.00000	24S.8W.6.110
30	26	4,245.0	4,252	-7.00000	7.00000	23S.8W.32.12113
30	26	4,245.0	4,251	-6.00000	6.00000	23S.8W.32.320
30	28	4,241.6	4,238	3.59961	3.59961	23S.8W.28.240
30	30	4,204.0	4,236	-32.00000	32.00000	23S.8W.13.41111
31	10	4,203.1	4,226	-22.90039	22.90039	25S.11W.25.210
31	16	4,200.8	4,245	-44.20020	44.2002	25S.10W.1.310
31	16	4,200.8	4,244	-43.20020	43.20020	25S.10W.11.220
31	18	4,224.0	4,258	-34.00000	34.00000	24S.9W.31.230
31	19	4,229.2	4,252	-22.80078	22.80078	24S.9W.29.210
31	20	4,231.9	4,252	-20.10059	20.10059	24S.9W.28.110
31	22	4,231.3	4,233	-1.70020	1.70020	24S.9W.14.110
31	25	4,234.4	4,233	1.39941	1.39941	24S.8W.5.110
31	29	4,206.8	4,221	-14.20020	14.20020	23S.8W.35.230

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block: Row	Location of block: Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
31	29	4,206.8	4,209	-2.20020	2.20020	23S.8W.25.310
31	30	4,181.0	4,177	4.00000	4.00000	23S.7W.30.114
31	31	4,172.7	4,135	37.69922	37.69922	23S.7W.16.130
31	32	4,187.9	4,150	37.89941	37.89941	23S.7W.10.440
31	32	4,187.9	4,185	2.89941	2.89941	23S.7W.2.440
32	14	4,186.6	4,208	-21.40039	21.40039	25S.10W.22.110
32	15	4,188.9	4,217	-28.10059	28.10059	25S.10W.15.42211
32	18	4,209.7	4,235	-25.30078	25.30078	25S.9W.6.410
32	18	4,209.7	4,226	-16.30078	16.30078	25S.9W.6.111
32	20	4,219.6	4,233	-13.40039	13.40039	24S.9W.27.210
32	21	4,222.3	4,223	-0.70020	0.70020	24S.9W.26.310
32	22	4,223.3	4,228	-4.70020	4.70020	24S.9W.23.210
32	27	4,223.0	4,221	2.00000	2.00000	24S.8W.3.410
32	30	4,144.7	4,128	16.69922	16.69922	23S.7W.32.110
32	30	4,144.7	4,150	-5.30078	5.30078	23S.7W.30.433
32	31	4,138.6	4,115	23.59961	23.59961	23S.7W.22.210
32	31	4,138.6	4,116	22.59961	22.59961	23S.7W.21.330
33	16	4,185.0	4,208	-23.00000	23.00000	25S.9W.18.410
33	20	4,207.6	4,219	-11.40039	11.40039	25S.9W.3.120
33	21	4,213.0	4,219	-6.00000	6.00000	24S.9W.35.310
33	23	4,216.8	4,216	0.79980	0.79980	24S.8W.30.100
33	24	4,218.3	4,240	-21.70020	21.70020	24S.8W.20.430
33	27	4,217.8	4,220	-2.20020	2.20020	24S.8W.11.220
33	28	4,205.4	4,186	19.39941	19.39941	24S.8W.1.230
33	30	4,117.6	4,119	-1.40039	1.40039	24S.7W.5.2133
34	10	4,182.5	4,209	-26.50000	26.50000	26S.10W.7.330
34	15	4,172.8	4,195	-22.20020	22.20020	25S.9W.30.110
34	18	4,185.2	4,213	-27.80078	27.80078	25S.9W.17.210
34	19	4,190.3	4,210	-19.70020	19.70020	25S.9W.10.310
34	21	4,200.7	4,209	-8.30078	8.30078	25S.9W.1.110
34	30	4,102.6	4,116	-13.40039	13.40039	23S.7W.34.200
35	12	4,171.8	4,162	9.79980	9.79980	26S.10W.10.220
35	13	4,169.0	4,167	2.00000	2.00000	26S.10W.3.440
35	13	4,169.0	4,166	3.00000	3.00000	26S.10W.2.430
35	15	4,165.4	4,173	-7.60059	7.60059	26S.10W.1.310

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin--Continued

Location of block Row	Location of block Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
35	17	4,166.1	4,196	-29.90039	29.90039	25S.9W.21.310
35	18	4,170.7	4,185	-14.30078	14.30078	25S.9W.22.210
35	19	4,175.0	4,192	-17.00000	17.00000	25S.9W.14.130
35	21	4,183.8	4,197	-13.20020	13.20020	25S.8W.18.110
35	30	4,093.8	4,104	-10.20020	10.20020	24S.7W.11.110
35	30	4,093.8	4,090	3.79980	3.79980	24S.7W.15.220
35	31	4,094.6	4,102	-7.40039	7.40039	24S.7W.1.110
35	31	4,094.6	4,088	6.59961	6.59961	24S.7W.11.130
35	33	4,119.1	4,085	34.09961	34.09961	23S.6W.30.000
35	34	4,136.0	4,085	51.00000	51.00000	23S.6W.27.310
35	35	4,146.9	4,100	46.89941	46.89941	23S.6W.22.440
36	11	4,159.6	4,150	9.59961	9.59961	26S.10W.21.130
36	12	4,158.1	4,159	-0.90039	0.90039	26S.10W.15.330
36	12	4,158.1	4,155	3.09961	3.09961	26S.10W.23.310
36	17	4,152.9	4,175	-22.10059	22.10059	25S.9W.34.110
36	17	4,152.9	4,165	-12.10059	12.10059	25S.9W.27.110
36	18	4,153.7	4,180	-26.30078	26.30078	25S.9W.26.330
36	20	4,162.1	4,189	-26.90039	26.90039	25S.9W.24.440
36	31	4,082.3	4,067	15.29980	15.29980	24S.7W.13.110
37	13	4,152.8	4,150	2.79980	2.79980	26S.10W.24.210
37	14	4,151.0	4,155	-4.00000	4.00000	26S.9W.18.120
37	18	4,144.2	4,165	-20.80078	20.80078	26S.9W.3.120
37	19	4,145.9	4,163	-17.10059	17.10059	26S.9W.2.21424
37	30	4,071.2	4,039	32.19971	32.19971	24S.7W.36.110
38	16	4,142.3	4,153	-10.70020	10.70020	26S.9W.15.310
39	16	4,136.8	4,140	-3.20020	3.20020	26S.9W.22.300
39	18	4,133.3	4,152	-18.70020	18.70020	26S.9W.12.130
39	19	4,131.6	4,142	-10.40039	10.40039	26S.8W.8.33342
39	29	4,055.0	4,026	29.00000	29.00000	25S.7W.2.444
40	13	4,135.9	4,127	8.89941	8.89941	27S.9W.6.41432
40	15	4,134.3	4,133	1.29980	1.29980	26S.9W.34.110
40	16	4,131.3	4,137	-5.70020	5.70020	26S.9W.26.200
40	17	4,129.4	4,143	-13.60059	13.60059	26S.9W.24.320
40	18	4,127.8	4,147	-19.20020	19.20020	26S.8W.18.440
41	17	4,123.3	4,135	-11.70020	11.70020	26S.9W.25.210

Table 10.--Summary of measured and simulated heads in the predevelopment simulation of the bolson-fill aquifer in the Mimbres Basin--Concluded

Location of block Row	Location of block Column	Simulated head	Measured head	Error (simulated-measured)	Absolute error	Well location number
41	18	4,122.1	4,135	-12.90039	12.90039	26S.8W.19.420
42	17	4,116.8	4,124	-7.20020	7.20020	26S.8W.31.200
42	18	4,116.1	4,129	-12.90039	12.90039	26S.8W.30.410
42	19	4,115.3	4,119	-3.70020	3.70020	26S.8W.29.22442
42	27	4,026.8	4,041	-14.20020	14.20020	26S.7W.2.11142
43	16	4,111.5	4,100	11.50000	11.50000	27S.9W.12.21223
43	17	4,110.7	4,093	17.69922	17.69922	27S.8W.5.100
43	18	4,110.3	4,108	2.29980	2.29980	26S.8W.31.000
44	16	4,104.6	4,088	16.59961	16.59961	27S.8W.8.110
45	18	4,064.1	4,073	-8.90039	8.90039	27S.8W.15.21223
46	17	4,043.0	4,065	-22.00000	22.00000	27S.8W.27.220
46	18	4,041.6	4,064	-22.40039	22.40039	27S.8W.15.000
46	18	4,041.6	4,057	-15.40039	15.40039	27S.8W.23.310
46	26	3,991.9	3,938	53.89990	53.89990	26S.7W.26.22412
47	17	4,027.7	4,018	9.69971	9.69971	28S.8W.2.11312
47	18	4,026.2	4,035	-8.80029	8.80029	27S.8W.25.340
47	21	4,002.0	3,941	61.00000	61.00000	27S.7W.17.44441
47	30	3,996.5	3,924	72.50000	72.50000	26S.6W.24.11113
48	15	4,000.1	4,021	-20.90039	20.90039	28S.8W.9.41222
49	15	3,982.1	3,999	-16.90039	16.90039	28S.8W.25.31111
49	17	3,979.3	3,973	6.29980	6.29980	28S.7W.19.13334
49	18	3,977.2	3,991	-13.80029	13.80029	28S.7W.7.41221
50	10	4,052.0	4,004	48.00000	48.00000	29S.8W.18.231
50	11	4,046.5	3,990	56.50000	56.50000	29S.8W.17.231
50	12	4,027.8	4,009	18.79980	18.79980	29S.8W.9.41111A
50	13	4,001.0	3,991	10.00000	10.00000	29S.8W.11.11313
50	16	3,960.0	3,971	-11.00000	11.00000	28S.7W.30.311
50	19	3,947.6	3,969	-21.40039	21.40039	28S.7W.21.2113
50	21	3,945.7	3,916	29.69971	29.69971	28S.7W.11.24444
50	29	3,960.1	3,923	37.09961	37.09961	27S.5W.7.44431
50	32	4,010.3	3,995	15.29980	15.29980	27S.5W.2.2222
51	14	3,953.6	3,990	-36.40039	36.40039	29S.8W.12.24444
51	14	3,953.6	3,991	-37.40039	37.40039	29S.8W.13.111
51	15	3,947.4	3,991	-43.60010	43.60010	29S.7W.7.43333
51	24	3,936.2	3,903	33.19971	33.19971	28S.6W.10.31143
52	19	3,918.8	3,901	17.79980	17.79980	29S.7W.12.2222

Table 11.–Estimated and simulated predevelopment ground-water budgets for the bolson-fill aquifer in the Mimbres Basin

[All values rounded, in acre-feet per year]

Inflow	Measured or estimated rate	Simulated rate
Mountain-front recharge:		
Net, upstream from Faywood[1]	20,400	8,000
Downstream from Faywood, north of section A-A′ on plate 2	20,000	14,300
South of section A-A′, north of Mexico-United States border	6,100	3,900
South of the Mexico-United States border	4,000	1,600
Infiltration from Mimbres River downstream from Faywood	10,100	9,900
Infiltration from Apache Tejo Spring	2,200	2,200
Underflow from Mangas Trench and Palomas Basin	8,400	100
Total inflow	71,200	40,000
Evapotranspiration		
Upstream from Faywood	3,400	4,200
From Florida Lake	700	700
Downstream from Faywood except playa lakes in Mexico	42,000	33,800
Playa lakes in Mexico	28,000	[2]1,300
Underflow near Mason Draw	500	0
Total outflow	74,600	40,000

[1]Net estimated mountain-front recharge upstream from Faywood is mountain-front recharge minus discharge to baseflow of the Mimbres River, or 25,200 minus 4,800 acre-feet (table 6).

[2]Includes net discharge simulated by the constant-head nodes and evapotranspiration simulated in blocks: row 52, columns 13-15; row 53, columns 17-19; row 54, columns 15-17 and 20; and row 55, columns 26-29.

Table 12.--Comparison of estimated and simulated total ground-water withdrawals from the bolson-fill aquifer in the Mimbres Basin

[--, no data]

Pumping period	Total withdrawals[1] by administrative block, in cubic feet per second	Total withdrawals in current model, in cubic feet per second	Difference in total withdrawals, in cubic feet per second
1931-35	14.14	13.06	1.08
1936-40	22.10	20.88	1.22
1941-45	44.19	41.14	3.05
1946-50	63.70	60.61	3.09
1951-55	90.37	85.05	5.32
1956-60	100.80	96.71	4.09
1961-65	127.80	123.22	4.58
1966-70	111.86	107.54	4.32
1971-75	164.47	158.79	5.68
1976-80	--	149.90	--
1981-85	--	97.10	--

[1]The ground-water depletion data compiled by the New Mexico State Engineer Office in administrative blocks aligned with the New Mexico township-and-range coordinate system. Each administrative block is equivalent to four sections (4 square miles).

Table 13.--Measured and simulated water-level declines, 1935-85, in the bolson-fill aquifer in the Mimbres Basin

Area	Cumulative measured decline (feet)	Cumulative simulated decline (feet)	Average error (feet)	Average absolute error (feet)	Absolute error (percent)	Average cumulative error (feet)
Upper San Vicente Arroyo	19.4	20.4	-1.8	4.4	23	-0.9
Columbus area	44.7	44.8	-0.7	13.0	29	-0.1
Tres Hermanas area	34.2	33.7	1.3	6.3	18	0.5
Deming area	20.8	21.0	-0.2	3.0	14	-0.2
Eastern extension[1]	12.0	12.1	-0.9	3.1	26	-0.2
Red Mountain area	22.6	22.1	-0.8	3.9	17	0.5
Mimbres Basin	22.6	22.4	-0.2	4.5	20	0.1

[1]Area east of the Florida Mountains.

Table 14.--Calculated consumptive use of ground water in the Mimbres Basin, 1931-85

[All values rounded; data from New Mexico State Engineer Office]

Date	Consumptive use, in acre-feet per year
1931-35	9,500
1936-40	15,100
1941-45	29,800
1946-50	43,900
1951-55	61,600
1956-60	70,000
1961-65	89,200
1966-70	77,900
1971-75	115,000
1976-80	108,500
1981-85	70,300

Table 15.--Simulated water budget for the bolson-fill aquifer in the Mimbres Basin

[All values in cubic feet per second]

Period	Predevelopment	[1]1931-35	[1]1971-75	[1]1981-85	[2]1931-85
In					
Storage	0.00	11.46	126.36	65.38	67.65
Constant head (playas in Mexico)	2.38	2.38	2.63	2.67	2.49
Recharge	55.13	55.13	55.13	55.13	55.13
Total in	57.51	68.98	184.12	123.18	125.27
Out					
Storage	0.00	0.68	0.32	2.95	0.86
Constant head (playas in Mexico)	4.13	4.13	3.36	3.35	3.79
Wells	[3]0.92	13.06	158.79	97.10	86.75
Evapotranspiration	52.51	51.13	21.65	19.84	33.94
Total out	57.56	68.99	184.12	123.25	125.34
Percent difference	-0.09	-0.02	0.00	-0.06	-0.05

[1]Final rates for period shown.
[2]Average rate for entire simulation.
[3]Represents evaporation from Florida Lake.