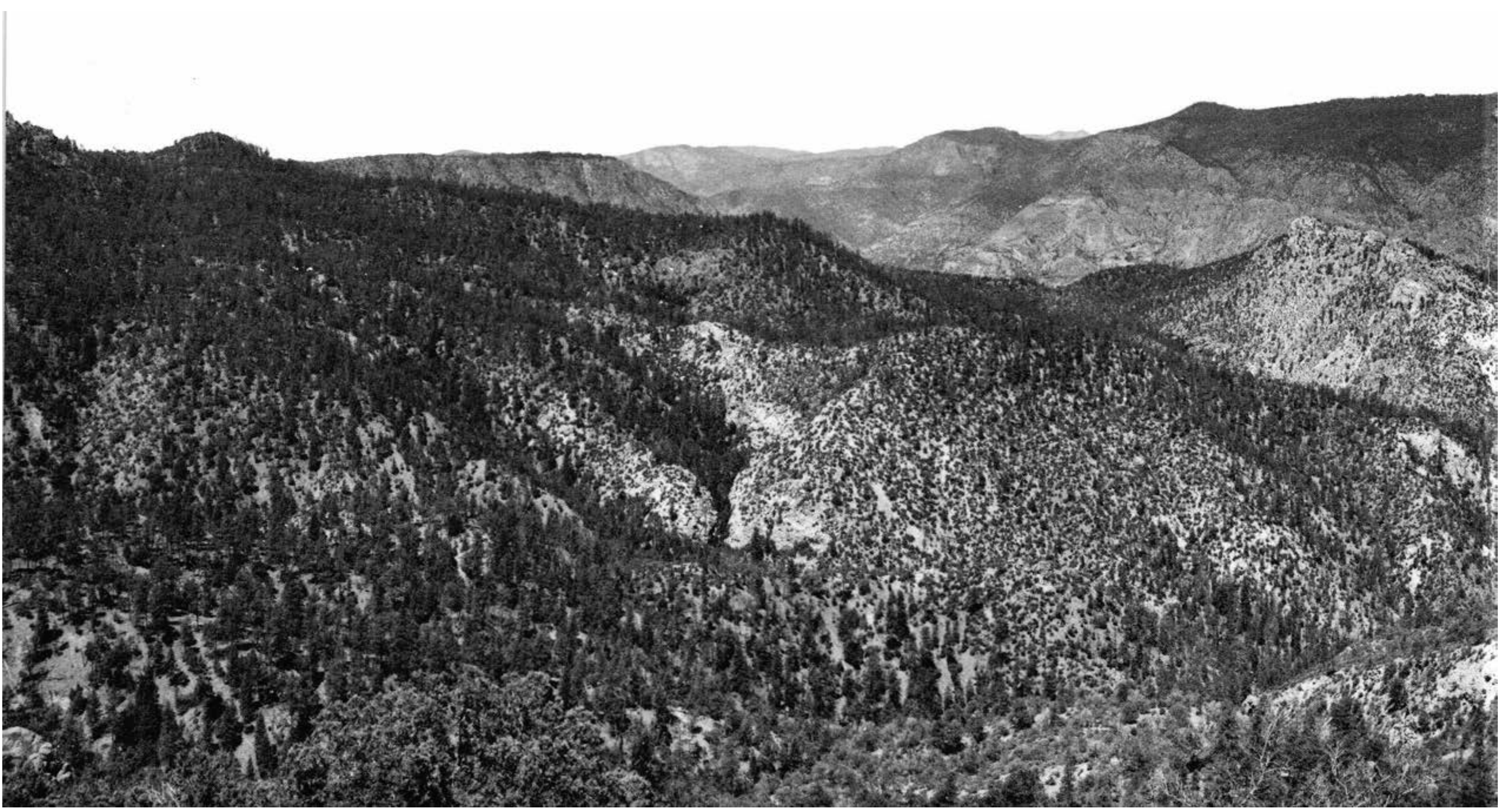
Water Resources and General Geology of Grant County, New Mexico

HYDROLOGIC REPORT 2 1972

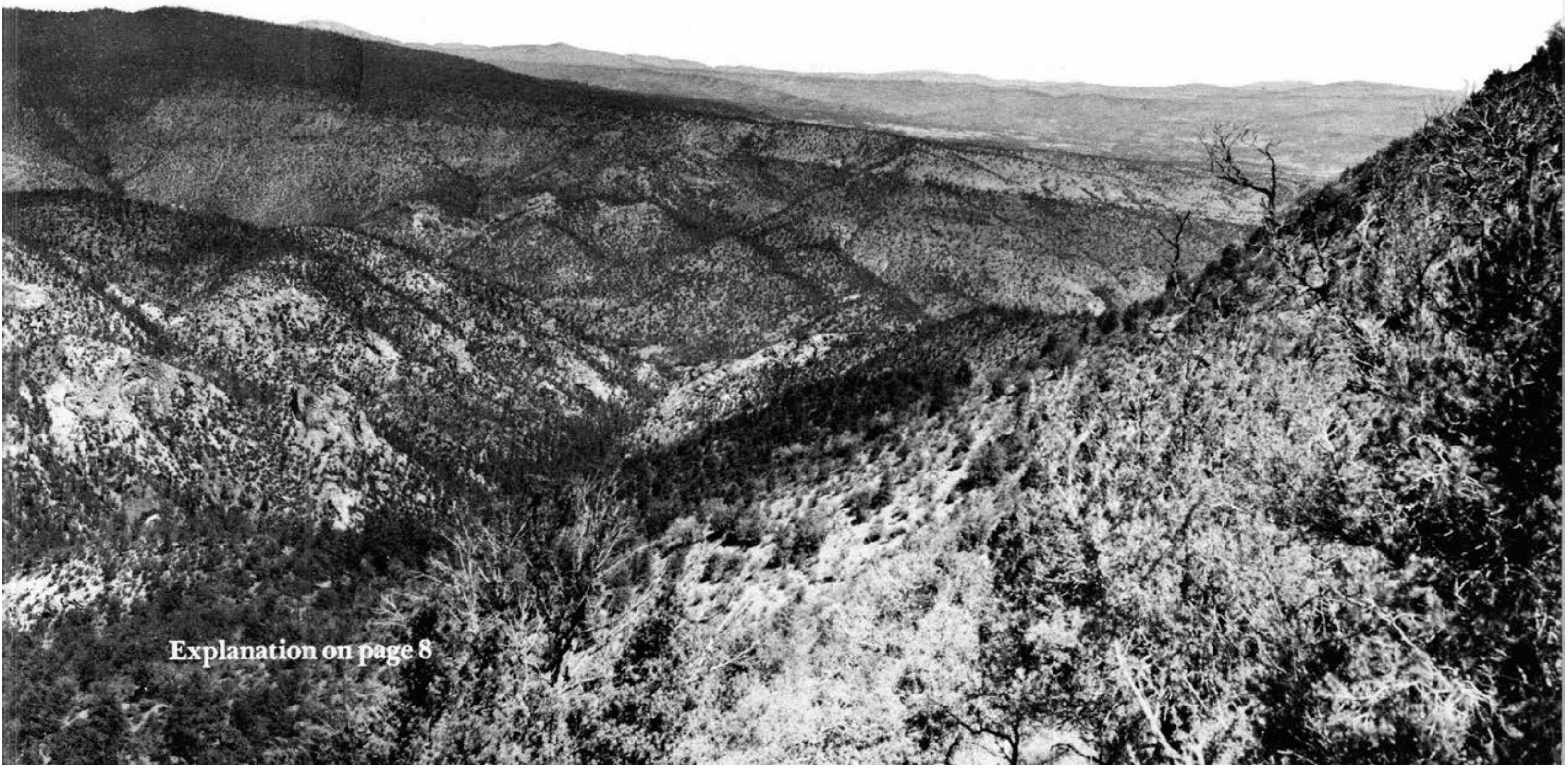
New Mexico State Bureau of Mines and Mineral Resources

Prepared in cooperation with:
The United States Geological Survey
The New Mexico State Engineer Office
The Grant County Commission



Water Resources and General Geology of Grant County, New Mexico

by F. D. Trauger
U.S. Geological Survey



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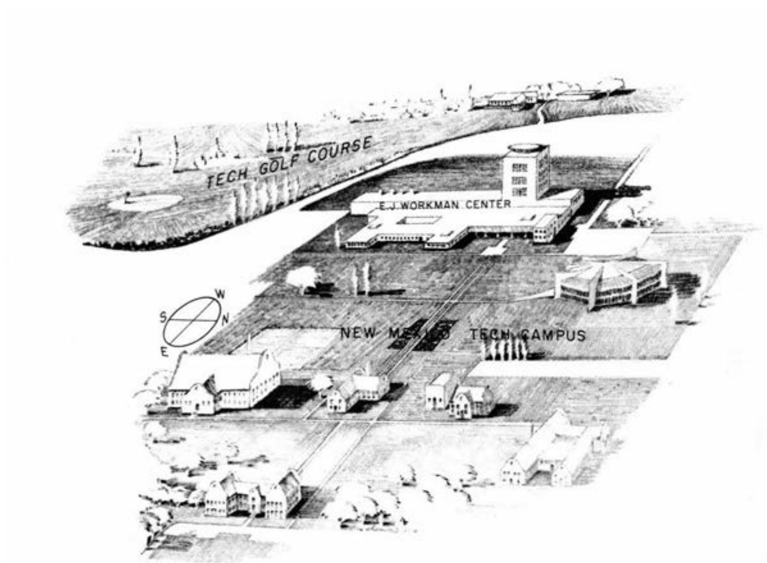

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Abstract

Grant County, in southwestern New Mexico, has an area of 3,970 square miles. The northern part is mountainous with peaks of about 10,000 feet. The southern part has bolson plains and isolated block-fault mountain ranges. The San Vicente basin, which contains a large body of ground water of good quality, is a northwestward extension of the bolson plains into the mountainous area. The principal cities are on the margins of this basin.

Climatic records from 1868 through 1970 show rhythmic, but not cyclic, variations in precipitation. The shape of the cumulative departure curve may indicate that the long period of below-average precipitation that began about 1945 may be drawing to a close.

The geologic structure is complex and involves the transition from Colorado Plateau structures in the north to Basin and Range structures in the south. The highland areas of the north are part of a plateau that has been broken into blocks by faulting. The principal fault zone comprises the Duck Creek-Mangas Creek-San Vicente Arroyo structural lowland. Total displacement along the east side of the zone may be as much as 15,000 feet.

Rock formations range in age from Precambrian to Holocene and include intrusive and volcanic igneous rocks, marine sediments, and continental deposits. The oldest rocks are schist, gneiss, greenstone, and granite of Precambrian age. Wells completed in granitic and metamorphic rocks yield from less than one-tenth gallon per minute to as much as 15 gallons per minute. Marine sedimentary rocks of Paleozoic and Cretaceous age attain thicknesses of 2,300 feet locally in central Grant County. The total thickness in the southern part of the county may be about 16,000 feet; all the marine sediments are of Cretaceous age. In the marine sediments, limestone units are most likely to yield water, with yields to wells from a few gallons per minute to several hundred. The marine shales and sandstones are not good aquifers, yields to wells being small. Volcanic and intrusive rocks ranging in age from Cretaceous through Holocene underlie a large part of the county. The intrusive rocks of Cretaceous and Tertiary-Cretaceous age commonly are associated with rich ore deposits.

The sequence of volcanic rocks and interbedded sediments of Tertiary age and of Quaternary-Tertiary age underlying the northeastern and northwestern highlands may be as much as 10,000 feet thick. Most of the volcanic rocks yield only small quantities of water towells. Welded tuffs form confining beds. Unconsolidated sediments interbedded with the pyroclastic and flow rocks may yield large amounts of water to wells locally. The most widespread continental sedimentary deposit is the Gila Conglomerate which consists mostly of fanglomerates, poorly-sorted conglomerates, coarse sandstones, and fine-grained sediments deposited in lakes; basalt flows are interbedded with conglomerates and sandstones locally. The total thickness may exceed 2,000 feet. Two major divisions of the Gila are recognized—a lower part, strongly indurated and locally deformed, that furnishes very little water to wells; and an upper part, generally undeformed and no more than slightly consolidated, that will yield as much as 500 or more gallons per minute to wells.

Sedimentary rocks of Quaternary age occur as terrace deposits along the streams and as alluvial fill in river valleys and bolsons. The river-valley deposits are not thick or extensive but irrigation wells yield as much as 2,500 gallons per minute.

The bolson deposits fill the broad basins such as Lordsburg and Hachita Valleys, and the San Vicente basin. Thicknesses are 1,600 feet locally, and may be more. Irrigation and industrial wells have yields ranging from 100 to 1, 500 gallons per minute.

The transmissivity of the upper Gila Conglomerate averages about 1,600 ft^2/day and the storage coefficient is about 0.04; the coefficients for the bolsonfill average about 4,000 and 0. 2, respectively. Water levels in the upper part of the Gila would be likely to drop below economic pumping levels before pumping would appreciably affect levels 4 to 5 miles away; the same is true of wells tapping the bolson fill.

Chemical quality of water generally is good. Ground water mostly is moderately hard to hard-60 to over 120 milligrams per liter of calcium and magnesium—but low in chloride, sulfate, and nitrate, and free of odor and color. Fluoride is present in amounts greater than 1.5 milligrams per liter in some ground and surface waters. Surface water generally contains about the same, or slightly more, dissolved solids than ground water.

The three principal mine and smelter operations in 1962 used approximately 10, 500 acre-feet of water, mostly ground water. Communities having public water-supply systems used a total of 1,640 acre-feet in 1965, all ground water. Water levels are declining rapidly in some municipal well fields, and slowly in other municipal well fields and the principal industrial well fields. All communities must either expand their present well fields or find new supplies within 5 to 15 years.

Adequate water supplies for existing and probable growth needs of communities and mining industries are available in the upper part of the Gila Conglomerate and in the bolson fill within 10 to 20 miles where needed. These supplies can be developed with little detriment to presently developed municipal, industrial, or agricultural supplies.

The report includes descriptive records of 1, 724 wells, test holes, and shafts, 45 springs or spring groups, driller's logs of 60 wells, chemical analyses of 224 samples of ground and surface water, a summary of streamflow records, water-level records of selected wells, and geologic and hydrologic maps.

Frontispiece—Gila River: The view is north toward the Gila Wilderness from a point on State Highway 15, downstream from the confluence of the West and East Forks of the Gila River. The bend in the river at the left side of the photograph is the approximate site of the gaging station operated from 1912 to 1919. Lower part of Gila Conglomerate (QTg) of late Tertiary age overlies basaltic andesite (Tba) of middle(?) Tertiary to Late Tertiary age; neither formation yields more than small amounts of water to wells.

Introduction

Grant County, an area of 3,970 square miles, lies between lat 31 51'45" to 33 12'30" N. ; long 107 40' to 109 03' W. in the southwestern part of New Mexico (fig. 1). The county extends westward from the crest of the Black Range to the Arizona- New Mexico State line and southward from the Mogollon Mountains almost to the Mexican border.

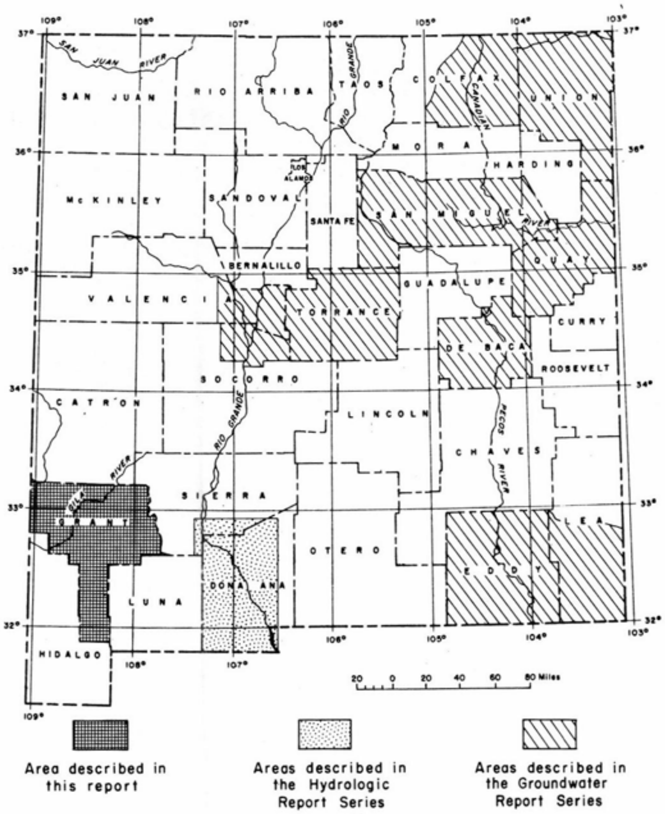


Figure 1—Index map showing areas described in water resources reports of New Mexico State Bureau of Mines and Mineral Resources.

Increasing demands for water and continuing drought conditions resulted in an acute shortage of water in most of Grant County in the early 1950's. The town of Central could not use a new distribution system because the municipal wells failed to yield enough water. Silver City was forced to ration water because of a steady decline of yields and water levels in wells in the Franks Ranch well field. Rural, domestic, and stock wells failed in many localities. Supplies of surface water for irrigation along the Gila and Mimbres Rivers were extremely short. Metal mining in the Santa Rita area was threatened with curtailment of normal development and expansionbecause of the prospects of a shortage of water.

The Grant County Commission, as a result of these conditions, in 1953 entered into a cooperative agreement with the U. S. Geological Survey to make a qualitative study of the ground-water resources of the county. New supplies of water for several communities were developed as an early result of the study. The County Commission withdrew from the program in 1956, at which time the New Mexico State Engineer and the New Mexico Bureau of Mines and Mineral Resources joined in the cooperation. Precipitation was only slightly below normal during 1956-63, with the result that cooperative activity on the study was greatly curtailed. The study was intensified in 1967 when recurring drought, an expansion of mining activities, and a sharp increase in urban populations focused attention on the need to develop additional supplies of water.

The principal objectives of the investigation were to: 1) collect basic data onthe occurrence of ground water in Grant County; 2) determine the general relation of streamflow and ground water; 3) relate the occurrence of ground water to the geology of the region and determine the principal aquifers; 4) determine the general chemical character of ground water available for development; 5) study present surface-water and ground-water development, appraise the potential for increased use of ground water for agricultural and industrial use, suggest areas of potential development and other ways of meeting water-supply problems; and 6) determine the availability of ground water for urban use and assist communities in locating ground water for immediate development.

The investigation included locating and describing most of the stock and rural domestic wells, and all industrial, irrigation, and municipal supply wells. The depths of the wells and the depths to water were measured where possible. Most of the larger springs, and many smaller ones, were visited and described. Water for chemical analyses was collected throughout the county from wells, springs, and mines. Radiochemical analyses were made of water from selected wells and springs. Most of the field work was done between March 1954 and April 1956; collection of basic data continued thereafter.

Rock formations were examined throughout the county and their water-bearing characteristics noted. Logs of wells were obtained from drillers and owners when possible. Geologic maps of various parts of the county and adjacent areas were examined and a geologic map of the county was compiled (fig. 2, in pocket).

An observation well net was established and measurements were made periodically to determine the pattern of fluctuation of water levels in the principal aquifers. Aquifer performance (pumping) tests were made for several wells and yields and drawdowns were measured at other wells where possible. A water-level contour map (fig. 3, in pocket) was prepared as fieldwork progressed in the developed areas, during 1954-57.

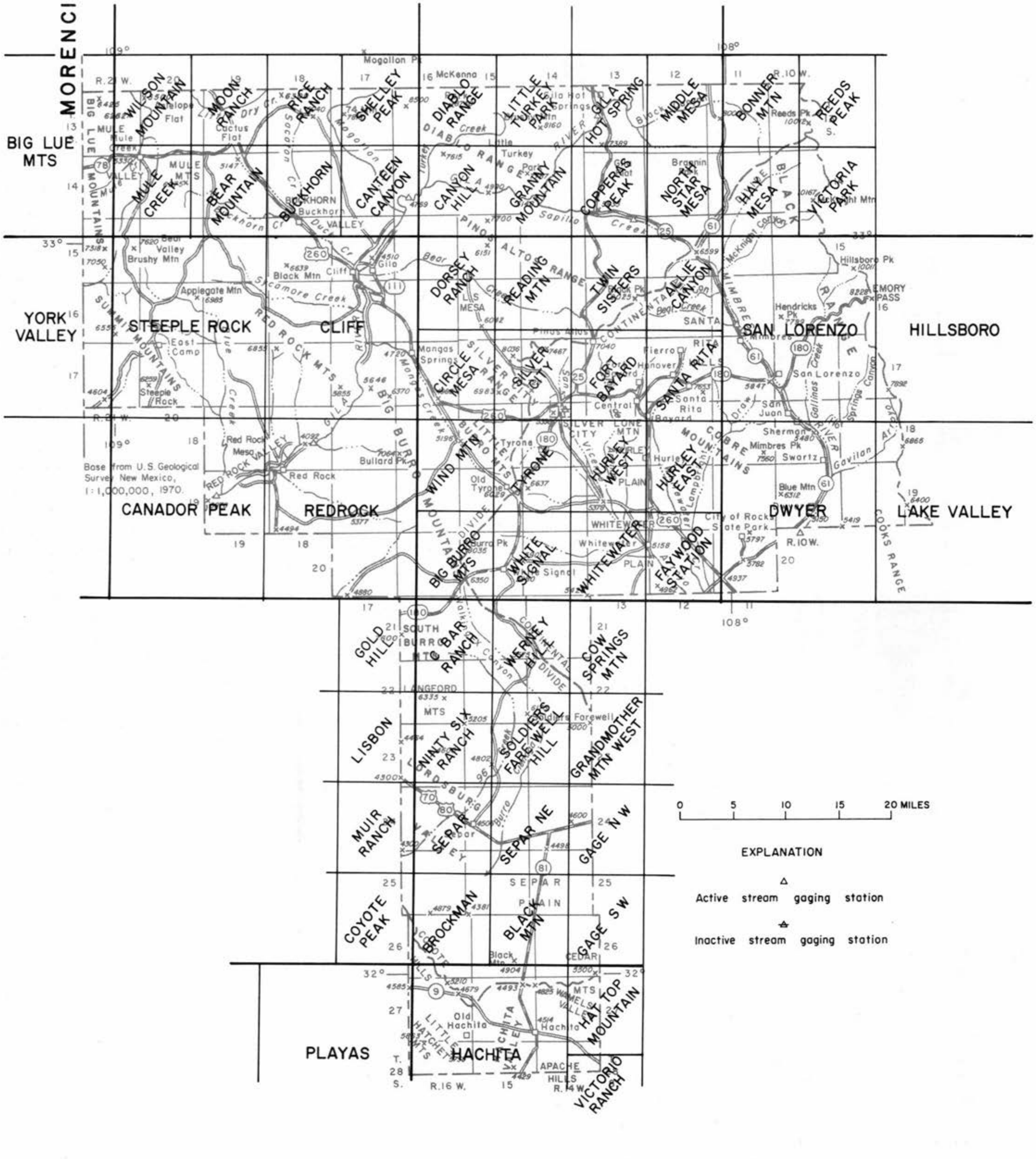


Figure 4—Index map showing available topographic maps.

Topographic maps (fig. 4) of the U. S. Geological Survey with scales ranging from 1 : 24, 000 to 1 : 125,000 were available for part of the county during fieldwork and were used as base maps for collection and plotting of data. A Soil Conservation Service field map was used in conjunction with uncontrolled aerial photograph mosaics for work in the eastern part of the Lordsburg Valley and adjacent areas not mapped topographically. Topographic maps, later available, were used to check previously determined locations. Controlled aerial mosaic photographs available for the northern part of the county were used in modifying geologic maps used for compilation, for determining well locations not shown on maps, and for estimating extent of vegetative cover in the river valleys.

PREVIOUS INVESTIGATIONS

References to the copper deposits of the Santa Rita area are found in Spanish records as early as 1804; also in 1807 notes made by the American explorer, Zebulon Pike, according to Spencer and Paige (1935, p. 5-11). Their report contains a summary of the history of mining in the Santa Rita area and gives a bibliography of the more important geologic and mining literature published up to 1935. References to other mining districts and incidental geologic notes are abundant in the literature since about 1860 when gold was discovered near Pinos Altos (Grafton, Lindgren, and Hill, in Lindgren, Gratton, and Gordon, 1910, p. 297). Darton (1928a) described "red beds" of the Abo Formation in Grant County and mapped (1928b) large areas not previously described in the literature.

The earliest detailed geologic mapping in the county was by Paige (1916) for the Silver City Folio. The copper deposits of the Tyrone area were mapped in detail by Paige (1922) a few years later. Lasky (1936) made a detailed study of the Bayard-Central area, and of the Little Hatchet Mountains (Lasky, 1947). These reports dealt mainly with the geology of ore deposits, but they included information on the occurrence of ground water that has been useful in the preparation of this report.

The first published ground-water study was made in the southern part of the county by Schwennesen and Hare (1918). The report discusses mainly areas that are now included in Hidalgo County, but it included Hachita Valley, still a part of Grant County. Some chemical analyses and well records in the report by Schwennesen and Hare have been used in this report.

White (1930) described infiltration and recharge in the Mimbres River channel and made estimates of infiltration rates based on stream-flow records. The validity of the estimates is subject to question because some of the flow records were later found to be seriously in error and the U. S. Geological Survey (1954c, p. 615-619) recommended they not be used.

Basic ground-water data for the Dwyer quadrangle were collected by Bushman (1955) in conjunctionwith geologic mapping by Elston (1957). No other hydrologic studies are known to have been made in the county.

The geologic map which accompanies this report is a compilation from published maps, none of which were used without some modifications. All principal sources of map information are indicated on the index map accompanying fig. 2, and lesser sources are included in the list of references for this report: Gillerman (1951, 1964); Gillerman and Whitebread (1956); Gillerman and others (1953); Jones and others (1963); Jones and others (1964); Lovering (1956); and Trauger (1960).

ACKNOWLEDGMENTS

The writer wishes to express appreciation to the many persons and organizations without whose cooperation this study could not have been made. He is especially indebted to the late Walter W. Woodward, to David Woodward, and to officials and employees of the towns of Silver City, Bayard, and Central, and the Kennecott Copper Corp. for help in the collection of basic data, to the well drillers who furnished logs and other data, and to Leedro Eby, C. C. Harkey, and A. V. Youngblood for their hospitality. The assistance of Frank Koopman, U. S. Geological Survey, in analyzing aquifer test data and determining hydrological coefficients is gratefully acknowledged. I. J. Winograd and Frank Collins collected basic data in the Separ-Hachita and Red-rock areas, respectively.

WELL-NUMBERING SYSTEM

The system of numbering wells and springs in this report is based on the Federal system of subdividing land into townships, ranges, and sections. The well number, which consists of four parts separated by periods, also indicates the location to the nearest 10-acre tract in the section. The first three parts represent, in reading order, the township south, the range west, and the section (fig. 5).

The fourth part of the number usually consists of three digits which indicate the 10-acre tract in which the well is located. The section is divided into quarters, quarter-quarters, etc. , and numbered 1, 2, 3, and 4 as indicated in fig. 5. The first digit of the fourth part of the well number gives the quarter section; the second digit gives the quarter-quarter, and the third digit designates the 10-acre tract. Thus well 14. 20.12. 342 is in the NE1/4SE1/4SW1/4 sec. 12, T. 14 S. , R. 20 W. Letters a, b, c, etc. , are added to the last part of the well number to designate the second, third, fourth, and succeeding wells listed in the same 10-acre tract.

The well numbers in tables 1, 2, and 3 are not given in full for each well. The wells are grouped

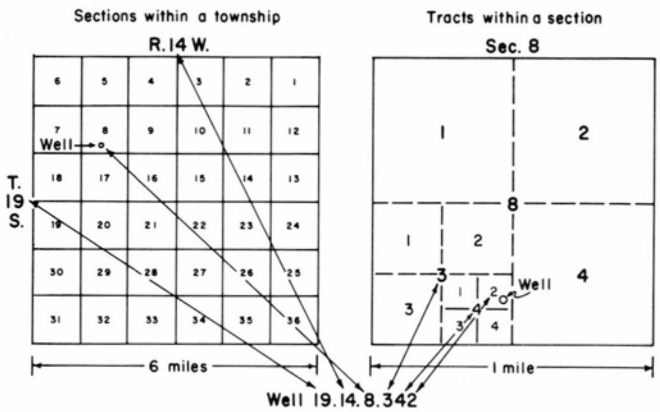


Figure 5—System of numbering wells and springs.

by townships and ranges for easier reading, and the full well number is used only for the first well in each township and range. The last two parts of the well number, showing the section and location in the section, are given for other wells in that township and range.

An asterisk (*) before the well number indicates that a chemical analysis is in table 14, and a dagger (t) indicates a driller's log is in table 15.

BASIC DATA, METHODS, AND DEFINITIONS

The basic data used to prepare this report were collected over a period of 14 years, during which time natural changes occurred that enhance the value of much of the earlier data and lend the weight of time to conclusions that, if supported only by single observations, would be less than convincing.

All basic data become more valuable with the passage of time because of the need for comparative material as both natural and economic changes take place. Basic data are the prime requisite for any planning that hopes to project successful courses of action relating to utilization and conservation of water resources. Thus, the longer the time for which climatic records, streamflow records, water-level records, population shift studies, and water-use records are available, the more accurate are the predictions that may be made using the accumulated records. In the final analysis, the only justification for collection of basic data, and scientific research in general, is to enable prediction. This fundamental concept emphasizes the need for continuing complete and accurate records of all aspects of water development and use.

Basic data presented in this report include: descriptive records of 1,724 wells, test holes, and shafts and 45 springs or spring groups; driller's logs of 60 wells; chemical analyses of 224 samples of ground and surface water; and water-level and flow records of selected wells and springs. The system used to designate the location of wells and springs is used also to designate the location of test holes, shafts, and sampling points on streams.

The owner listed was determined from county courthouse records as of November 1963. However, the year the well was drilled (table 12, column 3) and other miscellaneous data in the remarks column generally is that reported by the owner or tenant at the time of the visit.

The depths given for many wells are based on reports by owners or drillers because the depths could not be measured. The measured depth commonly represents the depth to which the well was drilled but in some wells caving may have taken place, and in others the sounding weight would not pass the pump cylinder.

Altitudes shown in the tables have been determined from topographic maps or by spirit level. Probable error is 5 feet or less in areas of low relief for which topographic maps are available; the probable error may exceed 20 feet in areas of high relief.

The stratigraphic water-bearing unit (aquifer) was determined by observation of outcrops, from well cuttings, or by interpretation from geologic maps. Only the principal water-bearing unit is indicated although water may be derived from two or more units. The principal aquifer for most wells is the geologic formation underlying the surface at the well site. The symbols used to designate the stratigraphic units are explained on the geologic map.

The chemical-analysis data in table 14 are for water collected from representative wells, springs, and streams throughout the county. Wells for sampling were selected to show the chemical character of the water in the principal aquifers in the various sections of the county. The significance of various constituents is shown in table 5 in the section on the quality of water.

Most of the samples were collected by personnel of the Geological Survey during the investigation. Some samples were collected during earlier investigations by personnel of other State and Federal agencies.

The question of quantity and quality arises in almost any discussion of water supply. References to quantity often are made in general terms such as "small," "moderate," "large," or "enough for house and stock. " References to quality commonly are made in terms such as "good, " "fair," "poor," "soft," and "hard." All these descriptive terms are relative and useful only if defined.

For the purposes of this report, the following values are assigned for use in general references to quantity: very small, a yield, discharge, or flow of less than 2 gpm; small, 2 to 20 gpm; moderate, 20 to 100 gpm; and large, over 100 gpm. A supply of 2 to 10 gpm is considered necessary for domestic and stock use, and supplies of 100 or more gpm are believed necessary for irrigation, depending on the scale of operations.

The terms used in this report to describe the quality of water are defined as follows: 1) "good quality" contains less than 200 mg/1 of dissolved solids and has a conductivity of less than about 300 micromhos; 2) "fair quality" contains 200 to 500 mg/1 of dissolved solids and has a conductivity of about 300 to 750 micromhos; 3) "poor quality" contains 500 to 1,000 mg/1 of dissolved solids and has a conductivity of about 750 to 1,300 micromhos.

The terms "soft" and "hard" commonly refer to the manner in which the water reacts with common soap or tends to deposit scale when boiled. "Hardness" is dependent upon the concentration of particular minerals and is discussed in detail in the section on quality of water. It may be noted here that the use of detergents in place of fat-derived soaps has removed much of the stigmafrom "hard water." The ability of detergents to lather is not affected by the minerals that cause "hardness," thus detergents are of no use in determining whether or not water is "soft" or "hard. "

Hardness under 100 mg/1 generally is not objectionable except for some industrial uses. Hardness of 200 to 300 mg/1 is noticeable and concentrations greater than 300 can be troublesome in many ways.

Definitions of hydrologic and related geologic terms are given in the glossary at the rear.

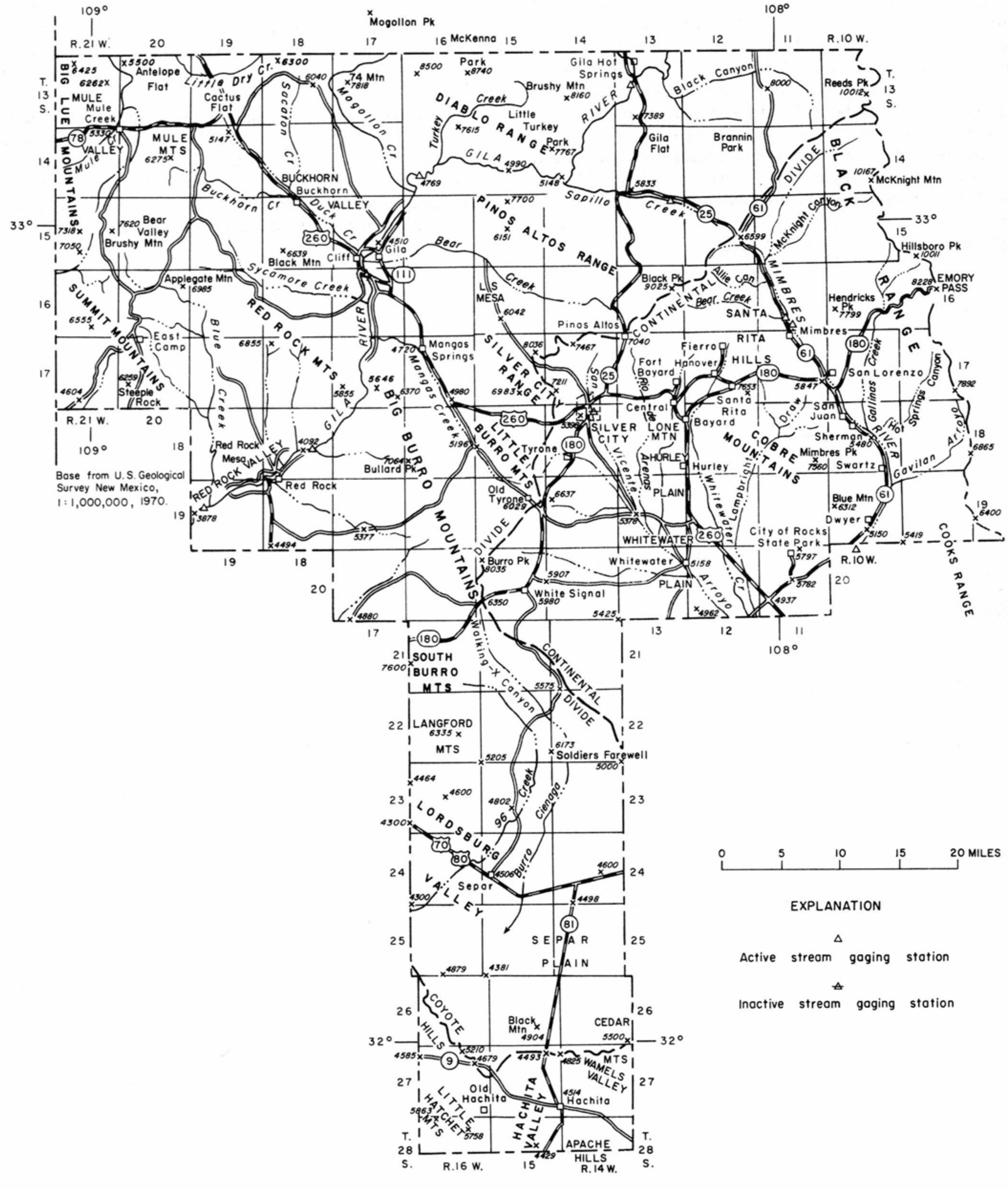


Figure 6—Index map showing places and features of reference.

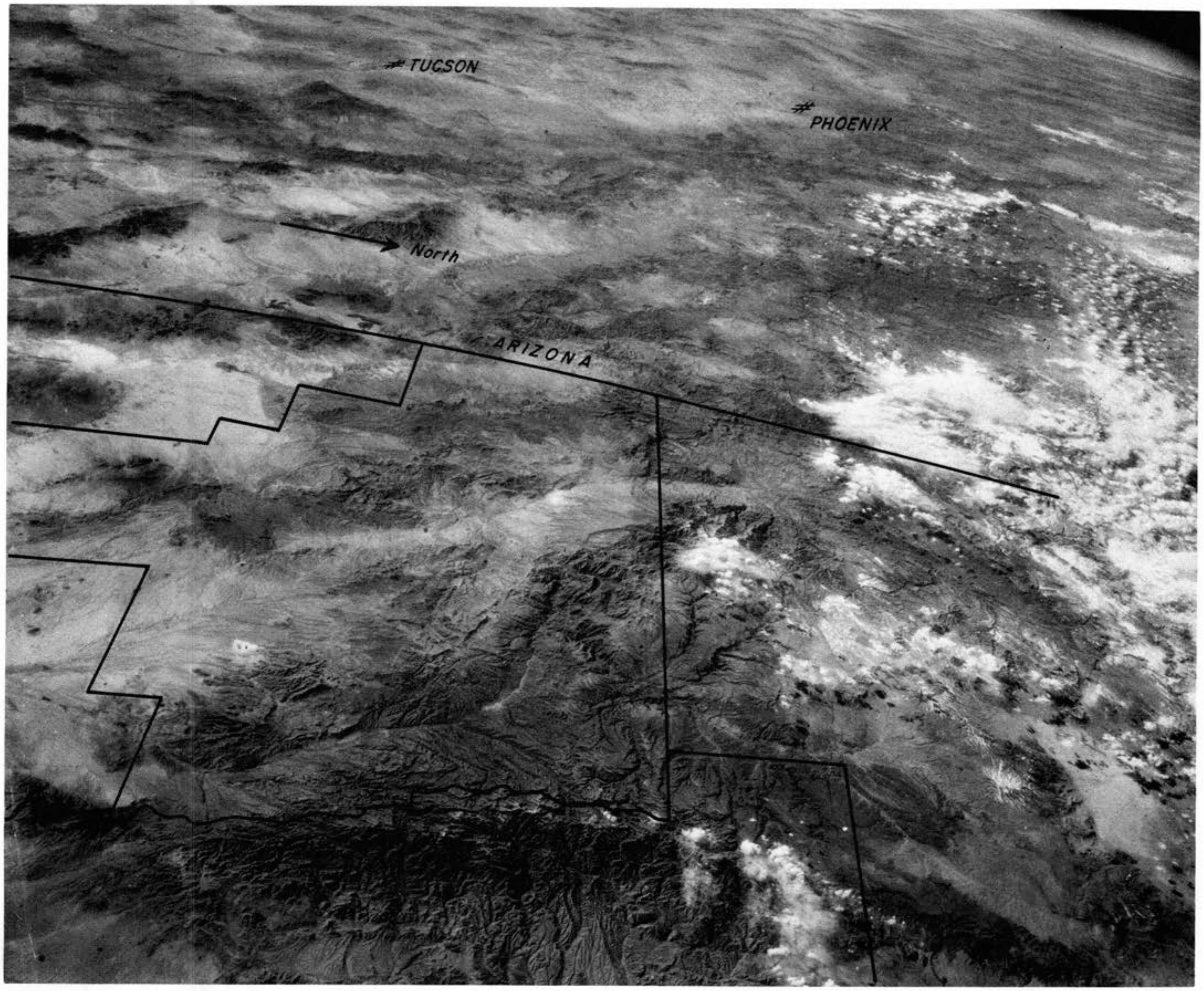


Figure 7–View of northern Grant County and adjacent areas from a Viking rocket launched from White Sands Missile Range; photographed from height of about 88 miles. The white patch in the lower left part of the photograph is the mine dump south of the Hurley smelter. It is the only manmade feature distinctly visible at this height. Pacific Ocean is on horizon in upper right corner. (Official U.S. Navy photograph, U.S. Naval Research Laboratory)

Geographic Setting

The physical geography of Grant County has determined to a large extent the type and degree of development that has taken place since mass settlement began about 1860. The forms of the land, and the natural endowments of minerals, climate, and water have been and will continue to be the principal factors determining development of the county.

TOPOGRAPHY

Grant County embraces wide reaches of plains, gently rolling to roughly sculptured hills, and magnificently rugged mountains. The Continental Divide, which separates drainage to the Pacific from drainage to the Atlantic, traces an irregular course from the northeast corner southwestward across the county. The principal topographic divisions, main drainages, and the locations of the principal communities are shown on fig. 6.

The northern two-thirds of the county, primarily an area of rugged highlands, is in the Datil section of the Colorado Plateau physiographic province as defined by Fenneman (1931, p. 278). The highlands are characterized by broad plateaus from which mountain ranges and isolated peaks rise to particular prominence. A pronounced structural lineament, the Mangas Trench, divides the highland into eastern and western components.

The southern panhandle, an area of plains and isolated mountain ranges, is in the Mexican Highland section of the Basin and Range province. Thus the topography provides sharp contrasts—the plains and valleys of the southern "lowlands" and the rugged mountains and plateaus of the northern highlands.

HIGHLAND AREAS

The crest of the Black Range, the southern part of which has at times been called the Mimbres Mountains, marks the easternboundary of both the county and the east component of the northern highlands (fig. 7). Altitudes of peaks along the crest of the range north of State Highway 180 are mostly above 9,000 feet; McKnight Mountain, at 10, 165 feet, is the highest point in the range. The Black Range is deeply canyoned and heavily forested at altitudes generally above 7,000 feet. The western slope of the range drops sharply to the valley of the Mimbres River where, at San Lorenzo, the altitude is about 5, 800 feet. The southern end of the range is at the county line. The Black Range extends northward beyond the northern boundary of the county.

The part of the eastern highland that lies west of the Black Range is characterized by rugged mountain ranges, isolated peaks, and deep canyons separated by well dissected forested plateaus and open

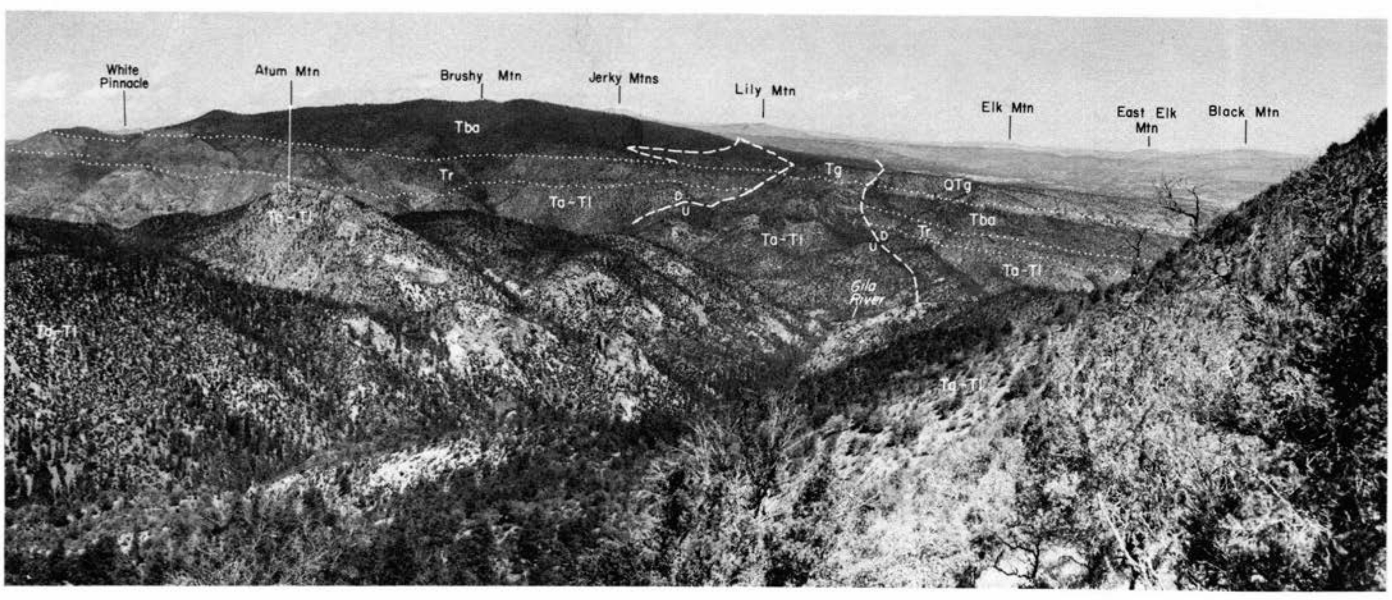


Figure 8—View of part of the northeastern highland; looking northwest into the Gila Wilderness area from State Highway 15, between Sapillo Creek and Gila Hot Springs. The Gila River flows from right through the deep canyon that lies between Alum and Brushy Mountains. Brushy Mountain, possibly a volcanic cone, is comprised of basalt (Tba) that overlies other volcanic rocks of middle Tertiary age (Ta, Tl, Tr). Alum Mountain is comprised of a hydrothermally altered andesite-latite sequence (Elston, 1968, p. 273). All rock formations dip into the Gila Sag—the basin-like lowland in the right distance—with dips ranging from 3° to 30°. Black Mountain is an andesitic-basaltic volcanic cone near the center of the sag. The Gila Conglomerate (QTg) was deposited in the sag, overlaps all the volcanic rocks of middle to early late Tertiary age, and is interbedded with basaltic rocks of late Tertiary age. None of the rocks in this upland area yield more than small quantities of water to wells.

"parks. "

The altitudes of the plateau areas average about 7,500 feet in the northeast and north-central part of the highland (fig. 8); the peaks and ridges rise generally to altitudes of 8,000 to 8, 500 feet. Toward the northwest, altitudes rise, the plateau areas become less prominent, the canyons deeper, and the terrain in general more wildly rugged. The maximum altitude of the eastern highland, 10,788 feet, is at Mogollon Peak, in Catron County, a few miles north of the Grant County line. This region comprises the greater part of the Gila Wilderness, the first area in the United States to be so designated when it was declared in 1924 by President Calvin Coolidge.

Southward, the plateau areas are progressively lower; the altitude of L S Mesa, north and west of Silver City, is about 6,000 feet.

Dissection of the plateau surface in the Cobre Mountains southeast of Bayard has left a series of even-crested, southward-sloping ridges that gradually become low hills, then merge with the White-water Plain at about the county line.

Altitudes of the western part of the northernhighland generally are lower; the relief, except along the western margin, is less abrupt than in the eastern highland. The altitude at Mule Creek, in Mule Valley, is about 5,330 feet; the highest point in the Mule Mountains, to the east, is about 6,275 feet. The terrain to the north, east, and west from Mule Creek rises rather gently to altitudes generally not more than 6,300 feet, and more commonly about 6,000 feet.

The terrain rises more steeply south and southwest from Mule Creek. About 9 miles south, at Brushy Mountain, the altitude is 7,620 feet, the highest point in the western highland. Altitudes of Tillie Hall and Yellow Jacket Peaks, west of Brushy Mountain, are 7, 319 and 7,050 feet, respectively. The eastern slopes of these peaks are relatively gentle

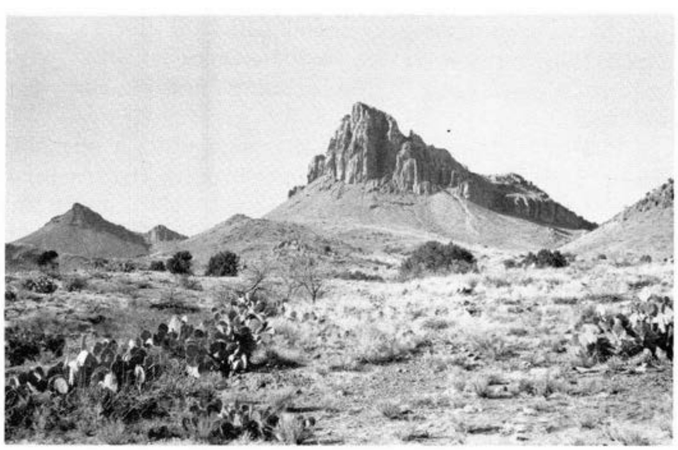


Figure 9—View of Steeple Rock, prominent landmark in western Grant County, at the south end of the Summit Mountains. The rock is a rhyolite tuff of the same age as the type Datil Formation. The tuff and underlying rocks, also of volcanic origin, yield only very small to small quantities of water.

and forested; the western slopes which are precipitous, rocky, and deeply canyoned, mark the western margin of the highland.

The altitude of the Summit Mountains south of Brushy Mountain is 6, 555 feet. The terrain slopes steeply southward from the Summit Mountains to an altitude of about 4,500 feet at the county line. Steeple Rock, an outlier south of the Summit Mountains, rises to an altitude of 6,259 feet, about 1,400 feet above the surrounding countryside; the peak is a prominent and historic landmark in the region (fig. 9).

Southeast from Brushy Mountain altitudes decrease to 5,855 feet at the south end of the Red Rock Mountains, from which the terrain slopes steeply to an altitude of 4,300 feet at the Gila River. The canyon cut by the river in this area is known as the Middle Gila Box. The terrain south of the Middle Gila Box regains an altitude of about 6,370 feet at Schoolhouse Mountain which is at the north end of the Big Burro Mountains.

The Big Burro Mountains are a southwestward extension of the northwestern highland; they form a mountain mass about 22 miles long and 4 to 12 miles wide.

Burro Peak, on the Continental Divide, and the highest point in the range, rises to 8,035 feet. In a distance of about 3 miles south from Burro Peak the altitude drops to about 6, 350 feet where State Highway 90 crosses the Continental Divide at the south end of the mountains.

The slopes of the Big Burro Mountains are not rocky or deeply canyoned and, except for the southern and northern ends, are relatively gentle. Pine forests cover the slopes at altitudes generally above 7, 500 feet; piñon and oak mantle the lower slopes.

The South Burro Mountains lie southwest of the Big Burros, and were erroneously called "Little Burro Mountains" in some earlier literature. They are the southernmost expression of the highlands, and are relatively low mountains having gentle slopes that rise to a maximum altitude of 7, 040 feet at Hornbrook Mountain.

The Little Burro Mountains lie to the northeast of the Big Burros—between the south end of the Big Burros and the Silver City Range. The Little Buroshave a steep western front that rises 500 to 1,100 feet above the Mangas Valley (fig. 10). The gentle, moderately eroded eastern slope merges with dissected bolson fill that lies between the Little Burros and the Silver City Range. Altitudes of peaks along the crest of the Little Burros are mostly between 6,247 (at Wind Mountain) at the north end of the range and 6,637 feet (at Tyrone Peak) at the south end of the range.

The Coyote Hills, and parts of the Little Hatchet Mountains, Cedar Mountains, and Apache Hills are located in the southernmost part of the county. These hills and mountains are block-fault ranges characterized by rocky ridges and peaks, barren of large vegetation, that rise starkly above the surrounding plains. A maximum altitude of 5,210 feet is attained

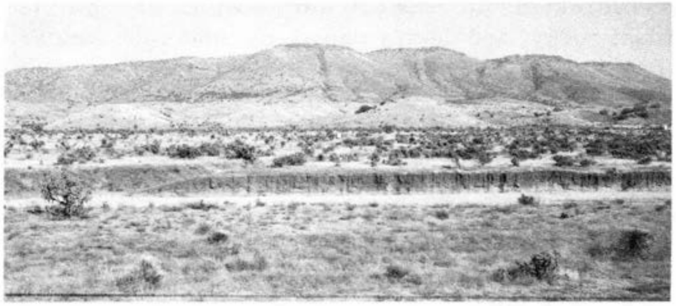


Figure 10—View of west front of the Little Burro Mountains, looking east across Mangas Valley. The rounded low hills stretching along the base of the range are cut in lakebeds and unconsolidated sand and gravel of the upper part of Gila Conglomerate, deposited after the last major uplift of the range. Alluvium of Holocene age underlies the valley floor. The channel banks in the foreground are from 6 to 8 feet high and have been cut in recent years. The white square is a recorder part of the shelter on well 18.15.31.234 which was finished in the upper Gila and yielded about 240 gpm when tested at a depth of 215 feet. Deepening to 400 feet reportedly did not improve the yield, according to the driller, but no further tests were made.

at the south end of the Coyote Hills; the altitude of the valley floor, less than a mile south of the crest, is about 4,650 feet. The Continental Divide follows the crest of the Coyote Hills northwesterly out of the county.

Only the north half of the Little Hatchet Mountains lies in Grant County. This part of the range is broad and generally low; outlying hills detached from the main mass are common and tongues of alluvial debris reach into the range from the surroundingbasin (Lasky, 1947, p. 8). Altitudes of peaks along the crest of Howell's Ridge are between 5,400 and 5,758 feet, and stand generally about 700 to 800 feet above the alluvial slopes along the base of the ridge. Hachita Peak, the highest point of the range at an altitude of 6,585 feet, lies 1-1/2 miles south of the Grant County line.

The northern foothills of the Apache Hills extend into the southeast corner of Grant County about 4 miles southeast of Hachita, but the main mass of the range lies south of the county.

The western end of the Cedar Mountains, a rocky, barren, northwest-trending range similar in appearance to the Little Hatchet Mountain, lies northwest of Hachita. The highest point in the Cedar Mountains in Grant County is at an altitude of about 5,500 feet; the highest point in the range is 6,217 feet at Flying W Mountain, 13 miles east of Hachita.

LOWLAND AREAS

About a third of Grant County's 3,970 square miles may be considered lowland. The principal lowland areas fall into two groups—long, relatively narrow valleys flanked by rugged highlands, and broad, irregularly shaped, basin-type plains commonly called bolsons. The lowland areas contain the largest reserves of available ground water in the county and are, therefore, of special importance to this study.

The Mimbres River and Sapillo Creek valleys, in the eastern part of the county, together form a lowland that trends northwest for a distance of about 40 miles and averages about 3 miles in width. The flood plains of the rivers in these two valleys range in width from less than a quarter of a mile to about 1 mile. Stream terraces generally border, and stand 10 to 50 feet above, the flood plains of the Mimbres and Sapillo and their larger tributaries.

The continuity of the Mimbres-Sapillo lowland is interrupted by no more than half a mile of hilly terrain forming a low divide which separates Gatton's Park (altitude about 6,500 feet) at the head of Sapillo Valley, from the valley floor of the West Fork of the Mimbres River. The Continental Divide crosses the lowland along this low divide.

A more or less continuous lowland follows the structural lineament that divides the northern highlands previously discussed. The principal components of this lowland are Duck Creek Valley, part of the Gila River Valley, and Mangas Valley. Lesser components of the lowland continue out of the county at the north end, and merge with the basin plains at the south end.

Duck Creek Valley slopes southward to a junction with the Gila Valley at Cliff. The Mangas Valley slopes northward and joins the Gila Valley about 7 miles south of Cliff. These valleys range in width from about 1/2 to 3 miles and, like the MimbresSapillo lowland, are bordered by low terraces and benchlands that extend the apparent width as much as a mile.

The Gila River crosses the western highland through a deep canyon—the Middle Gila Box—emerges at the northwest end of the Burro Mountains, then meanders for about 10 miles southwestward across a lowland locally termed Red Rock Valley. The valley is enclosed between steep slopes and cliffs of poorly to moderately well consolidated gravel. The flood plain of the valley ranges from 1/4 to 1-1/4 miles in width and it also is bordered by low terraces.

The gravel slopes and cliffs that rise along both sides of Red Rock Valley top out onto higher-level gravel plains at a distance of 1 to 4 miles north and south from the valley, and 400 to 600 feet above it. These plains were once a relatively smooth and continuous surface that sloped from the Summit and Red Rock Mountains to the basin plains that lie everywhere south of the highlands.

The broad sloping surface that extends south from the South Burro Mountains is a conspicuous feature as seen from U. S. Highway 70-80 (Interstate 10). The surface is, in part, underlainbybedrock at shallow depth, and in part by thick deposits of alluvial debris washed down from the mountains. Farther south, peaks of volcanic rock rise above the surface (fig. 11). The surface is gullied and furrowed by sheet-wash on the western side of the range, but is

Figure 11—View of the southern lowlands from the crest of Jacks Mountain at the south end of the Big Burro Mountains. The surface in the foreground and middle ground is underlain by granitic rocks of Precambrian age that yield only small amounts of water. The low hills just beyond the middle ground are formed of intrusive rocks of Tertiary age. The San Vicente basin, underlain by bolson fill, is visible as a light band between the low hills and the horizon.

not deeply dissected. However, on the east, it has been deeply trenched and the terrain is characterized by long, low, even-crested ridges separated by wide, flat-bottomed channels.

The slope of the surface flattens southward from the mountains. The gradient is about 300 feet per mile at most places near the foot of the range, decreases to about 150 feet per mile in the middle slopes between the mountains and the Lordsburg Valley, and is about 50 feet per mile in the vicinity of Separ on U. S. Highway 70-80 (Interstate 10).

The axis of Lordsburg Valley, a typical bolson about 10 to 12 miles wide, extends southeast across the panhandle of southern Grant County. The floor of the valley is a nearly featureless plain on which drainage lines are indistinct and discontinuous; alkali flats are common. The gradient of the axial drainage is about 5 to 10 feet per mile south of Separ. The area south and east of Separ is sometimes referred to as the "Separ Plain." The Continental Divide separates the Separ Plain from the Deming Basin to the east, and from the Hachita Valley to the south, but the terrain is so flat that the exact location of the divide in these areas has not been precisely determined.

Only the northern end of Hachita Valley lies in Grant County. The slope of the valley floor is south but the gradient is no more than 8 feet per mile in the distance between the Continental Divide and a point on the axis 1-1/2 miles west of Hachita.

The axial part of Hachita Valley in Grant County is about as flat as that of Lordsburg Valley but the areas of alkali flats are not present. The slopes from the axis of the valley up to the bordering mountains start more abruptly but are not as steep; gradients generally are between 75 and 100 feet per mile. The slopes are relatively smooth and have not been deeply gullied.

A broad lowland, here termed the San Vicente basin, extends northward into Grant County from the Mimbres Valley. This extension of the Mimbres Valley terminates against the Big Burro and Little Burro Mountains on the west, Silver City and Pinos Altos Ranges on the north, and the Cobre Mountains on the east. The slope of the terrain is from these mountains toward San Vicente Arroyo, an axial drainage whose lower course follows the structural lineament previously mentioned. The arroyo originates in the Pinos Altos Range and trends nearly south to the structural lineament, then southeast.

The surface of the San Vicente basin at some time in the geologic past was a relatively smooth plain mostly underlain by thick deposits of sand and gravel washed down from the surrounding highlands. Altitudes on this old plain, which is here named the San Vicente surface, were generally about 6,000 feet at the foot of the surrounding mountains, and were about 5,000 feet about 20 miles southeast of Silver City. That part of the San Vicente surface in the vicinity of Lone Mountain and the town of Bayard has been called the Bayard surface (Jones, 1953, p. 77), but the name, insofar as could be determined, was not meant by Jones to include all of the unconnected but genetically related surfaces of the lowland under discussion. The term San Vicente surface seems more appropriate for the broader concept.

The once smooth San Vicente surface is now furrowed and trenched by a multitude of sandy-bottomed dry washes and gullies that have largely destroyed the continuity of the old surface. Erosion has cut into the San Vicente surface as much as 200 feet around the margins of the basin where only small remnants of the original surface remain. The ridges are mostly sharp to rounded, and drainage lines are definite .

The dissection has been less intense at lower altitudes toward the central and southern part of the basin and east of San Vicente Arroyo where broad expanses of the San Vicente surface remain. The Silver City-Grant County Airport is on one of the remnants of the old surface which, from the airport north to Lone Mountain, is referred to as the Hurley Plain. This remnant surface, to the south, is called the Whitewater Plain.

The San Vicente basin is an important geographic subdivision of Grant County. It contains the principal towns and communities of the county but it is important also because it is underlain by an extensive reservoir of ground water which will yield moderate to large amounts of water to wells.

DRAINAGE

Most of the northern highlands of Grant County is drained by the Gila River. The headwaters of the Gila drain a large, roughly circular, topographic and structural basin of about 1,600 square miles, most of which lies north of Grant County. The confluence of the east and west forks is in Grant County, in sec. 8, T. 13 S., R. 13 W., and from that confluence the river takes a meandering, generally southwesterly, course across the county (frontispiece and fig. 8). The drainage area withinthe county is about 1,600 square miles.

The Gila flows mostly in deep canyons in the headwater areas and is perennial to a point about 4 miles northeast of Cliff (T. 15 S. , R. 17 W.) where large diversions for irrigation sometimes result in the channel downstream being dry during the growing season. The stream is perennial through the Middle Gila Box—from about sec. 16, T. 17 S. , R. 17 W. to sec. 23, T. 18 S., R. 18 W.—but the channel below the Box occasionally is dry in Red Rock Valley downstream from points where diversions are made.

The principal tributaries of the Gila River in Grant County are, in downstream order, Black Canyon, Sapillo, Turkey, Mogollon, Duck, Bear, Sycamore, Mangas, and Blue Creeks. Each of these tributaries is perennial in portions of its course and may be presumed to contribute underground flow to the Gila.

The Mimbres River drains approximately 460 square miles of the west slope of the Black Range and the eastern slopes of the Pinos Altos and Cobre Mountains in Grant County. The San Vicente Arroyo-Whitewater Creek drainage system, tributary to the Mimbres River south of the county line, drains the large lowland area (San Vicente basin) and adjacent slopes that lie between the Big Burro and Cobre Mountains—an area of about 390 square miles in Grant County.

The Mimbres River generally is perennial from just below the confluence with McKnight Canyon to San Lorenzo. Diversions for irrigation start near Mimbres, and the channel below San Lorenzo is dry much of the time.

Many of the larger tributaries of the Mimbres River, as of the Gila, have perennial flow in parts of their courses, and generally in the upper part rather than the lower. The lower parts of the tributary canyons are mostly broad and filled with alluvium into which the flow from the headwaters quickly disappears. The principal tributaries to the main stem of the Mimbres River in Grant County are McKnight Canyon, Allie Canyon, Bear Creek, Gallinas Creek, and Gavilan Creek. Of these, only Gallinas Creek has no perennial flow.

Legend says that a perennial creek once flowed approximately where San Vicente Arroyo now slashes through Silver City, and that Rio de Arenas, Cameron Creek, and Whitewater Creek, between Silver City and Santa Rita, were perennial in that area. These are now intermittent streams and if they were ever perennial it must have been prior to about 1885.

The San Francisco River does not flow through Grant County but drains the northwest corner through two tributaries, Mule Creek and Little Dry Creek. Little Dry Creek has no perennial flow, but Mule Creek is perennial through much of its course from a point about 3 miles north of the Mule Creek Post Office to its junction with the San Francisco River. The southern part of Grant County is drained by a nonintegrated system of washes and arroyos that descend from the various isolated hills and mountain ranges. Drainage that is tributary to Lordsburg Valley collects in an ill-defined axial channel known as Lordsburg Draw. The infrequent runoff flows northwest, swings around the north side of the town of Lordsburg in Hidalgo County, then flows southwest to South Alkali Lake in the Lower Animas Valley, which is a closed basin.

Walking X Canyon, which originates on the east side of the pass between the Big Burro and South Burro Mountains, is the only drainage of consequence that is tributary to Lordsburg Valley. There is a legend of perennial flow in the channel in T. 21 S. , R. 15 W. ; vestiges of orchards and old irrigation ditches at places along the banks tend to support the story.

Runoff tributary to Hachita Valley in Grant County is lost on the valley floor. Sharply definable, continuous channels are not well developed down the axis of the valley. However, runoff occurs generally once or twice a year during the summer rainy season. The road west from Hachita is not passable across the axis of the valley at these times until the generally short-lived flow subsides.

Flash-floods are common throughout the county during the summer rainy season and may be expected to occur at any place (fig. 12). The heaviest rainfall generally is over the higher ground, but the runoff may reach to the basin floors where no precipitation has fallen. The loss annually of a vehicle or two, and sometimes even a life, results when people prematurely attempt to drive across discharging arroyos. Vehicles become stalled and then may be swept down-channel if the flood rises still higher.

Figure 12—Floodflow in a normally dry wash crossing a road in Mangas Valley. The precipitation fell mainly on the Little Burro Mountains—the area depicted received only a brief shower. The water is about 3 feet deep below the base of the standing waves and the current could easily sweep a large vehicle from the road.

CLIMATE

Climate is a major element of the hydrology and ecology of any large area. Climate directly affects vegetation, soil, drainage characteristics, habitability, and, to a degree, the shape of the land (Trewartha, 1937, p. 3). Of the commonly measured elements of climate—precipitation, temperature, humidity, evaporation, and wind—precipitation is most important in hydrologic studies. All ground water and all stream runoff is derived from precipitation. How much precipitation falls, the distribution in time as well as space, and the factor of evaporation, controlled largely by temperature and wind, determine to a great extent the availability of water for use by living things.

Climatic data for this report have been taken from published and file records of the National Weather Service (formerly U. S. Weather Bureau), from New Mexico State Engineer Technical Reports (State Engineer, 1956a and 1956b), and from "The climate of New Mexico" (von Eschen, 1961). The State Engineer reports and the report by von Eschen were compiled mostly from records of the National Weather Service.

The climate of Grant County varies greatly but may be considered as essentially dry because in most areas evaporation exceeds precipitation. However, although most of the southern lowlands are arid, the northern highlands are locally humid. Some parts of Grant County are humid, but, as pointed out by Trewartha (1937, p. 358), the amount of precipitation alone is not sufficient data with which to determine whether a climate is arid, humid, or sub-humid. Evaporation, temperature, and seasonal distribution of precipitation determine the effectiveness of precipitation. The following rules-of-thumb will help identify climatic zones in Grant County: Perennial streams originate only in humid or sub-humid climates; the climate generally is considered humid where forests of spruce, fir, and aspen thrive; ponderosa pine is a characteristic vegetation type in subhumid climates; pinon, live oak, and juniper are common types of vegetation in semiarid climates; trees will not live in the arid climatic areas without supplemental watering.

The higher upland areas of Grant County are classified as humid because they support forests of spruce, fir, and aspen, generally have annual rainfalls of 18 inches or more (N. Mex. State Engineer, 1956a, p. 6), have average July temperatures less than 71. 5°F (22°C), and are the headwater areas for numerous perennial streams. Therefore, 18 inches of precipitation is considered here to mark the boundary between the humid and the subhumid to semiarid areas in Grant County.

The zones of subhumid climates in Grant County generally are bands that lie between the semiarid lowlands and the humid highlands. They are irregular in distribution and perhaps best characterized in Grant County bythe intermediate elevations where ponderosa pine are common.

The distinction between arid and semiarid is arbitrary but has been defined as one-half the amount of precipitation separating the semiarid from the humid (Koeppen, by Trewartha, 1937, p. 226). Thus the 9-inch isohyet (line of equal precipitation) distinguishes between arid and semiarid climates in Grant County.

The following quotation from von Eschen (1961, p. 61) concerning the climate of Silver City can be applied to similarly situated communities and areas of the county, with small allowances made for differences of a few hundred feet in altitude.

"—Because of the elevation, over a mile above sea level, summers are considerably cooler than at lower continental stations at this latitude. As a rule, midsummer maximum temperatures are in the 80s, with an average of only 27 days each year when the high temperature reaches or exceeds 90°. Readings of 100° are very rare. Rapid cooling after sundown, typical of higher mountain valleys, gives Silver City cool,, pleasant summer nights. Winters are characterized by moderatelywarm days, when shade temperatures during the warmest part of the day are near 50°. Averages show only two days in a normalwinter when the temperature fails to go above the freezing mark. Winter nights are generally cool, with freezing temperatures much of the time from early November through March. Readings below zero, however, have been recorded on only 18 days in the 28 years of record.

"Annual precipitation averages slightly above 15 inches—almost half of it falling in the July-September period. Practically all of this summer moisture is associated with brief afternoon and evening thundershowers and provides good grass in the surrounding area, where cattle and sheep graze the mountain ranges. Spring and fall are relatively dry. Only one or two days a month get as much as one-tenth inch of moisture. Winter precipitation is somewhat heavier, but only one day in 10 has one-tenth inch or more. Part of this winter precipitation falls as snow, with an occasional valley storm producing at least six inches. Snow usually melts rapidly because of the predominantly sunny weather and mild temperatures, although nearby mountains may remain snow covered most of the winter.

"There are no relative-humidity, sunshine, or wind records available for Silver City; so only a general statement on these elements is possible. Because of the lower temperatures, the relative humidity is somewhat higher than in the lower desert regions and probably averages near 55 percent for the year, ranging from about 75 percent in the cool early morning hours to 35 percent during the warmer part of the day and slightly lower during the drier spring and fall months. The sun shines approximately 70 percent of the possible hours, ranging up to near 80 percent in spring and fall. The city is well protected and experiences only light winds most of the time, but occasional velocities exceed 25 miles per hour in late winter and spring months. The growing season is approximately 180 days long, beginning with the average date of the last freeze in spring on April 27

Table 1--Monthly and annual mean of maximum and minimum air temperature, in degrees Fahrenheit, and the average monthly and annual precipitation, in inches, at selected stations in Grant County

Station and period of record[1]	Altitude (feet)	Temp. and Precip.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Bear Creek Rch. 1940-59	5,300	Max.													
		Min.													
		Precip.	1.11	1.11	1.18	0.62	0.22	0.59	2.29	3.29	1.31	1.14	0.56	0.90	14.32
Buckhorn 1940-60	4,900	Max.													
		Min.													
		Precip.	1.15	.83	.81	.59	.30	.57	2.38	2.71	1.52	1.05	.42	.82	13.15
Cliff, 10 mi.SE 1940-60	4,800	Max.	55.6	59.8	64.9	74.8	83.1	92.9	93.6	90.9	88.5	77.4	65.0	57.0	75.3
		Min.	21.4	23.0	28.1	35.3	41.6	52.2	59.8	58.2	49.5	39.4	25.6	21.3	38.0
		Precip.	.93	.70	.86	.33	.16	.50	2.51	2.84	1.04	1.24	.41	.64	12.16
Cureton Rch. 1940-60	5,200	Max.													
		Min.													
		Precip.	1.08	.83	.78	.31	20	.60	2.16	2.58	1.25	1.00	,53	.80	12.12
Ft. Bayard 1867-1960	6,152	Max.	51.9	55.3	60.1	68.4	76.6	86.5	86.4	84.4	80.4	71.1	60.3	52.5	69.5
		Min.	25.2	27.5	31.3	37.3	44.4	53.7	58.2	57.2	51.6	41.7	31.1	25.8	40.4
		Precip.	.85	.97	.75	.41	.40	.72	3.12	3.35	2.02	1.15	.71	.91	15.36
Gila, 6 mi. NE 1954-59	4,600	Max.	56.9	60.1	66.6	74.6	83.8	95.4	94.7	90.9	89.9	77.4	64.6	60.1	76.3
		Min.	24.7	25.8	29.8	36.5	40.2	52.1	59.4	57.9	47.3	40.3	24.7	22.9	38.5
		Precip.	.83	.94	.92	.50	.34	.32	3.04	2.94	1.22	1.63	.20	.50	13.38
Hachita 1934-60	4,504	Max.	55.8	61.6	68.0	76.9	85.0	94.4	94.2	91.5	87.8	77.5	65.8	58.4	76.4
		Min.	26.5	28.5	33.1	40.1	47.9	58.0	63.1	62.1	55.7	44.4	31.4	26.8	43.1
		Precip.	.47	.60	.53	.21	.17	.40	2.14	2.38	1.12	.88	.49	.71	10.10
Mimbres Ranger Station 1905-60	6,250	Max.	49.3	54.8	59.9	69.5	76.9	88.4	87.4	83.1	80.2	68.7	58.6	53.3	69.2
		Min.	19.3	23.7	25.4	30.8	36.9	49.3	54.1	53.8	45.4	36.9	24.3	21.0	35.0
		Precip.	1.15	1.05	.86	.52	.42	.97	3.45	3.29	1.98	1.20	.79	1.10	16.78
Pinos Altos 1911-60	7,000	Max.													
		Min.													
		Precip.	1.32	1.60	1.36	.73	.56	1.12	4.28	4.28	2.23	1.57	.80	1.47	21.32
Redrock 1905-64	4,150	Max.	57.1	62.8	68.1	79.0	87.7	96.3	96.1	91.8	88.1	79.5	67.1	59.1	77.7
		Min.	21.7	25.1	29.0	36.1	42.1	52.1	61.9	61.4	54.2	41.1	29.6	24.2	39.9
		Precip.	.61	.84	.70	.45	.25	.44	2.43	2.22	1.40	.91	.64	.93	11.82
Santa Rita[2] 1911-52	6,312	Mean Month Temp.	37.7	39.0	44.0	53.7	62.7	71.3	74.1	71.2	65.2	58.1	46.8	40.6	55.4
		Precip.	.85	1.06	.84	.52	.52	.99	3.65	3.65	2.33	1.26	.80	1.11	17.58
Silver City 1879-1960	5,937	Max.	48.9	53.0	58.1	66.8	75.9	86.3	86.7	84.7	80.4	69.8	58.3	50.5	68.3
		Min.	25.0	26.0	30.4	36.8	44.1	54.6	59.3	57.8	51.8	41.2	29.5	24.6	40.1
		Precip.	1.03	1.20	1.03	.57	.39	.72	3.09	3.30	1.84	1.32	.78	1.13	16.40
White Signal 1942-60	6,070	Max.													
		Min.													
		Precip.	1.49	1.07	.97	.40	.32	.86	2.47	2.21	1.32	.93	.35	.92	13.31
White Water 1945-60	5,150	Max.													
		Min.													
		Precip.	.64	.41	.61	.22	.21	.22	2.32	1.79	1.18	.84	.06	.28	8.78
Gila Hot Springs 1957-64	5,600	Max.	51.9	57.9	61.9	72.2	81.3	89.4	89.5	86.7	82.6	74.3	62.9	56.9	72.3
		Min.	15.6	19.5	22.9	29.7	35.0	43.7	53.6	53.3	45.6	34.5	24.4	18.7	33.0
		Precip.	.74	.57	.70	.62	.14	.56	2.64	2.72	2.03	1.44	.74	1.34	14.24

1/ Records are not necessarily continuous for the period indicated but are considered to be of sufficient duration to give a representative mean; temperature records at most stations are for appreciably shorter period than those for precipitation.

2/ Records kept by Kennecott Copper Corp.

and ending on October 24, the average date of the first freezing temperature in the fall. "

PRECIPITATION

Precipitation patterns in Grant County vary annually and the 9-inch isohyet shifts accordingly. All parts of Grant County may receive more than 9 inches of precipitation one year and the next year large areas may receive appreciably less than 9 inches. This unreliability of precipitation, common to arid and semiarid regions, makes necessary the careful accounting and management of water resources to support the ever-increasing population and industry.

The daily precipitation has been recorded at many places in Grant County for periods ranging from less than a year to more than 100 years. A summary of precipitation records in New Mexico (State Engineer, 1956b) includes the stations in Grant County at which data were collected in the period 1867-1954. These records, and subsequent data collected by the National Weather Service, show that the annual average precipitation ranges from about 8.8 inches at Whitewater to 21.3 inches at Pinos Altos (table 1).

Station records of precipitation in New Mexico go back only a little more than a century but the study of growth rings of certain species of trees has permitted approximations of earlier climatic conditions. Schulman (1956, p. 50) demonstrated a close correlation between rainfall and tree growth in the Gila River drainage basins for the period 1890 to 1950, and showed the validity of using tree ring growth to indicate general conditions of precipitation as early as the 1200's. Graphs drawn by Schulman (1956, p. 98) indicate that tree growth during the period 1825 to 1870 in the Colorado River basin, of which the Gila River is a part, generally was much greater than for the period since 1870, except for the relatively short period, 1910 to 1920.

The precipitation record at Fort Bayard, beginning in 1867 (fig. 13) includes a long period that has been unusually dry. It might be more realistic to consider the averages shown in table 1 and fig. 13 as representing "average drought" conditions. A report on drought conditions in southwestern United States published in 1951 stated that the current drought is considered to have begun in New Mexico and west Texas about 1943 (U. S. Department of Interior, 1951, p. 14), and Schulman (1956, p. 67) concluded that it is the most severe since that of the late 1200's. Precipitation continues to be much below normal—only 4 years of the 20 years since Schulman tabulated his data have had average or above-average rainfall.

Another interesting and significant result of Schulman's study was the discovery that, starting about 1635-40, an apparent tendency for swings of only 23 decades in length began and replaced the swings of many decades long (Schulman, 1956, p. 56). Rhythmic, though apparently not cyclic, swings show on the Fort Bayard records (fig. 13).

Both Schulman (1956, p. 63), and Tuan and Everard (1964, p. 295-297) stress the lack of evidence for any definite cyclic pattern. No pattern was found that would permit accurate long-range forecasting. However, their analyses and graphs do provide a basis for postulating trends. Thomas (1962, p. A40) pointed out that "some climatic fluctuations appear to have recurrence intervals sufficiently regular, and amplitudes sufficiently great, that they may be important considerations in long-range planning for water-resource development and utilization. "

The graph (fig. 13) showing the annual precipitation by water years (October through September), and the cumulative departure from average precipitation at Fort Bayard since 1867 indicates that a period of more abundant precipitation lasted from about 1874 to 1884, and that a period of generally scant precipitation began about 1885 and lasted until 1904. A comparison of the dry periods 1880 to 1904, and 1940 to 1971 on the graph shows similarities of pattern in duration and degree that suggest the present drought should be drawing to a close if the climatic pattern since 1868 is to continue.

An extended period of widely varying annual precipitation began about 1905 which was the wettest year of record. A similar period may be in prospect when the current drought breaks.

The effects of the generally below-average precipitation in the period 1886-96 probably were noticed immediately by those trying to dry-farm. Dry-farming would have been possible during the wet period 1874-84 but crop failures wouldhave been almost certain most of the years from 1886-1901 (fig. 13). However, the flow of perennial small streams and springs probably declined slowly during the late 1880's because reserves of ground water had built up and continued to feed the streams.

The settlers turned to wells for stock and domestic water as the small streams and springs eventually went dry. At first the wells were relatively shallow and mostly dug along the courses of former streams, but many of these wells soon went dry. Some of them may still be found, their dry bottoms many feet above the present level of water in nearby drilled wells (21. 15. 21. 341).

Drilled wells of small diameter and appreciable depth became increasingly practical as the windmill invaded the area. The windmill and piston pump was a timely device nearly as suited to this area as to the High Plains where it was first used extensively in this country. Irrigation wells were drilled later on the flood plains of the Gila and Mimbres Rivers to supplement the diminishing supplies of surface water.

TEMPERATURE

Temperature, as well as the amount of precipitation, is an important element of climate and is commonly a large factor in determining the desirability of an area for habitation. Areas having semiarid or

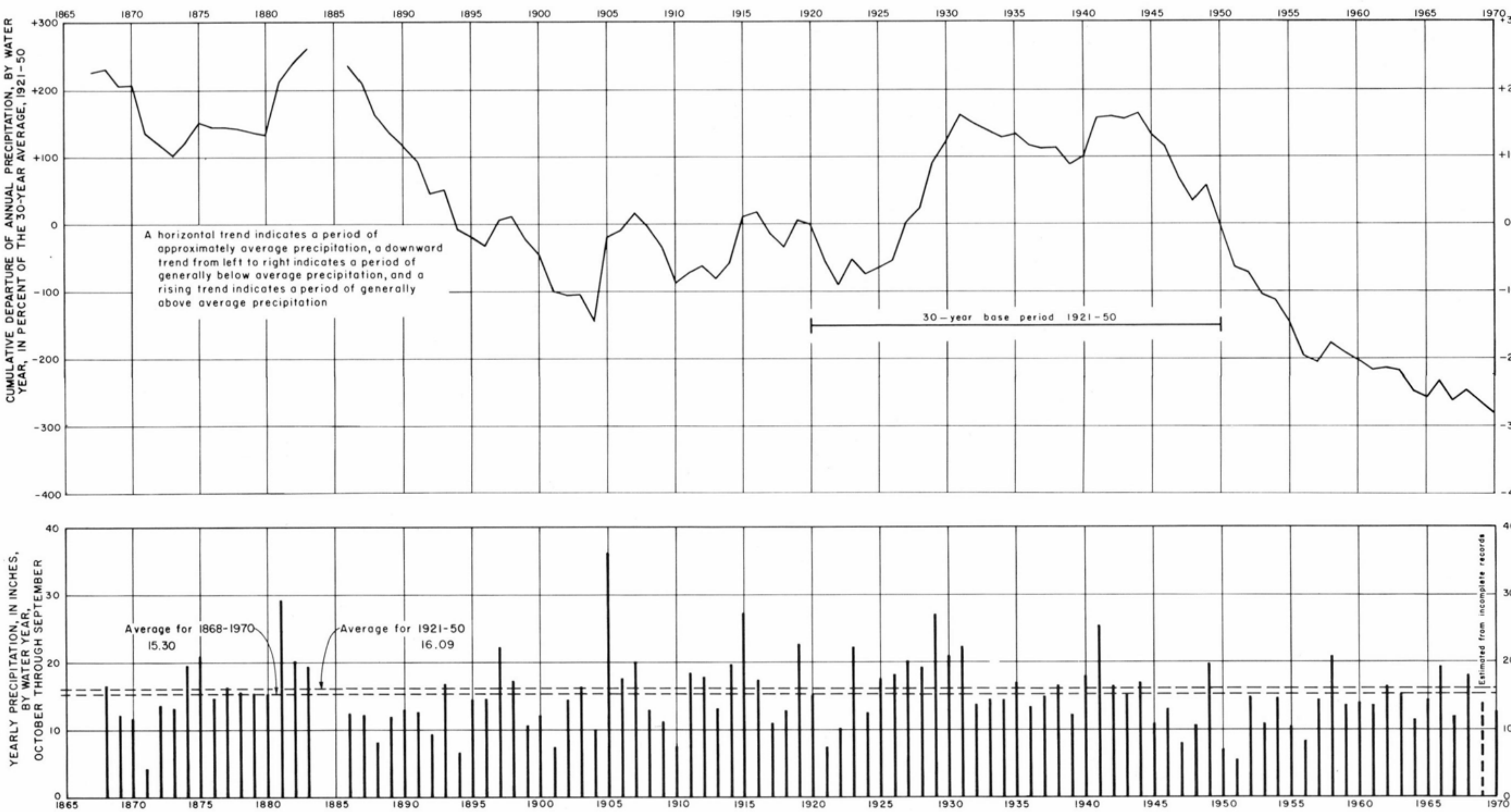


Figure 13 –Precipitation by water year (October through September) at Fort Bayard, and cumulative departure of annual precipitation from the average for the 30-year period 1921-50.

subhumid climates generally are pleasant places in which to live because the temperatures are neither searingly hot nor intensely cold, and the humidity generally is low.

The climate of the more populated areas of Grant County is semiarid, verging on subhumid, and the ranges in temperatures are moderate (table 1). At Silver City, for example, the annual average of maximum daily air temperature is 68. 3°F and the annual average minimum daily air temperature is 40. 1°F. The high temperature of record, 103°F, occurred July 12, 1958. A -13°F, the record low as of June, 1972, occurred on January 11, 1953. The mean temperatures at other locations in Grant County are given for comparison in table 1.

The climates of communities such as Pinos Altos, at appreciably higher altitudes than Silver City, differ mainly in having lower temperatures both in winter and summer, greater rainfall in the summer, and more snow in winter. Communities such as Hachita and Redrock, at lower altitudes, are warmer and drier.

EVAPORATION

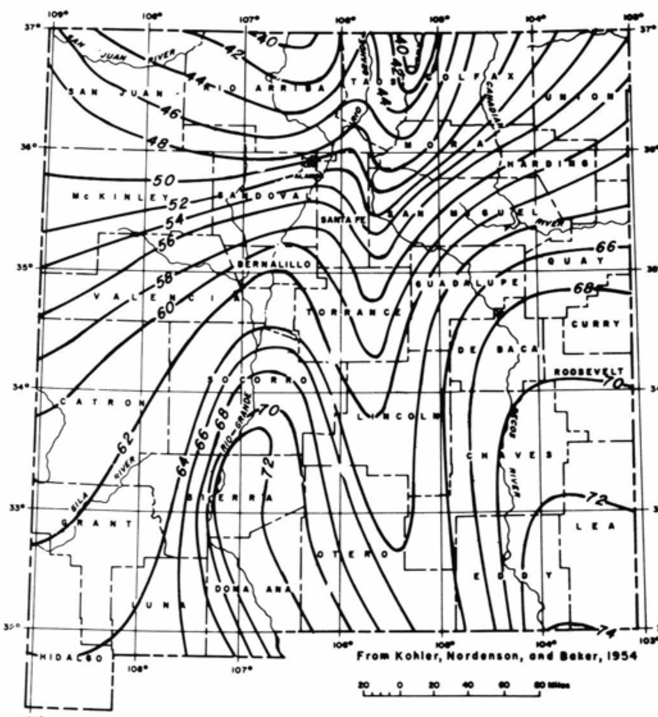
The loss of water to the atmosphere by processes of evaporation and transpiration (use by plantlife) becomes increasingly important with a decrease in annual precipitation. Plantlife can consume large quantities of water, especially along water courses such as the Gila and Mimbres Rivers, and evaporation can remove large quantities of water from streams, lakes, stock ponds, and the soil zone.

Transpiration losses measured in Safford Valley, Arizona show that a single cottonwood tree having a canopy 50 feet across maytranspire as much as 500 gallons per day (Gatewood, and others, 1950, p. 138). Saltcedar and willow also consume large quantities of water. Losses to evaporation from ponds and lakes in arid climates generally are large. An elevated Colorado-type evaporation pan was maintained continuouslyby personnel of Kennecott Copper Corp. at Santa Rita from about 1913 to 1947. The average monthly evaporation rate for the period of record as computed from monthly records in New Mexico State Engineer Technical Report 5, 1956, p. 268 is given below:

Average monthly evaporation in inches at Santa Rita, Grant County, New Mexico--altitude 6,312 feet; Special type land pan--3 feet square, Mounted on 10-foot platform

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
2.7	4.0	6.8	9.8	12.6	14.1	12.2	9.7	8.4	7.2	4.3	2.9	94.7

The standard Colorado-type pan usually is sunken and generally has larger losses than the standard Class "A" pan now used by the National Weather Service (U. S. Geological Survey, 1954a, p. 146). However, the annual loss indicated above is close to that indicated for the area by Kohler, Nordenson, and Baker (1959, plate 1). The elevated position of the pan at Santa Rita may have resulted in losses about the same as those from Class "A" pans. Dorroh (1946, p. 19) states that a factor of 0. 7 should be applied to most Class "A" pan data to approximate more nearlyevaporation loss from free water (ponds and lakes) surfaces. Losses from pond and lake surfaces in Grant County average about 64 inches annually (fig. 14). Generally, the smaller and shal-



EXPLANATION

Equal-loss lines showing estimated annual evaporation from lakes and reservoirs in New Mexico, in inches, for a 10-year period 1946-55; figures show gross or total evaporation, not adjusted for precipitation. Interval 2 inches; irregular where crowded.

Figure 14—Evaporation losses from open bodies of water in New Mexico.

lower the body of water, the greater are the losses by evaporation.

The loss of water by evaporation becomes impressive when stated quantitatively. Studies by Meyers (1962, p. 89) show that in the Gila River basin in New Mexico about 442 acres of small ponds and reservoirs lose about 2,260 acre-feet of water annually by evaporation, and that about 463 acres of stream and channel surfaces lose about 2,390 acre-feet annually. A stock pond having a surface area of 1 acre will lose nearly 5 acre-feet, or 1,600,000 gallons of water per year by evaporation.

ECONOMY

The economy of Grant County over the years has been as healthy and stable as perhaps any area of comparable size in New Mexico because supplies of water have been available, from one source or another, as needed. The economy rests on a triple base—mining, livestock, and agriculture—that supports a population essentially rural in character. Although nearly 70 percent of the population of the county lives in recognized communities, most of these communities are small and do not constitute urban centers in the usual sense. "Urban," as used in this report, refers to any community of 500 or more persons and the adjacent areas whose residents can quickly avail themselves of town markets and services. The influence of a fourth base, recreation, also dependent upon adequate water, has made itself felt in recent years and will become increasingly important.

As in most parts of the nation that are essentially rural in character, Grant County lost population in the decade 1950-60. Comparatively large losses in the rural areas were accompanied by small rises or relatively small net losses in the urban areas.

Population of Grant County, 1940-70
(U.S. Bureau of Census)

Division	1940	1950	1960	1970 1/
County	20,050	21,649	18,700	21,273
Rural	8,097	6,783	4,803	6,595 2/
Urban	(11,953)	(14,866)	(13,997)	14,678
Bayard	764	2,119	2,327	2,924
Central	1,759	1,511	1,075	1,629
Hurley	1,821	2,079	1,851	1,764
Santa Rita	2,565	2,135	1,772	-
Silver City	5,044	7,022	6,972	7,531
Tyrone	-	-	-	830 3/

1/ Preliminary report, U.S. Bureau of the Census, 1970.

2/ Includes several large trailer courts near Tyrone and the unincorporated communities of Cliff, Fierro, Fort Bayard, Gila, Hachita, Hanover, Pinos Altos, and San Lorenzo having a combined population estimated at 1,800.

3/ Estimated June 1970 by Personnel Office of Phelps Dodge Corp.

Losses from rural areas during 1940-60 resulted mainly from improvement of rural roads and the construction of consolidated school systems in urban areas. Population losses from the urban areas during 1951-60 resulted from curtailed activities of mines which had maintained a high level of employment through 1950 as a result of post-World War II stockpiling.

Movement of population from the cities, resulting from the curtailment of mining, was larger than apparent from the above table. The losses were offset by movement of rural population to the urban areas where schools and other facilities are concentrated. Ranching and farming have not been greatly curtailed—the operators now commute to their properties via a much improved system of highways and county roads.

During 1961-70 the trend away from the rural areas was reversed and the rural population gained by about 1,800 persons during the decade. Probably the rural population will increase further if nationally observed trends toward rural and suburban living continue. The populations of the urban areas are likely to increase sharply as activities are resumed or begun at some of the presently inactive mines and at new developments; thus the population of the county which increased in the decade 1960-70 probably will increase again during 1970-80.

Any appreciable increase of population in the urban areas is certain to create problems of water supply. None of the communities at this time have systems or water supplies adequate to meet sharply increased long-term demands. Most of them will need to improve their systems and develop additional supplies of water to meet even moderate increases in population and the steadily increasing per capita use of water that can be anticipated (Koopman, Trauger, and Basler, 1969, p. 21-22).

MINING

Indians mined turquoise near Tyrone and copper at Santa Rita before the Spanish moved into the country about 1800. Production of gold and silver, copper, lead, zinc, molybdenum, and sometimes fluorite and manganese, have contributed to the image of Grant County as one of this country's important mineralized areas.

The fortunes of other mining industries in Grant County have alternately waxed and waned but copper mining has grown, with only minor setbacks (resulting mostly from early disagreements with Apache Indians) since Don Francisco Manuel Elguea, wealthy merchant of Chihuahua City, Mexico, began operations at Santa Rita about 1805 (Christiansen, 1965, p. 233).

The copper industry in Grant County is at present a multi-million- dollar- a-ye ar operation. Kennecott Copper Corp. in 1965 employed about 1,650 men and women. Reportedly, huge deposits of copper ore have been discovered recently north of Santa Rita on property of the American Smelting and Refining Co. ; development is underway. The deposits now being developed by the Phelps-Dodge Corp. at Tyrone may prove to be the equal of those at Santa Rita and will provide an equally great economic asset to the county.

Production of gold and silver in Grant County virtually ceased when the United States entered World War II. A few places are worked sporadically, almost as a pastime, and in 1955 a small group of men were making an effort to produce gold from an old mine in the East Camp district near Steeplerock. Some gold is recovered as a byproduct of other metal mining activities, as is molybdenum concentrate at Kennecott's Hurley mill.

Lead and zinc deposits in the vicinity of Santa Rita and Bayard contain large reserves of ore, but production is sporadic and dependent on the world market, the state of which has not made continuous operations feasible in recent years. Most of the mines are maintained on a standby basis, ready to resume operations on relatively short notice. One mine, the Ground Hog, owned by American Smelting and Refining Co. , has been kept dewatered and has been yielding water of good quality at a rate of 500 gpm (gallons per minute) for many years. Other nearby mines also are pumped to keep them dry and the water produced from all the mines is fully utilized.

AGRICULTURE AND LIVESTOCK

The discovery of gold and silver at various places in Grant County during 1860-70 may have provided the first stimulus to permanent settlement but many veterans of the Civil War turned quickly to the land as a consequence of the Homestead Act that made federally- owned land available to the veterans. Prosperous farms were established in the rich bottom lands of the Mimbres and Gila Rivers, and stockmen staked their claims to grasslands that had a potential value far in excess of most seemingly more valuable mining properties. Many of the original farms and cattle ranches still are owned and operated by the families of the men and women who established them and who then survived the depredations of the Apache Chiefs, Cochise and Geronimo, and their warriors in the 1870's and early 1880's.

Surface water always has been available for irrigation along the Mimbres and Gila Rivers and supplies of surface water apparently were available from other sources in years past. Small streams that today containwater only occasionally reportedly were perennial in the 1870's and 1880's and had plentiful water for herds of cattle and flocks of sheep and goats. Some of these small streams such as Whisky, Cameron, and Mangas Creeks, afforded water for small-scale irrigation. Mangas Creek as late as 1900 flowed down a broad, grass-covered valley devoid of gullies, and according to John T. McMillen, a horse and wagon reportedly could cross at almost any point where now there are arroyos 20 to 30 feet deep. Walter W. Woodward in 1955 told the writer of successfully fishing in Red Rock Creek, in the Little Burro Mountains, when he was a boy living on his father's homestead about 1900.

RECREATION

The rugged, forested mountains and deep canyons of Grant County always have had an appeal to those who like their recreation primitive. Teddy Roosevelt once headquartered at the Lyons Ranch at Gila while he hunted and fished in what is now the Gila Wilderness. Recreational facilities have been increased in Grant County in recent years and new highways have made accessible to many people the areas of natural beauty that only a few had previously been able to enjoy. Water is a critical factor in the further development of recreational facilities in the county. The business of recreation can produce a much larger income than it does at present in the county if proper use is made of the available water supplies. Only a small part of the water so utilized need be lost to subsequent beneficial use.

Geologic Setting

The types of rocks in an area, their distribution, thickness, and general structure control the occurrence of water; these geologic factors must be known before the water resources can be appraised. Knowledge of the age of the rocks makes possible general predictions of their stratigraphic relations—vertical position with respect to each other—and so makes possible also prediction of their distribution beneath the surface. The younger rocks lie on top of the older rocks except where faulting and folding may have disturbed the normal sequence, and where younger igneous rocks intrude into older rocks.

AGE AND DISTRIBUTION OF ROCKS

The rocks that crop out in Grant County range in age from Precambrian to Holocene, and include intrusive and volcanic igneous rocks, marine sediments, and continental deposits. The oldest rocks are schist, gneiss, greenstone, and granite of Precambrian age more than 570 million years old. The largest areas of exposure of these rocks are in the Big Burro, South Burro, and Little Burro Mountains, and in the Silver City Range (fig. 2). They are exposed also at the north end of the Cooks Range (T. 19 S. , R. 9 W.), at several places near the central crest of the Black Range, and along the west side of the Mimbres Valley, west of San Lorenzo.

Marine sediments of Paleozoic age, 225-570 million years (m. y.) old, include shale, sandstone, limestone, and dolomite. Every period of the Paleozoic is represented in the geologic column. The deposits consist mostly of limestone and dolomite which crop out mainly in the central part of the county, from the Silver City Range east to the Mimbres Valley, and along the crest of the Black Range in the vicinity of Emory Pass. Minor but significant exposures occur also in the southern part of the county and in the Cooks Range.

The Mesozoic Era is represented only by rocks of Late Cretaceous age, 60-90 m. y. Sandstone, shale, and volcanic and intrusive rocks crop out in the same general areas as do the rocks of Paleozoic age. They are found also in the Little Burro Mountains, at the north end of the Big Burro Mountains, and in the Little Hatchet Mountains in the southwest corner of the county.

Volcanic rocks of Tertiary and Cretaceous age underlie a large area in the Summit Mountains northwest of Red Rock and a relatively small area in the Little Hatchet Mountains west of Hachita. Intrusive rocks of Cretaceous and Tertiary and Cretaceous age crop out in the central and southern parts of the county where they commonly are associated with mineral deposits.

Rocks of Tertiary and Quaternary and Tertiary age, 65 m. y. ago to the present, underlie nearly all of the northeastern and northwestern highlands and much of the central and southern parts of the county. These rocks are mostly of two types, volcanic and sedimentary.

The rocks exposed in the highlands are mostly of volcanic origin. They consist of flows of rhyolite, dacite, basalt, and associated pyroclastic rocks; some of the pyroclastic material was deposited in lakes to form well bedded tuffs. Most of the tuffs and volcanic agglomerates are massive and dense. The whole sequence may be more than 10,000 feet thick.

The sedimentary rocks of Quaternary and Tertiary age are mostly conglomerates and sandstones. Some fine-grained sediments, probably deposited in lakes, and some basalt flows are interbedded locally with the conglomerates and sandstones. These rocks generally occupy a position intermediate between the highlands and the valleys. They crop out around the margins and on the flanks of the mountain ranges, and they lie at varying depths beneath the surface of the lowland plains.

Rocks of Quaternary age, from about 2 to 3 m. y. ago to the present, are found mostly as gravel and sand in the stream valleys, as terrace deposits along the streams, and as alluvial fill in the bolsons. A Quaternary age has been assigned (Ballmann, 1960) to some rhyolitic volcanic rocks southeast of the South Burro Mountains, but Elston (1968, p. 239) has stated they are of Tertiary age. Basalt flows that overlie the bolson fill are conspicuous features about 7 miles north of Hachita, at the southern end of the county; basalt, underlain by conglomerate of possible early Quaternary or late Tertiary age, caps a long ridge immediately east of Hachita.

STRUCTURAL PATTERN OF GRANT COUNTY

The structural pattern of Grant County is complex, involving the transition from the Colorado Plateau structures of the northern part to the Basin and Range structures of the southern part (fig. 15). The transition zone, not sharply defined, is characterized by widespread, intensive, recurrent, normal faulting and by local, gentle folding. Both the faulting and the folding commonly were accompanied by local intrusions of igneous rock, and by widespread extrusion of volcanic rocks. The faulting resulted in extensive fracturing of all rocks involved, and the folding and intrusions opened joints in otherwise dense rocks.

The transition zone between Colorado Plateau and Basin and Range structures is a northwest-trending structural belt, some 50 to 75 miles wide, that includes most of the county. The zone is an element of the Deming axis (Turner, 1962, p. 60) or, as it

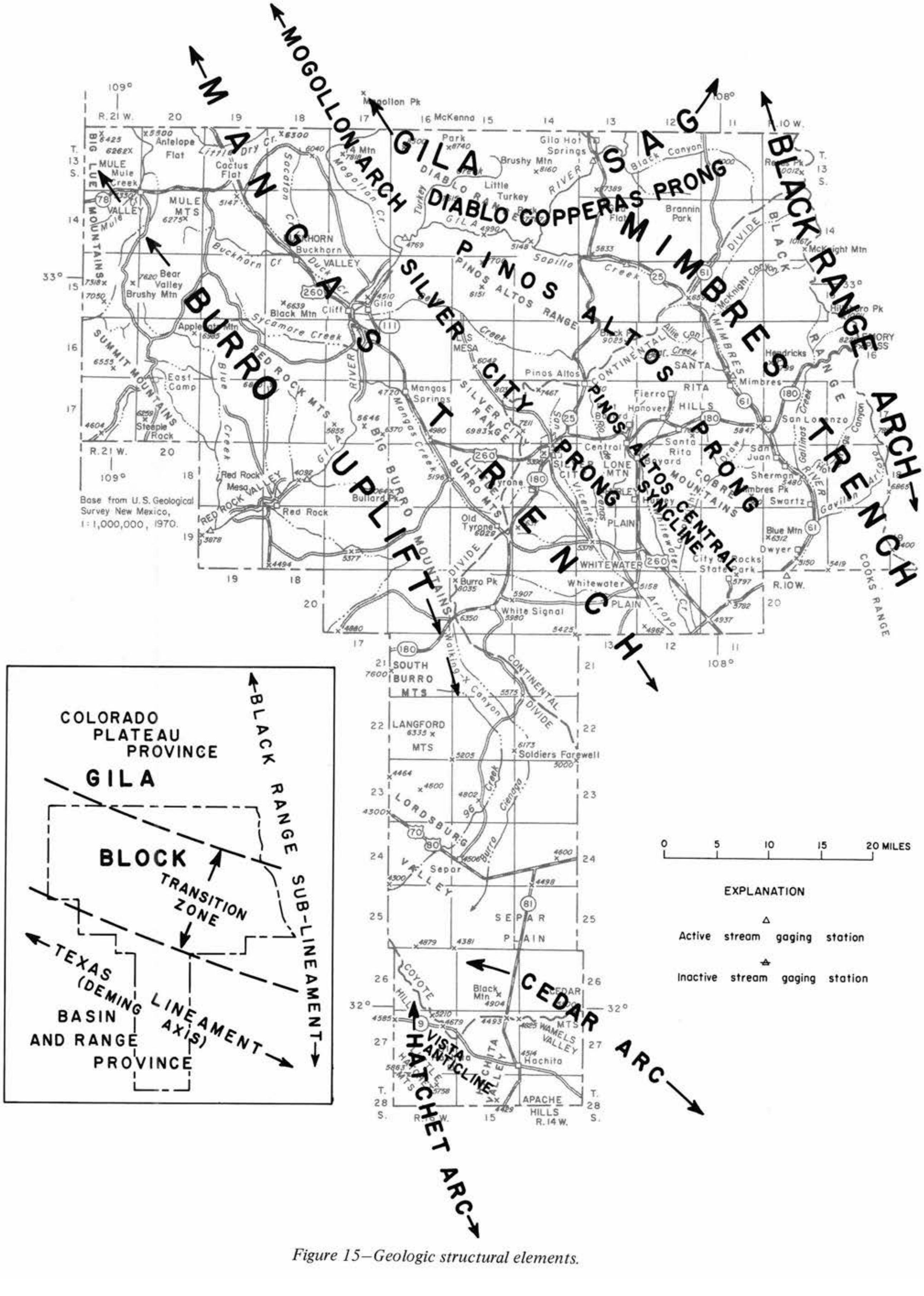


Figure 15—Geologic structural elements.

is better known, the Texas lineament, described by Kelley (1955, p. 61) as "—marking roughly the southern boundary of the plateau along the Mogollon Rim—one of the largest, longest and most prominent of the transverse lineaments on the North American continent. "

Divergent from the Texas lineament, and itself constituting a major structural feature in New Mexico, is a fault system that extends from the vicinity of Deming northward to the plains of San Augustin (off map), a distance of about 110 miles. Involved in this system of faulting and uplift is the Black Range, and the less extensive Cooks, Cuchillo, and Luera Ranges (off map).

The large, elevated, wedge-shaped area lying between the Texas lineament and the Black Range sub-lineament forms the major structural unit of Grant County and has been named the Gila block (Trauger, 1965, p. 184); it forms the south end of what Kelley has called the Mogollon Segment of the Colorado Plateau (Kelley, 1955, p. 58). However,

but extend southeast into Grant County. The mountains are developed from a domed and faulted structure termed the Mogollon arch (Trauger, 1965, p. 186). Ferguson's (1927, pl. 2) sections show the west-dipping limb of the arch in the vicinity of Mogollon, but the east limb has not been mapped to date. The Mogollon arch at about the Catron-Grant County line branches to form three distinct faulted structures that extend far into Grant County.

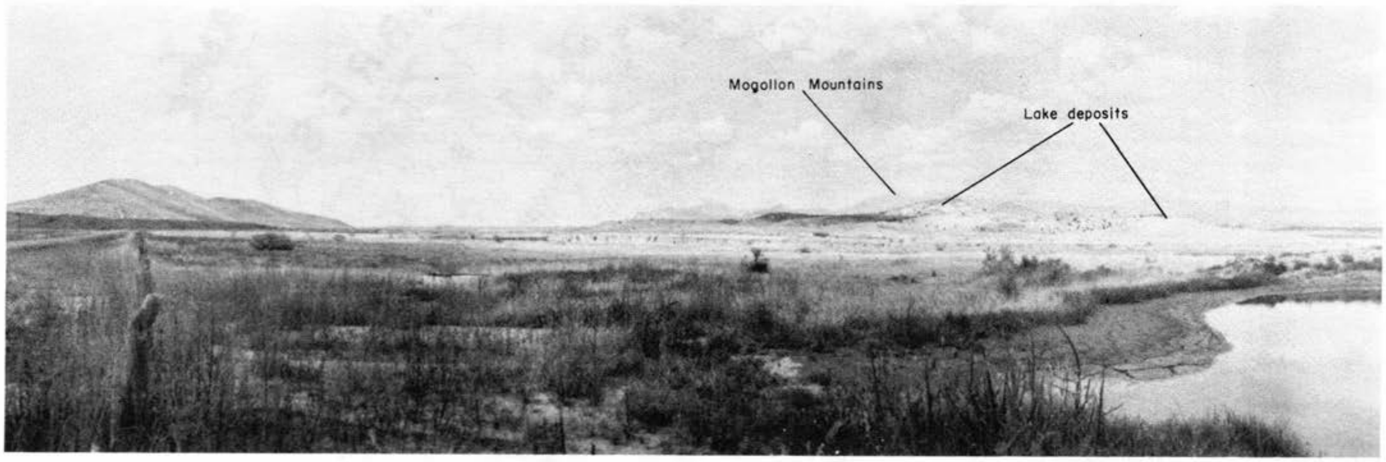


Figure 16—View of Duck Creek Valley; a part of the Mangas trench. Lake deposits in the upper part of the Gila Conglomerate are exposed in the low hills in the right middle ground (NW¼ sec. 29, T. 14 S., R. 18 W.); the western front of the northeastern highland (Mogollon Mountains) is on the right horizon. View covers 120°, west northwest to northeast, from well 14.18.30.444. Large yields are obtained from wells tapping the alluvium and upper part of Gila Conglomerate in this general area; some occurrences of artesian water are reported. The artesian aquifer is believed to be gravel and sand overlain by fine-grained lake deposits.

the Gilablock in some respects seems more closely related to Basin and Range structures than to the Colorado Plateau, although it is not a definite part of either structural province.

The Gilablock has been deformed by many lesser structures, most of which are faults associated with the larger uplift structures that define the block, but some of which are associated with, and result from, regional warping and intrusions of igneous rocks (Paige, 1916, p. 10). The relation of the intrusions and warping to the faulting is not everywhere clear. Some major structures, such as that which forms the Mogollon Mountains, disintegrate into several smaller elements, change character, and continue in their new form for long distances.

The Mogollon Mountains, the highest in southwestern New Mexico, lie mostly in Catron County

The valleys containing Duck Creek (fig. 16), Man-gas Creek (fig. 17), and San Vicente Arroyo form a major linear topographic feature of Grant County that is structurally controlled; this structure was named the Mangas trench by Trauger (1965, p. 186). The eastern side of the trench is well marked by normal faults trending along the west side of the Mogollon arch and the Silver City Range. The west side of the trench is well defined topographically by the Big Burro Mountains, but evidence of fault control is lacking except locally. Conglomerate has been faulted down against granite on the east side of the Big Burro Mountains near the Tyrone open-pit mine. Hewitt (1959) and Elston (1960) have mapped normal faults, downthrown to the east, that parallel the Mangas trench along the northeast side of the Burro uplift. Possibly other faults are concealed beneath the valley fill along the west side of the trench.

The valley system containing Sapillo Creek and the Mimbres River also is a linear feature that is structurally controlled. The west side of the Mimbres Valley is marked by the prominent system of normal faults that form the steep east-facing front of the Pinos Altos Range. The east side of the valley is well defined topographically but, like the west side of the Mangas trench, there is little evidence of fault control except locally. Kuellmer (1954, pl. 1) mapped normal faults, downthrown to the west, par-

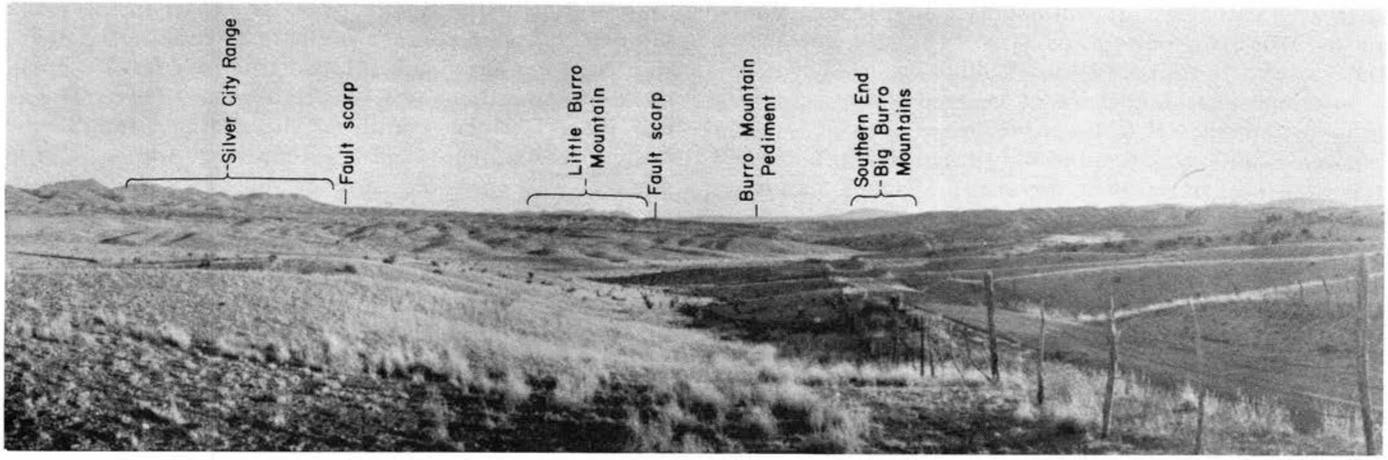


Figure 17—View of southern part of the Mangas trench; view covers 120°, looking south from a point (17.16.5.233) on State Highway 180. A master fault system bounds the east side of the trench, extending along the base of the Silver City Range; a related fault, possibly a branch from the master, extends along the west front of the Little Burro Mountains. Yields to wells tapping the Gila Conglomerate along the east side of the trench are mostly small; some large-yield wells have been developed in Mangas Valley and tap the alluvium and the upper part of the Gila Conglomerate. Yields from rocks of the uplands generally are very small to small.

alleling the valley, but nearer to the crest of the Black Range than to the valley.

A broad, synclinal structure, first described by Paige (1916, p. 10) and named the Pinos Altos-Central syncline by Lasky (1936, p. 49), lies between the east side of the Silver City Range and the west side of the Pinos Altos-Cobre Mountains. The syncline, some 16 miles wide and 1,500 feet deep (Ordonez, Baltosser, and Martin, 1955, p. 12), trends northwest, and the northern end terminates in the vicinity of Pinos Altos. The plunge is gently southeastward and the structure, being older than the bolson fill, disappears under the gravel. The floor of the syncline has been domed locally by intrusive rocks and broken by faulting.

The structure of the Gila block in the northern part of the county is characterized by centripetally dipping beds of sedimentary and volcanic rocks that form a large basin some 65 to 75 miles across. Only the southern rim of this basin lies in Grant County. Dips are gentle toward the center of the basin, generally not more than 10°, and commonly less than 5°.

The Lordsburg Valley, a broad, elongated northwest-trending structure, lies on the trace of the Texas Lineament and separates the transitional structures of the Gila block from the purely Basin and Range structures to the south. The structure of the bedrock under the valley fill is not known, but an irregular and probably highly faulted structure can be inferred from the occurrences of isolated exposures of rocks of Paleozoic age east and southeast of Separ, and from the fact that wells near these exposures have been drilled to depths of hundreds of feet without reaching bedrock. Records of oil well tests drilled in Hidalgo and Luna Counties show that the bolson fill may be at least 1, 800 feet deep near Lordsburg, and 2,800 feet deep near Deming (Dixon, Baltz, Stipp, and Bieberman, 1954, p. 30).

The mountain ranges and valleys south of Lordsburg Valley are block-faulted structures, only the northern ends of which extend into Grant County. The Coyote Hills and Little Hatchet Mountains in Grant County, and the Big Hatchet and Alamo Hueco Mountains south of the Grant County line are part of a large, arcing system of closely related fault structures; the Cedar Mountains and the Carrizalillo Hills (off map) form another arcing fault-block system. The pattern of exposures and the attitude of beds in the two systems and in the intervening hills indicate a complex structural interrelation, the details of which are yet to be determined.

Rock strata in the Coyote Hills and at the north end of the Little Hatchet Mountains dip northeast at angles ranging up to 70°. The strata may flatten under the alluvial fill. Inasmuch as the strata in the Cedar Mountains also dip to the northeast, major fault structures are inferred to be buried beneath the valley fill. Basalt flows of probable Holocene age overlying bolson fill north of Hachita may mark the general location of at least one such structure.

A concealed fault, buried beneath the valley fill, and extending along the west side of Hachita Valley, south of Old Hachita, was inferred by Trauger and Herrick (1962, p. 7) from the structure of the Little Hatchet Mountains as mapped by Lasky (1947, pl. 1) and by the shape of the water-level surface under the valley floor.

ROCK STRUCTURES AND GROUND WATER

The regional and local structure of rocks is a geologic factor that has a pronounced effect on the occurrence of ground water. Water may be under artesian conditions where it occurs in rocks that are overlain by less permeable rocks. Flowing wells have been developed in beds of limestone and shale in the central part of the county, in volcanic rocks in the Mimbres Valley and Silver City Range, and in the valley fill near Cliff and Buckhorn.

The internal structure of volcanic rocks locally may be conducive to the storage of water. Highly porous rubble zones commonly form at the base and top of a lava flow as it advances. Gases escaping from the molton rock in the final stages of cooling may produce bubbles and cavities having sufficient interconnection to permit free movement of water. Contraction joints commonly form as a flow cools and these joints can store and transmit appreciable amounts of water.

The internal structure of sedimentary rocks also influences the occurrence and storage of water. Bedding planes of both marine and continental deposits may inhibit or promote storage, movement, and recovery of water depending upon how the rock material varies in character along the bedding planes. Coarse, granular material in sheet-like structure between beds of fine, dense material may provide storage and facilitate lateral movement of water. On the other hand, laminae of fine clay in and between beds of coarse material may inhibit movement of water and adversely affect recovery of water even though storage has not been greatly impaired. Both types of structure are common in beds of the Gila Conglomerate, the principal aquifer in much of Grant County.

Solution channels in normally dense carbonate rocks such as limestone and dolomite are internal structures that greatly increase storage and enhance recovery of ground water. They are not common in the carbonate rocks but do occur locally.

Joints and fractures in rocks can serve as conduits for water and as natural reservoirs where such joints and fractures are well-developed over an appreciable area. Much of the relatively small amount of water recovered from the granitic rocks of the Burro Mountain area is found in joints and fractures.

Joints are cracks, or partings, in rock masses that occur later as a result of stresses present when the rock was formed. In general, joints in rocks become tighter with increasing depth, and at some point they become only incipient—there is no actual opening in the rock, but one will develop as overlying rock is removed either by erosion or excavation. Fractures are also partings and cracks but they more commonly result from stresses applied after the rock has formed.

Faults are large-scale fractures in the earth's surface along which there has been displacement of the two sides relative to one another. The displacement maybe of less than an inch or many miles, but more commonly amounts to a few tens to hundreds of feet. Movement along a fault plane maybe recurrent, in small increments that result eventually in large net displacements. Rarely do individual increments amount to more than a few feet.

Fault planes may act as barriers to the movement of ground water if clay, or fault gouge, has been formed along the plane by the grinding movement between the fault blocks. Faults also can interrupt the continuity of permeable beds by displacing them to a position against a relatively impermeable rock, or by raising them to a level above the regional water table. More commonly, however, faults and fault zones disrupt and fracture rock formations in such a way that the storage capacity and water-yielding characteristics are improved. For this reason, it generally is worthwhile to prospect for ground water in the vicinity of known faults. Thus it becomes important to recognize the principal structures, especially faults, in any region where ground water is scarce.

HOW TO USE THE GEOLOGIC MAP

The types of rocks present in Grant County, the areas in which they crop out, and their general water-bearing properties are shown in fig. 2; their stratigraphic relations, average thickness, and lithologic characteristics are shown in fig. 18. Diagrammatic cross sections showing subsurface relations are shown in fig. 19. These figures, when properly understood and used with the water-level contour map (fig. 3), can assist in determining the availability of ground water at most places and appraising the dependability of the supply.

To determine types of rock at a proposed well site, first find the general location of the map using the townships, range, and sectiondescription if necessary. Next, note the color pattern at this point, then refer to the map explanation on which is described briefly the type of exposed rock represented by that color pattern.

The range in thickness and the water-bearing characteristics of the various types of rock formations that might underly an area are given in fig. 18. The figure thus can be used to determine the type of rock that may occur beneath those found at the surface, and the approximate depth to an underlying aquifer. The rock units are arranged in the column with the oldest rocks at the bottom, the youngest rocks at the top.

Suppose that you wish to know what rock formation in an area is yielding water to wells. You learn from data for nearby wells (fig. 3) that the depth to water in the area of a proposed well is about 400 feet, and the rock exposed at the surface (fig. 2) is shown to be the Percha Shale (Dp)—then it could be presumed that the water found at 400 feet is in the underlying beds of the Fusselman or Montoya Dolomite (SOЄ) because the Percha Shale is no more than about 315 feet thick at most (fig. 18). However, both the Percha Shale and Fusselman Dolomite together could be as little as 330 feet thick, thus the aquifer might be the Montoya Dolomite. A careful examination of the sequence of rock cuttings removed from the well would enable one to determine which formation was yielding the water. This sort of problem points up the importance of keeping a good record of the types of rocks penetrated during drilling.

Or suppose you wish to determine what formation would be most likely to yield water in an area where there are no nearby wells. Determine from fig. 2 what formation is at the surface at the site. Find that formation in the columnar section (fig. 18) and note what rock units below it are most likely to yield the quantity of water you need, then add up the combined thickness of the overlying beds to determine the approximate depth to which a well would need to be drilled.

Some of the older rocks may not be found beneath the younger rocks—they may not have been deposited at that point, or they may have been stripped away by erosion before the younger rocks were deposited. The geologic cross sections (fig. 19) show the rocks that occur beneath the surface along the lines of the sections. It will be noted on the geologic map that in certain areas, as in the northern part of the county, the rocks of Paleozoic age are not known to occur at the surface. If they are present beneath the surface, they are buried beneath great thickness of volcanic rocks.

Granitic and metamorphic rocks of Precambrian age are widely exposed in the Burro Mountain area and are indicated by the purplish color on the geologic map (fig. 2). These are the oldest rocks in the region, and no younger sedimentary rocks would be found if drilling were started in these older rocks. Another example: a deep hole drilled at a point 2 to 3 miles north of Silver City would start in rocks of the Colorado Formation (darker green on the geologic map) and would penetrate possibly as much as 1,000 feet of sedimentary and igneous rocks of Cretaceous age before entering the rocks of Paleozoic age (blue tints on the geologic map).

The type of older rock that might be expected to occur under a younger rock in any given area can be determined by studying the geologic map (fig. 2) and the stratigraphic chart (fig. 18). As a general rule, when dealing with sedimentary or volcanic rocks, note on the map the other types of rocks in the vicinity. If older rocks are observed to crop out all around an area of younger rocks, or to lie at the center of an area of younger rock, the older rocks likely will be found beneath the younger rock. This rule does not hold for circumstances where a massive intrusion of igneous rock (as indicated by the "TKi" symbol on the geologic map) has pushed up, or into, older rocks, as in the Pinos Altos-Bayard-Santa Rita area and elsewhere. Such intrusions commonly lift, push aside, or drastically alter the intruded, or "host" rock, so that the host rock cannot be found by drilling through the intrusion.

The areas underlain by younger intrusive rocks can be determined on the geologic map by the characteristic bright red color. These rocks commonly produce little water and generally it is not practicable to attempt to drill through them to reach underlying water-bearing rocks.

The younger intrusive rocks also may form relatively thin sheet-like bodies that cut upward through overlying beds, or spread out between beds. Those that cut upward across beds are referred to as "dikes" and those that intrude between beds are called "sills. " Sometimes water-bearing sedimentary rocks may be found beneath sills. The sills commonly have no surface expression and their presence can be determined only by drilling or inferred at some placed by careful study of surrounding outcrops. Sills and dikes of quartz diorite have intruded the Colorado Formation in many places in the central part of the county. Thin but extensive quartz-diorite and albite-quartz porphyry sills are found in the shales and carbonate formations of the mining district of Fierro, Hanover, and Santa Rita.

Dikes commonly have prominent surface expression because they are resistant to erosion and they form distinct narrow "ribs" of rock that extend for appreciable distance across the land surface. They are especially prominent in the area between Silver City and Central, and are well exposed in the roadcuts along the highway between the two towns.

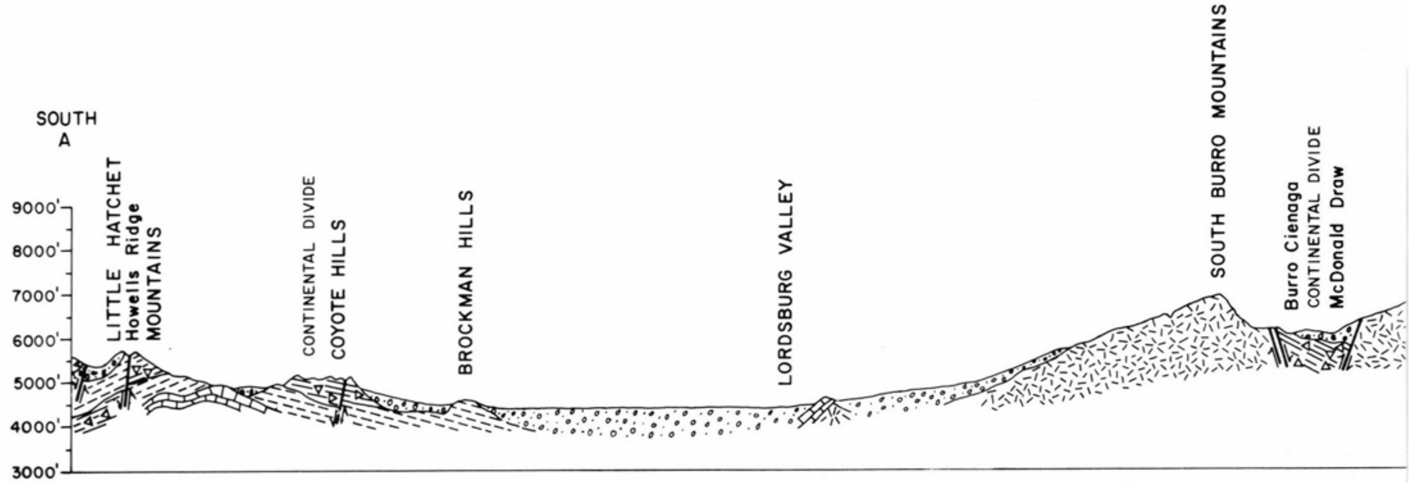
The kind of older rock that underlies the more central parts of the bolsons generally cannot be determined from surface exposures. These areas commonly are many miles from outcrops of older rocks; thus little or no data are available that allow reliable prediction. The bolson fill generally is of such great thickness in these areas as to make the question of the character of the basement rock unimportant insofar as the availability of ground water is concerned.

Figure 18—Generalized section of rock formations in Grant County.

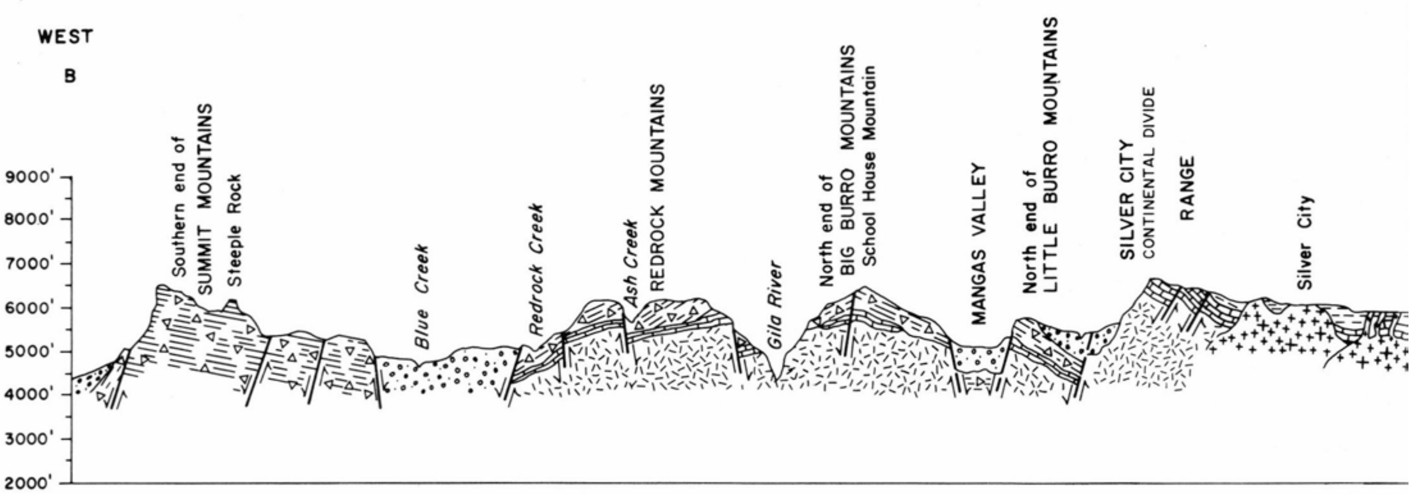
SYSTEM OR SERIES
QUATERNARY (Holocene and upper Pleistocene)
QUATERNARY AND UPPER TERTIARY (Middle Miocene to Pleistocece)
MIDDLE TERTIARY (lower Oligocene to upper Pliocene)
LOWER TERTIARY AND UPPER CRETACEOUS
UPPER CRETACEOUS
LOWER CRETACEOUS
LOWER PERMIAN
PENNSYLVANIAN
LOWER MISSISSIPPIAN
UPPER DEVONIAN
SILURIAN
UPPER ORDOVICIAN
LOWER ORDOVICIAN
LOWER ORDOVICIAN AND UPPER CAMBRIAN
PRECAMBRIAN

FORMATION OR TYPE OF ROCK	SYMBOL ON MAP	APPROXIMATE RANGE IN THICKNESS (FEET)	CHARACTER (Thickness of beds is approximate)	WATER SUPPLY
Alluvium	Qal	0-50	Alluvium--boulders, gravel, sand, silt, and clay under flood plains; as much as 75 feet thick in the Gila River valley and about 25 to 35 feet thick in the Mimbres River valley. Terrace gravel, mostly on slopes bordering the Gila and Mimbres Rivers and the Lordsburg valley, is thin and largely composed of rocks derived from the immediate vicinity. Bolson deposits, known from drill holes to be at least 1,600 feet thick, include unconsolidated gravel, sand, silt, and clay in the Lordsburg and Hachita valleys and San Vicente basin. The bolson deposits are heterogeneous mixtures of all rocks found in the surrounding uplands, mostly unconsolidated but locally cemented with carbonate, iron, or silica to form beds of caliche and "hardpan".	Alluvium along main streams yields as much as 2,200 gpm but generally less than 500 gpm to wells; bolson deposits yield as much as 1,500 gpm to wells locally and have potential for higher yields; terrace gravels generally not water bearing but locally yield as much as 300 gpm to wells along main stream channels; basalts are not known to be water bearing.
Terrace gravels	Qtg	0-125		
Alluvium and bolson deposits	Qab	0-1,600		
Basalt	Qb	0-500		
Gila Conglomerate	QTg	0-1,900+	Sedimentary deposits of continental origin as much as 1,900 feet thick, broadly distributed, and, in general, nonconformably to disconformably overlying all older rocks but locally intertongued and interbedded with the uppermost facies of the Tertiary volcanic sequence. Incoherent to strongly cemented fanglomerate, conglomerate, sandstone, and silt, some thick deposits of clay, especially in valley of Duck Creek where beds of diatomite also are found. Rapid lateral changes in composition due to local derivation of sediments. Nearly flat-lying to vertically dipping beds; locally faulted, particularly in the lower parts, and containing pronounced intraformational disconformities, particularly between what is referred to in this report as the lower and upper parts of the Gila; upper part of Gila is generally less consolidated and less deformed than the lower, contains interbedded flows of basaltic andesite.	Yields range from less than 1 gpm to 2,000 gpm to wells, depending upon the degree of consolidation and the locality. Yields generally are less than 20 gpm from the more consolidated beds of the lower part of the formation. Larger yields are mostly from local poorly consolidated beds in the upper part of the formation.
Volcanic rocks of wide variety ranging in age from 6 to 38 million years, and interbedded sediments. Includes all rocks previously referred to the Datil Formation, the Sugarlump Tuff, Kneeling Nun Tuff, Rubio Peak Formation, other named units in central Grant County, and similar rocks of equivalent age in the southern part of the county	Ta Tba Td Tl Tr Trp Ts Tsc	0-10,000+	Flows and sediments that include andesite (Ta), rhyolite (Tr), latite (Tl), dacite (Td), and basaltic andesite (Tba), their pyroclastic equivalents, interbedded water-deposited tuffs (Ts), and fine- to coarse-grained sediments including beds of boulders; widely distributed over northern and southern Grant County. A thick sequence of andesitic-rhyolitic-basaltic rocks has been recognized in broad areas and has been shown conclusively (Elston, 1965, 1968 a, b) to be cyclic and to have been repeated at least three times. The bulk of the eruptive rocks are rhyolitic and the most conspicuous and widespread types are rhyolite and quartz latite ash flow tuffs, such as the Kneeling Nun Tuff and Sugarlump Tuff (well exposed in southeast part of county). The Kneeling Nun is a welded tuff, as much as 400 feet thick, dense, compact, grayish purple weathering to buff and tending towards columnar jointing. The Sugarlump consists of as much as 1,400 feet of sandy, crossbedded water-laid tuffs, crystal tuffs, flows and breccias, most of which are white to green and pink. The Rubio Peak Formation (Trp) consists of as much as 3,200 feet of andesite and latite flows, agglomerates, breccias, tuffs, and tuffaceous sandstones and conglomerates, mostly dark gray to purple or black and known from drill holes to be at least 1,900 feet thick but probably much thicker.	The basalt, basaltic andesite, andesite, rhyolite, latite, and related volcanic and sedimentary rocks generally are locally water bearing and the yields commonly range from ½ to 10 gpm; a few wells yield as much as 40 gpm from sediments interbedded with the flow rocks. Coarse-grained sediments of the sequence may be the aquifer that yields as much as 500 gpm to wells in the Apache Tejo and Faywood area.
Volcanic rocks in Summit Mountains, Pinos Altos Mountains, and Steeple Rock area (Wimsattville and Virden Formations)	TKa TKab TKs TKd TKr	0-3,000 0-4,000	Andesite flows, tuffs, and flow breccias (TKa) as much as 3,000 feet thick; some flows vesicular, interbedded with rhyolite tuffs and latite flows, underlain locally by a sequence of porphyritic rhyolite flows and welded tuffs (TKr) as much as 200 feet thick; underlying the andesites and rhyolites is a sequence of grayish green to darker green dacite flows, tuffs and flow breccias (TKd); the dacite is host to most of the mineralization in the Steeple Rock mining district. Virden Formation of Elston (1960) in Steeple Rock area and Wimsattville Formation of Hernon and others (1953) in the Santa Rita area--local deposits of conglomerate, fanglomerate, sandstone, and shale as much as 4,000 feet thick near Steeple Rock and at least 1,100 feet thick near Santa Rita. Andesite breccia (TKab) in Pinos Altos Mountains.	The volcanic rocks in general yield less than ½ gpm to wells but locally as much as 25 gpm. The sedimentary rocks also are locally water bearing and yields generally are less than 10 gpm.
Hidalgo Volcanics	TKh	0-5,000	In Little Hatchet Mountains: Mostly basalt flows and pyroclastic rocks; some andesite; in the upper part locally includes as much as 200 feet of limestone, shale, and conglomerate.	Locally water bearing; yields to wells generally less than 2 gpm from volcanic rocks, 1 gpm from sedimentary beds.
Intrusive rocks	TKi	-	Dikes, sills, plugs, stocks, and laccoliths of varied composition; quartz diorite, monzonite, granodiorite, gabbro, near Silver City and Santa Rita, quartz monzonite and latite near Tyrone, rhyolite and latite dikes and rhyolite plugs near White Signal, monzonite porphyry in Blackhawk area, monzonite and diorite in Little Hatchet Mountains. These rocks have intruded and cut across or displaced older rocks in all areas of intrusive activity.	Locally water-bearing; yields range from 1/5 to 20 gpm.
Ringbone Shale	Kr	25-650	Black and green fissile shale, some sandstone and black limestone; 25 to 100 feet of volcanic rocks lie between lower and upper shale units.	Not known to be water bearing.
Skunk Ranch Cgl.	Ks	3,400	Mostly red and maroon conglomerate; includes much red clay-shale, some soft sandstone, locally a layer of augite basalt 0-200 feet thick.	Locally water bearing; yields to wells commonly less than ¼ gpm.
Colorado Formation	Kc	0-1,000	In central Grant County: Lower 200 feet gray-to-black fissile shale containing a few thin sandy layers and, locally, about 80 feet above the base, a 25 foot bed of sandstone overlain by beds containing oyster (gryphea) shells. Upper 800 feet tan, greenish-brown and white sandstone and arkose beds alternating with dark-green, brown, and black shale beds, some thin beds of brown to gray limestone, locally fossiliferous. Intensely intruded by dikes in the area between Silver City and Central.	Locally water bearing, occurrence highly unpredictable, yields generally range from less than 1/10 to 5 gpm; a few wells have yields of about 15 gpm.
Beartooth Quartzite	Kb	65-140	Thin bedded to massive, vitreous, fine- to very fine-grained sandstone containing thin shale partings; locally crossbedded; light-gray, weathering to reddish-brown; locally conglomeratic within upper 10 feet.	Not known to be water bearing.
Corbett Sandstone	Kc	1,500-4,000	In Little Hatchet Mountains: Mostly sandstone, locally quartzitic and massive, commonly ripple marked and crossbedded, locally thinly laminated; sandstone beds alternate with sandy shale beds 1 to 15 feet thick; includes several shaly and sandy limestone units.	Locally water bearing; yields to wells generally less than 4 gpm and commonly less than ½ gpm.
Howells Ridge Formation (Equivalent of Broken Jug Lm. and Playas Peak Fm.)	Kh	1,100(?)-5,200(?)	In Little Hatchet Mountains: In the lower part, as much as 4,700 feet of conglomerate, sandstone, red and green shale, and limestone; in middle part, as much as 400 feet of volcanic rocks--augite andesite flows and purple breccias; in upper part, 200-545 feet of massive and thin-bedded black limestone and massive crystalline creamy white limestone, locally fossiliferous and reeflike.	Locally water bearing; yields to wells generally less than 2 gpm, commonly less than ¼ gpm. Water from the shales and volcanic rocks is likely to have high concentrations of dissolved solids.
Abo Formation	Pa	0-640	Red beds (mostly red shale), siltstone, and limy mudstone containing lenses of limestone and chert conglomerate and thin local beds of olive-green to brown limestone.	Not known to be water bearing.
Syrena Formation		170-390	Bottom 35 to 40 feet of blocky to fissile, black, fetid silty limestone and lenses of limestone conglomerate, overlain by 30 feet of dense dark-gray silty limestone containing 3 to 4 inch nodules of blue-gray limestone, in turn overlain by 10 to 40 feet of olive-green to brown shale. Upper 100 to 280 feet alternating beds of pure gray limestone, silty limestone, and brown, yellow, and red shales.	Locally water bearing; yields to wells range from less than 1 to about 5 gpm.
Oswaldo Formation	₱M	330-420	Bottom 20 to 40 feet of gray to reddish shale (locally called Parting Shale Member); middle 250 to 300 feet of blue-gray dense, thick-bedded cherty limestone containing shale partings and local small to large lenses of coarse-grained sandstone 70 to 125 feet above the base; Upper 50 to 80 feet of alternating beds of pure limestone and silty limestone overlain by 3 to 5 feet of dense cherty limestone.	Locally water bearing; yields to wells range from less than 1 to about 25 gpm.
Lake Valley Limestone		300-400	Lower 15 to 40 feet thin-bedded, slabby, fossiliferous gray limestone and thin shale partings, overlain by 20 to 50 feet of light to dark-gray, thick-bedded, fine-grained, fossiliferous, cliff-forming limestone containing masses of black chert, middle part is 200 feet of alternating fossiliferous limestone and shaly limestone; the upper 110 feet is massive white to light-gray fossiliferous (crinoidal) limestone and marble containing white to light-gray nodules of chert.	Locally water bearing; yields to wells range from less than 1 to about 150 gpm.
Percha Shale	Dp	230-315	Lower 130 to 215 feet is black fissile shale containing very thin interbeds of blue-gray argillaceous limestone, tan calcareous shale, and white calcite layers near the base. Upper 100 feet is gray shale and limy shale beds containing abundant 1- to 4-inch fossiliferous limestone nodules and several beds of limestone.	Generally not water bearing but locally yields as much as 1 gpm to wells.
Fusselman Dolomite		100-300	Fine-grained massive dolomite containing sparse chert nodules; brownish-gray to gray on fresh surface, weathering to tan; fossiliferous but most fossils destroyed by dolomitization and local alteration as a result of mineralization.	Locally water bearing; yields to wells range from less than 1 to about 5 gpm.
Montoya Dolomite	SO€	350-470	Lower beds (0 to 40 feet) commonly medium- to coarse-grained sandstone containing grains of milky-white opalescent quartz; middle 200 feet mostly dark-gray to black (weathering light-gray to brown), fine-grained massive dolomite containing chert zones; upper 200 feet mostly white to light-gray finely crystalline thin-bedded limestone, some chert.	Locally water bearing; yields to wells range from less than 1 to about 50 gpm.
El Paso Limestone		500-520	Lower 400 feet mostly thin- to medium-bedded light-gray to gray-tan limestone and dolomite containing abundant thin crinkled and reticulated siliceous layers; some shale beds; numerous fossils in lower 150 feet. Upper 100 feet massive to thick-bedded finely crystalline light-gray limestone; nodular chert abundant in top few feet.	Locally water bearing; yields to wells range from less than 1 to about 200 gpm.
Bliss Formation		140-190	Conglomerate (locally) overlain by generally dense glauconitic and hematitic crossbedded sandstone and quartzite; contains some dolomite and limestone.	Not known to be water bearing.
Regional basement rocks	p€u p€g p€m	-	Granite, gneiss, mica schist, greenstone; the granitic and gneissic rocks in the Burro Mountains are deeply weathered locally.	Locally water bearing, yields to wells range from less than 1/10 gpm to about 15 gpm.

Adapted from Hayes, 1970, Jones, Hernon, and Moore, 1967, Lasky, 1947, and Zeller, 1970.

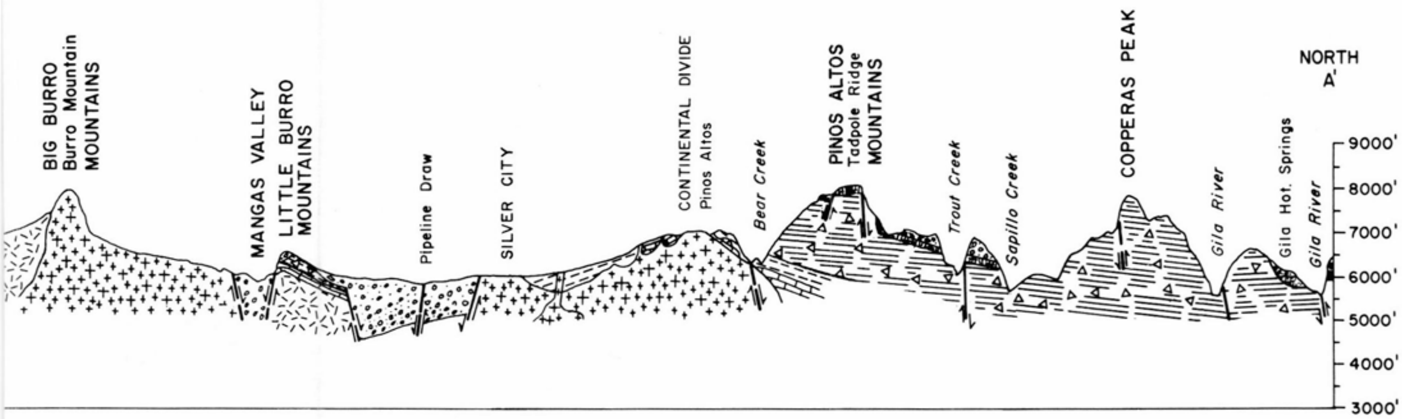


South to north from Little Hatchet Mountains through

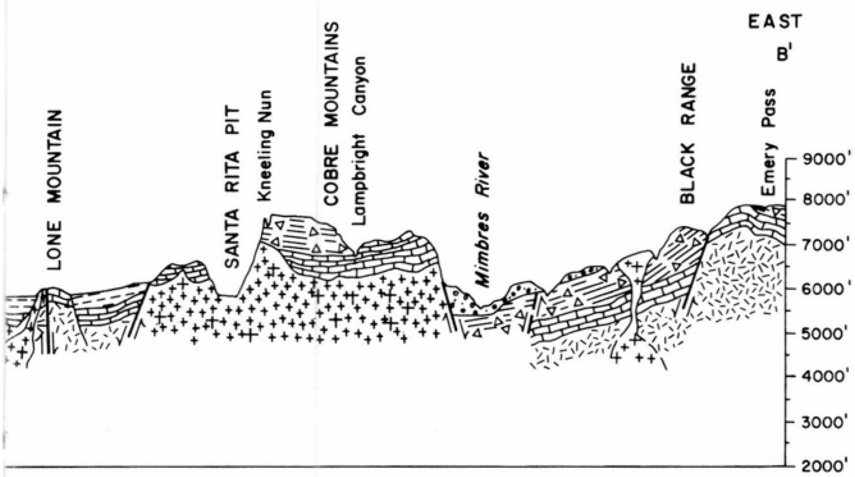


West to east from Summit Mountains

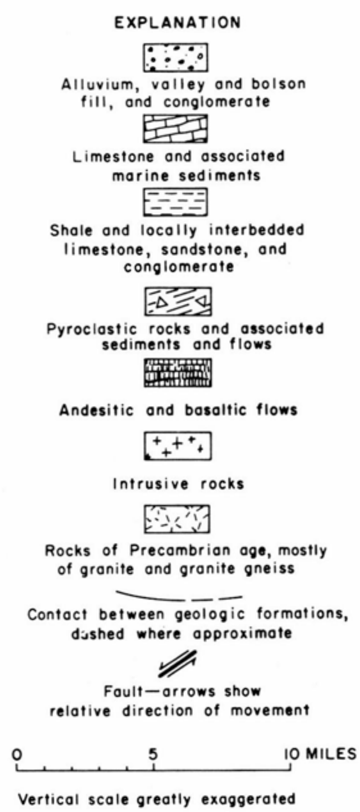
Figure 19—Diagrammatic



South Burro Mountains and Silver City to Gila Hot Springs.



through Silver City to the Black Range.



sections across Grant County.

Hydrogeology

Hydrogeology is the science that considers water and its relation to the rocks with which it is associated. It includes consideration of all aspects of water in relation to the rocks—its introduction into the rocks, its movement through and over the rocks, its discharge from the rocks, and any alteration of its character as a result of its association withthe various rocks with which it comes in contact.

The discussions that follow are intended to increase the understanding of the relation of water to the geologic environment and to help in the development and conservation of all the available water resources of Grant County.

Virtually all continental water, both surface water and ground water, can be assumed to come from atmospheric precipitation. The first step in what commonly is called "the hydrologic cycle" (fig. 20) is the precipitation of moisture in the form of rain or snow on the land surface. The rain that falls in light showers of short duration is mostly evaporated or, in small part, consumed by vegetation. However, some of the precipitation that falls during a period of heavy or prolonged rain or snowfall may move downward and through the soil zone, or through the streambeds, and be stored in the underlying rocks. This stored water is the source of all but a very small percentage of the water that issues from some springs or is pumped from a few wells.

Whether flowing off on the surface or soaking into the ground, precipitation enters a hydrologic system. A hydrologic system is any relatively large area in which the hydrologic characteristics are closely related and which can be isolated, or nearly so, from other areas for consideration of causes and effects pertaining to water. What occurs within one large hydrologic system may have little or no effect on the hydrology of adjacent systems except at outflow points.

A large hydrologic system such as the Gila River has distinct hydrologic divisions or subsystems. These units generally constitute tributary drainage basins such as Bear Creek and Duck Creek in which ground water behaves more or less uniformly and independently of adjacent units. Ground-water and surface-water units in a hydrologic system are closely related but the boundaries of these units do

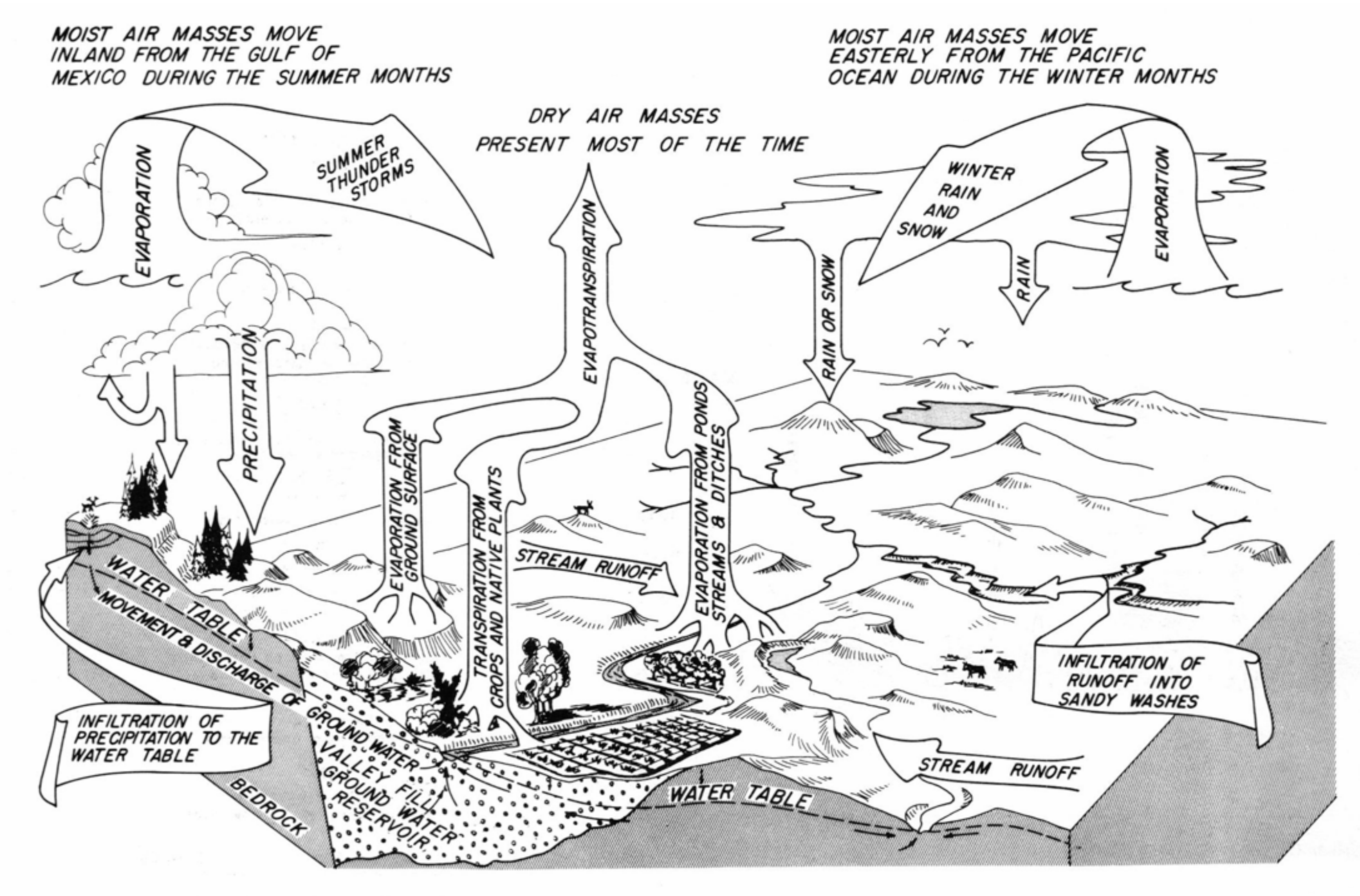


Figure 20—Hydrologic cycle in southwestern New Mexico.

not necessarily coincide.

Hydrologic units, like systems, can be separated from other units for study, development, and management. However, what occurs in one hydrologic unit of a system may noticeably affect other units of the system and consequently may affect the system as a whole.

Water in a hydrologic system or unit occurs mainly as surface water in streams, or as ground water. Water occurs also in systems as soil moisture and in other less obvious ways, none of which are significant in the problems treated in this report.

Many special terms are used to describe the occurrence of water in rocks. The terms used in this report, as well as some geologic terms, are defined in the Glossary of Hydrologic Terms at the rear of this report. Some basic hydrologic principles also are included in the glossary. Fig. 21 diagrams some of the conditions under which ground water occurs. For a more complete discussion of definitions and the principles of hydrology, see Meinzer (1923, a and b) and Tolman (1937).

HOW TO USE THE WATER-LEVEL CONTOUR MAP

The water-levelcontour map (fig. 3) may be used to determine the approximate depth at which water will stand below the land surface. The depth is determined by subtracting the altitude of the water-level surface at a particular place from the altitude of the land surface at that place. The difference is the depth at which the water will stand, in the absence of artesian conditions. If the location in question is near a well, the depth at that well may be used as an approximation, allowing for small differences in surface elevations.

The approximate altitude of the water level can be estimated for any point in the county by using the water-level contour map and interpolating altitudes between contours. The altitude of the land surface is shown by contours on topographic maps available locally for all of Grant County (fig. 4).

The water-level contour map has been drawn using water levels measured in wells for control points. Where wells are close together the map maybe considered accurate enough to permit estimates to within 10 to 25 feet. However, control points are widely scattered in some large areas. In those areas the contours are located only approximately; thus estimates of the depth to water can be only approximate. The depth to water may lower appreciably in areas of large withdrawals of water due to pumping. In those areas the depths to water indicated onthe map may no longer be useful for estimating the depth to water.

The water-level contour map may be used also to determine the direction of movement of ground water, and thus the areas of recharge and discharge. The direction of movement generally is downgradient and at right angles to the contours.

The spacing of the water-level contours can be an indication of the general availability of water in an area. Closely spaced contours commonly mean that the permeability of the rocks is low and that water moves slowly through the aquifer; as a consequence, the rocks do not yield much water to wells. On the other hand, wide spacing of contours commonly means the aquifer has greater permeability and will yield water readily. However, the close spacing of contours does not necessarily rule out the development of high-yield wells. For example, the overall permeability of the Gila Conglomerate is relatively low in many places and so the water-level contours are closely spaced. But within the total saturated thickness of the aquifer in these places there may be individual beds that have a high permeability. A well tapping one or more of these beds could develop a high yield.

ROCK TYPES AND WATER-BEARING CHARACTERISTICS

About fifty distinct rock units in Grant County have been named by various geologists over the years; an equal, or perhaps even greater number of rock units are unnamed. The rock units, named and unnamed, are grouped into four categories: 1) Metamorphic and intrusive igneous rocks; 2) extrusive igneous rocks—flows and pyroclastic deposits; 3) marine sedimentary rocks, and 4) continental sedimentary deposits. The rock units within each category have similar characteristics and the units, therefore, behave in similar manner as aquifers or as confining beds. The physical characteristics and water-bearing properties of the individual rock units are shown on figs. 2 and 18. The figures can be used as a guide to identify the rock units found in drilling, and as an aid in evaluating the prospects for obtaining water.

The important factors determining or controlling the occurrence of ground water are the physical properties of the rocks. For this reason the discussions of the various rock types found in Grant County are directed toward describing the physical characteristics that affect their water-bearing capabilities.

All the geologic formations present in Grant County yield water, at least locally, but the yields from most formations and rock units are small. Some yields are highly uncertain as to permanency. The largest quantities of water are produced from the alluvium and bolson fill; therefore, these deposits can be considered the principal aquifers.

INTRUSIVE AND METAMORPHIC ROCKS

Intrusive rocks as granite, diorite, and the porphyries are formed by solidification of molten rock beneath the surface of the earth. Metamorphic rocks

All inter-connected open spaces in rock formations are saturated below the water table (potentiometric surface), but the rocks will not yield much water to wells if the spaces--joints, fractures, and openings between particles--are few, very small, and widely spaced. Water can move downward easily and quickly through large cracks, fractures, and highly porous rock. As a result the water table may lie far below the surface of upland areas that are underlain by rocks that are permeable. Intrusive and metamorphic rocks generally are not permeable; volcanic and sedimentary rocks generally are permeable enough to allow infiltration and relatively rapid downward percolation of water.

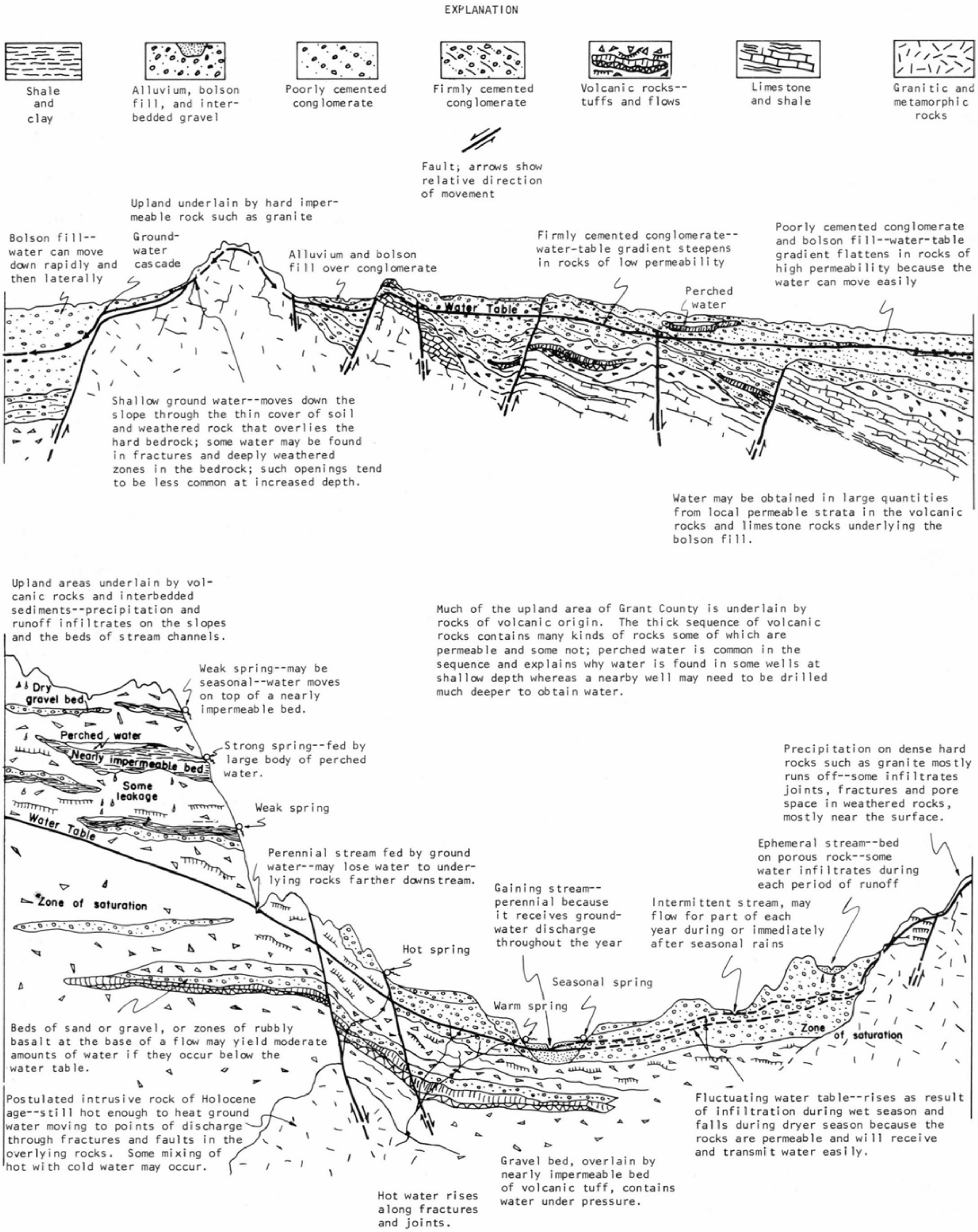


Figure 21–Schematic diagram showing occurrence of water under conditions commonly found in Grant County.

as schist, gneiss, and greenstone are formed from other rocks through processes of heat, pressure, and chemical change.

Granitic rocks (granite and similar rocks—p€g and TKi, fig. 2) are found mostly in the Big Burro and South Burro Mountains, exposed over broad areas and extending to undetermined depths. The granitic rocks range in color from light gray and pinkish gray to orange red. The community of Redrock takes its name from the exposures of the orange-red granite in the vicinity. The color is due to the abundance of orange-red feldspar crystals, a large part of the rock.

Less extensive outcrops of granitic rocks are exposed along the west front of the Little Burro Mountains and Silver City Range, in the Pinos Altos area, in Lone Mountain, the Black Range, and at the north end of the Cooks Range.

Gneiss and schist (p€m) are found mostly in the Big Burro Mountains area; greenstone (p€m) is found exposed along the foot of the mountains just west of San Lorenzo.

The granitic rocks in Grant County generally are coarse to medium grained, dense, relatively impermeable, and nonwater bearing except where deeply weathered and (or) intensely jointed (fig. 22a).

Figure 22a—Jointed and deeply weathered granitic rock (TKi) exposed in roadcut on the Silver City-Pinos Altos road. Water is found locally in very small to small quantities in such weathered granitic rocks.

These rocks commonly weather to loose aggregates of granular material and the weathering may penetrate to a depth of many tens of feet. The schist, phyllite, and greenstone are exposed only in small areas and are not known to yield water. They are, like the granitic rocks, mostly dense and impermeable, but do not weather as readily to loose aggregate (fig. 22b).

Yields to wells finished in the metamorphic and intrusive rocks range from less than one gpm to as much as 15 gpm. Reports of "dry holes" are common. Almost all the higher yields come from wells in granite where the rock is both deeply weathered and intensely jointed.

Davis and Turk (1964, p. 11) studied data for some 2,575 water wells drilled in granitic and metamorphic rocks in the eastern part of the United States, and in the Sierra Nevada of California. They determined that from 5 to 15 percent of wells drilled in unweathered rock were failures, 75 to 85 percent developed yields of less than 8 gpm, and 10 percent had yields of 50 gpm or more. They determined also that water production per foot of well decreases rapidly with increase in well depth, and the decrease is roughly tenfold between depths of 100 and 1,000 feet. Their analysis indicated that the depth of an economically feasible domestic well should be less than 150 to 250 feet in unweathered granitic rocks. Data available for Grant County indicate these conclusions also to be generally valid for areas underlain by granitic and metamorphic rocks.

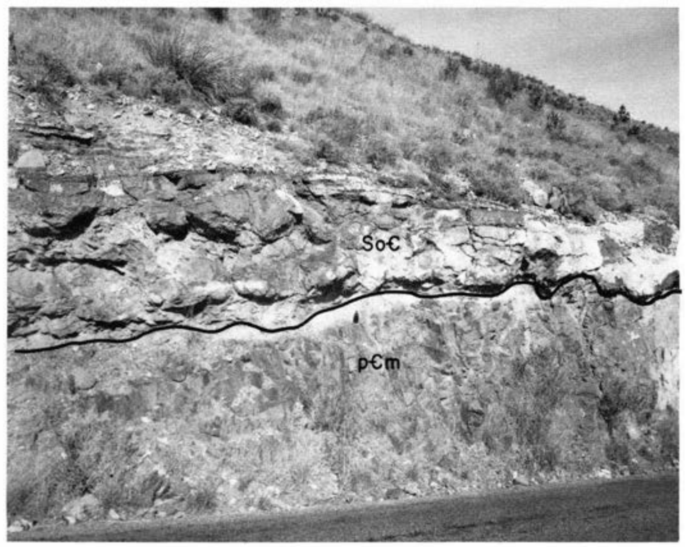


Figure 22b—Greenstone of Precambrian age (p€m) underlying the Bliss Formation (SO€) in roadcut on State Highway 90, about 1.5 miles west of junction with State Highway 61. The greenstone is weathered to a depth of about 1 foot below the contact, and below the weathered zone is dense and relatively impermeable. The Bliss Sandstone wherever found is mostly glauconitic, dense, well cemented, and relatively impermeable. No wells in Grant County are known to obtain water from either the Bliss or the greenstone.

Granite weathers from the land surface downward, and along the planes of both horizontal and vertical joints and fractures. Generally granitic rock is more solid with depth, and the joints and fractures become tighter; consequently, the rock is likely to contain smaller quantities of water at increasing depth. Davis and Turk (1964, p. 6) found that unweathered and unfractured granitic and metamorphic rocks generally will have less than one percent porosity, and will have permeabilities So small as to be almost negligible, but that porosity resulting from weathering commonly ranged from 30 to 50 percent.

The depth to which granite will weather is affected by the depth to which fractures and joints are open, past geologic and hydrologic conditions, topography, and the rock composition. The log of well 22.15. 17. 411 shows decomposed granite to a depth of 365 feet; the log of well 22.15.14.412 shows the granite decomposed to a depth of 260 feet. The main water supply in each well occurs at the bottom-hole depths, where the water is presumed to be on top of solid (unweathered) granite. The depth of weathered granite at these wells is believed to be exceptional. Generally granitic rocks in the region are weathered to no more than a few tens of feet.

Differences in mineral composition can result in zonal weathering in which the granite remains solid in places while decomposition proceeds around a solid core, or spheroid. These spheroids of solid granite, which may be mistaken for "boulders, " commonly have sharp contacts and generally are no more than a few feet thick. Examples can be seen in roadcuts where the highway to Lordsburg crosses the Big Burro Mountains.

The transition at depth from intensely weathered to solid granite generally is moderately abrupt, through a vertical distance of only 10 to 20 feet (Davis and Turk, 1964, p. 7); thus, a spheroidal zone may be suspected if solid rock is found "suddenly" while drilling. Weathered rock may be re-entered after drilling a few feet through the spheroid of solid rock. Water is most likely to be found near the bottom of the weathered zone, just above the main body of unweathered rock.

Granite generally is more deeply weathered under the flatter slopes than under the steeper slopes, and more open-jointed and fractured in the vicinity of large faults. The courses of many creek channels follow lines of faulting and jointing in the granite. Consequently, wells drilled along the major creek channels would seem to offer a better chance of finding water in joints and fractures than would wells drilled on the ridges and interstream areas. However, where deeply weathered granite underlies interstream areas, as south of the Burro Mountains, successful wells generally can be developed; yields commonly are small to very small.

Younger intrusive rocks—the dikes and sills of mostly Tertiary age—generally are also dense and do not contain water in quantities sufficient to supply wells. The dikes commonly act as dams to block the movement of ground water through otherwise permeable beds, and the sills may serve as the "floor" under bodies of perched water.

VOLCANIC ROCKS

Broad areas of Grant County are underlain by lava flows and pyroclastic (fragmental) material blown from volcanoes. Volcanic flow rocks, associated pyroclastic rocks, and some interbedded sediments have accumulated to great thicknesses in many parts of the county. Elston (1958, p. 58) has estimated the maximum thickness of volcanic rocks in the Mogollon Mountain region to be about 8,000 to 10,000 feet. The lava flows at some places, as near Cliff and Hachita, however, are no more than a few tens or hundreds of feet thick and few pyroclastic rocks are present.

About 5,000 feet of interbedded flows, pyroclastic rocks, and minor thicknesses of sediments are exposed in the canyon walls of Mogollon Creek from the summit of Mogollon Peak (altitude 10, 778 feet) in Catron County down to the mouth of the canyon in sec. 13, T. 13 S., R. 18 W., in Grant County. Ferguson (1927, p. 5-6) describes similar rocks in a sequence about 7,200 feet thick in the vicinity of Mogollon in Catron County just north of the Grant County line. Comparable thicknesses are believed to underlie most of the northern highland areas of Grant County. About 2,500 to 3, 000 feet of volcanic rocks are exposed in Dark Thunder Canyon from the summit of Tillie Hall Peak (altitude 7,318 feet) down to Smith Ranch (sec. 5, T. 16 S. , R. 21 W.) on the west side of the Summit Mountains; the base of this volcanic sequence is not exposed. Kuellmer (1954, pl. 1) shows a total thickness of about 3,200 feet for the volcanic rocks of Tertiary age on the west side of the Black Range. About 7, 700 feet of volcanic rocks of Cretaceous and Tertiary age were measured by Lasky (1947, p. 13) in the Little Hatchet Mountains.

The volcanic flow rocks may be grouped into two main categories distinguished by color and flow characteristics—dark-colored rocks that spread out in thin sheets over broad areas and lighter colored rocks that tend to accumulate as thick piles, not normally extending great distances from the point of eruption.

The pyroclastic rocks are associated mainly with the lighter colored flow rocks, and generally are also of light hue. However, unlike most of their associated flows, many of the pyroclastic rocks extend to great distances. The Kneeling Nun Tuff is an example of a broadly distributed and distinctive rock unit of pyroclastic origin.

Correlation of the thick sequence of volcanic rocks beneath most of the highland areas of the north part of Grant County has been a problem for years. Some of the distinctive lithologic units and sequences have been considered part of the Datil Formation. The Datil Formation was named by Winchester (1920, p. 4) for rocks exposed in the Datil Mountains north of Datil, and in the Bear Mountains north of Magdalena where he described a type section. Other equally distinct rock units of similar character and origin in Grant County were not included in the Datil Formation, because they did not seem to fit properly into Winchester's type section.

Elston (1968) has shown that the great bulk of the volcanic material in the region has resulted from cyclic eruptions of an andesite-rhyolite-basalt sequence repeated at least three times. Elston has shown also that the type Datil Formation at the type locality described by Winchester corresponds only to the first cycle of eruptions. Significantly the eruptions came from various centers; and no single cycle of rocks completely covered the area. Also significant is that rocks erupted from a center during a particular phase of one cycle are found to overlap rocks of a different phase being erupted frorr another center in an adjacent area. The intertonguing of different rock types from different centers has resulted in the extremely complex relationships found in the region.

Elston's (1970) compilations of potassium-argor dates (ages of rock units based on decomposition of radioactive material in the rocks) have shown that various rock units assigned to Winchester's type Datil are from about 29 to 38 million years (m. y.) old (Oligocene age). Many of the volcanic rocks in northern Grant County, similar in appearance and assigned to the Datil by Dane and Bachman (1965) or earlier workers, are within the same age range as recognized Datil rocks. However, other rock units that have been referred to the Datil are less than 21 m. y. The great bulk of the volcanic rocks in northern Grant County must, therefore, be of Oligocene and Miocene (middle Tertiary) age.

Some volcanic rocks of similar appearance and character in the Coyote Hills and Cedar Mountains of southern Grant County probably will be found to fall within the same age ranges as the type Datil rocks when potassium- argon dates are made; other rocks probably will be found to be somewhat younger, just as in the northern part of the county.

Partly to avoid perpetuating errors of correlation, and partly for purposes of simplifying the geologic map, rocks previously designated as Datil on earlier maps have not been shown separately on the geologic map (fig. 2). Instead, volcanic rocks of similar types (Tertiary to Quaternary and Tertiary) are shown in the same color. Whether or not given units should be assigned to the Datil Formation (or whether the Datil might better be assigned group status) is undetermined.

Dark-colored Flow Rocks

The dark flow rocks, mostly basalt or andesite, commonly are called "malpais. " The color ranges from medium gray to black, but purplish-gray and reddish-brown tones are common color variations. Balsatic flows generally are associated with less violent volcanic activity and occur as relatively quiet emissions from fissures. Successive flows at many places accumulated to form sequences several hundreds of feet thick. Elsewhere, single flows a few tens of feet thick lie betweenbeds of sand, gravel, or conglomerate (fig. 23). Andesite and basaltic flows may issue repeatedly from a central point and may in time build up a large mountain from which the flows spread in all directions. Black Mountain in Catron County, about 12 miles north of Gila Hot Springs, is a comparatively young volcano (Elston, 1965b, p. 172) from which lava spread far to the south into Grant County. The two Brushy Mountains, T. 14 S., R. 13 W. (fig. 8), and T. 15 S., R. 20 W.,

Figure 23—A thin basalt flow (Tba) interbedded with the lower part of the Gila Conglomerate (QTg), NW¼NE¼SE¼ sec. 8, T. 16 S., R. 17 W., southwest of Cliff. Wells finished in these types of rocks generally yield only small amounts of water. So-called "sheet water" sometimes is found at the rubbly base of a basalt flow where it may be perched on the dense upper surface of an underlying flow, on the clayey surface of a soil zone between flows, or on another nearly impermeable rock such as the lower part of the Gila Conglomerate.

are believed also to be basaltic volcanic cones of late Tertiary age.

The andesitic and basaltic rocks range from dense to extremely vesicular, from fine grained to porphyritic, and from massive to well jointed. Vesicular structure is conspicuous locally and the vesicles may be filled or partly filled with whitish minerals, commonly calcite or one of the zeolitic silica minerals.

The base of a thin lava flow commonly is a zone of scoria and rubble formed as the flow advanced and rolled over the crusted and broken surface that forms at the front of the flow. Thick flows generally retain sufficient heat to re-melt solidified blocks over which the flow advances.

Vertical and horizontal joints generally form in lava flows as the molten rock cools. Joints may be few and far apart, or numerous and closely spaced; and they may result in the formation of distinct massive columns or platy sheets that weather to a fragmental rubble.

Light-colored Flow Rocks

The light-colored flow rocks are mostly rhyolite or latite. The color ranges from nearly white to medium gray; varying shades of pink and orange red are common color variations, particularly on weathered surfaces.

Rhyolite and latite flows are less fluid than basalts and tend to build up locally thin accumulation of rock rather thanto spread out as thin sheets. The major vent areas also may build large mountains or volcanoes and these generally have steeper slopes than do the basalt cones. The rhyolitic rocks generally are dense, and jointing is apt to be complex; flow banding in intricate pattern is common. Rubbly zones may occur locally within flows and between individual flows.

Rhyolite and latite flows commonly are associated with explosive volcanic activity accompanied by ejection of large amounts of pyroclastic material with which the flows are interbedded (fig. 24a).

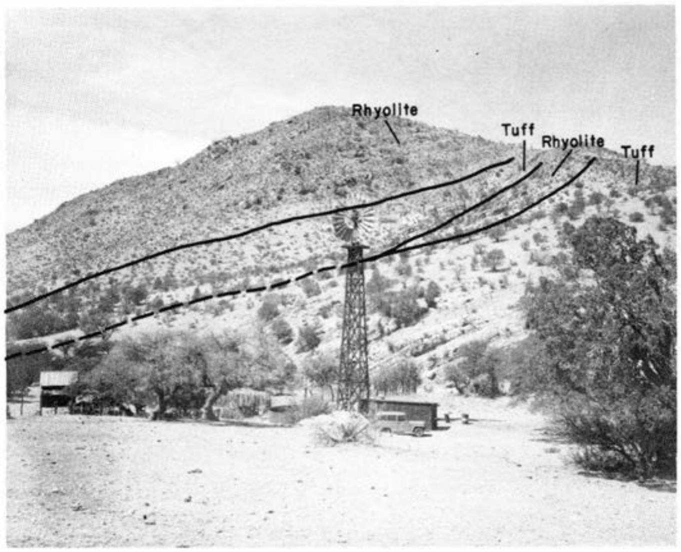


Figure 24a–Rhyolitic volcanic rocks of Tertiary age (Tr) in Carrizo Canyon, southwest flank of the Black Range; in the background is a faulted section of flow-banded stony rhyolite overlying bedded pumiceous rhyolite tuff; both are units of the Mimbres Peak Formation of Elston (1957, p. 27) which he later referred to as the Mimbres Peak Rhyolite (1965b, p. 174). The bedded tuffs at creek level dip southwest at about 30°. Well 18.9.16.442, in the foreground, obtains water from the volcanic rocks. It is about 375 feet deep and the static water level is about 280 feet below land surface; yield is reported small but reliable.

Pyroclastic Rocks

The pyroclastic rocks consist of material which was ejected aerially as fragmental material in the course of volcanic eruption. The fragments are similar in composition to flow rock if flows occur, but the color may be much different. They may range in size from minute particles to huge blocks. The smallest particles commonly are called "ash"; pumice is a light-colored glassy froth that will float and which generally breaks rapidly to tiny fragments; cinders and scoria generally are glassy to finely crystalline, light-gray to black fragments that are less than an inch in diameter.

Tuff is formed by consolidation of pyroclastic fragments; and when the larger fragments comprise up to 75 percent, the rock is called a tuff breccia. All these pyroclastic rocks are widely distributed in Grant County.

Pyroclastic rocks, such as the Kneeling Nun Tuff that forms the prominent rimrock above and southward from the Santa Rita Pit, were ejected at high temperatures that caused the fragments to partly or completely fuse after deposition (fig. 24b). Some of

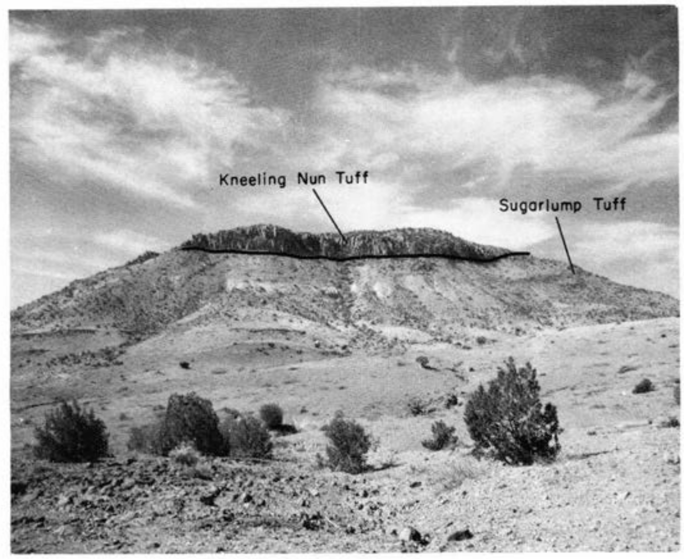


Figure 24b–Rhyolitic pyroclastic rocks of Tertiary age (Tr) comprise most of the deposits exposed in Blue Mountain in sec. 19, T. 19 S., R. 10 W. The Kneeling Nun Tuff caps the interbedded ashflows and water-deposited tuffs of Elston's Sugarlump Tuff.

the best exposures of pyroclastic rocks can be seen along state road 61 from San Lorenzo to Faywood Hot Spring in the Mimbres Valley (Elston and Netelbeck, 1965).

Dust-size particles of volcanic ash may be windborne to great distances and deposited as thin beds; ash deposits have been found interbedded with other rocks hundreds of miles from the nearest eruptive center. The coarser and heavier fragmental material falls close to the point of eruption where its accumulation helps to build up the volcanic cone. These accumulations of coarse fragments generally are highly permeable and allow rapid infiltration of precipitation. They are excellent aquifers where they lie below the water table.

Almost every thick sequence of pyroclastic rocks contains discontinuous interbeds of clay, silt, sand, and gravel. They form because the streams continue to erode and deposit sediments even as the volcanic rocks are being erupted. Lava flows may dam the rivers and create temporary lakes into which volcanic ash settles and coarser material is carried by the river's. To determine locally if a rock is purely of volcanic origin, or is a mixture of pyroclastic and sedimentary material can be difficult.

Some of the sediments, especially the coarser materials, may serve as aquifers and yield small to large amounts of water. The rock unit designated by the symbol "Ts" on the geologic map contains water - bearing beds. However, some sediments found interbedded with the pyroclastic and flow rocks are mixtures of clay and sand, ash, pumice, anc coarse pyroclastic material. They generally are poor aquifers, but locally may yield a few gallons per minute (gpm); commonly they are confining beds because of their poor sorting.

Most of the pyroclastic rocks are dense, massive, and relatively impermeable; therefore, poor aquifers. A formation as the Kneeling Nun Tuff is more likely to be a confining bed rather than ar aquifer. Effective porosity in the massive pyroelastic rocks, as in the flows, is limited largely tc joints and fractures which tend to be closed at depth, Deposits of coarse, unconsolidated volcanic fragments make good aquifers if they occur below the water table, but such occurrences are uncommon and unpredictable. They are most apt to be found as relatively thin layers interbedded with flow rocks.

Well- sorted water- deposited beds of mostly pyro-elastic material are found locally interbedded with flows and tuffs in the Little Burro Mountains, Pinos Altos Mountains, Santa Rita Hills, and Cobre Mountains. These beds are known to yield water to stock wells (19. 10. 7. 232, 19. 10. 29. 211, and others) in the vicinity of Dwyer, and are believed to be the source of artesian water in well 19. 10. 33. 221.

MARINE SEDIMENTARY ROCKS

The marine sediments consist of two types, carbonate rocks and elastic rocks. The carbonate rocks are limestone and dolomite composed of carbonates of calcium and magnesium. The elastic rocks are shale, siltstone, and conglomerate derived from the weathering and disintegration of other rocks. Thick sections of both types crop out in the central and southern parts of Grant County.

The marine sediments in the central part are not as thick as those in the southern part. The aggregate thickness in the Silver City-Santa Rita area ranges from about 3,200 feet to 4,400 feet. The carbonate rocks range from about 1, 800 to 2, 300 feet and the elastics from about 1, 400 to 2,100 feet. In the Little Hatchet Mountain area, Lasky (1947, p. 12) measured continuous exposures ranging from 17, 000 to 21, 000 feet thick and reported a possible aggregate thickness of about 26,500 feet. Carbonate rocks make up about 6, 000 feet and elastics 12, 000 feet in measured sections having a total thickness of about 18, 000 feet.

The greatest thickness of marine sediments penetrated by wells in the Silver City-Santa Rita area is the 2, 275 feet drilled in well 19. 12. 19. 132d at Apache Tejo (log, table 15). About 1, 900 feet were penetrated in well 17. 12. 23. 413a (see log) near Santa Rita. The Beartooth Quartzite and the Colorado Formation of Cretaceous age, which average about 1, 100 feet thick in this area, are missing in these two wells; the sediments penetrated are mostly carbonate rocks of Paleozoic age.

Marine carbonate and elastic rocks generally are intimately associated. Thin beds of one type are commonly interlayered in thick sequences of the other type. Units such as the Howells Ridge and Syrena Formations may contain both types in thick beds of nearly equal proportions.

Marine sedimentary rocks are exposed or lie at shallow depth in about 150 square miles, or about 4 percent of the county. However, about 75 percent of the population of the county lives in this area. The distribution of the marine rocks and the occurrence of water in these rocks, therefore, is significant.

The pattern of surface exposures and the logs of wells 19. 10. 27. 234 and 19. 12. 19. 132a (table 15) indicate that marine sediments underlie all the volcanic rocks between the Mimbres Valley and a line along the west side of the Silver City Range and San Vicente Arroyo at least to the county line. Exposures of lower Paleozoic rocks in the Lordsburg Valley and the thick marine sediments in the Little and Big Hatchet Mountains indicate that similar deposits also underlie the bolson fill of southern Grant County. These rocks could be reached by deep wells.

The depth to the marine deposits in the bolsons is conjectural. The bolson fill is several thousands of feet thick locally; as much as 7,000 feet of volcanic rocks could lie between the base of the bolson fill and the top of the marine sediments.

Carbonate Rocks

The carbonate rocks are massive to thin bedded, generally dense, finely crystalline, commonly sandy, silty, and cherty (fig. 25a). The colors range from nearly white through all shades of gray to black; some weather to shades of tan and brown. Fossils are common in all but a few of the limestone beds but are rare in the dolomite and marble.

Figure 25a—The Oswaldo Formation (ℙM), composed mostly of limestone, is exposed in the roadcut in Gooseneck Hill west of Hanover. Limestone beds in the Oswaldo generally are dense, and some beds contain abundant chert. Joints and bedding planes generally are open near the land surface and closed at depth. Yields to wells are very small to small.

Figure 25b—Fractured and brecciated zone in the Oswaldo Formation (IPM) resulting from a minor fault having only a few feet of displacement. Such brecciated zones where penetrated below the water table can yield moderate to large quantities of water to wells.

Joints and fractures are well developed only in the vicinity of faults, folds, and large intrusive bodies (fig. 25b). Solution cavities and channels are not conspicuous in any outcrops and are uncommon at most places underground in the Santa Rita-Bayard mining district (oral commun. , Don Miller and Keith Lobiano, U. S. Geological Survey, 1954, and R. M. Hernon, U.S. Geological Survey, 1965). Miller and Lobiano also reported that limestones in the mines commonly are brecciated along fault zones and have cavities enlarged by solution. However, they are dense and relatively nonporous away from the faults and brecciated zones.

Lasky's (1947) descriptions of carbonate rocks in the Little Hatchet Mountains and the appearance of the rocks underground indicate that in that area also they are mostly dense, finely crystalline and not apt to be good aquifers. However, Lasky also noted the development of solution channels in zones of faulting and brecciation.

The knowledge that solution channels are likely to occur in zones of faulting canbe utilized to advantage in searching for ground water in the carbonate rocks. Wells drilled to enter fault zones below the regionalwater table have a better chance of developing moderate to large supplies of water than do wells drilled in the carbonate rocks where there are no faults.

Carbonate rocks are more likely to yield water in Grant County than other marine rocks. Yields range from very small to large depending on the structure of the rock, the depth of penetration, and the topographic position. Wells drilled deeply into these rocks are likely to find more joints and fractures and develop moderate to large supplies of water. Shallow wells that penetrate a relatively few feet below the water table seldom yield more than a few gallons per minute. Well 17. 14. 32.233 near Silver City penetrated only 76 feet below the water table in the carbonate rocks; the yield was initially 1-1/2 gpm and that reportedly declined to less than 1 gpm within a year.

Most domestic and stock wells that penetrate less than 100 feet below the water table in the carbonate rocks produce less than 5 gpm; the results of deeper penetration are revealed by records of other wells. Well 17. 12. 20. 244a, near Hanover, penetrated 13E feet below the water table and yielded about 9 gpm. Well 17.12. 23. 413, 998 feet deep (log, table 15), bottomed in the Percha Shale after penetrating all the upper Paleozoic rocks; it reached 516 feet below the water table; the yield is about 185 gpm. Well 17.12. 23. 413a, 2,115 feet deep (log, table 15) reached 1,135 feet below the water table and penetrated the Precambrian bedrock. The yield, believed to be all from lower Paleozoic rocks, was about 235 gpm.

The American mine in the Little Hatchet Mountains is in carbonate rocks of Early Cretaceous age that were intruded by monzonite. Lasky (1947, p. 85-87) shows some 1,600 feet of tunnels below a water level of about 50 feet and cites reports that 125 to 150 gpm were pumped to keep the mine dewatered to the 250-foot level. The dewatering extended over a wide area and drained nearby mines as well. Lasky interpreted these reports to indicate that ground water was moving "through a system of fairly open channelways. " The channelways are primarily joints and fractures in the carbonate rocks. The reports, considered reliable, suggest that the occurrence of water in the carbonate rocks is about the same in both the central and southern parts of the county.

Joints, fractures, and solution channels in the carbonate rocks may not be numerous but they are sufficiently well developed and interconnected to allow easy movement of water. As a consequence, water that infiltrates these rocks on the hill slopes can move quickly down to the water table which, as Lasky (1936, p. 10) noted in the Bayard area, lies at about the same altitude as the streambeds.

It may be inferred that the best place to find the water table at a shallow depth in areas underlain by the carbonate rocks is near the channel of a major stream. However, because of the generally low porosity and small amount of water in these rocks, it may be necessary to drill at least 100 feet below the water table to obtain a supply of water adequate for domestic or stock use.

Perched water is common in both the carbonate and elastic rocks, and any water found appreciably above the level of nearby streambeds or the water surface as shown in fig. 3 is likely to be perched. The supporting bed in the carbonate rocks generally is a layer of siliceous limestone or fine-grained elastic rock as shale or siltstone.

Clastic Rocks

The marine elastic rocks consist of shale, shaly sandstone, and lesser amounts of siltstone and con-

Figure 26a—Hard, well-cemented sandstone bed in the Colorado Formation (Kc) exposed in roadcut on State Highway 180 west of Central. Blasting has opened joints and fractures that normally would be closed. Most sandstone beds in the Colorado Formation are dense and yield only very small amounts of water.

glomerate. The shales range from light tan, red, and yellow through dark green, and brown to black. The sandstone is mostly light colored, tan to light gray or white, and well cemented (fig. 26a). Lasky (1947, p. 24) mentions the occurrence of black sands in the Corbett Sandstone in the Little Hatchet Mountains.

Clean, well-sorted beds of sandstone are uncommon; most contain appreciable amounts of shale and silt. On the other hand, thick beds of shale containing little or no sand are found in all areas underlain by the marine clastic rocks.

Clastic rocks of marine origin are not good aquifers in Grant County. None of the clastic units are known to yield more than small amounts of water. Reports indicate that dry holes have been drilled to depths as great as 300 feet in the Colorado Formation in the area between Silver City and Bayard. However, as a general rule, a well drilled 200 to 300 feet below the water table in the marine clastics can be expected to yield a supply of water adequate for domestic and stock use.

Artesian water has been found in both the carbonate and clastic rocks in the central part of the county. Wells 17. 14. 21. 323 and 17. 14. 22. 331 developed small flows from depths of 690 and 145 feet, respectively. These two wells were drilled in the Colorado Formation; the water is presumed to be in beds of sandstone and to be confined by shale.

The occurrences of artesian water in the Colorado Formation appear encouraging. However, they are exceptions rather than the rule, and they serve to point up a situation where artesian flow, dry holes, low yields, and uncertain supplies are found in the same general area and in the same rock formation.

A lack of pattern in the occurrence of water has been noted in all areas underlain by the Colorado Formation, but the situation becomes chaotic in the area between Silver City and Central owing to the intrusion of a complex system of dikes (fig. 26b).

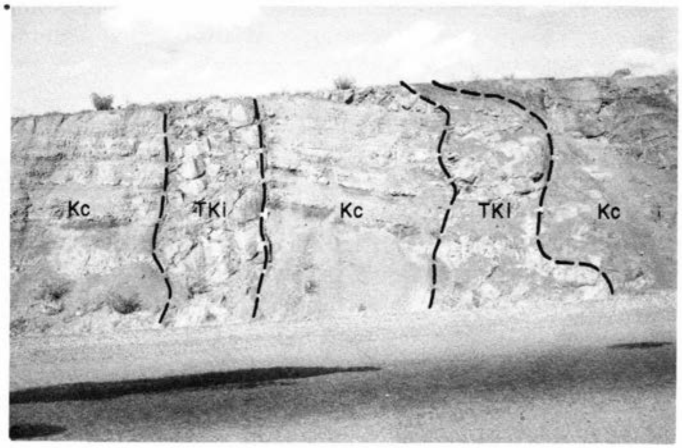


Figure 26b—Beds of the Colorado Formation (Kc) cut by basic igneous dikes (TKi) of Tertiary age—roadcut on State Highway 180 just east of Silver City. The Colorado Formation yields very small to small amounts of water and the widespread occurrence of dikes makes finding water uncertain.

Water-table contours (fig. 3) based on moderately scattered wells, indicate a rather uniform southerly slope to the water table in conformance with the general slope of the land surface. Reports of well owners indicate, however, the lack of uniformity of occurrence of water. One well may penetrate several hundreds of feet and be relatively dry, then pass through a dike and find water that will rise in the well. Another nearby well may encounter water at much shallower depths, or not at all, even though drilled deeper than the neighboring well.

The dike systemtrends roughly north-south to N. 30° E. , more or less parallel to the general slope of the land surface. Consequently, the influence of the dikes on the elevation and general slope of the water table is minimized, but may have a profound influence on individual wells.

No well in the general area between Silver City and Central is known to produce more than a few gpm. Many of the wells have histories of depletion and subsequent deepening until more water was found. The data suggest that the Colorado Formation, inherently a poor aquifer, has been made poorer as a result of compartmentalization by the dike system.

Water occurs in the compartment-like bodies or pockets formed by the crosscutting and intersection of dikes, and initial yields to wells may be ample. However, these pockets may be depleted rapidly and a well that first had an adequate yield may be dry within a few months.

CONTINENTAL SEDIMENTARY DEPOSITS

The continental sedimentary deposits are the largest and most important sources of ground water. These deposits comprise several named geologic formations and many unnamed sedimentary units of sequences, all laid down on the land surface by streams, in lakes, or by the wind; similar deposits are currently accumulating at many places. They consist of unconsolidated deposits of boulders and gravel, sand, silt, and clay, and their consolidated equivalents— conglomerate, sandstone, siltst one , and mudstone.

Continental deposits that have been given formational names are the Gila Conglomerate (Gilbert, 1875, p. 540), the Wimsatville Formation of Hernon, Jones, and Moore (1953, p. 120), Virden Formation of Elston (1960), and Ringbone Shale (Lasky, 1947, p. 18-19). Formations as the Datil, Rubio Peak, and Hidalgo Volcanics, consisting mainly of volcanic rocks, contain interbeds of sand and gravel that locally may yield water.

Poor sorting and a large content of fine-grained, tuffaceous material is characteristic of almost all the named formations except the upper part of the Gila Conglomerate. Consequently, most are poor aquifers.

Continental sedimentary deposits are locally interbedded with volcanic rocks of Cretaceous and Tertiary age (fig. 23), but they are most common as the thick deposits of Quaternary age that fill the valleys and underlie the slopes up to the higher mountains. These continental sedimentary deposits are also found locally capping mesas in the upland are as .

Gila Conglomerate

The Gila Conglomerate (late Tertiary and early Quaternary) is the best known and most widespread of the continental deposits in Grant County. The Gila consists of poorly sorted sediments that range from unconsolidated to strongly consolidated. The sediments are nonbedded to well bedded and locally are monolithic. Two major divisions of the Gila, an upper and a lower, can be recognized throughout. Lake deposits interbedded with some sand and gravel underlie a broad area in the northwest part and constitute a locally important subdivision of the upper part of the Gila. Other subdivisions of the Gila have been recognized locally but are not important to this study.

The mode of origin of most of Gila, with the exception of the lake deposits, is analogous to the present formation of overlapping alluvial fans along the fronts of block-fault mountain ranges.

The upper and lower parts of the Gila are difficult to differentiate in many places because they are gradational and their lithology is similar. Where they are unconformable the contacts generally are concealed by mantles of weathered rock; the weathered products of similar conglomerates and related deposits are not easily distinguished. For this reason, the units were not mapped on a countywide basis. The principal differences are degree of consolidation and lithologic character of included constituent rocks.

The lower part of the Gila generally is strongly indurated, and locally deformed and intruded by younger volcanic rocks (figs. 27a, b). Older basalt flows can be found locally interbedded with the clastic rocks, particularly in the lower part of the Gila (fig. 23). One of two andesitic basalt flows in the basal part of the Gila Conglomerate exposed at the spillway at Roberts Lake has been dated by potassium-argon methods and assigned a middle Miocene age of 20.6+0.5 million years (Elston and Damon, 1970, p. AVI-6). The upper part of the Gila also has some interbedded basalt flows, but they are not as prevalent as in the lower part. A flow in the upper-

Figure 27a— Basaltic dike (Tba) intruding lower part of Gila Conglomerate (QTg); on Cottonwood Creek, west side of the Silver City Range, adjacent to well 17.15.7.313. The dike is a feeder to a basalt flow higher in the section.

Figure 27b—Lower part of Gila Conglomerate (QTg), dipping southwest, on the north side of the dike shown in "a." The man is standing beside a projection of basalt (Tba) from the main body of the feeder dike.

most part of the Gila, visible as a rimrock east of the community of Mimbres, has been dated at 6.3+ 0.4 million years (Elston, 1968, p. 239), thus of late Pliocene age.

The clastic materials of the lower part of the Gila consist mostly of fragments of light-colored volcanic rocks derived by weathering from the thick and widespread volcanic deposits of Oligocene to middle Miocene age. The conglomerates are coarse; the larger rock fragments are characteristically subrounded to angular, and the matrix binding them contains a high percentage of fine sand, silt, and tuffaceous materials (figs. 28a, b). Good exposures of the lower part of the Gila can be seen in a creek-

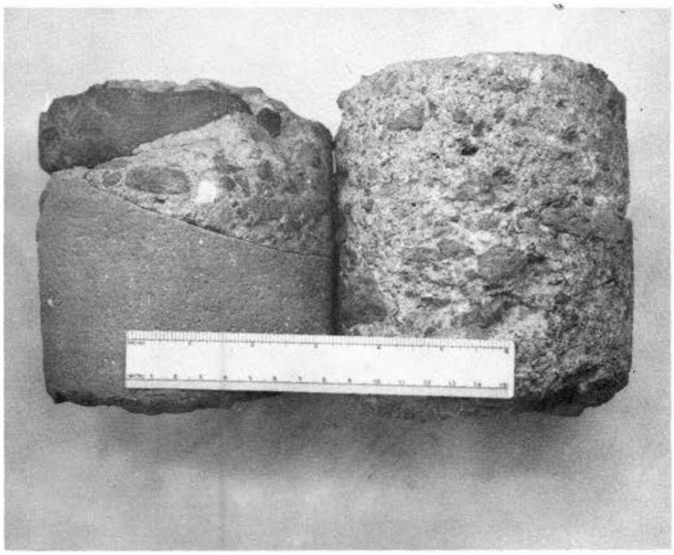


Figure 28a–Cores of the lower part of Gila Conglomerate (QTg) taken from test well 19.14.1.143a in Pipe Line Draw. The well reportedly was drilled to a depth of 1,003 feet, the static water level was about 134 feet below land surface, and the well could be bailed dry.

Figure 28b–Lower part of Gila Conglomerate (QTg) exposed in bank of draw in the NW¼ sec. 16, T. 18 S., R. 14 W., about 1 mile southwest of Silver City. Most of the large angular blocks of rock, some as much as a foot across, are composed of rhyolite or andesite. The beds dip easterly at about 3 to 4°.

Figure 29a–Lower part of Gila Conglomerate (QTg), dipping about 25° west, exposed in Pipe Line Draw, just north of Tyrone. Pipe Line Draw is believed to have developed along the trace of a major fault zone. The lower part of the Gila is widely exposed east of the draw where the upper part is absent generally and wells produce only small amounts of water. However, from 700 to 900 feet of the upper part has been penetrated in wells west of the draw, and some of the wells have large yields.

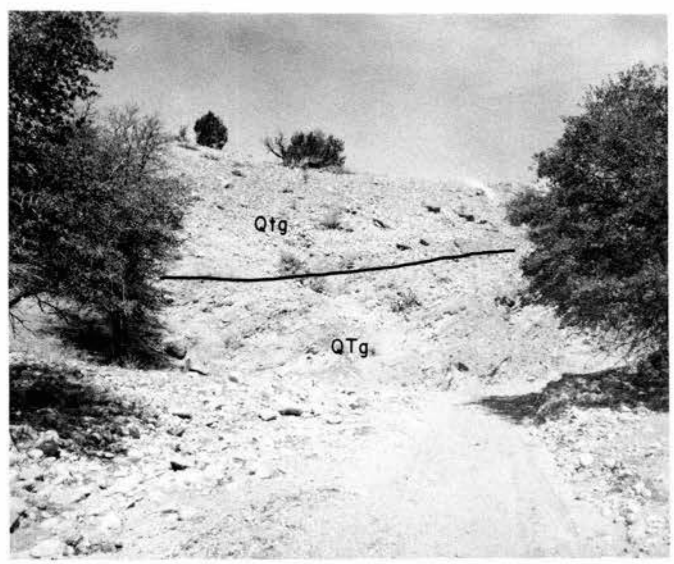


Figure 29b–Lower part of Gila Conglomerate (QTg), dipping about 44° southwest, exposed in Carrizo Creek on the west side of the Black Range. Terrace gravel (Qtg) of Quaternary age overlies the Gila. The terrace gravels generally are thin and above the water table; they rarely yield water except where perched water or sheet water may be found locally in small quantities.

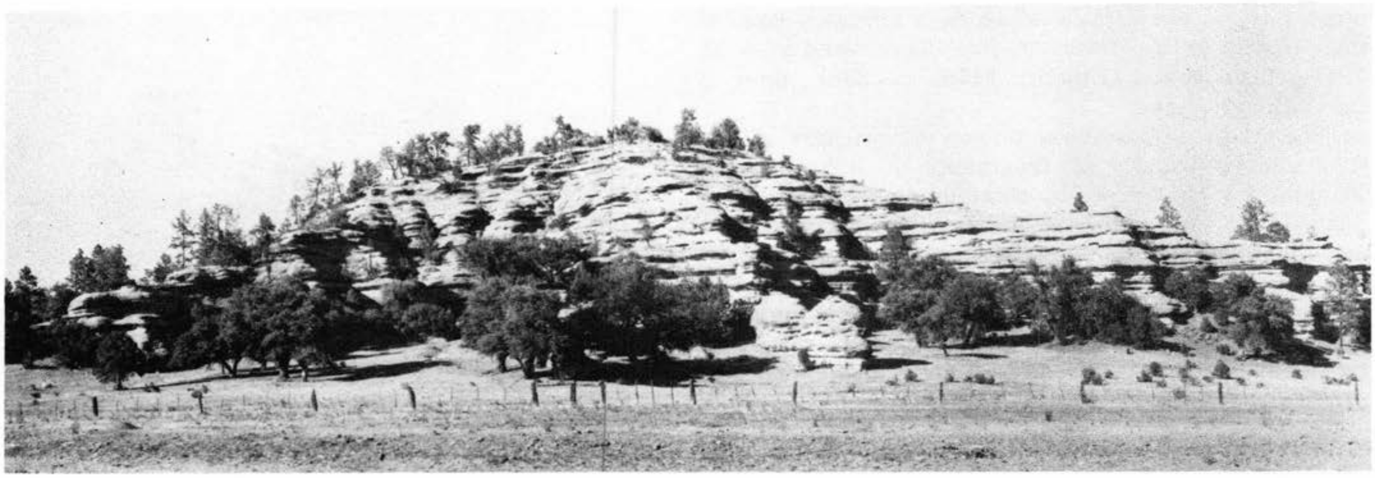


Figure 30—Nearly flat beds of Gila Conglomerate (QTg) exposed east of State Highway 61, 1.4 miles north of the Mimbres Ranger Station. Differential weathering of alternately well cemented and moderately cemented beds is responsible for the etched relief of the outcrop. Yields to wells tapping the lower part of the Gila in this area generally are small; most wells obtain water at shallow depth in the alluvium overlying the Gila.

bank in the NW1/4 sec. 16, T. 18 S. , R. 14 W. , (fig. 28b); in Pipe Line Draw, SE1/4 sec. 29, T. 18 S. , R. 14 W. , (fig. 29a); in the banks of Carrizo Creek (Black Range) in the SE1/4 sec. 21, T. 18 S., R. 9 W. , (fig. 29b), and along the highway in the upper Mimbres Valley, north of Mimbres Ranger Station, in sec. 36, T. 15 S., R. 11 W. , (fig. 30).

The base of the lower part of the Gila is well exposed at stream-bed level in Wind Canyon, in the SW1/4 sec. 9, T. 18 S., R. 15 W. Large angular blocks of volcanic rock in a matrix of tuffaceous sand and related volcanic debris lie unconformably on older volcanic flow rocks. Bedding cannot be discerned in this lowermost part of the Gila Conglomerate. The size and extreme angularity of the larger rock masses, some of them several feet in diameter, indicate rapid accumulation and proximity to source.

The upper part of the Gila Conglomerate generally is no more than slightly consolidated. It may be somewhat deformed locally but much of the apparent dip results from deposition on slopes that fanned out from the base of the uplands from which the deposits came.

Thick sections of the upper part of the Gila are exposed west of Pipe Line Draw in road cuts on State Highway 90 between Silver City and Lordsburg, in the cliffs that border the Gila River near Redrock, in the gravelly slopes that border the Mimbres and Mangas Valleys (figs. 31a, b), and along State Highway 180 where the road descends into the Valley of Little Dry Creek just south of the Grant-Catron county line.

Figure 31a—Upper part of Gila Conglomerate (QTg), cut by small fault, exposed in roadcut on State Highway 90, 0.75 mile southwest of Tyrone. These beds, which contain much weathered granitic material generally are poorly consolidated. They yield moderate to large amounts of water where found below the regional water table.

Figure 31b—Uppermost part of the Gila Conglomerate (QTg) exposed in roadcut on State Highway 90, east of San Lorenzo. Note alternation of coarse and finer bedded deposits, none of which are more than poorly consolidated. The upper part of the Gila near San Lorenzo yields large amounts of water locally.

The composition of the upper part of the Gila varies more from place to place than does the lower part even though the two parts were formed in the same manner. The variation resulted because greater variety of rocks were exposed to erosior when the upper part of the Gila was deposited. The lower part was derived mainly by erosion of the volcanic rocks of Tertiary age which covered nearly al] older rocks. The upper part of the Gila was deposited after an interval of time in which many of the rocks of the region, including the lower part of the Gila, were faulted and deformed. The deformation and faulting raised some of the older nonvolcanic rocks and made them also subject to erosion. Al] of the older rocks thus have contributed material to the upper part of the Gila; therefore, its component sediments have a variety not found in the lower part.

The ability to distinguish between the upper and lower parts of the Gila, in drill holes, is important in the search for ground water. The lower part of the Gila furnishes very little water to wells; the upper part can furnish moderate to large amounts.

Because erosion of the lower part of the Gila also contributed sediment to the upper part, distinguishing between the two on the basis of rock types is difficult. They are best distinguished at the surface by percentage of volcanic rocks, degree of consolidation, attitude, and stratigraphic and topographic position. The hardness, or degree of consolidation, and the percentage of volcanic rocks locally, help differentiate the two parts in drill holes.

Well 18. 14. 30. 324 in Silver City's Woodward Ranch well field penetrated about 890 feet of unconsolidated to poorly consolidated deposits considered to be the upper part of the Gila. The deposits consist largely of feldspar and quartz fragments derived from the granitic rocks in the Big Burro Mountains. At about 890 feet the drill entered very hard conglomerate, composed mostly of volcanic rock, considered to be the lower part of the Gila. The well had a drawdown of about 110 feet after pumping 400 gpm continuously for 2 weeks. All of the water came from the upper part of the Gila.

A test well (19.14.1. 143a) in Pipe Line Draw, about 5 miles east-southeast of the Woodward well, penetrated 1,003 feet (log, table 15) of the firmly cemented lower part of the Gila (fig. 26a). This well, drilled in 1944 for Silver City, reportedly would yield no more than 40 gpm when tested. The yields of these two wells show the characteristic difference in hydrology between the upper and lower parts; and why recognizing them in drill holes is important.

Lake Deposits and their Origin

One consequence of the last period of general and rather severe faulting and deformation in this region was the disruption of major lines of drainage and the subsequent formation of some large but temporary lakes. Finely bedded clay, silt, volcanic ash, and diatomite (siliceous material derived from microscopic plantlife called diatoms) was deposited in the quiet waters of the lakes. Coarse-grained deposits were laid down generally on the margins and where streams entered the lakes. The most extensive deposits are in the Duck Creek Valley where they are exposed in the banks of Duck Creek (fig. 32) in low hills (erosional remnants) that rise from the valley floor (fig. 16), and in the lower slopes along the western margin of the valley north of Buckhorn. The lake deposits in Duck Creek Valley may be as much as 1, 000 feet thick.

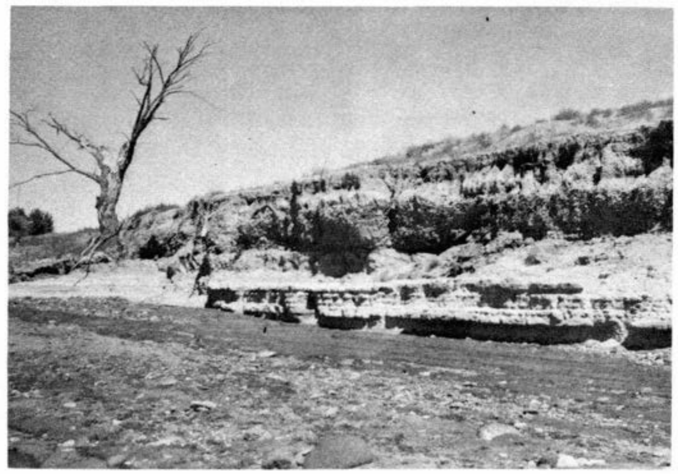


Figure 32—Lake deposits exposed in banks of Duck Creek, near Buckhorn (SW¼ sec. 11, T. 15 S., R. 18 W). The deposits are in the uppermost part of the Gila Conglomerate (QTg). They were laid down in a lake that occupied the valley for a brief time following the last major uplift of the Mogollon-Silver City-Little Burro Mountain Ranges. The beds of clay and silt confine water locally in deposits of sand and gravel.

Other probable lake deposits in the upper part of the Gila crop out in the low hills south of the community of Gila, and in Mangas Valley. These deposits are at least several hundreds of feet thick.

The beds of gravel and sand in the lake deposits locally yield large quantities of water. Some water is found confined under beds of clay. Wells 15. 17. -29. 442 and 15.18. 4. 241 flow but the hydrostatic heads are low and yields are small.

The origin of the lakes is conjectural; but ter-ace, mesa, and divide altitudes, the character of the deposits at various places, and the structural pattern of the area lead to the following hypothesis: the Gila and San Francisco Rivers were parts of a single large drainage system before the Mogollon Mountains, Silver City Range, and Little Burro Mountains were uplifted. The ancestral Gila River (before the uplift) flowed southeast down a broad valley, the ancestral "Mangas Trench," in which it had deposited the alluvial debris that now constitutes the lower part of the Gila Conglomerate.

The uplift of the Little Burro Mountains was rapid enough to block the ancestral Gila River and create a lake that reached from the south end of the Little Burros northward to about 20 miles north of the Grant-Catron county line.

The concurrent uplift of the Mogollon Mountains and Silver City Range greatly rejuvenated the streams that drained the region. Coarse alluvial fill in the old channels was carried into the newly formed lake. The early deposits constitute most of what is considered to be the upper part of the Gila. Much of it was derived from the lower part of the Gila Conglomerate that had been elevated and deformed during the uplift.

The quantity of gravel and associated sediments dumped into the lake by Mogollon, Dry (in Catron County), and Little Dry Creeks was particularly great, and was concentrated in a relatively small area. The deposits accumulated rapidly and a barrier was built across the lake, dividing it and thus creating two separate lakes. The northern lake, fed by what is now the upper San Francisco drainage, found an outlet to the west across a relatively low area, the southern part of which is now known as Antelope Flats in Catron County. The southern lake, fed by the headwaters of the present Gila River, developed an outlet to the west across low ground at the northern end of the Big Burro Mountains.

The faulting that formed these lakes probably was contemporary with similar faulting in the MimbresSapillo Valleys (the Mimbres trench), which parallels the Mangas Valley trench. Elston and Damon (1970, p. AVI-7) concluded on the basis of K-Ar age dates, that block faulting in the Mimbres-Sapillo Valley had virtually ceased about 6 m. y. The lakes probably were short lived and ceased to exist long before the advent of Pleistocene (ice age) time as a result of both filling with sediments and lowering of their outlets by downcutting.

Downcutting would have been rapid at the outlets of the lakes because gradients were steep and the rock relatively nonresistant. The rivers quickly cut deep narrow gorges, the spectacular canyons that still are accessible only by horseback or foot travel.

The lakes dwindled as the outlets cut down to the level of the lake beds; erosion of the lake deposits began on the margins of the lake even as sediments continued to be deposited in the remaining waters. The lakes did not endure at any one level long enough for waves to cut extensive benches or build gravel terraces that would survive erosion during the wet pluvial cycles of Pleistocene time. The low gravel hills bordering the west side of the Little Burro Mountains (fig. 10) may be one of the few remnants of such gravel terraces in Mangas Valley.

Terrace Gravel

Deposits of gravel cap low ridges and overlie older rocks throughout the foothill areas. These terrace gravels are only slightly older than the alluvium filling the valleys; and were laid down over generally flat surfaces prior to the uplifts and rejuvenation of streams that occurred in late Pleistocene and Holocene time. Erosion that followed deposition of the terrace gravels has left some discontinuous gravel and sand deposits above the present level of streams (fig. 33). These terrace gravels

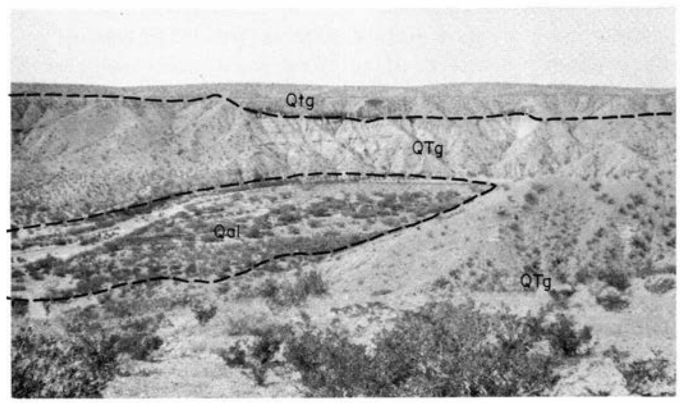


Figure 33—Terrace gravel of Quaternary age (Qtg—probably Pleistocene) unconformably overlying the upper part of Gila Conglomerate (QTg) along Blue Creek, near center of sec. 17, T. 18 S., R. 19 W. The terrace gravels are above the water table which in this area is over 100 feet below the normally dry channel of Blue Creek. The channel is filled with alluvium (Qal) to depths generally of not more than 20 feet.

generally are thin and drained of water because of their high position above the stream channels. Small amounts of water are found in the gravel where extensive deposits overlie relatively impermeable rocks.

Alluvium

The sand and gravel in the channels and under the flood plains of the rivers and creeks are unconsolidated continental deposits of Holocene age commonly referred to as alluvium (fig. 18); also included in this category is the material immediately underlying the surface of the valley floors (bolsons) in the vicinity of Whitewater, Faywood, Separ, and Hachita. The composition and texture of the alluvium and bolson deposits is varied because the streams that deposit them flow across rocks of many types and pick up material of all kinds. The texture ranges from fine to coarse—from clay to beds of boulders. The bolson deposits are similar in physical character to river channel and floodplain deposits but the channel and floodplain deposits generally are thin whereas bolson deposits attain great thickness.

Core drilling for damsites on the floodplain of the Gila River show the valley fill to be as much as 101 feet thick locally (NW1/4, sec. 19, T. 19 S., R. 10 W.) near Redrock (U. S. Bureau of Reclamation, 1930, p. 228). However, in general it is less than that; logs of wells suggest it averages about 40 feet in the broader parts of the river valley.

The alluvium under the floodplain of the Mimbres Valley at the McSherry Range (sec. 27, T. 19 S., R. 10 W.) near Dwyer is about 25 feet thick. However, the log of irrigation well 17.11.13.343 on the Horace Bounds ranch in the Mimbres Valley near San Lorenzo, shows the alluvium there to be at least 55 feet thick.

The alluvium inthe channels of major tributaries to the Gila and Mimbres generally is not more than 5 to 20 feet thick although locally maybe appreciably more. Most of the tributaries are actively downcutting. Alluvium that accumulates during periods of low flow is moved downstream during periods of flood flow; thick deposits do not generally have an opportunity to form.

Alluvium of Holocene age filled many shallow upland valleys during an earlier cycle of deposition that began about 1300 A.D. (Leopold and Snyder, 1951). The alluvium in most of the larger valleys contained ground water tapped by shallow dug wells during the settlement of the region in the period 1865-85. A regional cycle of erosion that began in the period 1875-95 (Hastings and Turner, 1966, p. 45), has caused extensive gullying and cutting of arroyos. Perhaps the best examples are in Mangas Valley, Buckhorn Valley, and along San Vicente Arroyo (fig. 34) where underlying bedrock now is exposed at places in the stream channel, and arroyo banks are 20 to 30 feet high.

Figure 34–Alluvium (Qal) of Holocene age exposed in banks of San Vicente Arroyo; view looking downstream from the bridge 6 miles northwest of Whitewater. The arroyo, cut since about 1890, has acted as a drain to lower water levels that once were within 5 to 10 feet of the surface along much of the valley. The arroyo at this point is about 30 feet deep; note man at base of bank.

The gullying had the same effect as would the construction of drains—the shallow ground - water levels in the alluviated valleys lowered to the extent that the wells tapping the shallow water bodies went dry and, locally, large trees died (fig. 32).

The cause of the regionwide gullying has been argued for many years and commonly has been attributed to overgrazing. However, Leopold (1951, p. 356) and Hastings and Turner (1966, p. 284-289) present strong arguments that show climatic changes are chiefly responsible, and that grazing has been only a contributing factor.

Probably no large amounts of water were ever stored in the alluviated valleys. The water supply furnished by the early-day wells probably was no more dependable than that of many of the present-day shallow wells tapping water in the alluvium of the upland valleys. The water levels in these wells fluctuate with the seasons now, and they probably fluctuated in the past also.

The shallow alluvial wells of most of the upland valleys yield only small amounts of water. Wells tapping the alluvial aquifer under the floodplain of the Gila River in the vicinity of Redrock yield as much as 2,250 gpm (19. 19. 1. 142). Yields are as high as 2,000 gpm and average 850 gpm onthe floodplain of the Gila near Cliff and Gila. Yields near Buckhorn on Duck Creek are as high as 1,100 gpm and average about 500 gpm. Two wells on Mangas Creek near Mangas Springs yield 1, 100 and 1, 400 gpm, respectively; but these wells might be getting some water from the upper part of the Gila Conglomerate.

The alluvium in the valley of the Mimbres River southward from about San Lorenzo can yield large amounts of water. However, the yields are generally smaller than from wells along the Gila because the alluvial fill is generally thinner. Wells tapping the alluvium near San Lorenzo have yields of about 300 gpm. Well 17. 11. 24. 214 yields about 800 gpm but much of the water from this well is believed to come from the upper part of the Gila Conglomerate.

The coarse alluvium in the uppermost reaches of the channels of major tributaries to the Gila and Mimbres Rivers, and in the larger water courses that drain to the Lordsburg-Deming valley, also generally contains appreciable amounts of water. However, the alluvial aquifers generally will not sustain large yields because the fill is thin and the valleys narrow. Locally, wells may sustain large yields of water seasonally but not annually.

The water table in the tributary channels commonly is near the land surface, but sometimes is far below the surface. Where the water table is deep, perched water may be found in the gravelly fill.

Bolson Deposits

Bolson deposits is a term applied to alluvial sediments that fill broad intermontane areas as the

Lordsburg and Hachita Valleys; and the extension of the Mimbres Valley into the Faywood - Whitewater area of the San Vicente basin. The oldest parts of the fill probably are equivalent to the lower part of the Gila Conglomerate. They were deposited when the last major phase of block faluting began about 20 million years ago (Elston and Damon, 1970, p. AVI7). Bolson fill at intermediate depths probably is equivalent in age to the upper part of the Gila. The upper part of the bolson fill contains material eroded from the Gila Conglomerate and older rocks during Quaternary time; particularly during the Pleistocene.

The bolson deposits are a heterogeneous mixture of rock from the surrounding uplands. Mostly unconsolidated, some beds may be locally cemented with calcium carbonate, limonite (iron oxide), or silica to varying degrees. Most of these cemented beds, regardless of the depth at which they are now found, were cemented when they were within a few feet of the land surface, and when that surface remained stable for an appreciable time. These hardpan (limonite - cemented) and caliche (carbonate-cemented) layers may be a few inches or many feet thick, and are sometimes mistakenfor bedrock when found during drilling. Samples of deep bolson fill from oil well tests are available for examination at the New Mexico State Bureau of Mines and Mineral Resources (Bieberman, Crespin, 1955).

The bolson deposits range in thickness from a few feet where they lap onto the bedrock along the foothills to several thousand feet in the central parts of the valleys. Oil well test 20. 11. 31. 113, 2-1/2 miles southwest of Faywood, bottomed in bolson fill at a depth of 1,607 feet. Another well test, in Luna County about 9 miles southeast of Faywood, was drilled in bolson fill to a depth of 6, 171 feet; an oil well test near Hachita was drilled to a depth of 1,070 feet inbolson fill (Dixon and others, 1954, p. 30-31). These and other tests in southwestern New Mexico show that the bolson deposits are of great thickness in most of the large valleys; the full thickness is not known. These deposits along with alluvium and the upper part of the Gila Conglomerate constitute a ground-water reservoir of great capacity.

The bolson deposits in general are not as well sorted as the deposits under the floodplains, thus yields to wells are somewhat smaller than those from the stream alluvium. Irrigation and industrial wells tapping bolson fill near Faywood and Whitewater yield from about 100 to 1, 500 gpm, and average about 600 gpm. Some of the higher yields may come from volcanic rocks associated with the bolson fill. Well 24.15.33.232, drilled adjacent to U. S. Highway 70-80 (Interstate 10) near Separ to supply road construction water, has a yield of about 400 gpm. Well 24. 16. 31. 122, drilled for irrigation in the Lordsburg Valley just inside Grant County, reportedly produces 1,200 gpm.

Streamflow

Two principal types of stream discharge, base flow and floodflow, can be defined for most purposes of streamflow analysis. Only base flow need be considered in detail for this report to make conclusions concerning ground-water discharge to streams. Base flow consists only of ground-water discharge in the absence of upstream reservoirs and perennial snowfields.

Base flow represents a more or less steady minimum flow characteristic of the stream or river at a particular point and time. Base flow at a point may vary somewhat seasonally or over a longer period of time, but does not change rapidly, as within hours or, generally, even within a few weeks.

Seasonal changes in base flow may result as vegetation flourishes and consumes ground water otherwise discharged to the stream. Long-term changes in base flow may occur as a result of prolonged wet or dry cycles when ground-water storage is increased or reduced regionally with subsequent compensating changes in discharge to streams throughout the area.

Grant County does not have perennial snowfields and at the present time, has only a few small reservoirs on tributary streams. For practical purposes, all base flow may be considered to come from ground-water discharge. However, large reservoirs on the Gila and Mimbres Rivers are being considered.

In general, construction of large storage reservoirs disturbs the natural regimen of the stream, mostly below the reservoir, and creates new flow patterns unrelated to the natural patterns. Base flow below a dam is either stopped completely or masked by highly variable controlled releases from the reservoir. If, after construction of alarge storage reservoir, releases are regulated to provide a perennial flow at specified rates below the reservoir, that flow might be considered as base flow. Base flow implies, generally, the least flow that occurs at any particular point on a stream at a given time.

Hydrologically, a flood is any unusually large flow in a stream whether it does damage or not. Floodflow results most commonly from heavy or prolonged precipitation somewhere in the watershed, or from unusually rapid melting of snowpack by unseasonably warm rains as occurred during the winter floods on the Gila River in December 1965. Floodflow may continue for periods of time ranging from minutes to days; and it subsides generally to normal flow within a time proportional to the duration of the floodflow. Accidental releases of water from reservoirs may result in floodflows; such floods commonly are catastrophic.

The discharge of the Gila and Mimbres Rivers and some of their tributaries has been measured periodically at several places (fig. 6). Summaries of the measurements, which are not continuous at all stations, have been published by the U. S. Geological Survey (1954b, 1954c, 1955, 1956, 1960, 1964a, b, 1965-69, and 1970a, b). These statistics are the basis for the flow records cited in the discussions that follow, and for the streamflow averages in table 2. Miscellaneous measurements, not given in table 2, have been made at other points and the data have been published in the references cited.

The monthly averages shown in table 2 represent the averages of all flow combined. For those months when precipitation results in considerable surface runoff, floodflow may greatly exceed base flow. However, for some months as May and June, precipitation normally is too scant for surface runoff. The winter snowpack on the mountain watershed has, in most years, largely melted by the end of May. For these reasons, the flow rates for these months, particularly June, are consistently the lowest for the year. Thus, streamflow during the month of June is minimum base flow for the Gila and Mimbres Rivers; and for practical purposes, the flow is considered to come entirely from ground-water discharge.

Ground water is discharged to the Gila River and some of its tributaries from a few large springs such as Gila Hot Springs, Dorsey Spring, and Allan Springs. But a much greater amount of ground water is discharged in less conspicuous manner from small springs and seeps in and along stream channels. Mangas Springs is an example of this type of discharge. Water begins to appear in the channel of Mangas Creek just above Mangas (17.16.9.311); where about 100 gpm issues from several orifices and seeps along the bank. The flow continues to increase until, at a point about one quarter of a mile downstream (fig. 35), it averages about 1. 6 cfs (cubic feet per second) or 720 gpm. The flow at a point about 3/4 of a mile further downstream averages about 1. 8 cfs (810 gpm).

In like manner, the channels of the Gila and Mimbres Rivers gain flow downstream. By comparing the flows at selected points progressively downstream and taking into consideration factors as evaporation and plant transpiration, the total amount of ground water accrual to streamflow may be estimated.

GILA RIVER

A comparison of flow measurements (table 2) at four gaging stations on the Gila River (fig. 6) for the same period of time shows that the river alternately gains and loses water in its course. The river emerges from the Mogollon Mountains through a box canyon (sec. 19, T. 14 S. , R. 16 W.) called Upper Box, Hooker Dam site, or Hooker site. The June

Table 2--Runoff at gaging stations in Grant County

Station, drainage area in square miles, and location	Years and period of record[1]	Average monthly and annual runoff in acre-feet (upper figure) and cubic foot per second (lower figure)[2]: Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual	Acre-feet per square miles of drainage area	Inches over drainage area	Maximum and minimum annual runoff in acre-feet, and the year: Maximum	Minimum	Flow extremes of record in cubic feet per second, and date: Maximum	Minimum
Gila River near Gila Hot Springs[3], 1,600 (approx.), 13.13.8.433	7 1912-19	11,300 / 184	4,420 / 74.4	8,430 / 137	12,200 / 198	11,500 / 205	21,780 / 354	22,730 / 382	11,720 / 190	4,390 / 73.8	7,630 / 124	7,480 / 122	4,530 / 76.1	128,500 / 177	80.3	1.51	303,900 / 1915	35,000 / 1918	(no record)	26 7-28-13
Sapillo Creek below Lake Roberts, 78, 14.13.34.443	6 1965-70	254 / 4.13	203 / 3.41	562 / 9.14	288 / 4.69	367 / 6.46	512 / 8.32	174 / 2.92	142 / 2.30	124 / 2.08	156 / 2.53	646 / 10.5	320 / 5.37	3,750 / 5.18	48.1	.90	7,720 / 1966	1,360 / 1969	1,210 / 9-23-64	No flow at times
Gila River near Gila, 1,864, 14.16.30.112	44 1914-70	5,330 / 86.7	4,400 / 73.9	6,640 / 108	8,330 / 135	10,280 / 183	17,000 / 276	11,890 / 200	7,390 / 120	3,160 / 53.1	4,610 / 75.0	8,350 / 136	7,100 / 119	92,470 / 128	49.6	.93	273,900 / 1941	34,690 / 1956	25,400 / 9-29-41	15 7-7-56
Gila River near Cliff, 2,438, 16.17.4.323	9 1942-51	3,850 / 62.5	4,430 / 74.4	7,300 / 118.8	13,000 / 211	8,625 / 154	16,220 / 264	10,700 / 180	5,540 / 90.0	2,070 / 34.8	3,200 / 52.0	7,100 / 115	5,300 / 89.0	85,810 / 119	35.2	.66	294,400 / 1949	44,300 / 1946	17,000 / 1-14-49	5.8 7-27-46
Gila River near Redrock, 2,829, 18.18.23.143	51 1905-70	7,920 / 129	6,960 / 117	11,120 / 181	13,570 / 221	16,280 / 290	24,750 / 402	16,920 / 284	9,580 / 156	3,920 / 65.9	6,800 / 111	12,310 / 200	9,850 / 166	140,300 / 194	49.6	.93	484,000 / 1915	34,370 / 1951	40,000 / 9-29-41	2.2 8-5-47
Gila River below Blue Creek, 3,203, 19.19.18.344	45 1914-70	7,180 / 117	5,760 / 96.8	9,630 / 157	12,930 / 210	14,660 / 261	23,320 / 379	15,750 / 265	8,180 / 133	2,780 / 46.7	6,780 / 110	14,270 / 232	10,140 / 170	122,300 / 169	38.1	.72	409,900 / 1941	31,270 / 1956	41,700 / 9-29-41	1 7-14-34
Mogollon Creek near Cliff, 69, 13.18.13.443	3 1968-70	172 / 2.79	317 / 5.33	794 / 12.9	2,850 / 46.4	4,390 / 76.6	4,920 / 80.1	4,120 / 69.3	1,800 / 29.3	155 / 2.61	316 / 5.15	634 / 10.3	362 / 6.08	20,840 / 28.7	302	5.66	46,790 / 1968	7,160 / 1969	10,800 / 8-12-68	No flow at times
Mangas Creek near Mangas Springs[4], 190, 17.16.5.341	4 1954-56 1965-66	93.5 / 1.52	112 / 1.88	123 / 2.00	121 / 1.97	120 / 2.14	124 / 2.08	103 / 1.73	91.6 / 1.49	79.1 / 1.33	91.6 / 1.49	139 / 2.26	97.0 / 1.63	1,300 / 1.79	6.84	.13	1,250 / 1955	-- / --	(no record)	.76[5] 7-12-54
Mimbres River at McKnight damsite, 97.3, 16.11.6.434	6 1965-70	97 / 1.58	4.9 / .083	237 / 3.85	184 / 3.01	306 / 5.35	910 / 14.8	768 / 12.9	215 / 3.50	19 / .315	2.8 / .045	616 / 10.0	402 / 6.76	3,760 / 5.18	38.6	.72	11,490 / 1968	5.8 / 1969	840 / 8-5-68	No flow at times
Bear Canyon near Mimbres, 14.5, 16.11.28.313	18 1938-55	18.4 / .30	12.5 / .21	12.6 / .20	41.3 / .67	85.3 / 1.52	131 / 2.13	48.4 / .81	39.7 / .64	46.3 / .78	50.4 / .82	21.2 / .34	68.9 / 1.16	576 / .80	39.7	.73	1,820 / 1941	0 / 1947	123 / 9-29-41	0[6]
Mimbres River near Mimbres, 152, 16.11.33.142	47 1922-70	471 / 7.66	405 / 6.81	502 / 8.16	509 / 8.28	675 / 12.1	1,200 / 19.5	1,030 / 17.3	611 / 9.94	329 / 5.53	472 / 7.68	811 / 13.2	625 / 10.5	7,580 / 10.5	50.3	.94	21,810 / 1941	1,930 / 1954	1,560 / 8-2-52	.7 7-22-47 8-10-51
Mimbres River near Faywood, 460, 20.10.7.100	39 1909-55 1963-68	344 / 5.59	330 / 5.55	690 / 11.2	998 / 16.2	1,080 / 19.3	1,590 / 25.9	877 / 14.7	443 / 7.20	257 / 4.32	666 / 10.8	1,910 / 31.1	1,020 / 17.1	10,460 / 12.7	22.7	.35	35,950 / 1949	1,070 / 1948	20,000 / 8-4-39	No flow at times
San Vicente Arroyo at Silver City, 26.5, 18.14.3.412	12 1954-65	39.3 / .64	4.77 / .08	10.1 / .16	17.6 / .29	4.11 / .07	13.3 / .22	2.54 / .04	1.68 / .03	25.9 / .44	167 / 2.71	215 / 3.49	56.6 / .95	582 / .80	22.0	.41	1,210 / 1954	327 / 1955	4,680[7] 8-16-63	No flow at times

1/ Number of years of record indicated is the maximum for any one month.
2/ Monthly averages include years for which only partial records are available; data are mostly taken from continuous stage recorders.
3/ Formerly published as Gila near Silver City.
4/ Averages are based on monthly and semi-monthly measurements of base flow. Miscellaneous measurements-not a regular gaging station.
5/ Channel diked off a short distance upstream from point of measurement and about 3/4 cfs diverted by pumping.
6/ No flow for many days in most years -- discharge controlled by dam.
7/ A destructive flood (discharge estimated to exceed 10,000 cfs) occurred July 21, 1895, destroyed main street of Silver City, and created the channel currently known as "The Big Ditch" (San Vincente Arroyo).

Figure 35—Determination of the discharge of Mangas Creek with both a 6-inch Parshall flume and a standard current meter. The flow at this point, a quarter of a mile below Mangas Springs, averages about 1.6 cfs (720 gpm). The flow half a mile further downstream averages about 1.8 cfs (810 gpm).

flow at the Hooker gaging station (table 2, Gila River near Gila) just below Hooker site averaged 45 cfs for the 10-year period 1942-51. The June flow at Steel Bridge gaging station (table 2, Gila River near Cliff), 10 miles below the Hooker gage, averaged 35 *cfs* for the same period. The flow at the Redrock gaging station (table 2, Gila River near Redrock), about 20 miles below the Steel Bridge station, averaged 40 cfs, and the flow at the Blue Creek gaging station (table 2, Gila River below Blue Creek), 14 miles farther downstream, averaged 32 cfs. However, if evapotranspiration losses are accounted for, the river is found to gain water in all three reaches.

Aerial photographs show that the open water and wetted sand width of the Gila River averages about 130 feet in the 10-mile reach between Hooker site and Steel Bridge gaging station. Evaporation from an open-water surface and from wetted sand is about 7/10 of pan evaporation (Dorroh, 1946, p. 19; Gatewood and others, 1950, p. 48). Using a June pan evaporation rate of about 14 inches and a total area of about 160 acres for the 10-mile reach of the river, plus main canals, a channel evaporation loss of about 130 acre-feet is calculated for the month of June. . About 4,000 acres of land were irrigated annually in the river valley between the two gaging stations during 1942-51 (U. S. Geol. Survey, 1954b, p. 590). According to Heindl (1965, p. 21), about 1/4 of the total is applied in June, commonly the warmest and driest month of the growing season. This quantity of water assures that the irrigated crops will have all the water they need.

Application of the Blaney-Criddle formula (Blaney and Criddle, 1962) for determining consumptive use and utilization of factors and coefficients derived for areas and crops in Grant County (Blaney and Hanson, 1965), shows consumptive use for pasture grass, small grains, corn, and alfalfa averages about 0.43 foot of water for the month of June. Thus, if 4, 000 acres are irrigated, 0. 43 x 4,000 or 1, 720 acre-feet of water will be consumed by irrigated crops and pasture. The water applied in excess of plant requirements will infiltrate to the water table.

Native vegetation (mostly cottonwood and willow) that draws water from the zone of saturation and the capillary fringe is estimated from aerial photographs to be equal to a solid cover of about 600 acres. Gatewood (1950, p. 195) showed that in Safford Valley, Arizona, under conditions similar to those along the Gila in Grant County, these types of vegetation, commonly referred to collectively as "phreatophytes, " used about 1 acre-foot of water per month per acre for 100 percent cover. The phreatophytes thus transpire about 600 acre-feet during June, which is equal to a continuous flow of 10 cfs.

Evapotranspiration losses between Hooker and Steel Bridge were calculated to be about 2,450 acre-feet in June, the equivalent of 41 cfs steady flow.

Adding the calculated evapotranspiration losses to the measured discharge of 35 cfs at the bridge gives a calculated flow of about 76 cfs at the Steel Bridge gage. Subtracting the measured flow (45 cfs) at the Hooker gage from the calculated flow at the bridge gage indicates an accrual of about 31 cfs in the reach of approximately 10 miles between the two stations—an average gain of 3.1 cfs per mile. This accrual is all ground-water discharge. Surface flow from tributaries normally does not enter the Gila in this reach during June.

A similar analysis of the reach between the Steel Bridge gage and the Redrock gage about 20 miles downstream shows an approximate evapotranspiration loss of about 820 acre-feet—equivalent to a steady flow of about 14 cfs. This estimate is based on 200 acres of open water (including main ditches) and wetted sand, 500 acres of irrigated land, and 435 acres of phreatophyte cover. Adding the 14 cfs losses to the measured flow of 40 cfs at the Redrock gage gives a calculated flow of 54 cfs at the Redrock gage. Subtracting the measured flow at the bridge (35 cfs) from the calculated flow at Redrock indicates an accrual of 19 cfs between the two stations, or 1 cfs per mile.

Evapotranspiration losses between the Redrock gage and the Blue Creek gage (19. 19. 18. 344), downstream about 14 miles by river course, are about 1, 690 acre-feet, equivalent to a steady flow of 28 cfs. This estimate is based on 210 acres of open water and wetted sand (including main ditches), 730 acres of irrigated land, and phreatophyte cover of about 750 acres. The 28 cfs loss added to the measured discharge of 32 cfs at the Blue Creek gage gives a calculated flow of 60 cfs at Blue Creek. Subtracting the measured flow of 40 cfs at Redrock gage from the calculated flow at Blue Creek gage indicates an accrual of 20 cfs between the two stations, or 1. 5 cfs per mile.

Although the accrual rates show that the Gila is a gaining stream, they do not indicate the reasons for such large differences in rate of accrual per mile of stream. The area of watershed for each contributing reach appears to be the controlling factor. Where a large watershed with numerous tributary streams contributes to a short reach of stream, the rate of accrual could be expected to be large per mile of stream. This relation seems to hold for the Gila in this area.

The reach of the Gila River between the Hooker and SteelBridge gaging stations has a drainage area of 574 square miles (Hale, Reiland, and Beverage, 1965, p. 58). The accrual of 31 cfs from this area gives an accrual rate of 0.054 cfs (24 gpm) per square mile of drainage area. The area is underlain by a slightly greater proportion of the Gila Conglomerate than rocks of volcanic origin (fig. 2). These rocks are not highly permeable and they do not store large amounts of water, but the Gila, in general, probably will store more water than the volcanic rocks.

The drainage area tributary to the Gila River between the Steel Bridge and Redrock gaging station is 390 square miles and the accrual of 19 cfs gives an accrual rate of about 0. 049 cfs (22 gpm) per square mile which is only 10 percent less than the reach above. However, this drainage area is underlain by an appreciably greater proportion of igneous rocks, both intrusive and volcanic, which are relatively dense and impermeable. They do not absorb and store much water; rather, they cause rapid runoff of precipitation.

The drainage area tributary to the Gila between the Redrock and Blue Creek gages is 374 square miles and the accrual of 20 cfs gives an accrual rate of 0.054 cfs (24 gpm) per square mile, the same unit area runoff as for the reach from Hooker to Steel Bridge. The rocks underlying the RedrockBlue Creek drainage area are about equally igneous and sedimentary. The differences in lithology might explain part of the slight differences in unit area runoff, but the differences are not significant and probably are within the limits of error for the method used.

The principal source of the accrual to the various reaches between Hooker Dam site and the Blue Creek gage is believed to be underflow in the channels of the tributary streams such as Mogollon, Duck, Bear, and Mangas Creeks; Greenwood Canyon; Sycamore Creek; House, Swan, and Road Canyons; and Blue Creek. These tributaries have broad alluvium-filled valleys that are reservoirs for ground water in transit to the river.

MIMBRES RIVER

Water appears in the channel of the Mimbres River in about the NE1/4 sec. 7, T. 16 S. , R. 11 W. The channel below that point generally contains water down to about the county line; but at times, parts of this reach are dry because of diversions for irrigation. Also, in late spring before the rainy season starts, the channel may be dry in many places. However, the channel gravels generally remain saturated within a few inches or feet of the land surface and flow reappears with the first rains of summer.

The June discharge of the Mimbres River at the Mimbres gaging station (table 2, Mimbres River near Mimbres) averaged 5. 2 cfs for the 10 years 1942-51; the June discharge at the Faywood station (table 2, Mimbres River near Faywood), about 25 miles downstream, averaged 4. 0 cfs for the same period.

Evapotranspiration losses for June in the reach between gaging stations average about 1,220 acre-feet, the equivalent of a steady flow of 21 cfs. This estimate is based on losses of 710 acre-feet from 1, 645 acres of irrigated land, 460 acre-feet from phreatophytes, and about 50 acre-feet from 65 acres of open water and wetted sand. The 21 cfs calculated evapotranspiration loss added to the flow of 4 cfs measured at the Faywood gage, less the measured flow at the Mimbres gage (5 cfs) yields a ground water accrual of about 20 cfs, or about 1,200 acre-feet per month during the summer months.

The accrual is about 0. 84 cfs per mile of channel. The drainage area of the reach is about 308 square miles and the accrual is about 0. 068 cfs per square mile of drainage area.

TRIBUTARY STREAMS

Ground water discharges into many of the principal tributaries of the Gila and Mimbres Rivers in sufficient quantities to maintain perennial flow in at least parts of their channels. The flow commonly is perennial in the upper to middle reaches and absent from the lower reaches where the canyons are wide and filled with alluvium. The water table ranges in depth from the surface to a few feet below the streambed in most of the mountainous reaches, and the streamflow may disappear and reappear at intervals along the channel. However, in the lower reaches of these larger tributaries the water table may be many feet below the streambed. The intervening interval is never fully saturated, and the stream flows only during periods when runoff exceeds the rate of infiltration of water.

Although the streambeds may be dry, the flow that disappears in some upper reach generally continues to move downgradient through the channel fill. The significant quantity of water that moves as underflow in normally dry tributaries can be demonstrated by examining Sapillo Creek. The channel above Lake Roberts is dry most of the time but the lake is maintained by underflow, which has been shown to average about 2 cfs on the basis of spillway discharge and evaporation losses (Elston, Weber, and Trauger, 1965, p. 59). Miscellaneous flow measurements (U. S. Geol. Survey, 1962, p. 184) show that Sapillo Creek gains an additional 2 cfs flow in the next 2 miles below Lake Roberts; the base flow at about the Heart Bar Ranch headquarters was 4.3 cfs in May 1962.

Mangas Creek and Bear Creek near Cliff are other examples of tributaries to the Gila that have appreciable underflow. The channel of Mangas Creek has no surface flow above Mangas Springs. Measurements made by the U. S. Geological Survey at a measuring point (17.16.5.341) below the springs show that the minimum base flow from ground-water discharge occurs in June and averages about 1.4 cfs (table 2). Fluctuations in the base flow in June were observed to be directly related to the operation of irrigation wells a quarter to half a mile above the springs. The wells tap underflow that normally would discharge through the springs.

The underflow in Bear Creek just east of Cliff probably is as large or larger than that of Mangas Creek. The drainage area lies generally at higher altitudes and receives more precipitation. Bear Creek receives the discharge of Dorsey and Allan Springs (table 13), which had a combined flow of about 200 gpm in 1954 following several dry years. The creek is perennial in its upper reaches; the surface flow, which disappears into the channel fill in about sec. 29, T. 15 S. , R. 16 W. , was estimated to be 2 to 3 cfs at 15. 16. 24. 300 in 1954. Large capacity wells in 15.17. 25. 0 obtain water from the underflow in the channel of Bear Creek near Cliff.

If Bear and Mangas Creeks each contribute as much as 3 to 4 cfs in underflow to the Gila River, and if large tributaries such as Mogollon, Duck, and Sycamore Creeks contribute amounts proportional to their drainage areas, a major part of the groundwater accrual to the Gila in Grant County apparently is tributary underflow.

Ground water moves also to the Mimbres River as underflow in the larger tributaries such as Bear, Allie, McKnight, Noonday, and Gallinas canyons. Bear Canyon, Allie Canyon, and other large drainage systems that originate in the Pinos Altos and Black Ranges, and which are tributary to the Mimbres, have some perennial flow as a result of groundwater discharge. The flow disappears in the broad lower reaches where the fill is deeper.

Underflow in Bear Canyon supplies much of the water stored behind Bear Canyon dam. The measurements of discharge (table 2) at the Bear Canyon gage show approximately the volume of ground water being discharged tothe canyon (part of the discharge at the gage is accumulation from floodflow). Allie Canyon and other large tributaries to the Mimbres probably discharge comparable amounts of water as underflow. However, the pattern of discharge to the Mimbres may be appreciably different from that to the Gila. The discharge to the Gila is sufficient to maintain perennial flow throughout its course in Grant County, even during periods when diversions are made for irrigation. The channel of the Mimbres commonly is dry in some reaches, even during the non-irrigation season.

The drainage areas of the tributaries to the Mimbres are, in general, much smaller than those to the Gila; the stream gradients are steeper and precipitation runoff is less. Less water is stored initially in the channel sands and gravels of the Mimbres tributaries and the steep gradients result in more rapid movement of the underflow. The under-flow in the Mimbres tributaries is more seasonal than in those of the Gila, and at times is insufficient to maintain flow in the channel.

FLOW RECORDS

Important uses of flow records are the determination of total watershed yield and peak floodflow for purposes of planning storage reservoirs, bridges, highways, and flood-control structures. Records of floodflow have been obtained at all regular gaging stations, but at few other points.

The discharge of San Vicente Arroyo was measured at Silver City by means of an automatic continuous water-stage recorder during the period August 1953 to September 1964. The discharge measurements were made to determine the flow pattern and the approximate annual discharge, and thus establish the feasibility of constructing a large storage reservoir to conserve flood runoff for later use by the city.

The annual average discharge in San Vicente Arroyo, mostly floodflow (table 2), was 0.81 cfs for 11 years of record, or about 580 acre-feet per year. The discharge ranged from a low of 327 acre-feet in 1955 to a high of 1,210 acre-feet in the water year October 1953-September 1954. The records show that the average annual flow was less than 0. 65 cfs (470 acre-feet) for the 2 consecutive years, 1955-56. By far the greatest part of the discharge comes in the 2 months, July and August, and monthly discharge of less than 5 acre-feet is common for the remainder of the year.

A small amount of perennial flow, estimated to vary from 20 to 30 gpm, generally appears in the channel below the gage. This flow, which averages about 40 acre-feet annually, is not included in the above annual flood discharge records. The flow is derived from ground-water discharge, return seepage from yard watering, and probable line losses from the city water system. The arroyo acts as a natural drain for nearly all of the city area.

The annual pan evaporation rate at Silver City is similar to that at Santa Rita—about 95 inches, or nearly 8 feet per year. The equivalent loss from open water should be about 5-1/2 feet (7/10 of that from a pan) or 5-1/2 acre-feet per acre of water surface.

If a reservoir in the northern part of Silver City had an initial area of about 120 acres, uniform slopes, a capacity of about 350 acre-feet of water, and was filled by July runoff, it would be dry by the following June as a result of evaporation losses alone.

A larger reservoir covering a greater area would provide more storage for those occasional years such as 1953 when runoff was about 1,200 acre-feet but the results would be about the same. The increased area of the lake surface would increase evaporation losses proportionately, increment after August would be scant, and little or no water would carry over in storage to the following June. For most years the reservoir bed would be an unsightly dry to muddy expanse littered with flood debris.

Evaporation losses are less in reservoirs that are narrow and deep rather than broad and shallow. The level of a small deep reservoir can be maintained with less inflow than a broad shallow reservoir of equal volume. For example, a dam about 30 feet high across a narrow point in San Vicente Arroyo, where the bedrock is exposed near the Silver City railroad depot, would create a small lake approximately 2,000 feet long averaging about 200 feet wide and about 15 feet deep. Such a lake would have a capacity of about 135 acre-feet but a surface area of only 9 acres.

Evaporation losses from the lake would be about 50 acre-feet per year or about 4 acre-feet per month, which is equivalent to continuous flow of about 30 gpm. However, most of the months of little or no storm runoff are also the winter months when evaporation losses would be minimal.

Except for May, the months having the highest evaporation losses are also those which generally show an average streamflow of more than 4 acre-feet. A small reservoir such as described would be maintained by normal storm-runoff increment except during periods of almost no flow such as those which occurred from September-December 1953, September-November 1955, and February-June 1960. Even then, the losses would not be extreme; the lake level would have lowered only 4 feet in the February-June period.

The flow records demonstrate that the floodflow discharge of San Vicente Arroyo during 1953-64 would not have sustained a large reservoir, but a small reservoir would have been full by the end of August during each year of record. Normal inflow plus supplemental water at the rate of 30 gpm for relatively short periods of time would have maintained nearly full capacity in a small reservoir provided no leakage occurred through the bedrock.

Seepage losses from the lake would be negligible because of the virtually impermeable bedrock that underlies the alluvium into which the arroyo is cut. Possibly the 20- to 30-gpm flow commonly present in the channelwould be adequate to maintainthe lake without supplemental water.

Ground-water Recharge, Movement and Discharge

Recharge, movement, and discharge of ground water are so intimately related that they should be considered together. Two types of recharge and discharge—natural and artificial—are recognized. Natural occurs without stimulation or interference by man. Artificial recharge and discharge results from man's actions. The rate of movement of ground water in an aquifer controls recharge and discharge and should be considered in the development of supplies of ground water.

Recharge, the rate and direction of movement of ground water, and particularly the discharge can be influenced by man to varying degrees, but generally the effects are only local. Knowledge concerning recharge, movement, and discharge helps to predict what will happen if development takes place, and can help in determining what actions might be practical to conserve and increase water supplies. The purpose of this section is to point out where, how, and in what approximate volume recharge and discharge take place and at what rate water moves through the aquifer. How this knowledge canbe best utilized to develop available supplies of ground and surface water will be discussed in the section on problems.

A ground-water system nearly inbalance is indicated by water levels that do not change appreciably or that vary rhythmically. The amount of recharge must be nearly equal to discharge—the measure of one is approximately a measure of the other. Hydrologic systems are never in perfect balance, particularly in semiarid regions such as Grant County, mainly because of fluctuations in rainfall; removal of ground water by pumping, or the diversion of streamflow for irrigation acts to increase the imbalance. Water levels and artesian pressures are changing constantly; they rise in an aquifer when recharge exceeds discharge, and decline when discharge exceeds recharge. Confined water also may respond to such natural influences as changes in atmospheric pressure and earth tides.

All water for recharge is derived ultimately from precipitation; therefore, a primary natural cause of an upward or downward trend in water levels is the annual and long-term deviation from average precipitation. Thus, the graph showing the cumulative departure from average precipitation (fig. 13) is an index to natural trends in water levels in both artesian and unconfined aquifers. However, the natural trends in water-level fluctuations can be modified locally by man's use of ground water. Pumping from wells changes points of discharge in the system, and irrigation or other water spreading can recharge an aquifer at times and places that appreciably alter the natural regimen.

Natural upward trends in water levels that might normally result from above-average precipitation can be slowed or even reversed locally by the effects of increasing the discharge from wells; trends upward can be accelerated by adding imported or salvaged water to recharge areas. Natural trends downward, resulting from below-average precipitation, can be accelerated or reversed in similar manner.

Long-term records of water-level fluctuations in wells are used in this report to determine what changes in ground-water storage have occurred over the years. Pumping-test records are used to determine the rate of movement of water, to predict long-term effects of pumping on water levels, and to determine the supply of ground water available.

Measurement of water levels in the Bayard city wells began in 1948 and in Silver City's Woodward Ranch well field in 1954. Other wells in the county have been measured since 1954 to determine trends in water levels and to relate these trends to natural and man-made causes.

The periodic water-level measurements obtained for Grant County have been published by the State Engineer Office in annual reports on water levels in New Mexico (Reeder and others, 1962, 1962a; Ballance, 1962, 1963, 1965; Ballance and others, 1962; Busch, 1966; Busch and Hudson, 1967-70). Hydrographs included in this report are based upon these measurements.

Hydrographs show the daily, annual, or longterm trend of the water levels depending on the frequency of measurements. The hydrographs in this report were drawnfor selected wells to show water-level conditions in areas of heavy pumping compared with those in areas of light use, to demonstrate the occurrence of recharge, to show the effects of recharge and discharge on water levels, and to indicate changes in storage in several parts of the county.

RECHARGE

Natural recharge of aquifers takes place by infiltration of precipitation and streamflow into soil cover, alluvium or outcrops of porous bedrock, and by movement of water from one aquifer to another, as where an artesian aquifer discharges water to overlying beds. Artificial recharge may be accomplished by injecting water into wells, or by spreading or discharging water onto permeable surfaces underlain by unsaturated porous rocks.

Natural recharge in semiarid regions occurs mainly as infiltration in the beds of streams and arroyos during periods of flood runoff. The generally sandy and porous beds afford a point of easy entry and a place of temporary storage for large quantities of water. The hydrograph for well 17.15. 7. 313 shows the immediate effect on the water level of runoff in a nearby, normally dry, channel—the water level rose 35 feet (fig. 36) after a period of particularly heavy rainfall and prolonged runoff.

A flood crest several feet high was observed crossing U. S. Highway 260 at Greenwood Canyon (sec. 29, T. 16 S. , R. 16 W.) in the summer of 1955, a steadily diminishing flow continued for nearly an hour but the runoff did not reach the Gila River about 4. 5 miles downstream. The flow, except for probable small evaporation losses, was fully absorbed in the sandy channel.

The broad San Vicente basin with its relatively low surface gradient and intricate drainage net is an important recharge area. The arroyos and washes are cut in the Gila Conglomerate and older bolson fill; channels are sand filled, thus the infiltration potential is high. The bordering uplands provide appreciable runoff in the form of intermittent flood-flow and most of such flow infiltrates the channel beds.

Additional data on recharge to presently developed and potential aquifers is given below for the Franks Ranch well field, the Bayard well field, the Gila River Valley, and San Vicente Arroyo.

The first hydrogen-bomb experiment (November 1952) released some tritium to the atmosphere; but the first bomb to release large quantities was in March 1954. Much of the tritium released to the atmosphere during hydrogen-bomb tests returned to the earth's surface in precipitation, and some of that precipitation became recharge. Ground water containing anomalously high concentrations of tritium can thus be used as an index to determine whether or not recharge has occurred since 1954. Water from the No. 2 well in the Franks Ranch well field, and from other wells in the vicinity, was collected in April 1957 and tested for tritium. von Buttlar and Wendt (1958) found that tritium had appeared in some ground waters in Grant County by 1957 but not in water pumped from the Franks Ranch well field.

Radiochemical analyses (table 3) show only a normal tritium background count in water collected from the Franks Ranch No. 2 well in April 1957, indicating that recharge from precipitation since March 1954 had not yet reached the wells in the Franks Ranch well field or the aquifers supplying wells 17. 16. 11. 113 and 18. 15. 25. 442a.

The tritium count in water collected in April 1957 from wells 17. 15. 17. 313 and 17. 16. 24. 113a shows that the shallow aquifers supplying those wells had received recharge from precipitation that fell between March 1954 and April 1957.

The Franks Ranch No. 2 well was again sampled in February 1966 and tritium was present in the water (table 3). The absence of tritium in 1957 and the presence in 1966 indicates that recharge from precipitation and runoff since March 1954 has reached the well field.

The annual and long-term trends of water levels in the Bayard City well field (fig. 37) show that the aquifer receives annual seasonal recharge from precipitation. The aquifer tapped by the well field is the alluvium and is connected with the stream. The water table is about 50 feet below the land surface at the well field; whenever flood runoff occurs, some water infiltrates down to the water table. Water levels in this field generally decline in the spring when precipitation is scanty and the wells are pumped heavily; water levels rise with the advent of the rainy season that usually occurs in July.

The hydrographs for the Bayard well field and for nearby wells (fig. 38) show that periods of declines or rises may be continuous for one or more years but that the water levels in general remain within a certain range. They remain within this range because recharge occurs when Cameron Creek flows. Some flow occurs almost every year; therefore, some recharge occurs every year. In years of above-normal precipitation the recharge is more than adequate to offset the effects of pumping and water levels rise to above-average levels.

A comparison of the hydrographs of water levels in the Bayard area with the graph showing cumulative departure from normal precipitation shows close correlation between recharge and precipitation where the aquifers are shallow and stream connected. Such relations hold true for all the aquifers in Grant County but they are not so obvious or pronounced for those aquifers which are deep and (or) at greater distances from a stream course. The correlation between recharge and precipitation is sometimes obscured by special circumstances.

Recharge patterns independent of seasonal and long-term precipitation trends can be shown for the shallow alluvial aquifer of the Gila River valley in the vicinity of Cliff and Gila, and, by inference, for the remainder of the Gila River valley and the Mimbres valley where conditions are similar. Hydrographs of wells 15. 17. 27. 312, 15. 17. 29. 112, and 15.17.29. 442a (fig. 39) indicate that recharge occurs annually and is little affected by deviations from average annual precipitation. The water levels decline slightly each year during the irrigating season but recover fully following irrigation. This pattern of de cline and recovery results be cause the Gila River is perennial through the valley and the valley fill is highly permeable. Ground water removed by pumping is replaced rapidly by infiltration of excess irrigation water and streamflow. This pattern of recharge will occur as long as the Gila River continues to have a perennial flow through the valley.

Another example of recharge that is partly artificial is demonstrated by data from an observation well in San Vicente Arroyo, and by the shape of the water-table contours along the arroyo. San Vicente Arroyo carries some flood runoff almost every year (table 2); flow is confined in a well defined channel (established during the great flood of July 21, 1895), but it seldom reaches the Mimbres River about 6

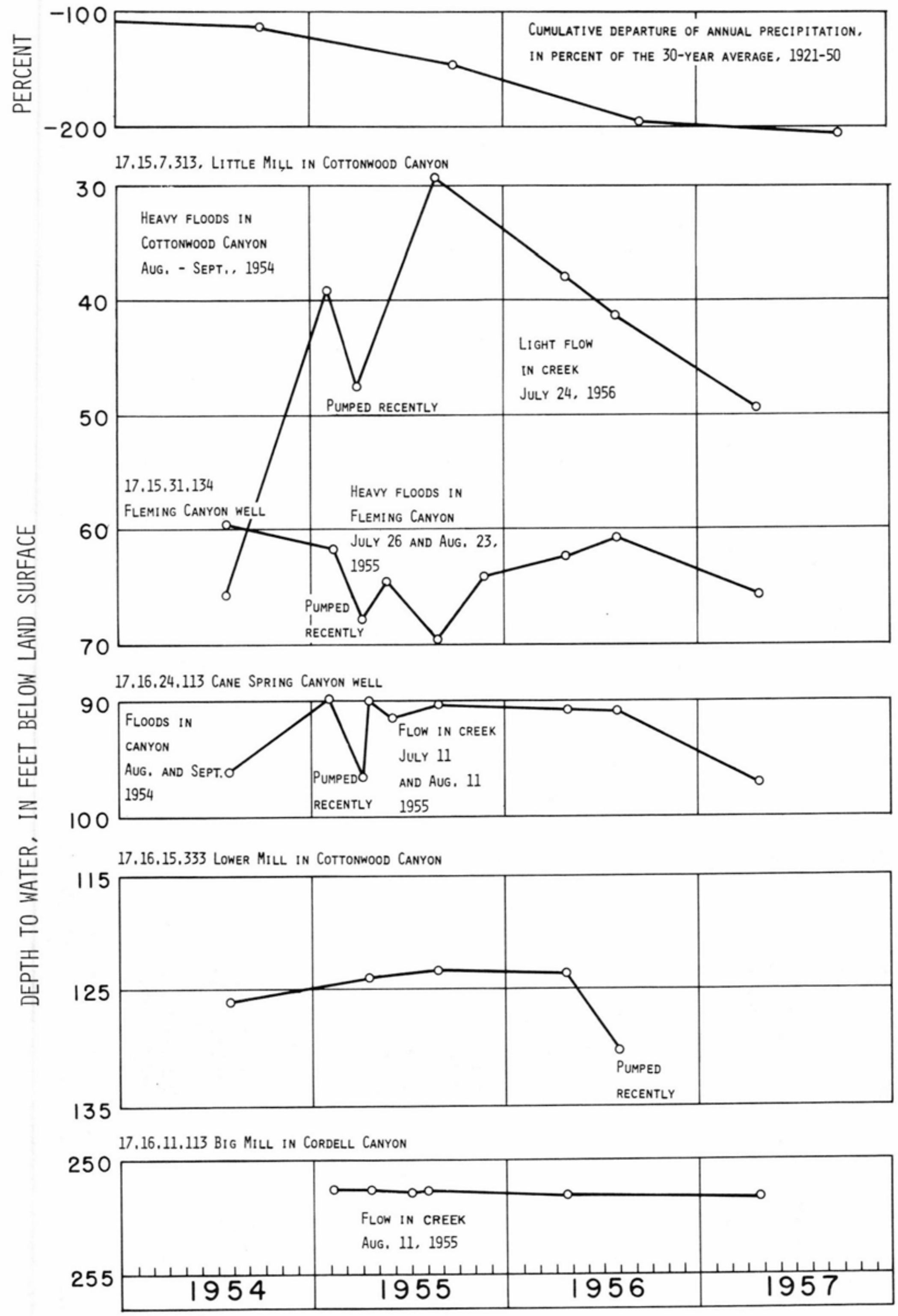


Figure 36—Hydrographs of five wells tapping alluvium or bolson deposits on west side of Silver City Range; at top, cumulative departure in percent of average precipitation.

Table 3--Radiochemical analyses of water from selected wells and springs in Grant County

EXPLANATION

Beta-gamma activity, radium, and uranium analyses by the U.S. Geological Survey; tritium analyses by Dr. Haro von Buttlar, New Mexico Institute of Mining and Technology; samples collected by author.

μμc/l: micro-micro curies per liter
μg/l: micro-grams per liter
T-units: ratio of one tritium atom per 10^{18} hydrogen atoms.

Location number	Owner and name	Date collected	Beta-gamma activity (bga) in μμc/l	Radium (Ra) in μμc/l	Uranium (U) in μg/l	Tritium[1] (T) in T-units
13.13. 5.241	D. A. Campbell Gila Hot Springs	7-25-62	12 ± 2	less than 0.1	1.4 ± 0.1	-
17.15. 7.313	John McMillen Upper Cottonwood mill	5-25-56 4-20-57	- less than 17	- less than 0.1	- 1.1	22.0 -
17.16.11.113	John McMillen Big mill	4-25-56 4-20-57	- less than 11	- less than 0.1	- 1.1	3.1[2] -
17.16.24.113a	John McMillen Cane Springs mill	4-25-56 4-20-57	- less than 14	- less than 0.1	- 1.4	9.9 -
18.15.11.313a	Town of Silver City Franks Ranch well field, Well No. 1	11-11-54 4- 1-57 2-25-66	less than 14 - -	less than 0.1 - -	1.8 - -	- 3.5 ± 0.3 9.8 ± 0.8
18.15.25.442a	Walter Woodward Upper well at house	4- 1-57 4-21-57	- less than 14	- less than 0.1	- 1.2	4.0 ± 0.4 -
20.11.20.243	Kennecott Copper Corp. Faywood Hot Spring	4- 1-57 4-19-57	- 19	- 29	- 0.1	3.2 ± 0.3 -

1/ See references, von Buttlar, 1959, and von Buttlar and Wendt, 1958

2/ Error probably exceeds 10%

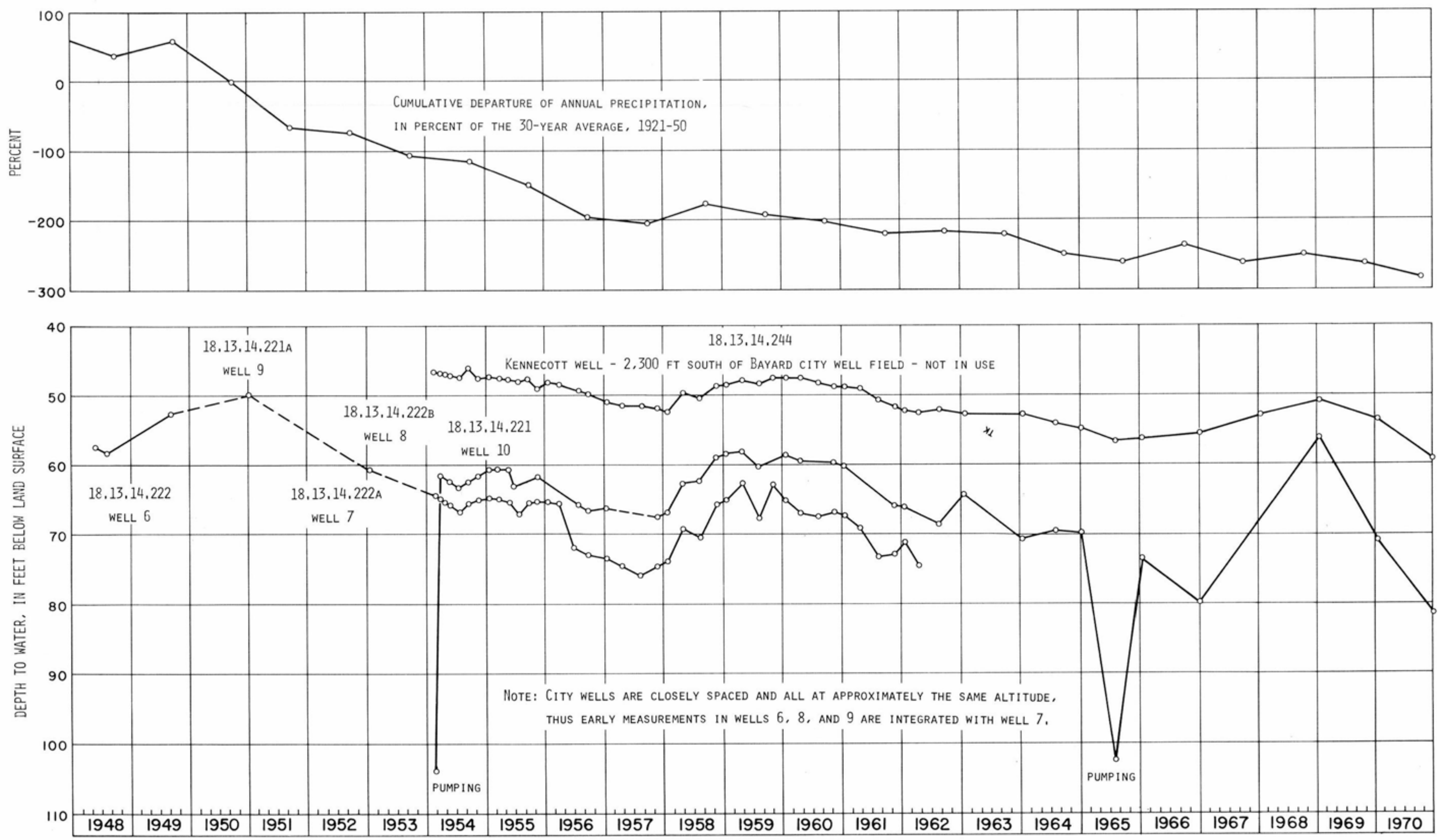


Figure 37—Hydrographs of three wells in and near the village of Bayard well field on Cameron Creek; at top, cumulative departure in percent of average precipitation.

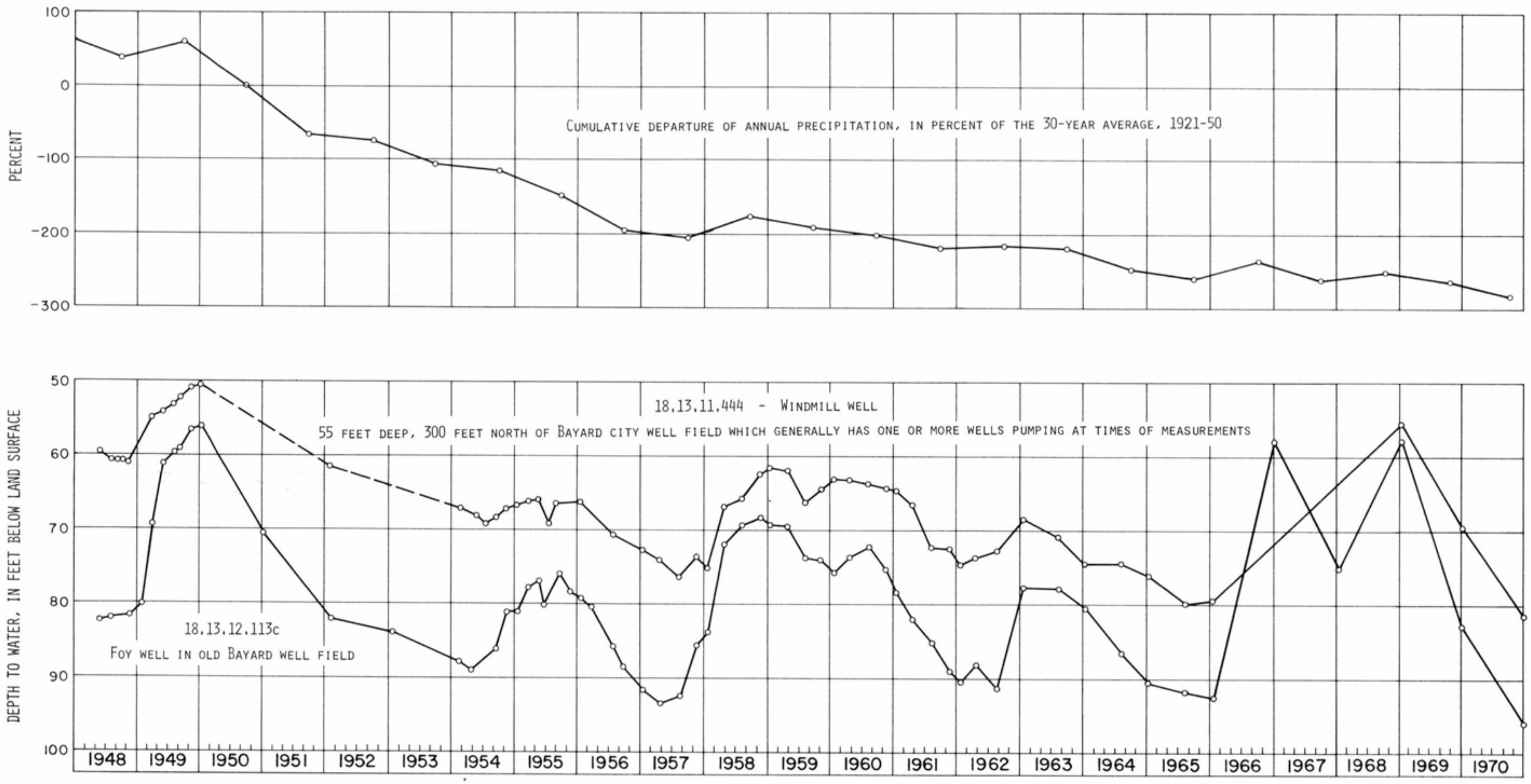


Figure 38–Hydrographs of two wells on Cameron Creek, up-valley from Bayard City well field; at top, cumulative departure in percent of average precipitation.

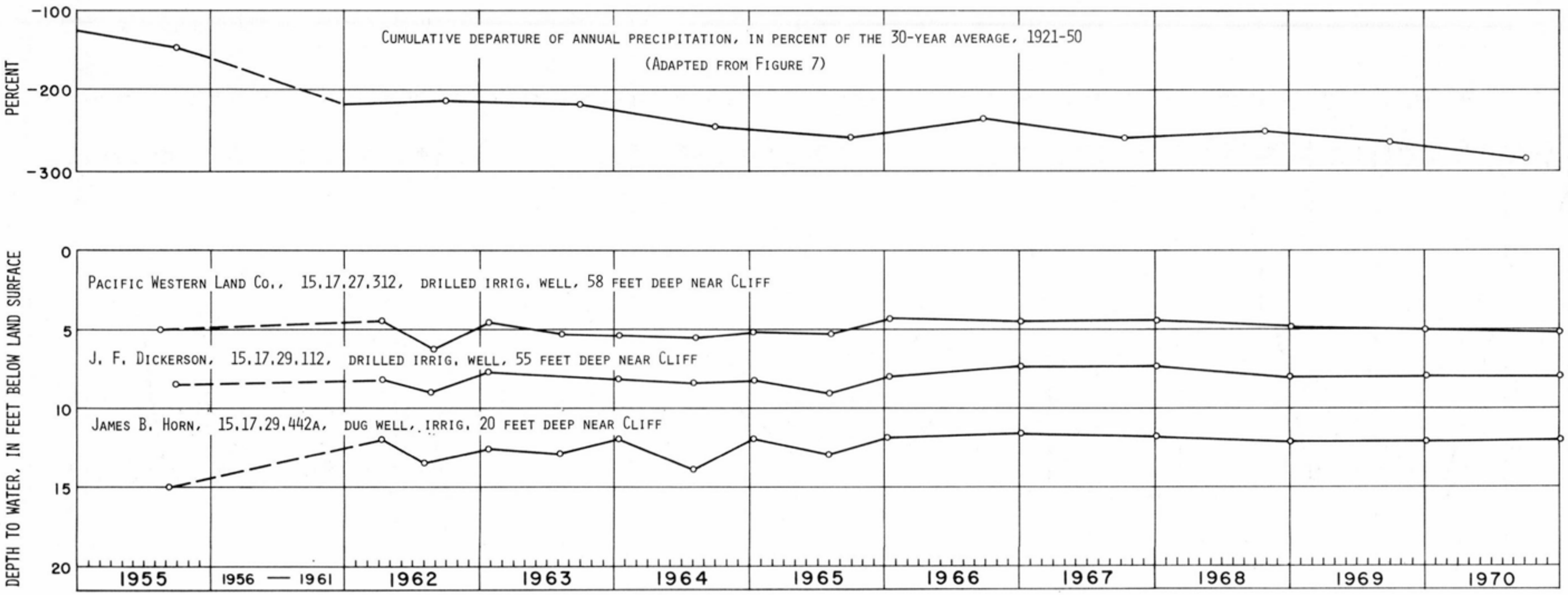


Figure 39—Hydrographs of three wells near Cliff and Gila, on flood plains of Duck Creek and Gila River; at top, cumulative departure in percent of average precipitation.

miles southwest of the county line (26 miles southeast of Silver City).

Water - level contours (fig. 3) south of about 18. 14. 36. 000 bow downstream, thus indicating that the water table is higher under the stream channel and that the alluvium is being recharged.

A graphic water-level recorder was in operation for a year (1955-56)on an unused well (19.13.29.421) at the Jim McCauley ranch on San Vicente Arroyo; periodic measurements were made after the recorder was removed. The well is about 1,200 feet from the channel of the arroyo which is incised 35 to 40 feet into the old flood plain.

The water level in the McCauley well has shown an almost continuous upward trend since measure ments began in 1954 (fig. 40). Sharp rises were noted on the water-level recorder tracing soon after floods in the arroyo reached the area. The upward trend of the water level is at variance with the observations made of water levels in all other wells (except those in the Gila Valley mentioned above), which have shown downward trends that correlate with trends in the cumulative departure curve (fig. 13). The continuing rise in the McCaulry well can be attributed to the discharge of waste water from the Silver City public supply system.

Silver City has for many years discharged its waste water to San Vicente Arroyo about a mile southeast of town. The quantity was not large in earlier years when water use was small, but the

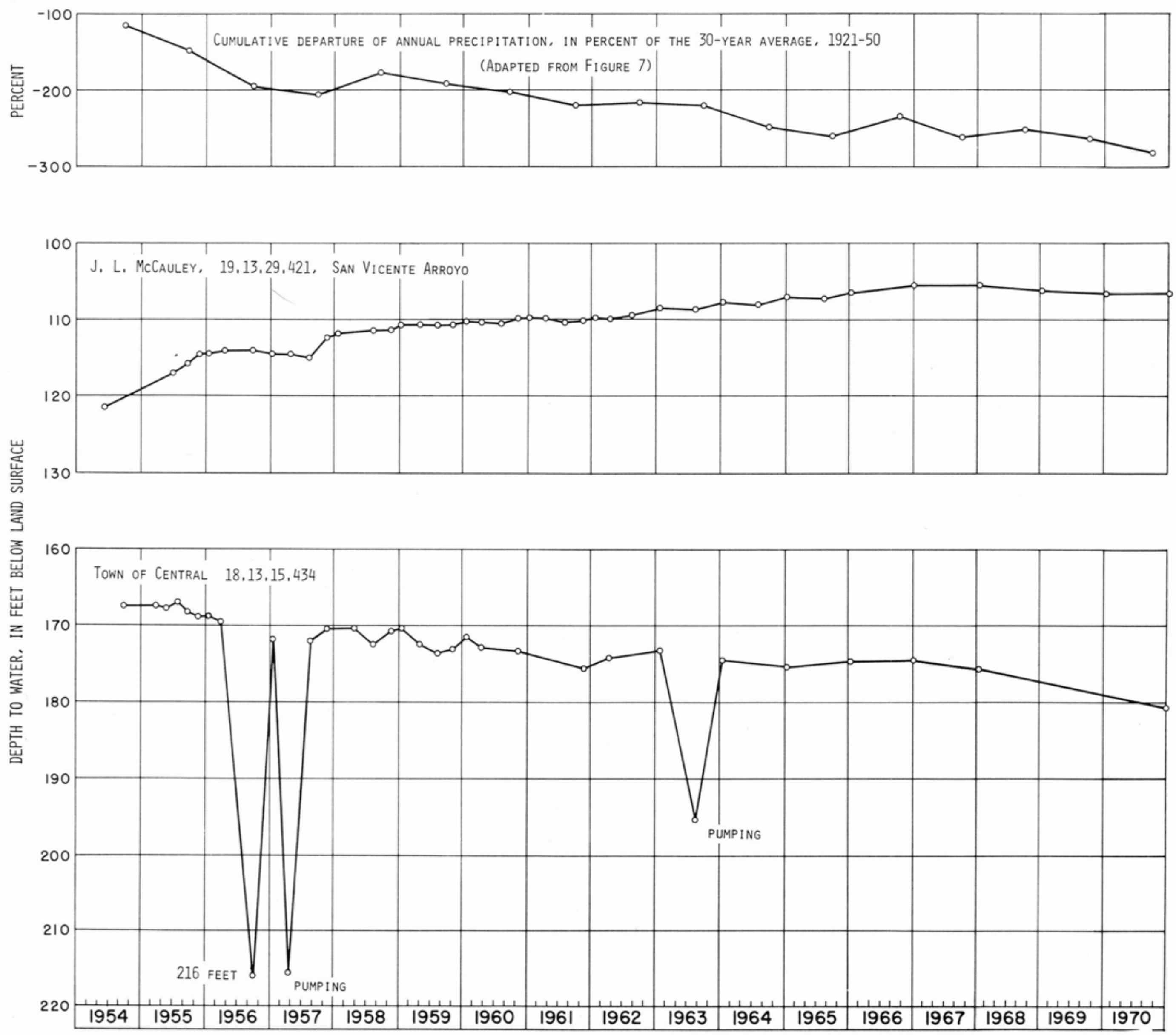


Figure 40—Hydrographs of wells 18.13.15.434 (near Central) and 19.13.29.421 (near San Vicente Arroyo); at top, cumulative departure in percent of average precipitation.

discharge had increased markedly since about 1945 when the Franks Ranch well field was developed. The addition of the Woodward well field to the Silver City water system in 1958 resulted in increased water use and increased discharge of waste water. Waste discharge in 1965 averaged about 12 million gallons per month (one-half the average city pumpage), or an amount equal to a steady flow of about 270 gpm (0. 6 cfs).

The waste water constitutes a source of artificial recharge to the upper part of the San Vicente Arroyo hydrologic system. The volume of artificial recharge has been sufficient to reverse, in the San Vicente Arroyo, the downward trend of the water levels observed elsewhere in the county. The recharge from waste disposal represents in part new or imported water to the San Vicente Arroyo-Mimbres hydrologic system because part of the water is taken from the Gila River drainage basin across the Continental Divide.

The effect of the artificial recharge on water levels in the McCauley well, some 10 miles down channel, has been indirect, rather than direct. Whether waste water has moved underground that far is doubtful. The waste water has built up the water table in the channel fill downstream from the point of discharge. This build-up has made possible the flow of floodwater greater distances downstream before it is absorbed by the channel fill. Thus, each natural flow overrides the artificial-recharge water and recharges the aquifer progressively to greater distances downstream than it would if waste water had not been placed in the channel upstream.

Natural recharge to the bolson fill and alluvial aquifers occurs primarily in arroyos but recharge directly from adjacent upland areas also occurs. Feth (1964) described situations where geologic conditions permit movement of water from rock formations of the uplands directly into the aquifers of the valleys. Precipitation infiltrates fractured and jointed rock of the uplands, and the joints and fractures channel water downslope. Alluvium and bolson fill generally laps onto the bedrock slopes around the basin margins and the water in the bedrock moves downgradient under the overlap, and into the bolson fill.

AMOUNT OF RECHARGE

The question commonly is asked: "What percentage of the precipitation becomes recharge?" The question and the answer may be academic—not expected to produce a practical result—but they are of interest and can be used to advantage in planning, either to produce tangible results or prevent large unnecessary expenditures.

One method of computing natural recharge is based on recognition of the fact that over along period of time the ground-water recharge equals natural ground-water discharge, as represented by ground-water accrual to a hydrologic system. The following analysis shows the magnitude of recharge in relation to total precipitation.

The figures derived for ground-water accrual and base flow to the Gila and Mimbres Rivers can be used, with additional assumptions, to estimate the percent of precipitation that becomes ground water. The results are only estimates because assumed values are used for some factors. Further, the rock types upon which the precipitation and runoff occur are varied; infiltration would approach 100 percent on a loose sandy gravel; and there would be none on an outcrop of unweathered granite.

Ground-water discharge to reaches of the Gila River between the gaging stations at Hooker damsite and at Blue Creek averages approximately 83 cfs. This inflow to the river represents most of the natural recharge to about 1,340 square miles of the Gila drainage basin. Ground water discharged by evapotranspiration in tributary canyons such as Mogollon, Bear, Sycamore, and Mangas Creeks is estimated. The valleys of these creeks and a few others have only scattered stands of vegetation in localities where water tables are close enough to the surface to allow some evapotranspiration losses. Elsewhere the water table is too far below the surface to be reached by plants.

Evapotranspiration in these tributaries is assumed to be about 5 percent of that from native vegetation on the flood plain of the Gila River (based on an estimate of about 1/20 as much vegetative cover), or about 70 acre-feet in June, and equivalent to an average steady flow of about 1. 2 cfs.

Discharge due to net consumptive use from the few domestic and stock wells scattered throughout the drainage area probably is not more than 0.1 cfs, and so not considered.

Total ground-water discharge from the drainage area between Hooker damsite and Blue Creek gages during June is thus about 84 cfs, or 5,000 acre-feet. Because these figures also represent the theoretical base flow of the Gila River for this area, they can be considered also to be the average monthly ground-water discharge in this part of the basin; annual recharge (equal to discharge) is thus about 5,000 x 12, or 60,000 acre-feet.

The annual precipitation on the drainage area ranges from a low of about 12 inches at Redrock to a high of about 24 inches onthe headwaters of Mogollon Creek, and 21 inches on the headwaters of Bear Creek near Pinos Altos (table 1). The average on the area is estimated to be about 18 inches.

Annual precipitation at a rate of 18 inches per year on 1,340 square miles of drainage would amount to about 1, 300,000 acre-feet. Recharge of 60, 000 acre-feet per year to this area amounts to about 4.6 percent of the annual precipitation, or about 0.8 inch out of 18 inches.

The annual recharge rate for the Mimbres River watershed between the Mimbres and Faywood gages is estimated at 4. 8 percent (0. 87 inch) based upon an estimated average annual precipitation of 18 inches over a watershed of about .308 square miles

(300, 000 acre-feet), and recharge (equal to groundwater discharge) of about 14,300 acre-feet annually.

These percentages are appreciably higher than have been estimated for the plains areas tothe south where Reeder (1957, p. 25) and Doty (1960, p. 15) determined that about 1 percent of the average annual precipitation becomes recharge in the Animas and Playas Valleys. Conditions of climate, topography, rock outcrops, and ground cover, however, are more conducive to recharge in the highlands than in the plains.

Possible sources of error leading to the higher estimates of infiltration are the estimates of evapotranspiration which, if too high, give accrual and recharge estimates that are also too high. However, the estimates of average precipitation, if in error, probably also are too high; but, if they were lower, the percentage of infiltration would be higher still. The two most likely sources of error thus tend to compensate. The estimates of percentage of infiltration are believed to be reasonable.

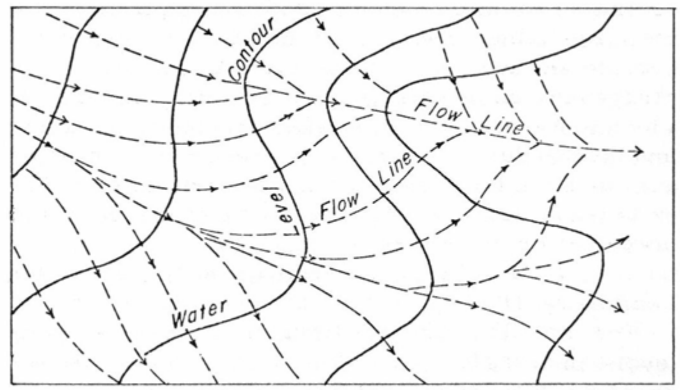
The flow of Mangas Creek (table 2) below Mangas Spring is base flow and represents ground water discharged at that one point in Mangas Valley. The discharge is about 1, 300 acre-feet annually. Average precipitation is about 14 inches on a watershed (above the springs) of about 120,000 acres, or 138, 000 acre-feet annually. The measured flow of the springs alone is thus about 0. 9 percent of the total precipitation. The measured flow does not include underflow in the channel, which may be equal to or even greater than the surface flow. Neither does it include ground water moving through the valley fill (across the width of the valley) that bypasses the springs.

If the channel underflow equals surface flow, the percentage of precipitation that becomes recharge would be 1.8. Estimates of the amount of discharge through the valley fill, that bypasses the springs and channel, range from about 1, 700 to 2,200 acre-feet annually. These quantities, if added to the measured surface discharge and possible channel under-flow, give infiltration rates ranging from 3. 0 to 3. 5 percent of the total precipitation on the Mangas watershed above Mangas Springs. This estimate agrees reasonably with estimates for the Gila and Mimbres watersheds.

DIRECTION OF MOVEMENT

Ground water moves downslope (down the hydraulic gradient) just as does water in streams on the land surface. Ground water follows more or less regular paths depending upon the configuration of the land surface and the bedrock, and the character of the rock material. Only under rather rare circumstances does water move underground in well defined channels; most of the cited underground rivers are myth. Geologic conditions under which underground streams may develop are not known in Grant County.

Ground water will flow more readily through the more permeable parts of an aquifer, and may not follow a course parallel to the land surface gradient. The general direction of movement of ground water in a given locality can be determined from the water-level contour map (fig. 3) by drawing directionof-flow arrows or "flow lines," perpendicular to the contour lines, as in the sketch below.



Flow lines commonly will diverge from large ridges or mountains, and converge toward valleys, which act as natural drains. The flow lines serve to define the principal areas of recharge and discharge. Areas of convergence of ground-water flow lines commonly are the best places to prospect for water.

The valleys of the Gila and Mimbres Rivers and their major tributaries are the natural drains for most of Grant County. Ground water moves toward these valleys and discharges to the rivers or moves underground down the river valleys. Water that moves into the Gila and its tributaries may ultimately leave the state; all other natural drains feed ground water to aquifers in the Lordsburg, Deming, and Hachita areas.

DISCHARGE

Natural discharge of ground water may occur from springs, as effluent seepage along a stream channel, as evapotranspiration, and as movement from one aquifer to another. Artificial discharge in Grant County is mostly from wells, and from some mining works.

The discharge of all springs listed in table 13 (see rear) is about 1, 000 gpm (2. 2 cfs), or 1, 600 acre-feet per year. The table includes all major springs in the county and most of the smaller springs; an estimated 400 acre-feet may be added to include discharge from springs not visited, making the total spring discharge about 2, 000 acre-feet per year.

Some of the discharge, such as part of that from Allen Spring and Dorsey Spring, may percolate to another aquifer and thence to the rivers; the percentage of such return is believed to be small and is disregarded in this inventory of discharge.

The estimates of base flow contributed by ground-water discharge to the Gila and Mimbres Rivers in Grant County total about 10,400 acre-feet per month, or 125,000 acre-feet per year. Ground water discharged to the two principal drainage systems and from springs totals an estimated 127, 000 acre-feet annually.

Not included in the above total is ground water discharged by evapotranspiration in miscellaneous drainages to the Lordsburg and Deming plains where the water table locally is within 10 to 35 feet of the surface and available to some types of plants. Evapotranspiration losses from these drainage areas, which are mostly on the southern flanks of the Burro and South Burro Mountains, are small compared with those in the Gila and Mimbres drainage basins. However, they may amount to as much as 1, 000 acre-feet or more annually.

The water table in the Grant County part of the Lordsburg, Deming, and Hachita Valleys is too deep to be reached by plants. Discharge occurs naturally only by underground flow to areas in Luna and Hidalgo counties. Discharge to the surface can be accomplished only artificially from wells where the water table is below the reach of plants.

Ground water is pumped from wells and mining works for rural and domestic use, for urban and industrial supply, and for irrigation. No appreciable amount of water is pumped solely for recreational use.

An estimated 1, 500 domestic and stock wells are used in Grant County. Each well, if pumped at a rate of 3 gpm for 8 hours a day, 180 days of the year, would yield about 0. 8 acre-feet of water annually. The annual yield of all domestic and stock wells on this basis would be about 1,200 acre-feet.

As much as half of the water pumped from stock and domestic wells probably is lost through overflow, evaporation, and spillage from stock tanks, thus the pumpage does not necessarily represent water requirements. A part of the water discharged to septic tanks is returned to the hydrologic system.

Public water-supply systems provide domestic and commercial water to the communities of Bayard, Central, Hachita, Hurley, Santa Rita, Silver City, Tyrone, and Vanadium. The combined discharge from wells (and mine shafts) to supply these communities in 1965 was about 1,640 acre-feet a year. Much of this water, probably between 50 and 75 percent, was returned to ground-water storage via sewage disposal plants that discharge to arroyos, and by infiltration from septic tanks.

Industrial use of water is primarily for the production and processing of ores. Data provided by various mine and mill operators (Gilkey and Stotelmeyer, 1965, p. 38-47) indicate that in 1962 about 5, 800 gpm or 9,300 acre-feet annually were pumped to meet industrial needs of the mining industry; another 700 gpm was obtained from other sources. Additional pumping to supply other relatively small industrial demands, and expanded mining activities is estimated to have increased total pumpage by 1966 to 7,000 gpm or about 11,000 acre-feet per year. This water is almost all fully utilized; probably not more than 10 percent is returned to the hydrologic system.

Ground water is not used extensively for irrigation; annual pumpage for this purpose varies from year to year depending on factors as precipitation and availability of surface water. The average annual pumpage in recent years, determined by personnel of the New Mexico State Engineer Office, is about 4, 500 acre-feet (written commun. , 1966).

Irrigation water is applied mostly to porous soils on the flood plains of the rivers where the water table is seldom more than a few feet below the land surface. As a consequence of the permeable character of the soils and the shallow depth to water, an estimated 50 percent of the water applied returns to the water table. The net discharge is thus about 2, 000 acre-feet.

Much concern has been expressed by many people on the subject of diminishing supplies of ground water. As a consequence, many studies have been made in an effort to determine just what is happening locally, regionally, and worldwide. Certainly some aquifers are being depleted over broad areas because of pumping discharge but these are manmade effects and not the result of some regional or worldwide drying up of our water supplies as suggested at times. Fishel (1956, p. 434) in his studies of long-term trends of ground-water levels in the United States found that "no long-term trends of rise or decline of the water levels are discernible in areas not affected by pumping. As the weather cycle changes, many of the water levels that are now at low stage will rise to a high stage and many water levels that are now at a high stage will decline to a low stage. "

In Grant County, away from the heavily pumped areas of the city well fields, and south of Hurley, progressive depletion of ground water is not noticeable. Data indicate that water levels generally in the past have been both higher (1870-90) and lower (1935-55) than at present. Natural discharge to streams, and underground through the bolson fill, has not yet been appreciably, or even noticeably affected by pumping discharge.

Average natural discharge is equal to average natural recharge in an undeveloped aquifer and the aquifer system is in dynamic equilibrium. The balance is disturbed when pumping begins and the result is a decrease in the natural discharge somewhere in the hydrologic system. Eventually, though generally not immediately, the average discharge must be diminished by an amount approximately equal to the average rate of pumping.

Discharge by underflow through the valley fill in the Gila and Mimbres Valleys and through bolson fill can be estimated by using the formula:

$$Q(\text{in cubic ft/day}) = KIbW$$

or

$$Q(\text{in gal/day}) = KIbW(7.48)$$

where Q = the quantity of water per day, K is the hydraulic conductivity in feet per day, I is the inclination (gradient) of the potentiometric surface in feet per foot (determined from contours on the water-level contour map by dividing the gradient in ft/mile by 5, 280), b is the saturated thickness of the aquifer in feet, W is the width of the section in feet, and 7. 48 equals gallons per cubic foot.

The valley fill at the gaging station on the Gila River below Blue Creek, near the Hidalgo-Grant County line, is about 100 feet thick and the valley at that point is about 235 feet wide (U. S. Bureau of Reclamation, 1930, p. 228). The gradient is 15 feet per mile, or 15 = 5,280 = 0.0028 ft/ft; the hydraulic conductivity of the gravel-sand aquifer is about 300 ft/day (table 4).

Application of the second formula given above (Q = 300 x 0. 0028 x 100 x 235 x 7.48) indicates that approximately 150,000 gpd (105 gpm, or 170 acre-feet per year) are discharged as underflow inthe channel at the Blue Creek gage.

The hydraulic conductivity of the valley fill (assorted sand and gravel) in the Mimbres Valley in the vicinity of Dwyer is probably no more than about 100 ft/day, the gradient is about 35 feet per mile (0.0066 ft/ft), the saturated thickness of the aquifer is about 30 feet, and the valley is about 400 feet wide at the Faywood gaging station 1 mile downstream from the county line. Approximately 60,000 gpd (40 gpm, or 65 acre-feet per year) pass the gage as underflow to the Mimbres Valley in Luna County.

Relatively high-yield wells near Mangas Springs in Mangas Valley indicate moderately high transmissivity in that area. The gradients vary from 75 to 100 feet per mile (0. 014 to 0. 019 ft/ft) and the width across the valley is about 2 miles (10,000 ft). If the hydraulic conductivity is as much as 300 ft/day and the saturated thickness averages about 80 feet (see log, 17. 16. 9. 343), then discharge through the fill may range from 3,000 to 4,000 acre-feet per year.

The amount of ground water moving through the bolson fill at the county line southwest of Faywood also can be calculated roughly using the transmissivity (hydraulic conductivity x saturated thickness), as determined from pumping tests, in the formula for volume of discharge. The transmissivity of wells in the Warmsprings, Faywood, and Whitewater areas ranges from about 70 to 5,100 ft^2/day and averages about 2,500 ft^2/day for .15 wells. With a potentiometric gradient of about 30 feet per mile (0. 0056 ft/ft), ground-water flow across a section 1 mile (5,280 ft) wide is 2,500 x 0.0056 x 5,280 x 7.48, or on the order of 600,000 gpd, or 675 acre-feet a year. Assuming that the same transmissivity persists in the bolson fill along a 16-mile line extending southwest from Faywood, the amount of ground water moving into the Deming basin from the watershed of San Vicente Arroyo and its tributaries is estimated to be about 10, 800 acre-feet per year.

The transmissivity of materials in the alluvial fans along the base of the Burro and South Burro Mountains is much lower than in the bolson fill in San Vicente Arroyo. Low yields of wells penetrating the fans indicate that the transmissivity averages less than 130 ft^2/day. Thus, even with gradients averaging 100 feet per mile (0.019 ft/ft), the amount of groundwater moving to the Lordsburg basin probably does not exceed 10, 000 gpd per mile of cross section, or about 10 acre-feet per year per mile.

RATE OF MOVEMENT

The average rate at which water moves underground is determined by the effective porosity and the permeability of the aquifer, and by the hydraulic gradient, all highly variable factors. The rate of movement can be influenced by man by changing these factors but it cannot be done easily or over a large area. However, knowledge of the approximate average rate at which water moves underground, and the greater rate at which pumping effects move outward from a pumped well, can be helpful in planning the conservation, development, and use of water. Such knowledge can help avoid expenditures of large sums of money on programs that would not be economical. For example, building ground-water recharge structures is impractical if the water put into storage, or an equivalent amount, cannot be recovered for subsequent beneficial use where needed. Also, drilling one or two widely spaced wells is more practical if they will produce as much as four or five wells closely spaced and mutually interfering with one another.

Water rarely remains motionless in underground storage; it moves through the aquifer at varying rates depending largely on the head differential, the size of the rock particles comprising the aquifer, and (or) the shape and size of the pore spaces. These factors mayvary greatly within short distances in an aquifer; therefore, any computed velocity for water moving through an aquifer in an assumed straight line of flow must be considered approximate. The approximate velocity can be calculated by applying the equation

$$\overline{V} = \frac{KI}{P_e}$$

where V is the average interstitial velocity of water in feet per day, K is the hydraulic conductivity (permeability) in ft/day (feet per day), I is the hydraulic gradient in feet per foot (determined from contours on the water-level surface map by dividing the gradient in ft/mile by 5, 280), and P_e is the effective porosity.

In applying the above equation, modified from Wisler and Brater (1949, p. 226), the specific yield of the rock, expressed as a decimal, has in the past usually been considered synonymous with, and substituted for effective porosity in the formula. Lohman and others (1970, p. 29) have discouraged such use because the terms are not synonymous except for a few types of rock material.

Effective porosity is, however, equal to total

*Table 4--Hydrologic characteristics of rock materials found in Grant County*1/

	Rock type composing the aquifer	Total porosity (percent of volume)	Specific yield 2/ (percent of volume)	Hydraulic conductivity (K) 3/ (feet per day)	Water yielding characteristic 4/
CONSOLIDATED ROCKS	Granite, gneiss, schist, greenstone, quartzite 5/	0.02- 0.6	0.0- 0.05	0.00013	Very small
	Basalt, andesite, rhyolite, minimal vesicularity & jointing 5/	.1 - .5	.0- 1	.01 - .5	Very small to small
	Basalt, vesicular, brecciated, jointed	5 -10	4 - 9	5 - 500	Moderate to large
	Tuff, compacted or welded 5/	5 -10	1 - 2	.01 - .7	Very small
	Tuff, sandy tuff, agglomerate 5/	15 -25	5 -10	.7 - 10	Small to moderate
	Limestone, dolomite, marble 5/	.2 - 5	.1- 4	.07 - 3	Very small to moderate
	Shale and sandy shale, siltstone	20 -40	.5-10	.0013- .13	Very small
	Sandstone, fine to medium, weakly to firmly cemented	15 -30	5 -15	.13 - 1.3	Small
	Conglomerate or sandstone, well cemented (lower Gila)	5 -10	.1- 2	.0013- .7	Very small
	Conglomerate, poorly cemented (upper Gila)	15 -30	10 -25	1 - 10	Small to large
UNCONSOLIDATED ROCKS — Bolson, channel, flood plain, and lake deposits	Clay and silty clay, dense, massive to bedded; no coarser material	50 -60	0 - 2	0 $-10x1^{-6}$	Very small
	Clay and silt, 65-70%; very fine to fine sand, 25-30%; medium to very coarse sand, 5%	50 -60	2 - 5	0 $-10x1^{-5}$	Very small
	Silt and clay, 90-95%; very fine to medium sand, 5-10%	50 -60	10 -20	.03 - .3	Small
	Silt and medium to very fine sand, 70-90%; clay, 10-30%	45 -55	25 -35	1 - 3	Small
	Sand, assorted, 75-80%; fine gravel, 5-20%; silt, less than 5%	35 -40	20 -30	3 - 5	Small
	Sand, very fine to medium, 45-50%; sand, coarse to very coarse, 40-50%; silt, less than 5%	35 -45	25 -40	5 - 15	Small to moderate
	Sand, fine to very fine, 60-70%; silt, 20-25%; clay, less than 10%	50 -55	40 -45	10 - 20	Small to moderate
	Sand, assorted, 65-75%; gravel, 15-30%; silt and clay, 1-5%	25 -40	20 -35	20 - 100	Moderate to large
	Sand, medium to very coarse, 60-80%; gravel, 10-30%; silt and fine to very fine sand, 1-5%; no clay	35 -60	32 -53	100 - 300	Large
	Gravel, 25-45%; medium to very coarse sand, 45-70%; silt and fine to very fine sand, 1-5%; no clay	25 -45	23 -42	300 - 500	Large
	Gravel, 25-75%; medium to very coarse sand, 25-65%; silt and fine to very fine sand, 5-10%; no clay	25 -35	22 -32	500 - 1,000	Large to very large
	Gravel, 70-90%; medium to very coarse sand, 20-30%; silt and fine to very fine sand, less than 10%; no clay	25 -40	24 -38	1,000 -10,000	Very large

1/ Values are based on pumping tests and observations of rock characteristics in Grant County, and on data for rock types and aquifers of similar character in other areas as reported by the following: Conover and Akin, 1942 (p. 258); Johnson, (1966); Meinzer, 1923a (p.10-11); Stearns, 1927 (p. 164-168); Wenzel, 1942 (p. 13); Wilson, 1965 (p. 1-361).

2/ Specific yield and storage coefficient (see section on "hydrologic terms") are nearly equivalent for water-table conditions. Under artesian conditions the storage coefficient commonly ranges between .001 and .00001 (10^{-3} to 10^{-5}), for most rocks, and is about 10^{-6} per foot of thickness of the aquifer. Thus the storage coefficient of a confined aquifer 200 feet thick would be approximately 2×10^{-4}.

3/ The term "hydraulic conductivity", represented by the letter "K", and expressed as feet per day, replaces the term "field coefficient of permeability" (P_f) expressed commonly as gpd per sq. ft. P_f is equal to K x 7.48 gal/cubic ft. The hydraulic conductivity x the thickness in feet of the aquifer gives the "transmissivity" of the entire aquifer thus an aquifer 200 feet thick having an average hydraulic conductivity of 130 would have a transmissivity of 26,000 ft^2 per day. The term "transmissivity", (T) expressed as "ft^2/day" (feet squared per day) replaces the term "coefficient of transmissibility", commonly expressed as gpd per foot (gallons per day per foot); gpd per foot is equal to ft^2/day x 7.48 gal/cubic ft. It is a function of the total thickness of the aquifer, and therefore partial penetration of the aquifer gives an apparent transmissivity that may differ appreciably from the true transmissivity, especially if penetration is less than one-half the saturated thickness of the aquifer.

4/ Very small, less than 2 gpm; small, 2-20 gpm; moderate, 20-100 gpm; large, 100-1,000 gpm; very large, more than 1,000 gpm. In general, the smaller the yield, the greater the drawdown in feet per gallon per minute of water pumped. Water levels in wells tapping the granites, clays, and well-cemented conglomerates and sandstones may draw down as much as 50-100 feet at pumping rates of 1-2 gpm.

5/ Values for deeply weathered rock and rocks well-jointed, or fractured by faulting, may be an order of magnitude greater.

porosity for unconsolidated sediments, and for a few consolidated rocks such as limestones that have only joint or solution-developed porosity. If percentages for effective porosity are not given, total porosity should be used in the equation instead of specific yield. Because specific yield has been used so exclusively in the past, most references and compilations give values for specific yield, and do not give values for total or effective porosity. However, the following example will show clearly why specific yield should not be used in the equation, especially for fine to very fine-grained sediments.

Using samples reported by Wenzel (1942, p. 13), water in an unconsolidated material consisting of 65 percent silt and clay, having a porosity of about 60 percent, a hydraulic conductivity of about 0.00003 (3×110^{-5}) ft/day, and a gradient of about 0. 2 ft/ft, would move at a rate of 1×10^{-5} feet per day; but if the specific yield of about 9 percent is substituted, the indicated velocity is 7×10^{-5} feet per day, or about 7 times too high. The difference would be even greater if the percentage of clay were higher. However, in a material containing only 35 percent clay and silt, having a porosity of 50 percent, and a hydraulic conductivity of about 10 ft/day, the velocity would be about 4 feet per day. Substituting the specific yield value of about 45 percent gives a velocity of 4-1/2 feet, which is of the same order of magnitude.

The above relation suggests a method of utilizing the values for specific yield given in reports as Johnson's (1966) compilation of specific yields. Eckis (1934) presents a graph, reproduced by Johnson (1966, fig. 3), showing the relation of porosity, specific yield, and specific retention for unconsolidated sediments ranging from sandy clay to boulders. The porosity of sediments ranging in grain size from medium sand to boulders generally is 15 to 3 percent greater, respectively, than the specific yield; for sediments ranging from sandy clay to medium sand the porosity is from 30 to 15 percent greater, respectively. Estimates of the total porosity, specific yield, and hydraulic conductivity of rock types commonly found in Grant County are given in table 4.

The approximate total porosity for consolidated rocks also can be estimated from table 4. The effective porosity may be appreciably less than the total porosity in such rocks because many of the voids maybe isolated. Only the system of connected voids will transmit or yield water. Thus, the specific yield may be used to estimate the effective porosity. The effective porosity always would be somewhat greater than the specific yield in consolidated rocks because some water is retained on the walls of the voids. The difference between the effective porosity and specific yield in the consolidated rocks would have the same relation as in unconsolidated rocks—the smaller the voids, the greater the difference. In a fine-grained, well-cemented sandstone the specific yield could be as much as 30 percent less than the total porosity, whereas in a vesicular, brecciated, and jointed basalt having relatively large void spaces, the total porosity could be no more than 2 to 5 percent greater than the specific yield.

Hydraulic conductivity values for the Gila Conglomerate, bolson fill, and river-valley deposits range from less than 0.13 to about 800 ft/day. Generally poorly sorted sediments and the firmly to well-cemented sandstones and conglomerates have low hydraulic conductivities, commonly less than 0. 1 and seldom more than 2 ft/day. The higher hydraulic conductivities (over 50 ft/day) apply mostly to the better- sorted de posits of unconsolidated gravel and coarse-to-medium sand that contain only small percentages of very fine sand, silt, and clay.

The unconsolidated flood plain deposits in the vicinity of Cliff and Gila, and near San Lorenzo, have an average porosity of about 30 percent (expressed as 0. 30 in applying the formula); the hydraulic gradient is about 13 feet per mile (0.0025 ft/ft), and the hydraulic conductivity is about 167 ft/day. Applying the formula for the rate of movement, and using the average porosity, we find that water moves through these flood plain deposits at a rate of (167 x 0.0025)/ O. 25, or about 1.4 ft/day, or 500 feet per year. Similar deposits in Redrock Valley have hydraulic conductivities as high as 800 ft/day and average interstitial velocities through these deposits would be proportionately greater, or about 2,400 feet per year. High rates of movement through the flood plain deposits contribute to rapid recovery of water levels in the vicinity of a pumping well on the flood plain and near the river after pumping ceases.

The hydraulic conductivity for the upper part of the Gila Conglomerate, determined by aquifer tests, is about 4 ft/day at Silver City's Woodward Ranch and Franks Ranch well fields. The porosity of the beds averages about 20 percent and the hydraulic gradients are about 100 feet per mile (0. 019 ft/ft). Thus, water in these well fields is moving at an average rate of about 0. 4 feet (4-1/2 inches) per day, or 135 feet per year.

The hydraulic gradients locally steepen and flatten as indicated by the changes in spacing of the water-level surface contours (fig. 3). The average gradient between the Franks Ranch field and the Gila River is about 75 feet per mile (0. 014 ft/ft) and the average rate of movement of ground water down the gradient is about 0. 3 feet (3-1/2 inches) per day, or 105 feet per year.

Rate of movement of water through the bolson fill is about the same as through the Gila Conglomerate despite the generally greater permeability and porosity of the fill. The permeability of the upper part of the bolson fill in irrigated areas in the lower Mimbres Valley near Deming is about 23 ft/day (Conover and Akin, 1942, p. 258) and the porosity is about 25 percent. However the hydraulic gradients in the area commonly are no more than 20 to 30 feet per mile (0. 0039 to 0. 0057 ft/ft). The water moves at a rate of about 0.3 feet (4 inches) per day, or 120 feet per year. Rates of movement similar to those in the lower Mimbres Valley are assumed for the bolson fill near Faywood, Whitewater, and Separ because geologic and hydrologic conditions in those areas are similar and the hydraulic gradients are only slightly, if any, greater.

Generally the rate of movement of water underground is not important in considering the development of supplies of ground water because the movement in most places is slow. However, knowing the actual rate of movement of water is important when contaminants enter the aquifer and it becomes necessary to determine how rapidly they may spread.

EXTENSION OF PUMPING EFFECTS

The rate at which pumping effects move outward from a well or well field generally is a much more important factor for consideration than the rate of movement of water in the aquifer. Pumping effects move outward from the well independently of the actual movement of the water because they are the result of change in hydraulic potential (head) and thus are transmitted rapidly through the aquifer.

The effects of pumping maybe observed as a lowering of the water level in wells tapping an aquifer. When pumping starts in a well tapping a confined aquifer, water levels may drop appreciably, and almost immediately, even in wells at distances of several miles or more. Large effects generally do not occur at such distances in wells that tap unconfined aquifers. The effects generally are of intermediate magnitude in semiconfined (leaky) aquifers.

The close correlation (fig. 41) of changes in barometric pressure in the Silver City area with changes in water levels in the Woodward Ranch well field No. 1 well (18.14. 30. 324) indicates that semiconfined water occurs in the Gila Conglomerate. The water level in well 18. 15. 36. 422, a mile away from the well field, reportedly rose about 5 feet when water was first found, indicating a degree of confinement in the aquifer at that point also. This conclusion is substantiated by results of pumpingtests inthe area.

A 14-day pumping test was made in September and October 1956, on the Woodward Ranch No. 1 well (18.14. 30. 324), which fully penetrates the poorly consolidated upper part of the Gila Conglomerate. Water levels were measured in well 18. 15. 36. 422 (1 mile away), in well 18. 14. 30. 312 (the No. 2 well, 1, 350 feet away) and in well 18.15. 25. 442 at the Woodward Ranch headquarters, 2,600 feet away. All of these wells tap the upper part of the Gila. The level in the, No. 2 well began to drop 1 hour and 45 minutes after the No. 1 well started pumping (fig. 42). The response, which was more rapid than would be expected under water-table conditions and not as rapid as would be expected under artesian conditions, indicates semiconfined hydrologic connections between the two wells. The decline in the No. 2 well was about 9. 4 feet by the time pumping stopped October 10.

The levels in both of the more distant observation wells, 18. 15. 25. 442 (2, 600 ft) and 18. 15. 36. 442 (1 mile) fluctuated during the test, but only slightly. A comparison of barometric pressures and water levels showed water in the vicinity of both wells to be semiconfined; thus it was not certain at the time of the test whether the small fluctuations noted were the result of pumping the No. 1 well or due to changes of barometric pressure. However, later estimates, using an approximate 50-percent barometric efficiency determined from the records, indicated the water level in well 18. 15. 25.442 declined about 0. 3 foot as a result of pumping the No. 1 well for two weeks. Again, this decline, though small, confirms that semiconfined conditions prevail in well 18.15. 25. 442 and, by inference, in all the wells observed in the area of the test.

The distance that pumping effects can be observed depends in general upon the transmissivity and storage coefficient of the water-bearing beds, the volume of the water pumped, and the duration of the pumping. Where the aquifer is semiconfined, leakage from confined beds and slow drainage from overlying beds also may be a critical factor. Recharging and discharging boundaries also may be important in determining the distance that pumping effects can be detected and the decline in the water level.

The approximate decline of the water level at any location near a pumping well can be computed by using an average storage coefficient and transmissivity, and the average volume and duration of pumping, in conjunction with water levels measured in the pumped well and in one or more nearby observation wells. Data on volume and duration of pumping, and for water levels such as were collected during the test pumping of well 18.14. 30. 324 are essential for computing long-term effects of pumping.

Many methods for analyzing aquifer test data have been devised, many of them based on the original Theis (1935) formula, and all of them assuming that certain conditions prevail in the aquifer. All the required conditions for any method are rarely present, and so other methods of analysis have been devised to take into consideration special conditions. No single present method of analysis can include all the factors that influence the behavior of ground water under pumping conditions. The commonly used Jacob straight-line plot method (Cooper and Jacob, 1946), derived from the Theis formula, assumes that the aquifer is uniform in all directions, that all water is derived from the beds tapped by the well, and that overlying beds are completely drained as the water level lowers with continued pumping. The Hantush (1957) "leaky aquifer" method assumes that water pumped from wells tapping semiconfined beds comes in part from overlying unconfined beds without depleting their storage; regular recharge to the overlying beds also is assumed.

Neither of these assumptions fully satisfies the conditions in the Silver City well fields. The Gila Conglomerate, the principal aquifer, is not uniform in all directions. In the earlier stages of pumping some water is trapped in overlying thin sand string-

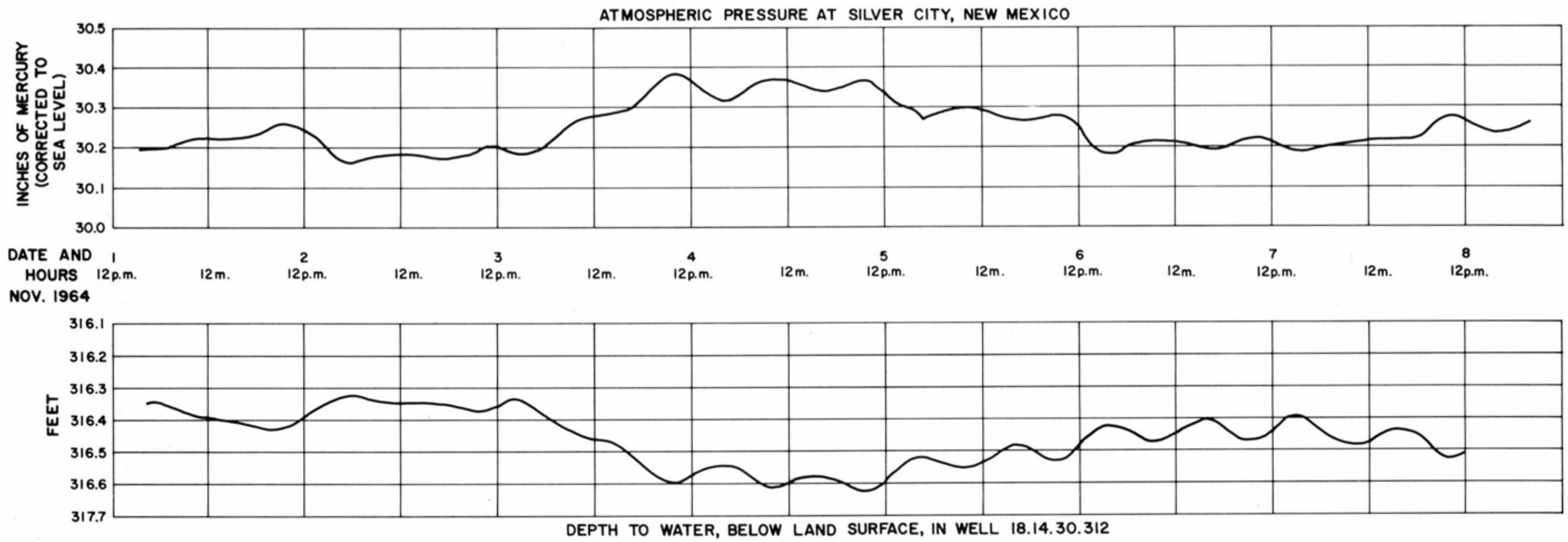


Figure 41–Hydrograph of well 18.14.30.312 in Woodward well field; at top, barometric pressure near the well site.

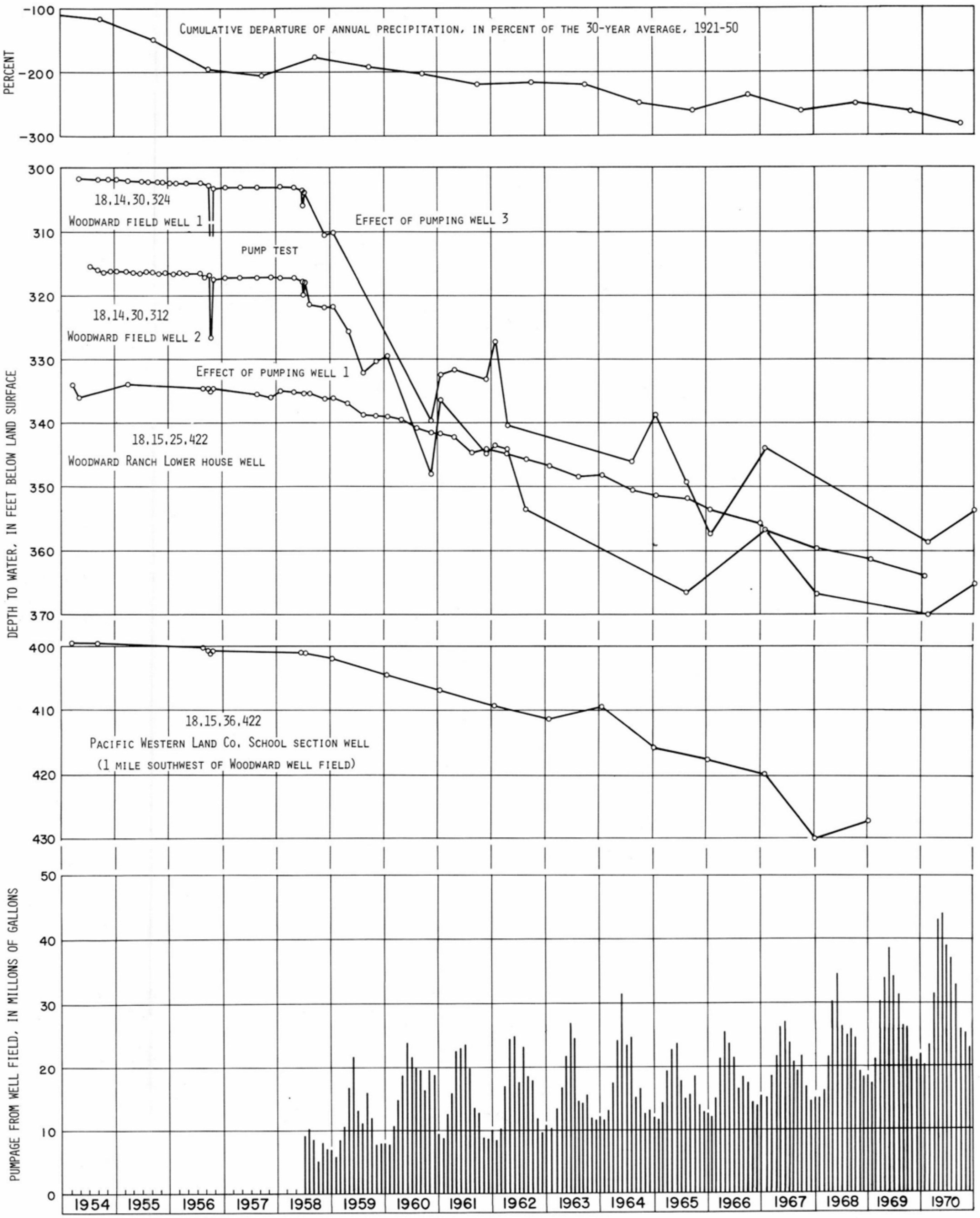


Figure 42—Pumpage and water levels of four wells in vicinity of Woodward well field; at top, cumulative departure in percent of average precipitation.

ers between layers of clayey material. This water drains slowly to the lowered water table and results in conditions that satisfy the "leaky aquifer" assumption of Hantush. But in time the overlying sandy beds are drained and no longer yield water; the assumptions of the Hantush method no longer apply and conditions more nearly approach those required of the Jacob straight-line plot method. Thus the duration of the test, whether long or short term, can be important in determining the validity of the results depending on conditions in the aquifer and the method of analysis used. One method could give satisfactory results using data collected during the early part of a pump test, and another method would need to be used for later data after conditions had changed.

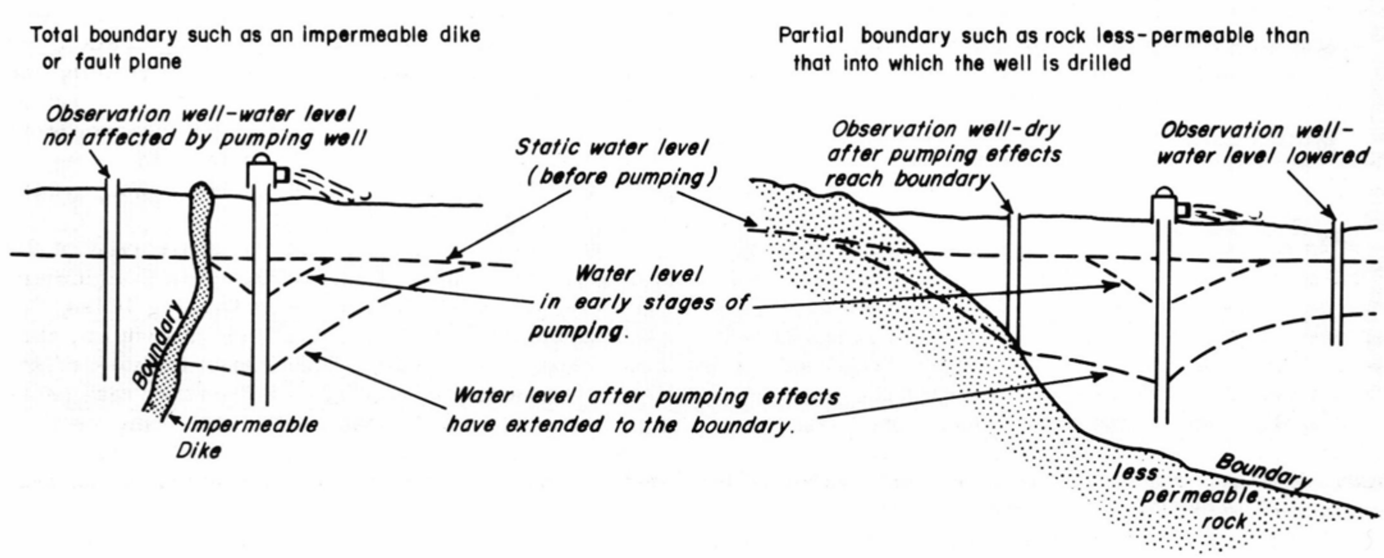
The prediction of declines in water levels resulting from pumping can be further complicated by obscure geologic conditions that are likely to be overlooked. The amount and rate of decline may be greatly influenced by abrupt changes in the rock formations as from gravel to volcanic rock, or granite, or by the presence of structures such as faults. The harder, denser rocks or the faults, may act as barriers to the movement of water. The presence of nearly impermeable rock between, adjacent to, or immediately beneath either the pumped well or the observed well will have a pronounced effect on the rate of decline in both wells. Such natural barriers to the free movement of water, or boundaries as they usually are called, are common and exist not only in the vicinity of both the Woodward and Franks Ranch well fields but over much of the county. Another nearby well, pumping at the same rate, will have approximately the same effect as a boundary.

Conversely, an increase in the permeability of the formation outward from the well, or the presence of a nearby stream, may facilitate movement of water to the well, and result in reducing the rate of the water-level decline. The more permeable beds and the stream are considered also to be boundaries; they usually are referred to as recharging boundaries because their effect is to increase the quantity of water flowing toward the well beyond that which would occur if they were not present.

If a boundary having the effect of a total barrier is between a pumping well and a nearby well, the water level in the nearby well will not be affected by the pumping well. However, the level in the pumped well will decline much more rapidly in the presence of an effective boundary. A much more common situation is the presence of one or more partial boundaries near the wells—boundaries that do not block all movement of water, but tend to change the overall or average hydraulic characteristics of the aquifer. The result would be a somewhat greater decline in the wells than would be computed mathematically without knowledge of the boundaries. A partial boundary could be simply a change in the character of the formation, as from sandy to more clayey, with a resulting decrease in the permeability.

The practical effect of a boundary is to cut off or diminish the flow of water toward a pumping well by reducing the contributing area. If the pumping rate remains the same, then the remaining area must make up the difference, therefore, water levels decline at a more rapid rate. Declines can be slowed only by reducing the rate of pumping. Where wells are closely spaced with overlapping cones of depression, the effect is much the same as a boundary. The effects of pumping may not be evident immediately where boundaries are located beyond the farthest well in an area. Time must be allowed for the pumping effects to reach the boundary and be reflected back to the wells. The effects of distant boundaries may be noted soon in artesian aquifers, more slowly in semi-artesian, and generally only after appreciable length of time under water-table conditions.

The sketches below illustrate the effect of total and partial boundaries on water levels in pumping and nearby wells:



When water levels have declined at predictable and steady rates for some time, then accelerate or level off sharply, at the same pumping rate, a change in hydrologic conditions is indicated. In general, an increased rate of decline would indicate a boundary; a decrease in the rate of decline would indicate an increased supply of water. The effect of a single boundary would be to approximately double the predicted rate of decline of water levels in both the pumping well and observation well.

Aquifer tests conducted on wells in both Silver City well fields ranged from several hours to 14 days. Analysis of the test data by the Jacob and Hantush methods indicated that the aquifer coefficients determined from the short tests did not agree with those determined from the longer tests, nor did they yield theoretical results that matched observed long-term trends either, but they were in better agreement than those of the short tests. The coefficient derived from the Hantush method for a leaky aquifer came closest to matching what actually happened in the well fields during short pump tests, and during the early stages of use of the well field.

The various methods of analysis yielded storage coefficients that ranged from about 0.02 to 0.15, and transmissivities that ranged from 550 to 3, 000 ft^2/ day; however, a storage coefficient of about 0.04 and a transmissivity of 1, 300 ft^2/day gave the best results in computing drawdowns that matched observed trends. These coefficients are believed to be representative for wells that fully penetrate the upper part of the Gila in that general area and southeasterly for a distance of about 4 to 5 miles. The coefficients probably are somewhat higher 5 to 9 miles farther southeast.

Yields from individual wells in the Woodward Ranch well field range from about 300 to 500 gpm; the yield from the well field for the period July 1958 through December 1968, 10-1/2 years, averaged about 400 gpm. In the computation of theoretical drawdowns, the following were assumed: 1) no water was immediately available for recharge and that pumping was from storage, 2) a single well in the center of the Woodward Ranch well field was pumped continuously at a rate of 400 gpm, 3) the transmissivity was about 1,300 ft^2/day, and 4) the storage coefficient of the aquifer was 0. 04.

Using these values and the Jacob straight-line plot method as outlined by Ferris and others (1962, p. 98-100), it was determined that the water table at a distance of 1 mile should be lowered about 2. 5 feet at the end of 1 year. The decline should be less than half a foot at a distance of 2 miles, and would not be measurable at a distance of 5 miles. The theoretical effect at 1 mile after 10-1/2 years should be a decline of about 11 feet. After the Woodward Ranch well field had been in operation for 1 year (as of July 1, 1958) the water level in observation well 18. 15. 36. 442, about 1 mile away, had declined 2 feet, a little less than the theoretical decline as computed by the Jacob straight-line method.

This less-than-theoretical decline in conjunction with the knowledge that the aquifer is semiconfined suggests that the aquifer is receiving some recharge from overlying beds, as postulated by the Hantush method of analysis. However, after the field had been in operation 10-1/2 years (through December 1968) the water level in well 18. 15. 36. 422 had declined about 23 feet, or about double the theoretical decline computed by the Jacob method, and more than double that computed by the Hantush method.

This greater-than-theoretical decline as computed by either the Hantush or Jacob method indicates not only that the overlying beds had been drained by the end of 10-1/2 years, but that the effects of boundaries were being observed.

At least two boundaries may be present (fig. 2)a major fault zone to the east along Pipe Line Draw, and the contact of the Gila Conglomerate and the volcanic rocks of the Little Burro Mountains to the west.

The coefficients for the Gila Conglomerate in the vicinity of the Franks Ranch well field were determined from the 25-year trends of water levels and from pumping records made available by the Silver City Water Department. The transmissivity was found to average about 650 ft^2/day, just one-half as much as in the vicinity of the Woodward Ranch well field. However, the storage coefficient of 0. 04 was about the same (Koopman, Trauger, and Basler, 1969, p. 21). In general, the coefficients for the Gila are believed to decrease in value toward the north, east, and west from the Franks Ranch well field, and to increase toward the south. For that reason coefficients determined from the 14 - day pumping test of well 18. 14. 30. 324 (fig. 43) in the Woodward Ranch well field were used to calculate the theoretical long-term lowering of the water levels in the Gila Conglomerate south of the well field. The coefficients for the aquifer in the Woodward Ranch well field are believed to be representative of a much larger area of potential development than the coefficients for the aquifer near the Franks Ranch well field.

The comparison of theoretical pumping effects with actual occurrence in the well field indicates that the results of short-term pumping tests (less than two days) are mostly useful for determining the approximate potential of the aquifer to yield water, and for selecting well equipment. Short-term tests should be used with reservations for computing the pumping effects that might result from many years of pumping large volumes of water.

The storage coefficient and transmissivity of the bolson fill are higher than for the Gila Conglomerate; thus, yields from most wells tapping bolson fill are appreciably greater, with less drawdown, than those tapping the Gila. The transmissivity of the bolson fill near Faywood and Whitewater may be as high as 5,300 ft^2/day. Data from the Mimbres Valley (Conover and Akin, 1942, p. 258) indicate the average transmissivity in the irrigated areas near Deming is about 6, 400 ft^2/day. Assuming that a single well near Whitewater pumps 1,000 gpm con-

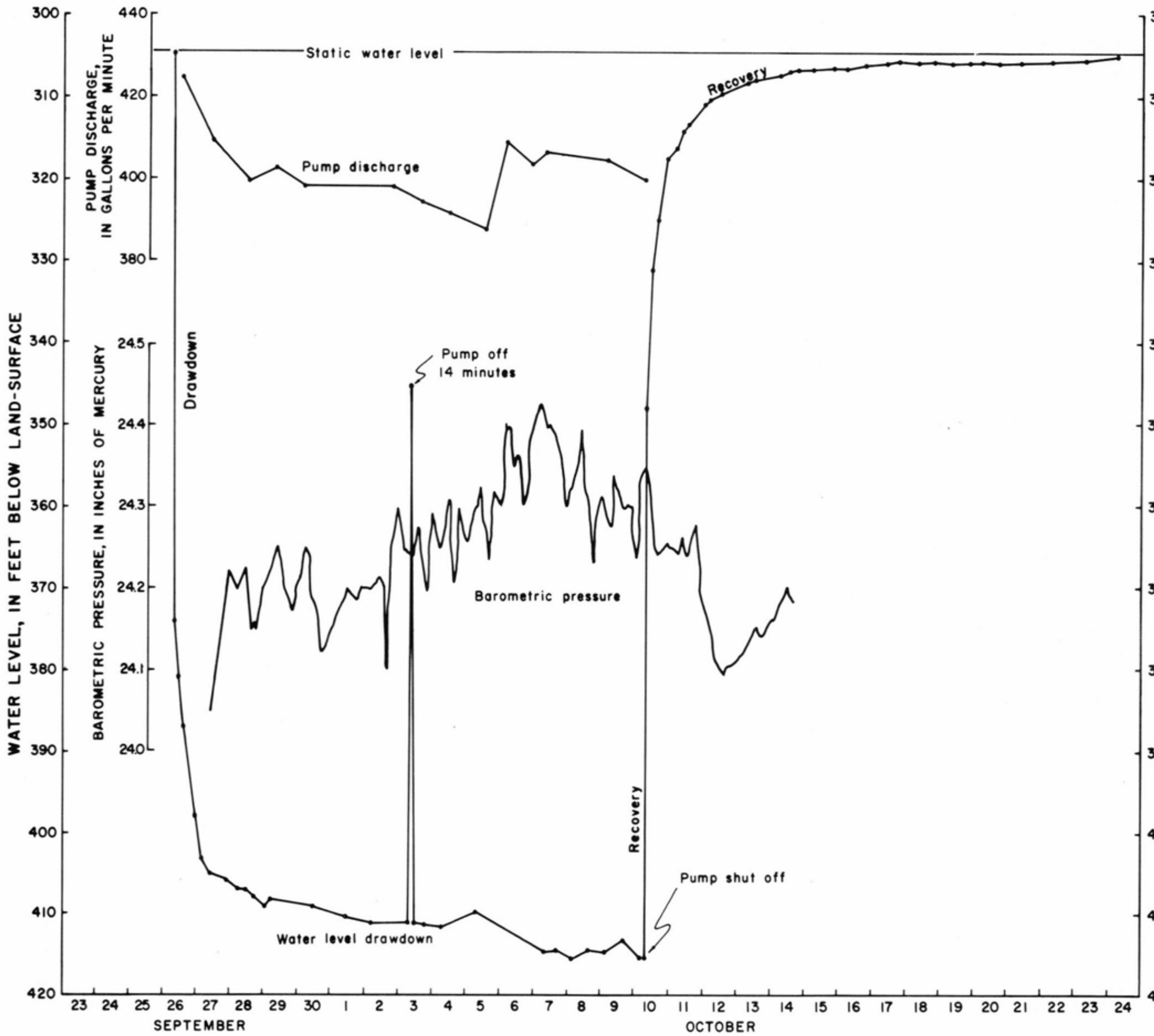


Figure 43—Water levels in well 18.14.30.324 (Woodward No. 1), pump discharge, and barometric pressure during aquifer test, September-October 1956.

tinuously from storage, that the aquifer is relatively homogeneous throughout the area, that the storage coefficient is 0.15, and that the transmissivity is 5,300 ft^2/day, then the water table at a distance of 1 mile would be lowered a little less than 2 feet at the end of 1 year. The decline would not be measurable at a distance of 2 miles. The effect at a distance of 4 miles after 20 years wouldbe a decline of about 2 feet.

The effects of pumping on ground-water storage and movement are increased with increased development; where the effect of one or two wells might go unnoticed, the effects of pumping hundreds of wells may soon become apparent. The net effect at a given distance of pumping from a relatively small compact well field can be calculated by assuming the total yield to be from one well located at the mean center of the pumping wells.

Graphs (fig. 44) prepared by using the coefficients of storage and transmissivity calculated for the Gila Conglomerate and the bolson fill provide a quick method for estimating roughly the long-term drawdown effects (changes in storage) of pumping from these two important aquifers. The effects shown as feet of drawdown are approximate for any particular area because the coefficients are not the same throughout the aquifer and the effect of local geologic conditions with respect to hydrologic boundaries is not represented.

The relatively slow movement of pumping effects in the Gila Conglomerate and bolson fill should be considered when the development of ground water is planned. Interference between pumping wells more than 1,500 to 2,000 feet apart in the bolson fill is

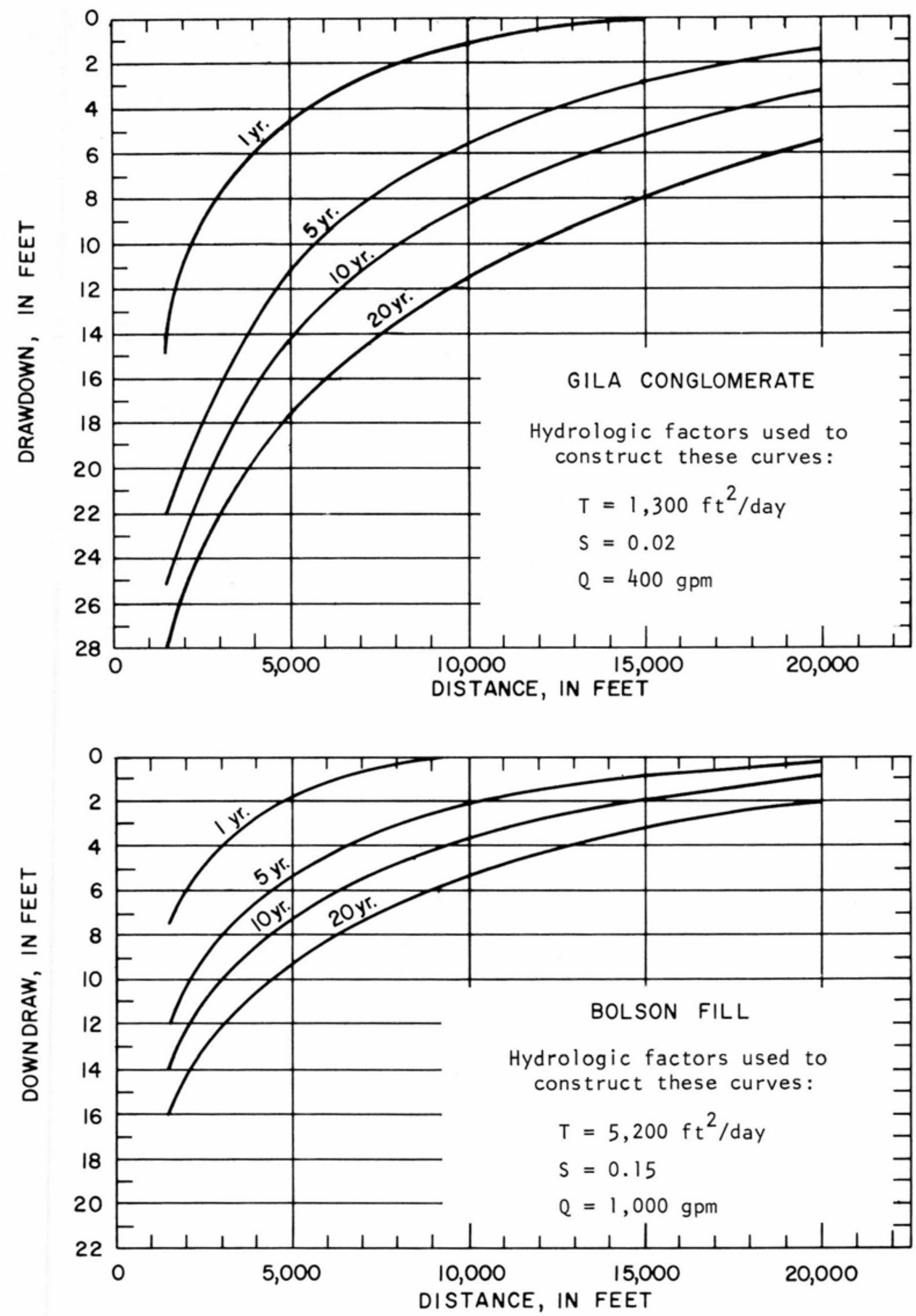


Figure 44—Drawdown versus distance for use in estimating effects of pumping at a steady rate, Q, from wells tapping the Gila Conglomerate and the bolson fill.

not apt to affect pumping efficiency to any serious degree short of years of operation. Water levels in the vicinity of Faywood, Whitewater, and Apache Tejo (fig. 45) have been lowered after many years of pumping from large capacity wells but the water-table contours (fig. 3) have shifted only slightly as a result. These small displacements show that the gross effects of heavy pumping under water-table conditions diminish rapidly with distance from the pumping wells—a result to be expected in view of the slow movement of pumping effects through the bolson fill.

Although pumping effects theoretically reach out eventually to all parts of an unconfined aquifer as the bolson fill, the effects more than a few miles away will be small and might not be distinguishable from larger natural fluctuation, even after many years of pumping. Presumably the pumping of water from the Franks Ranch well field will someday diminish the natural discharge to the Gila River some 16 miles away by an amount equal to the water pumped.

Hydrologic barriers that would prevent the effects of pumping at the Franks Ranch well field from

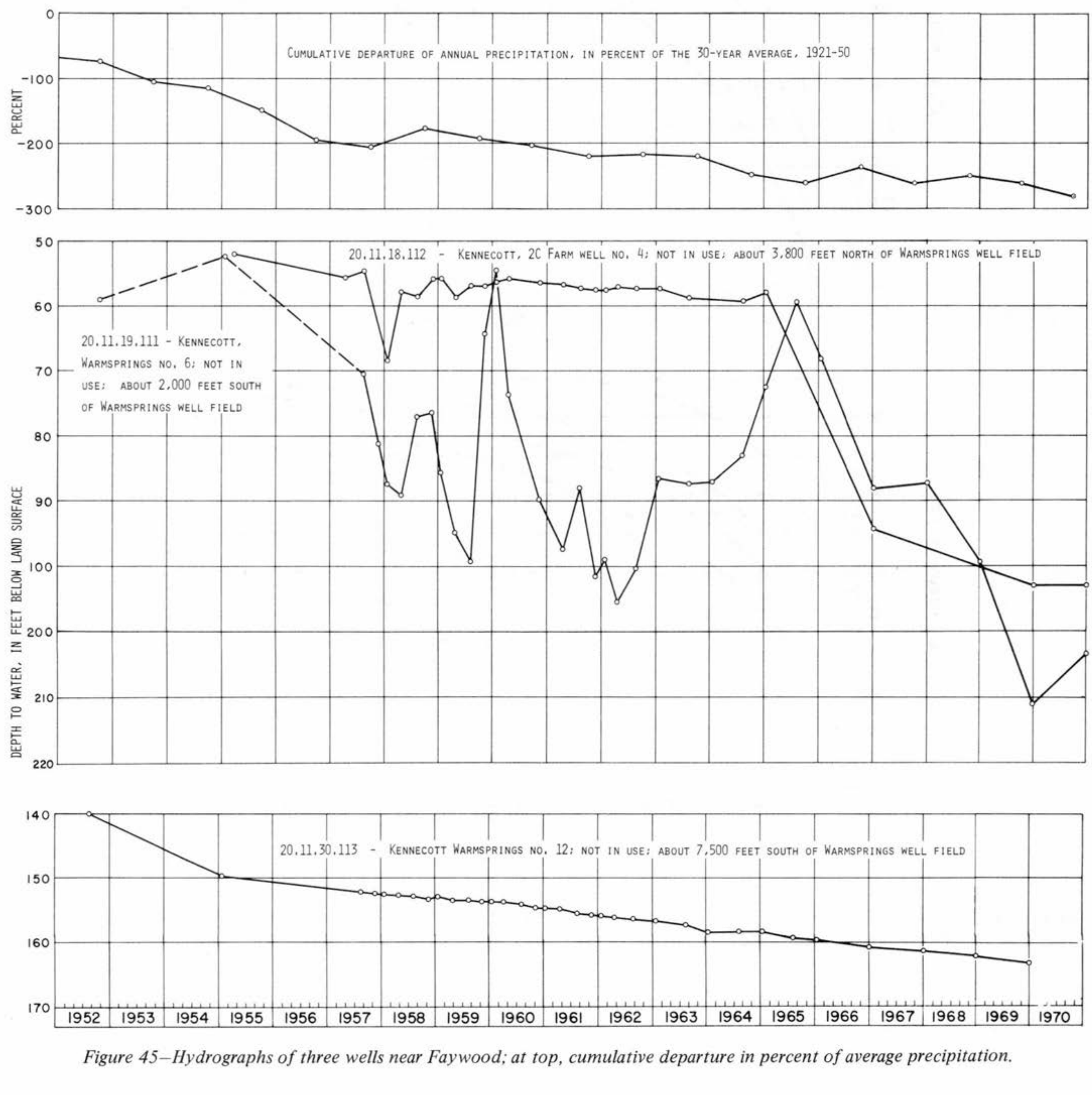


Figure 45—Hydrographs of three wells near Faywood; at top, cumulative departure in percent of average precipitation.

reaching the Gila River, or the effects of pumping of the Woodward field from reaching the irrigated areas of the Deming basin, are not known. In either case, however, the magnitude of the effects would be so small as to be virtually undetectable. The natural fluctuations of the daily and annual discharge of the Gila River are much greater than the amount of water pumped daily or annually from Franks Ranch. Diminished flow due to pumping, therefore, probably could not be detected. Also, the effects of pumping at the Woodward field presumably would be spread out over the entire bolson portion of the Deming basin. Annual pumpage at the Woodward field was about 725 acre-feet in 1967. That amount of water, if removed from the water body under the 23 townships surrounding Deming would lower the water table about 0.007 feet (assuming a porosity of about 20 percent for the aquifer). If the effect were restricted to the water table under the 50,000 irrigated acres, the lowering would be only 0. 07 foot (3/4 inch).

Water levels in the vicinity of a field of large-yield wells may decline sharply over the years but interference between individual wells is not likely to result in appreciable loss of well efficiency unless the wells are too closely grouped. Under water-table and semiconfined conditions well fields separated by as much as 3 to 5 miles will not interfere or affect one another to any important degree, short of decades of operation. Water levels and yields of individual wells in a well field would be more likely to drop below critical pumping levels as defined by Koopman, Trauger, and Basler (1969, p. 24) before they would seriously affect levels in a field as much as 4 to 5 miles away.

Quality of Water

The suitability of the water for various uses depends upon the type and quantity of dissolved and suspended matter. Concentrations of common constituents are reported in table 3 in milligrams per liter (mg/1). Milligrams per liter are approximately the same as parts per million (ppm) for concentrations up to 7, 000 units. A concentration of 1 milligram of calcium per liter (mg/1) is equivalent to 1 gram of calcium dissolved in 1, 000 liters of solution. By comparison, 1 pound of calcium dissolved in 1 million pounds of water (120, 000 gallons) would yield water having 1 ppm of calcium.

Most of the substances dissolved or suspended in water have been picked up as the water passes over or through soils and rock formations; some, however, are added to the water as a result of man's activities. In general, and within limits, the longer the water is in contact with the rock formation, the greater the concentration of the dissolved mineral matter. The base flow in rivers generally contains less dissolved mineral matter in the upper reaches than in the lower reaches because the ground water which feeds the lower reaches commonly has traveled a longer time and a longer path underground than the water which feeds the upper reaches. However, many factors can influence the solubility of a particular rock, or the ability of water to dissolve the various minerals in rocks.

Water eventually can become saturated with a particular mineral under certain conditions, and thereafter the water will not dissolve any more of that mineral unless conditions change. Changes might occur that result in some precipitation of the dissolved mineral matter. The changes most apt to cause the concentration of a particular mineral to vary are changes of temperature and pressure, or the introduction of a different mineral. For example, as water from a hot spring rises to the surface the pressure drops and the water cools, often causing the precipitation of some of the dissolved minerals. Water from a spring or well may be clear when drawn. However, when the water contacts the air, the iron may unite with oxygen resulting in the precipitation of red iron oxide.

Physical properties of water as temperature, specific conductance (ability to transmit electrical current), and pH are characteristics that determine usability. Temperature is independent of chemical content but the specific conductance is more or less proportional to the total dissolved solids, so that a large content of dissolved or suspended solids in water results in the water having a high specific conductance.

Standards for judging the chemical quality of water for drinking and food processing are set forth by the U. S. Public Health Service (1962). The significance of the various constituents commonly found in water is described by Hem (1959), and in the [California] State Water Pollution Control Board' s "Water Quality Criteria (1963). " These references have been used extensivelyto prepare table 5 which summarizes the quality of surface and ground water in Grant County.

WATER FROM WELLS AND SPRINGS

Shallow ground water generally has less mineral matter than water at greater depths in the same area. As a rule, the ground water under the beds of streams or arroyos, where recharge by relatively fresh floodwater occurs frequently, contains less mineral matter than water in adjacent rock formations.

In general, the chemical character of water in an aquifer remains relatively constant through the years in a given area. It changes when some change occurs in the hydrologic cycle that affects the relationship of water to soluble materials and sediments. Such changes are rarely natural—generally they are induced or introduced by the activities of man.

The tendency for the quality of ground water to remain the same under natural conditions is shown by comparisons of analyses of water from wells and springs (table 14, at rear) collected at intervals ranging from 5 to 42 years. Water from Faywood Hot Springs (20. 11. 20. 243, table 3) shows no appreciable chemical differences between samples collected at 5-year intervals. Water from two sets of paired wells (25.16.21.443 and 443a, and 26.15.15.- 321 and 321a), in the Lordsburg Valley show little change in water quality between the first sampling in 1913 and the second in 1955. Samples of water from supply wells for Bayard (18.14. 30. 221 and 221a), Central (18.13.15. 434), and Silver City (18. 14. 30. 312 and 324; 18. 15. 10. 441) show no significant changes in chemical quality in the period 1954-65. The appearance of tritium, previously discussed, is the only significant change noted in the 11-year interval.

The 104 complete analyses and 124 partial analyses in table 14 show only the chemical characteristics of the water. No determinations of bacterial content were made; thus, the analyses do not indicate the sanitary condition of the water.

Ground water in nearly all of Grant County is suitable for domestic, livestock, irrigation, and most industrial uses. Water of poor quality unfit for general use is found locally, but such occurrences are not common and generally are not predictable.

Water unsuitable for domestic use has been found in a small area along Duck Creek Valley, near Cliff. One analysis (15.18. 2.333, table 14) and several reports indicate that some water in this area contains large concentrations of sodium carbonate. The source of the carbonate is not known but the aquifer is the Gila Conglomerate, probably lake deposits of the upper part of the formation.

Although generally of good quality, ground water is nearly everywhere moderately hard to hard. Ground water in areas underlain by limestone, shale, and sandstone of marine origin (fig. 2) is likely to be very hard. Water from well 17. 12. 20. 244a (table 14) and from Allen Springs (16. 15. 26. 412) is characteristic of that from a limestone aquifer, the hardness due almost entirely to calcium bicarbonate. Water from the Colorado Formation and Percha Shale is apt to have a high concentration of calcium sulfate in addition to calcium bicarbonate. Well 17.14.10.432 (table 14) taps the Colorado Formation; and the water contains 618 ppm of sulfate—somewhat high even for a shale aquifer.

Water from rocks of volcanic origin generally is appreciably softer than that from sedimentary rocks and, except in mineralized zones, the water is also freer of most other dissolved solids. The analyses of water from well 16.19.11.414 and spring 17. 13. - 2. 411 show the characteristic chemical content of water in the volcanic aquifers in the nonmineralized and nonthermal areas.

Most of the ground water used comes from the Gila Conglomerate, from sand, gravel, and conglomerate aquifers of the river valleys, and from the bolson fill. The water ranges from very soft (16.17.9.242) to very hard (17.14.34.321). The hardness generally is intermediate between that of water from the limestone aquifers and that from the volcanic rocks.

Water in the bolson fill in the southern part of the county commonly is more alkaline than that in the north, and, therefore, softer; however, the total dissolved solids are generally greater and the overall quality not as good as in the north.

Ground water may be unfit or undesirable for domestic use because of the presence of a single constituent in quantities that exceed the acceptable limits given in table 5. Iron and fluoride are two such constituents that occur commonly in the ground water.

IRON

Iron is one of the most troublesome elements carried by water. Aside from contributing a distinct and undesirable taste, iron will precipitate as the red oxide on plumbing fixtures and on wet laundry soon after the water containing the iron comes in contact with air.

Iron in water maybe removed before use by aeration or filtering. The commonest and easiest method is to spray the water into the air and recover it in a tank under the spray. The oxidized iron will settle out as a red precipitate. Iron may be removed also by filtering first through crushed limestone, then through a sand filter. Water treaters for removing iron are available commercially; they work on the same principle as water softeners and are relatively simple to operate and maintain.

FLUORIDE

Fluoride is possibly the one constituent that occurs in water in Grant County in concentrations that could make the water unfit for human use. The higher concentrations, those over 5 mg/1 (milligrams per liter), are found mostly in hot springs and warm-water wells. Any well water having a temperature appreciably above normal for the area should be tested for fluoride. No simple economical process is presently available for removing excess fluoride from individual home water supplies. The high concentrations of fluoride commonly found in some domestic wells apparently do not affect the use of water for any domestic purpose except drinking and the preparation of those foods that take up large quantities of water.

RADIOCHEMICALS

Water from seven wells and springs was analyzed for radiochemicals to determine primarily the concentration of tritium, and thus learn something concerning the age of the water and time of recharge. The analyses (table 3) show also the concentration of natural uranium and radium. In general the concentrations are low and do not exceed amounts normal and safe for human use. However, the water from Faywood Hot Spring contains 29 micromicrocuries per liter of radium—well above the 3 micromicrocuries recommended for drinking water used as a regular supply (U. S. Public Health Service, 1962, p. 58). The concentration of radium does not affect the suitability of the water for bathing.

TEMPERATURE

The temperature of stream water in Grant County depends on the daily and seasonal temperatures, thus varies greatly, but generally is a little above the mean monthly air temperature during any given month.

Ground-water temperatures are much more constant than those of streams, especially as the depth to water increases. Normally the temperature of ground water at a water table near the land surface is about the same as the mean annual air temperature for the area. However, the temperature in open dug wells may vary appreciably from season to season because of the freer circultaion of air between the well and the atmosphere.

The mean annual air temperature in Grant County ranges from about 15.4°C (59. 7°F) at Hachita to 12. 3°C (52.1°F) at the Mimbres Ranger Station. The mean annual temperature for other areas in

Table 5--Common chemical constituents and properties of water and

[Significant and recommended limits are mostly those set forth by the California State Water Quality Control Board (1963). Constituent has no harmful physiological effect unless specified.]

Constituent or property	Principal sources	Significance	Recommended limits for selected uses (Limits expressed as parts per million, ppm, except for percent sodium, sodium adsorption ratio, specific conductance, and pH.)	Range in concentrations or values for samples analyzed	Number of determinations	Number of determinations more than (>), or less than (<), selected concentrations
					SW-Surface water GW-Ground water	
Silica (SiO_2)	Silicate minerals abundant in all igneous rocks, and in quartzose sedimentary and metamorphic rocks.	Forms hard scale in boilers and pipes. Inhibits deterioration of zeolite-type water softeners. May prevent corrosion in pipes by forming a protective coating.	1 ppm for boiler feed water at pressures over 400 psi; 5 to 40 ppm for lower pressures; 20 to 100 ppm for other industrial processes.	SW 26 to 61 GW 2 to 76	SW 8 GW 99	SW 6>39 GW 29<30 58<40 22>49
Iron (Fe)	Iron-bearing minerals present in most rocks and in suspended sediments in rivers, also in effluent from some industrial process water. Iron may be added to water in contact with well casing, pipes, and storage tanks.	Objectionable taste if over 0.1 to 1.0 ppm, depending on taste sensitivity. Over 0.2 ppm causes yellow stains on laundry, porcelain, and glass. Objectionable for many industrial, food processing, and beverage uses. Cattle will not drink enough water if it is high in iron--milk production and weight gain may be affected. Supports growth of certain bacteria that may clog wells and cause bad taste; can plug casing perforations and reduce porosity of aquifers adjacent to casing.	Sum of iron and manganese in domestic and stock supplies should not exceed 0.3 ppm. Traces for electroplating; not over 0.1 to 0.2 ppm for most industrial use.	SW 0.00 to 1.4[1/] GW 0.0 to 5.8 [1/] (One anomalously high concentration of 18 ppm not included.)	SW 4 8 GW 13 44	SW 2>0.3 (Total iron) 1>0.01 (Iron in solution) GW 7>0.3 (Total iron) 35<0.1 (Iron in solution) 4>0.3 (Iron in solution)
Calcium (Ca)	A major constituent of many types of rocks but especially of limestone, dolomite, and gypsum or gypsiferous shale; also may be contained in sewage and industrial waste.	With magnesium causes most of the hardness and scale-forming properties of water; breaks down soap lather but does not affect detergents. Desirable in water for irrigation especially where soils are tight because of unfavorable sodium ratio.	30 ppm for drinking and cooking, but higher concentrations not known to adversely affect health. 5 ppm for boiler feed water.	SW 25 to 71 GW 2.0 to 562	SW 8 GW 100	SW 4>30 GW 5<10 22<30 14>100
Magnesium (Mg)	A principle constituent in dolomite, and common in most limestone and igneous rocks.	Similar to calcium in causing hardness and scale, and in improving the permeability of alkaline soils. Salts of magnesium at high concentrations have a laxative and diuretic effect on humans and livestock.	30 ppm if sulfate exceeds 250 ppm, otherwise 125 ppm for drinking and culinary water; also 30 ppm for brewing. Cattle can become adjusted to 5,000 ppm of magnesium compounds.	SW 6 to 20 GW 0.2 to 111	SW 8 GW 102	SW 1>15 GW 25<10 13>30
Sodium (Na) plus potassium (K)	Salt beds and clay minerals; also contained in sewage and industrial wastes.	In high concentrations will act as a cathartic and is toxic to most plants; high ratio of sodium to the sum of calcium and magnesium in soils tends to destroy permeability and increase pH (alkalinity). Causes foaming in boilers when concentration exceeds 50 ppm.	May contain up to 115 ppm for general domestic use; over 200 ppm may be injurious in drinking water. 50 ppm for boiler water. 2,000 ppm limit for livestock, 7,000 ppm toxic to chicks.	SW 17 to 109 GW 5.1 to 519	SW 8 GW 117	SW 3>50 GW 6<10 39>50 9>115 4>200
Other metals Aluminum (Al) Copper (Cu) Lead (Pb) Zinc (Zn)	Al--abundant in most igneous and metamorphic rocks and in clastic sediments. Cu--copper-bearing minerals, copper and brass pipes, and salts of copper placed in water to control organisms. Pb--lead-bearing minerals, lead pipes, mining and industrial wastes. Zn--Zinc-bearing minerals and waste from industrial processes.	Aluminum--may cause trouble in some industrial processes and be injurious to plants. Copper--objectionable taste, toxic to some degree to plants, some livestock, and nearly all aquatic life at concentrations over 1.0; troublesome in most processing waters. Lead--cumulative poison in humans and livestock. Zinc--objectionable taste; can form toxic poisons in acid drinks such as lemonade; toxic to plants when concentrations exceed low levels; all aquatic life sensitive.	Al--1 ppm for general irrigation, 0.25 ppm for most industrial processes. Cu--1 ppm for domestic use, 1.5 ppm for livestock, 0.1 ppm for irrigation, and not over 0.02 for fish. Pb--0.05 ppm for domestic use, 0.5 ppm for livestock, traces for electroplating. Zn--5 ppm for most domestic use, stock, and irrigation; 1 ppm for fish.	GW (Al)0.00 to 0.1 (Cu)0.0 to 0.05 (Pb)0.00 to 0.04 (Zn)0.0 to 1.5	GW (Al)6 (Cu)5 (Pb)5 (Zn)5	GW (Al)2<0.1 (Cu)4<0.05 (Pb)4<0.04 (Zn)2<0.3
Bicarbonate (HCO_3) and carbonate (CO_3)	Limestone and dolomite, and calcareous materials found in most sedimentary rocks.	In combination with calcium and magnesium forms scale and releases carbon dioxide gas which combines with water to form carbonic acid. A high ratio of carbonate and bicarbonate to alkaline earths may cause the water to be unsuitable for irrigation.	350 ppm for domestic use, 60 ppm for brewing and carbonated beverages, and 20 to 200 ppm for boiler use, depending on pressures. See hardness.	SW (HCO_3)143 to 292 (CO_3)0 to 16 GW (HCO_3)36 to 1,390 (CO_3)0 to 646	SW (HCO_3)9 (CO_3) 9 GW (HCO_3)219 (CO_3)205	SW (HCO_3)5>200 (CO_3)3>5 GW (HCO_3)11<100 14>350 (CO_3)174<1 2>30

[1/] Includes both "total iron" and "iron in solution"--see text and explanation for Table 3.

summary of analyses of water in Grant County

Constituent or property	Principal sources	Significance	Recommended limits for selected uses (Limits expressed as parts per million, ppm, except for percent sodium, sodium adsorption ratio, specific conductance, and pH.)	Range in concentrations or values for samples analyzed	Number of determinations	Number of determinations more than (>), or less than (<), selected concentrations
				SW-Surface water GW-Ground water		
Sulfate (SO_4)	Gypsum, anhydrite, iron pyrite, and sulfides of other heavy metals in mineralized areas; also from oxidized organic matter containing sulfur, and in waste from industrial processes.	In combination with calcium and magnesium forms hard scale. High concentrations as magnesium or sodium sulfate may act as a laxative and can be toxic to some plants.	500 ppm for domestic and stock use; 2,000 ppm may cause weakening of cattle; 200 ppm for irrigation.	SW 4 to 78 GW 4 to 1,519	SW 7 GW 131	SW 1>50 GW 48>50 26>100 9>500
Chloride (Cl)	Most sedimentary rocks and soils, particularly salt beds. Sewage, and industrial waste.	In combination with sodium, potassium, calcium, and magnesium imparts salty taste. May be toxic to plants at concentrations as low as 100 ppm, depending on type; can accelerate corrosion of pipes.	250 ppm for domestic use, 1,500 ppm for stock and wildlife, 100 ppm for irrigation, and 50 ppm for most industrial supplies.	SW 1.8 to 32 GW 2 to 745	SW 9 GW 215	SW 5>20 GW 20>40 5>100
Fluoride (F)	The minerals fluorite and apatite, and volcanic or fumarolic gases--common in water from hot springs and warm-water wells.	Reduces incidence of tooth decay in children when concentration is 0.5 to 1.5 ppm; more than about 1.5 ppm causes mottling of tooth enamel in children. Concentrations of more than 5 ppm may cause fluorosis of the bone.	0.8 to 1.7 ppm for domestic and stock use, depending on the annual average of maximum daily air temperature ranging from 50° to 90.5° F. 1.0 ppm for food processing.	SW 0.3 to 3.6 GW Wells 0.1 to 8.0 Hot springs 6.0 to 16.0	SW 8 GW Wells 93 Hot springs 7	SW 5>1.7 GW 36>0.8 17>1.7
Nitrate (NO_3)	Nitrogen-fixing plants (legumes), decayed organic matter, sewage, animal waste, nitrate fertilizers, and nitrates in the soil.	Values higher than 5 to 10 ppm may suggest pollution. More than about 44 ppm may cause methemoglobanemia (infant cyanosis); nitrate in water used for irrigation generally is beneficial for its fertilizing value.	45 ppm for general domestic use, 10 ppm for infant feeding; less than 30 ppm for brewing and some industrial processes; 2,800 ppm toxic to cattle.	SW 0.4 to 4.0 GW 0 to 225	SW 8 GW 103	SW 1>3.0 GW 30>10 6>45
Dissolved solids (Total concentration)	Rocks, soils, and industrial and sewage effluents.	High concentrations are harmful to plant and animal life and undesirable for most industrial uses. Soil and drainage conditions determine to a large degree the total concentration allowable for irrigation. The human system generally cannot adjust to concentrations of 4,000 or more ppm.	1,000 ppm for domestic use, higher if no better is available; over 4,000 ppm generally considered unfit for human use, and over 7,000 ppm unfit for cattle, less than 1,000 ppm for most industrial uses and not over 3,000 for irrigation use.	SW 196 to 434 GW 116 to 2,310	SW 8 GW 99	SW 5>250 GW 26<250 22>500 10>1,000
Hardness (as $CaCO_3$) Calcium, magnesium--hardness equivalent to the carbonate and bicarbonate present. Noncarbonate--hardness in excess of that due to carbonate and bicarbonate; most commonly due to sulfate.	Mainly calcium and magnesium in solution with carbonate, bicarbonate, chloride and sulfate; iron and other metals cause hardness but ordinarily are present only in small amounts. Return flow from irrigation drainage generally is increased in hardness.	Hard water causes excessive soap consumption, scale in hot water heaters, boilers and pipes, and toughening of cooked vegetables but is not known to have detrimental physiological effects. Tends to prevent corrosion of metals. Produces finer grained structure in baking; excessively hard water retards fermentation and is detrimental in most industrial processes.	Water having a hardness of more than 100 ppm generally considered to be hard; 200 to 300 ppm for brewing; 0 to 50 ppm for laundering; 80 ppm for boiler feed water at 0 to 150 pounds per square inch.	SW ($CaCO_3$)90 to 259 (Non CO_3)0 to 20 GW (Ca-Mg)4 to 1,613	SW 9 9 GW 201 183	SW ($CaCO_3$)2<100 (Non CO_3)1>0 GW ($CaCO_3$)41<100 136<200 32>300
Percent sodium	The ratio of sodium to the sum of calcium, magnesium, potassium, and other cations, expressed as a percentage.	A high percent sodium indicates generally an alkaline water use of which can impair soil tilth and permeability; the total dissolved solids is a factor in determining whether or not a high percent sodium will be detrimental.	The effect on soils does not generally become important until the percentage rises above 50; conditions of drainage and permeability may permit use of high percent sodium water.	SW 23 to 67 GW 4 to 95	SW 8 GW 101	SW 6<50 GW 84<50 10>75
Sodium-adsorption ratio (SAR)	Relative proportion of sodium to calcium and magnesium in water.	Index of sodium hazard in irrigation water. An increase in value indicates a decrease in suitability of water for irrigation.	Less than 3.0 usually satisfactory on all soils. More than 26 generally unsatisfactory.	SW 0.6 to 4.4 GW 0.1 to 16.0	SW 8 GW 62	SW 1>3 GW 13>3 5>10
Specific conductance (micromhos at 25°C)	A measure of the ability of water to conduct an electrical current as a result of the presence of dissolved matter in the water.	An increase in value indicates an increase in dissolved solids.	More than 1,500 generally exceeds standards for domestic water. More than 3,000 unsuitable for irrigation under most conditions.	SW 240 to 672 GW 120 to 3,860	SW 9 GW 198	SW 4>500 GW 35>750 11>1,500 2>2,500
pH (hydrogen ion concentration expressed as pH)	A measure of the dissociation of water (H_2O) into hydrogen (H) ions (acid) and hydroxyl (OH) ions (base), expressed as a number in a scale ranging from 1 to 14 in which pure neutral water has a value of 7.	Values increasing from 1 to 7 indicate decreasing acidity; values increasing over 7 indicate increasing alkalinity. Affects taste, corrosivity, and many industrial processes. Values below 7 desirable for irrigation water applied to alkaline soils, but increases the corrosion action of water toward concrete and metal.	No limit in domestic and stock water; 7.5 for food canning and freezing, 6.5 to 7.0 for brewing. More than 9.0 unsuitable for irrigation use; optimum pH for culture of most lawn grasses and acid-loving plants such as roses is 5.5 to 6.5.	SW 7.0 to 8.7 GW 6.6 to 9.4	SW 9 GW 137	SW 6>7.5 4>8.0 GW 6<7.0 65<7.6 72>7.5 19>7.9 2>8.9

Grant County can also be obtained by averaging maximum and minimum temperatures in table 1.

The temperature of ground water increases with depth because the earth temperature increases with depth. The worldwide average rate of increase is 1°C (1. 8°F) per 100 feet of depth.

Water at a depth of 500 feet in a well should, theoretically, have a temperature of 5°C (9 °F) higher than the mean annual air temperature for the area. However, the earth-temperature gradient can vary appreciably from region to region, and may be considerably higher in areas of volcanic activity.

Water-well temperature data indicate that the gradient may be greater than the worldwide normal in parts of Grant County. The mean annual air temperature in the vicinity of Cliff and Gila is about 14°C (57°F), but the temperature of ground water at depths of 100 or more feet commonly is as much as 4.5 to 5.5°C (8 to 10°F) above the presumed normal for the well depth, and some are as much as 14°C (25°F) above the normal. These latter may be classified as thermal waters and the high temperatures must be attributed to some cause other than a steep thermal gradient. The area near Faywood, Dwyer, and Schwartz is another in which well waters commonly have temperatures above normal for the well depth.

The occurrence of high concentrations of fluoride in many of these thermalwaters suggests the possibility of mixing meteoric and juvenile water. However, the low concentrations of constituents as chloride imply some other source for the fluoride.

All of the hot springs in Grant County and most of the wells having water with above-normal temperatures are on or near the trace of major faults systems and in areas underlain by volcanic rocks of Tertiary and possibly Quaternary age.

WATER FROM MINES

In general, ground water in the vicinity of sulfide-ore bodies contains undesirable, though not necessarily harmful, concentrations of iron and sulfate. Ground water in and near other types of commercial metal-ore deposits may be entirely satisfactory for most uses. For example, the water pumped at a rate of 500 gpm from the American Smelting and Refining Company's Groundhog mine (17. 12. 32. 444, table 14) contains no concentrations of minerals in excess of public health standard limits for drinking water.

However, the water from U. S. Smelting Refining and Mining Company's nearby Blackhawk shaft (17.12.29.242, table 14) contains 778 mg/1 of sulfate, which exceeds public health standard limits for drinking water. An old mine (17.13.6.143) at the west edge of Pinos Altos also exceeds the sulfate limit. The water from both of these mines is otherwise satisfactory for domestic use.

Many communities in eastern New Mexico and west Texas use water that has an appreciably higher concentration of sulfate than that in the mines because no better water is available. The human system can become adjusted rather quickly to constant use of water rich in sulfate but the casual user may experience some problems (see Sulfate, table 5).

No simple, low-cost method of treating sulfate-rich water for home use is available at this time. The sulfate can be removed by deionization but the process generally is not economically feasible for a single domestic water supply.

Treatment on a large scale, as for community supply, may be practical. One approach would be the use of a strong-base anion resin in the chloride cycle to treat approximately two-thirds of the water having sulfate concentrations as those from the mines. The process would exchange all of the anions, the bicarbonate, sulfates, and fluorides for chemically equivalent amounts of chloride ion from the resin. If this treated water were then blended with the one-third untreated water, the resulting mixture would contain about 200 mg/1 of sulfate and would meet Public Health Service standards for sulfate concentrations.

Experimentation with water-treatment processes has increased greatly in the past few years and new methods of economically treating water to remove particular constituents are being developed for both domestic and industrial supplies. Water should not be summarily rejected because of mineral content, especially when a better quality water is not available. Possibly the water could be treated and made usable with one of the newer treatment processes.

WATER FROM STREAMS

Records of the temperature and sediment load of water in the Gila River near the town of Gila (Hooker damsite) have been kept since July 1959; a monthly check of the chemical quality has been made since June 1963. The data for 1959 are published in the U. S. Geological Survey Water Supply Paper 1645, p. 151 (1964c); and in Water Supply Papers 1745 (1960), 1885 (1961), 1945 (1962), and 1951 (1963) which are in preparation. Data for 1964 are published in Water Quality Records in New Mexico (U. S. Geol. Survey, 1964d, p. 154). Miscellaneous analyses of water from the Gila River, and from Sapillo Creek, Bear Creek, and the Mimbres River, are given in table 14.

The average monthly temperature of water in the Gila River at Hooker damsite during the 1964 water year ranged from a low of 4°C (40°F) in January to a high of 27°C (80°F) in August.

The specific conductance (in micromhos at 25°C) during the 1964 water year ranged from a high of 374 on July 17 to a low of 251 on September 27. These relatively low specific conductances indicate an average total dissolved solids content of about 220mg/l. The calcium-magnesium hardness ranged from 54 mg/1 in May to 92 in September; the sulfate content did not exceed 45 gm/1.

Fluoride concentrations ranged from 1.5 to 3. 8 mg/l. The higher concentrations occur generally in late spring when the river flow is low and is derived mainly from ground-water discharge. The numerous hot springs upstream from the sampling point undoubtedly are a principal source of fluoride.

The suspended sediment load of any river or creek varies greatly and is dependent not only upon the magnitude of the flow, but also upon the character of the terrain from which the flow is derived. Heavy precipitation on terrain underlain by relatively soft rocks as the Gila Conglomerate will result in a greater sediment load than the same amount of precipitation on a hard-rock surface. Many other factors influence sediment load, but a discussion of all these factors is not within the scope of this report.

The sediment load carried by streams of Grant County generally is lowest during the periods of low flow. The Gila River at the Hooker gage in June of 1964 carried an average sediment concentration of about 10 mg/1, or three-fourths ton per day; the mean daily discharge was about 28 cfs. The sediment concentration in September averaged about 740 mg/1, or 3, 740 tons per day; the mean daily discharge was about 340 cfs (U.S. Geol. Survey, 1964d).

The Mimbres River is not sampled periodically, but chemical analyses indicate the water in the vicinity of Mimbres is about the same quality with respect to total solids as the Gila River at Hooker damsite; however, the constituents differ. The Mimbres water contains more calcium and magnesium but less sulfate and fluoride.

The water in the Mimbres River, like that of the Gila, shows a sharp increase in dissolved solids downstream. A sample of water taken May 24, 1955, at the Mimbres gaging station contained 196 mg/1 of dissolved solids and a sample taken the same day at the Faywood gaging station contained 434 mg/l. The increase in dissolved solids is believed due in part to enrichment by return seepage from irrigation water, and in part to inflow of ground water having greater concentrations of dissolved solids.

The Mimbres River, like the Gila, has a low sediment load during periods of low flow, and a much greater load during floods and periods of sustained high flow.

Present and Potential Water Supply

Water problems do not exist in any area until man moves into the area and begins to use water. Whether the supply is surface water or ground water, when use starts water problems arise. Man has contended for the right to use water since long before recorded history. Aboriginal man fought his fellow beings and the wild beasts for the right to occupy areas where water was available. Today man still argues and fights for water—sometimes with the same fury as in the past. However, more commonly now than in the past, the disputes are settled by law.

Most of Grant County lies within parts of three declared underground water basins (fig. 3) wherein the State Engineer has jurisdiction over the appropriation of ground water. Knowledge of the laws controlling the use of water is desirable before extensive development is undertaken. Discussion of New Mexico statutes is outside the scope of this report. General information on the subject is available in Hutchins (1955); more detailed information is available in New Mexico Legislature (1968), and New Mexico State Engineer (1953, 1966).

Jurisdiction by the State Engineer is not restricted to development for agricultural use, but is applied to all users. No particular beneficial use of water is deemed to have statutory preference over some other beneficial use. In an area where the available water supplies are fully utilized, then such supplies are in the market place and will tend to pass to uses that yield the highest economic return.

Solving the problems created when men disturb the natural regimen of water is possible only through a full understanding of how ground and surface water are related to each other and the environment. These relationships, treated in the preceding sections, provide the background for the discussions that follow. The possibility of applying a solution previously discussed to other problems will become apparent.

INDUSTRIAL USES

The industrial use of water in Grant County is confined almost entirely to the mining industry. Relatively insignificant amounts of water are used by dairies, laundries, and similar small industries and businesses which have no water problems, or at most, only minor problems because they obtain water from municipal supply systems.

Nearly all of the mines in Grant County yield some waste water. The water may carry undesirable mineralmatter, which can contaminate aquifers supplying nearby domestic and stock wells. The improper or careless disposal of mine-waste water could seriously damage the quality of water in the major aquifers, and the surface flow as well. An aquifer, once it is contaminated, may be permanently impaired to a degree that prevents use of its water for most purposes.

Most of the water produced from mines is utilized either in operations of the producing mine or for other purposes. Water from several mines in the vicinity of Vanadium, Santa Rita, and Hanover is utilized for domestic purposes and, as mentioned earlier, all the water (500 gpm) pumped from the Groundhog mine east of Bayard is utilized by Kennecott Copper Corp.

An assured supply of water to maintain the Santa Rita pit and Hurley smelter operation has long been a goal of the Kennecott Copper Corp. Yields from several well fields tapping aquifers in the area southeast of Hurley declined under heavy draft to the extent that most of the wells were abandoned in recent years.

New and more productive well fields drawing from extensive aquifers have been developed or acquired at widely scattered points up to 12 miles southeast of Hurley. To continue the trend of expansion of recent years, additional supplies probably will be needed in the near future.

Details of water use and requirements of the Kennecott Copper Corp. , the U. S. Smelting, Refining and Mining Co. at Vanadium, and the New Jersey Zinc Co. at Hanover are given by Gilkey and Stotelmeyer (1965, p. 38-47).

Kennecott Copper Corp. in 1962 required the continuous addition of 6,140 gpm of new water—water not previously used in the operation—to maintain all industrial systems and supporting services, except residential. About 920 gpm were needed at Santa Rita and 5, 220 gpm were needed at Hurley. About 300 gpm at Hurley and 250 gpm at Santa Rita were obtained from impounded surface runoff; about 140 gpm at Hurley was derived from moisture in the ore. The balance, or some 5, 450 gpm (9, 400 acre-feet per year), was obtained by pumping from wells or mines. Of this quantity, about 650 gpm comes from wells and mines in the vicinity of the Santa Rita pit, and the balance from the area south of Hurley.

The U. S. Smelting Refining and Mining Co. at Vanadium uses about 105 gpm, all obtained from a nearby inactive mine. The New Jersey Zinc Co., at Hanover, requires about 285 gpm of new water for all of its operation including about 25 gpm for domestic supplies to nearby homes and office buildings. The water all comes from mine workings; some water is purchased from other nearby mining companies.

The approximately 6, 500 gpm of new water used in 1962 by the three companies mentioned above is equal to about 10,000 acre-feet annually, or about seven times the amount of water used by the communities of Bayard, Central, Hurley, Santa Rita, and Silver City.

The Phelps Dodge Corp. in the summer of 1966 began open-pit mining operations at old Tyrone. Depths to water in the vicinity of Tyrone range from about 110 feet on the floor of Mangas Valley, north of town, to 510 feet on the Continental Divide south of the old town. Large quantities of ground water will be produced as the pit is developed below these levels. Both the production and disposal of that water can cause problems.

The development of an open-pit operation comparable in scope to Santa Rita will result in the eventual formation of a large cone of depression and will affect water levels over a broad area. Some wells near the developing Tyrone open pit have shown a steady decline (fig. 46) in recent years as a result of natural climatic trends. The decline in well 19. 15. 10. 324 was continuing in 1970 and may accelerate as the pit is deepened and water is drained from surrounding areas. However, the trend downward in well 18.15. 32. 234 on the floor of Mangas Valley, 4 miles northwest of the pit, was reversed during 1969. The rise of nearly 13 feet in 1 year was more than double the decline of 5. 77 feet in the 14-1/2-year period August 1954 to January 1969.

The reason for the sharp rise in the water level in well 18. 15. 32. 234 must be attributed to recharge resulting from operations at the new mine at Tyrone. Surface water discharge down Mangas Creek was not above normal in 1969. However, a series of tailings ponds in tributary valleys along the east side of Mangas Valley, east and southeast of the well, was placed in operation. Although waste water probably has moved from the tailing ponds toward the main valley (and the well) by way of the gravel and sand fill in the tributary channels, most of this initial rise in the well probably is due to head effects rather than to the actual movement of water from the ponds to the well which is about 1 mile away.

The sharp rise of the water level in well 18. 15. -32.234 may be duplicated in other wells equally distant from the pit and down the hydraulic gradient as a result of the operation of the tailings ponds. However, the pit development will most likely cause sharp declines of water levels in wells 2 to 3 miles or more in all directions, as has happened at the Santa Rita pit (fig. 3).

The water produced from mines at Tyrone presumably will be fully utilized eventually; but before that time, problems concerned with changes in quality of water in local aquifers could develop.

The old supply well for the original townsite of Tyrone reportedly still produces water of good quality for the headquarters and other mine buildings; the quality is good elsewhere in the area except possibly in the more highly mineralized zones where the pit will be opened. Available analyses (table 14) indicate all ground water in the vicinity of Tyrone at this time is chemically unsuitable for drinking.

Mine-waste water from the pit likely will be acid in character and contain undesirable concentrations of iron and sulfate. Waste water may contaminate the ground water locally if discharged to the alluvi um of Mangas Valley or to the Brick Kiln Gulch and lower Oak Grove Creek drainage system, just as the quality of ground water in the alluvium of Whitewater Creek below Santa Rita and Hurley was impaired many years ago. A single large discharge of highly mineralized waste water into the drainage system of Mangas Creek could greatly affect the ground water in the valley, and ultimately could affect the quality of water in the Gila River.

The development of new mines at Tyrone and in the vicinity of Fierro and Hanover, and expanded activities at present mines, may double the requirements of water to meet industrial needs in Grant County within the next 10 years.

The greater part of the increased need will result from the development of the new open-pit mine at Tyrone; however, enough water for that operation reportedly is available through water rights on the Gila River acquired by the Phelps Dodge Corp.

Additional large supplies of water for mining and milling operations near Fierro and Hanover, and in most other mining districts in Grant County, may be difficult to find and to develop locally without interfering to some extent with present urban and domestic supplies.

Although almost all mines produce some water, only a few produce more water than is needed for the mining operation and associated activities. In general, large supplies of water are available but not near the mineral deposits; water in the quantities needed for ore processing and smelting must be brought to the mine or the ore taken to the water. Developing adequate water for mining and milling operations will very likely always be a problem in Grant County, but the problem will mostly be one of economics, not availability of water.

Many improvements have been made in recent years in developing techniques to generate electrical power from geothermal waters. Kiersch (1964) has described occurrences of geothermal steam at several places in the United States and discusses many of the factors involved in the economic development of power from geothermal sources. His discussions of successful operations in other areas suggest that geothermal steam may provide an additional industrial use of groundwater in Grant County.

Thermal water is found in both wells and springs in the county and the temperature of one spring (13. 15. 5.241) is 64°C (147°F). Possibly some of the thermal waters may come from geothermal reservoirs that could, if tapped at depth, supply energy for geothermal power units.

Economical production of electrical power by geothermal power units generally requires an appreciable volume of hot water, preferably in the form of steam. The source of the water commonly is an aquifer at comparatively great depth. According to Bodvarsson (1966, p. 124) wells tapping such aquifers may have to be 2,000 to 5,000 feet deep, and may produce up to 100 tons of steam per hour (about 400 gpm of water). In general, about 10 tons of steam (40 gpm of water) per hour will produce 1,000

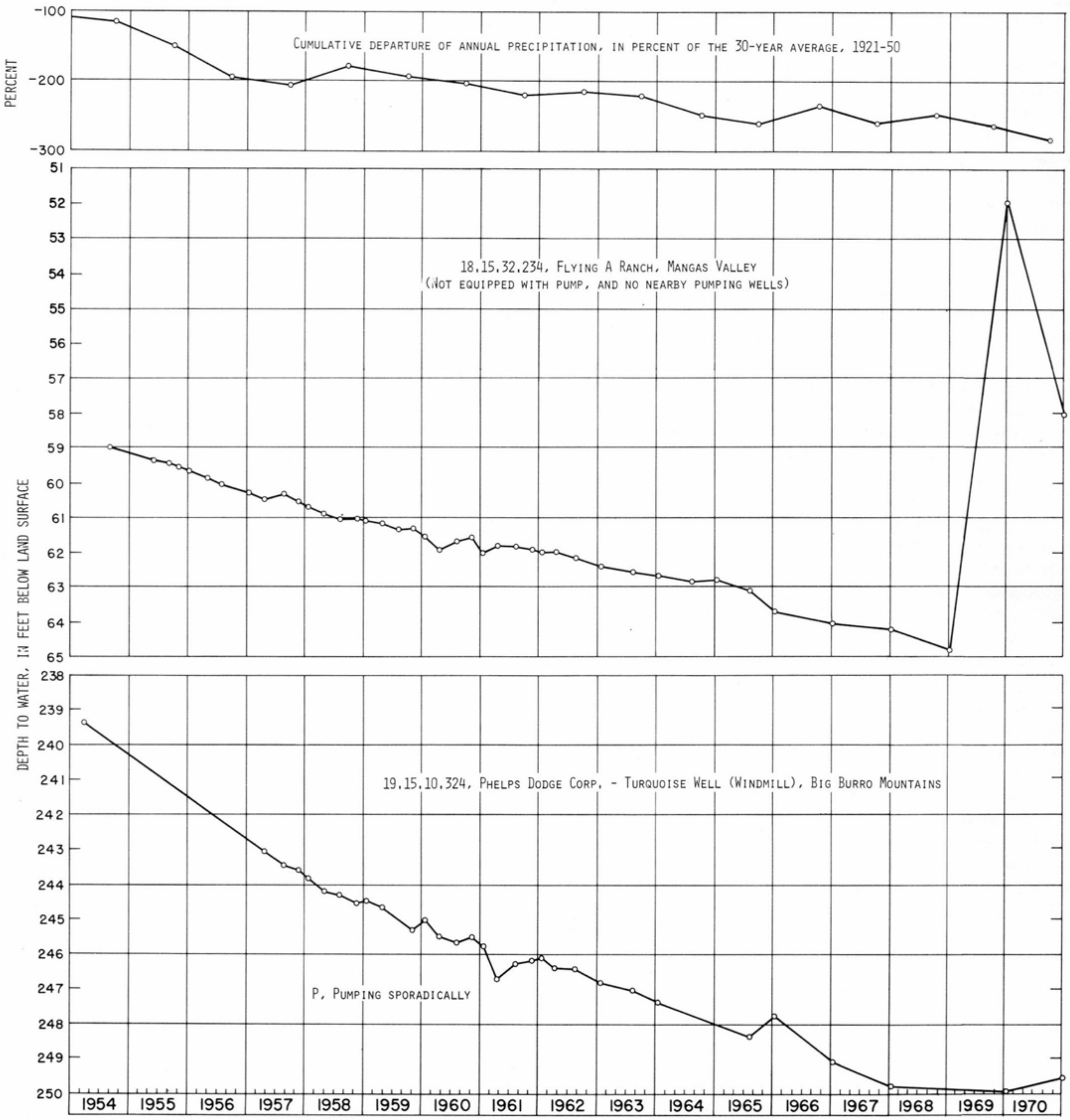


Figure 46—Hydrographs of two wells in Mangas Valley; at top, cumulative departure in percent of average precipitation.

kwh (kilowatt hours). At the Geysers geothermal field in California, 1 kilowatt of electricity can be generated by 20 pounds of steam (2. 4 gallons of water) run directly from the ground into the turbogenerator (Bowen, 1971, p. 198).

The actual amount of steam needed per 1,000 kwh of energy produced depends on the temperatures and pressures under which the water is found. Heat and pressure alone are not enough to assure a successful geothermal power supply. Water may be under high pressure, and at high temperatures, but if the permeability of the containing rock is low, the rate of flow might be inadequate to supply a power unit.

The problems that might arise from a large yield of thermal water should not be serious. Most of the steam produced probably would be condensed, used as coolant in the power-production cycle, and ultimately discharged by evaporation. If the dissolved solids, concentrated by evaporation, were dumped on the land surface, they could cause contamination of shallow ground water and surface waters. Most thermal water in Grant County contains fluoride in concentrations considered harmful to humans. Care would have to be taken to assure that ground and surface waters were not made unusable by addition of fluoride-rich waste materials from geothermal wells.

The principal water problem of industry is essentially the same as that of the cities—adequacy of supply for both the present and future development. Problems of quality and disposal are mostly minor at present. However, the possibility will always remain that mining operations could adversely affect the suitability of water for human use.

The water needs and associated problems of the cities and of industry are so similar, and the welfare of each group so interdependent that all parties concerned must work together to solve a mutual problem.

The large supplies of water needed by the mining industry, now and for future development, are available but they are the same supplies needed by cities and agriculture. Cooperative planning in the development of these supplies can preclude detrimental competition between the cities, the mining industry, and individual land owners.

URBAN USES

Details of the various water-supply systems and water-use requirements of the communities in Grant County having populations of 100 or more are given by Dinwiddie, Mourant, and Basler (1966a). Pumpage by the communities with public distribution systems amounted to about 1,640 acre-feet in 1965. The annual pumpage and per capita use of water of the larger communities is summarized in table 6; pumpage for 1956 is included for comparisons.

Water usage in nearly all communities has increased steadily over the years. Probably the single most important factor controlling the increased use of water has been availability. The problems of water supply for Silver City, Central, Bayard, and Pinos Altos will be discussed in some detail. Their problems, in one form or another, are experienced by most other communities in the county.

The water supply for Silver City prior to 1945 was unreliable at all times and inadequate much of the time. The water supply obtained from Allen Springs (16. 15. 26. 412) fluctuated and was particularly subject to interruption due to pipeline and power failures. Extensive early exploration to develop large-yield wells during 1910 to 1944 was unsuccessful. Although an apparently large and reliable supply of water became available in 1945 with completion of the Franks Ranch well field, it soon proved to be inadequate and rationing of water was necessary by 1955.

The Franks Ranch well field was operated at nearly full capacity most of the time during 1953 and water levels declined at what seemed to city officials an alarming rate (fig. 47). The need for more water made necessary the expansion of existing facilities and instigated a search for additional supplies of water. An early result of this investigation, which was started in 1953, was the expansion of the Franks field by the addition of one new well in 1954, and the location and development of the Woodward Ranch well field. Three wells were drilled in the period 1954-56 on the Woodward Ranch and the Woodward field was put into operation in July 1958. A reliable and adequate water supply was then available for almost the first time in the history of the city. A fourth well was drilled in the Woodward field in 1966 to meet increasing demands for water. A report by Koopman and others (1969) indicated that additional water would be needed in the near future.

The per-capita use of water in Silver City since 1958 has increased appreciably. Table 7 shows the annual pumpage, by water years, since October 1945. Although the population of Silver City declined slightly from 1950 to 1960, the annual water usage increased from about 175 to 271 million gallons, or about 55 percent.

The per-capita use in 1950 was about 70 gpd (gallons per day); in 1965, about 110 gpd; and in 1970, 140 gpd. By comparison, the average per-capita use in Albuquerque, which has long had the advantage of both low water rates and adequate supply, was 133 gpd in 1950, and 181 gpd in 1964; the 1964 January (minimum) usage was 96 gpd and the June (maximum) usage was 314 gpd (Dinwiddie, Mourant, and Basler, 1966, p. 12).

The daily per-capita use of water in Silver City, and in other communities of Grant County, will continue to increase if inexpensive and plentiful water is available, and as new homes having more water-using conveniences are built and older homes are modernized.

Water usage by Silver City in the normally dry warm months of May and June is at least double the monthly use in winter (table 8). Peak demands eventually will approach a summer to winter water-

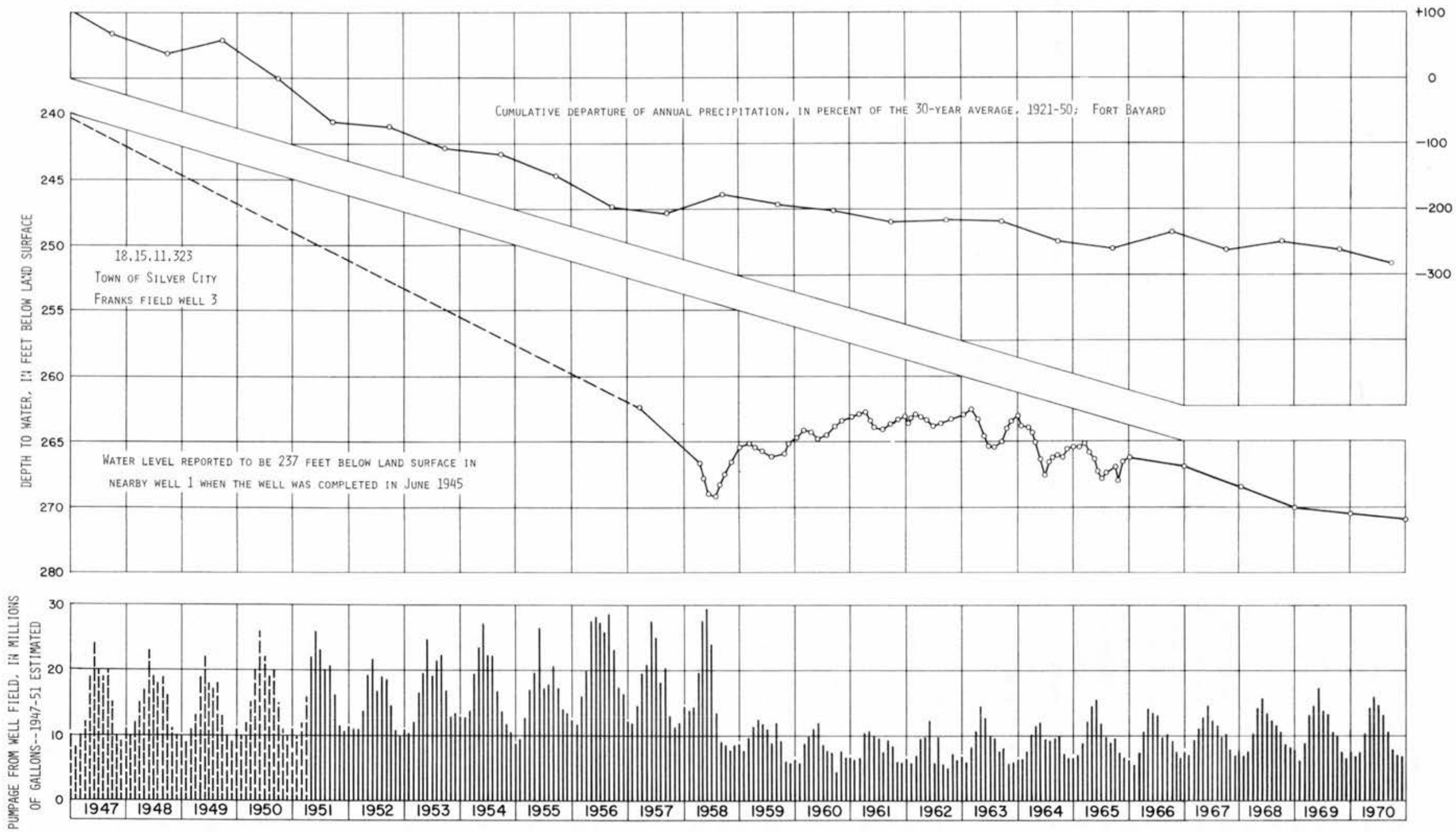


Figure 47—Pumpage and water levels in well 3 (18.15.11.323) in the Franks Ranch well field; at top, cumulative departure in percent of average precipitation.

use ratio of 3 to 1 as they have in Albuquerque and most other cities in New Mexico having water supplies adequate for all domestic needs. All communities in Grant County will need to find and develop additional supplies of ground water.

Silver City and the town of Central can expand their present well fields and increase distribution and storage facilities. This will result in increased pumping costs as water levels are lowered and yields per well become less. Both cities have well fields that tap deep aquifers in the upper part of the Gila Conglomerate. The deep aquifers are not as sensitive to short-term periods of drought as are shallow alluvial aquifers, but neither are they recharged as rapidly as the shallow aquifers during periods of normal and above-normal precipitation.

Water levels in the Central well field and in both of the Silver City well fields are declining (figs. 40, 42, 47), primarily as a result of pumping water from storage in the aquifer. A small amount of the decline is the result of the continuing natural depletion of ground water as indicated by the cumulative departure curve shown in fig. 13 (at rear).

The downward trend of water levels in the Franks Ranch well field was halted temporarily due to decreased pumping when the Woodward field went into production in 1958. Levels rose slightly upon reduction of pumping as water from the surrounding aquifer moved into the steeper central part of the cone of depression created by the well field. When the decline resumed it was a slower rate due to the reduced rate of pumping. The decline from 1945 to 1958 averaged about 2.25 feet per year. The present rate is about 1.25 feet per year. The rate of decline will increase or decrease as the rate of pumping is increased or decreased.

The declines in the Woodward Ranch well field averaged about 6.75 feet per year from 1958 to 1965. Approximately one half of the decline from June of 1958 to June of 1967 occurred in the first 2 years of pumping. The rate of decline will continue to decrease as the cone of depressionbroadens, provided withdrawals of water remain about the same. An increase in withdrawals will result in continued declines of 3 to 5 feet per year, and perhaps more if the increase is appreciable.

The decline of water levels in the Central well field has averaged about 1 foot per year since the field was put into production in 1955. Although the decline is relatively slow, the aquifer supplying the wells is not extensive and the boundaries of the basin are relatively close to the well field. Pumping effects probably have already reached the boundaries of the aquifer. Therefore, water levels will continue to decline uniformly if pumping rates remain nearly constant. However, an increase inthe rate of pumping is anticipated and that increase will further accelerate the decline of water levels.

Pumpage from the Central well field will need to be increased to meet the increased demand created by population growth. The increase in population has resulted mostly from the movement into Central of large numbers of the people who had been living in Santa Rita. Expansion of mining operations at the. Santa Rita pit made necessary the progressive abandonment of the Santa Rita townsite.

The village of Bayard faces an annually recurring problem of water supply, particularly in April, May, and June because the aquifer supplying the city well field is shallow, limited in extent, and dependent upon recharge from the annual summer runoff in Cameron Creek. The slight downward trend in the water levels in recent years can be attributed mostly to the effects of deficient precipitation, not heavy pumping. Pumping effects in the Bayard well field (fig. 37) are minor events compared to the natural changes.

The demands placed upon the Bayard water system also have increased sharply as the result of the influx of population from Santa Rita. The increase can be expected to continue, though perhaps at a slower rate, after the Santa Rita population has been relocated. Bayard experienced shortages of water when the population was appreciably less than it is at present, therefore, another succession of dry years as those from 1945 to 1951 (fig. 13) could result in an acute shortage of water for the greater population.

Several small unincorporated communities in Grant County have populations ranging from about 50 to 200 persons and the communities are well situated with respect to supplies of water. Residents in and near Cliff and Gila on the Gila River, and of San Lorenzo in the Mimbres Valley should have no problems obtaining adequate supplies of water for domestic use. The aquifers are shallow and recharged regularly by infiltration from the rivers. Water levels in the bolson fill underlying the community of Hachita are relatively deep, about 300 feet, but water is available and levels are not likely to fluctuate greatly due to periods of drought.

Several communities of a hundred or more population—Arenas Valley, Fierro, Hanover, Pinos Altos—in central Grant County get water from individual home wells. In general, the aquifers near these communities will yield only a few gallons per minute per well, and individual homes and entire communities are particularly vulnerable to shortages of water.

The community of Pinos Altos has a perennially short supply of water resulting from high topographic situation and the absence of reliable aquifers close by. Private wells supply adequate water for most homes in times of normal to above-normal precipitation, but the supplies are apt to be short in times of drought. Some homes rely upon cisterns for supplemental water. Additional development of wells in the town area could result in shortages in all wells, even during periods of normal precipitation.

The principal aquifer supplying wells in Pinos Altos is the soil cover, locally as much as 20 feet thick, and the underlying weathered and decomposed granitic rock. Dug wells commonly are sunk a few feet into the granitic rock to provide storage for the

Table 6--Urban use of water in Grant County

Community	Calendar Year	Population 1/	Ground water pumped (Millions of gallons)	Acre-feet
Bayard	1956	2,250	60,500,000	185
	1965	3,000	76,900,000 2/	236
Central	1956	1,300	13,800,000	42
	1965	2,000	22,900,000	70
Hachita	1956	150	--	--
	1965	125	2,300,000 3/	7
Hurley and North Hurley	1956	2,000	--	--
	1965	2,200	66,100,000	203
Santa Rita 4/	1956	1,900	17,300,000	53
	1965	1,000	16,000,000	49
Silver City	1956	7,000	216,000,000	673
	1965	7,600	312,900,000	960
	1970	7,531 5/	486,037,000	1,491

1/ From figures furnished by the cities, or estimated from U.S. Bureau of Census records (1960 and 1970).

2/ Master meter broken from April 1964 to May 1965; pumpage for period January-May estimated--based on pumpage during the same period for previous and succeeding years, and the precipitation records.

3/ Estimated.

4/ Razing of town will be completed by 1970; population and water use partly estimated. The usage will decline to zero but will be compensated by equivalent increases in nearby communities.

5/ The city in 1970 furnished water to an estimated additional 950 persons living outside the city limits, and to the town of Tyrone (est. pop. 830).

Table 7--Silver City water usage, by water years, October through September, in millions of gallons[1/]

Water Year	Annual pumpage	Population	Water Year	Annual pumpage	Population
1946	2/		1960	270.6	6,972
47	170		61	273.1	
48	178		62	281.2	
49	174		63	293.9	
1950	200.0	7,022	64	317.9	7,500 (est.)
51	195		65	312.9	
52	177.7		66	322.8	
53	200.0		67	353.1	
54	202.0		68	387.4	
55	197.7	7,000 (est.)	69	446.6	
56	216.0		1970	482.6	7,531[3/]
57	226.1		71	520.7	
58	229.1				
59	247.8				

1/ Data from city records; all water metered at the well fields after April 1951. Estimates of pumpage from the Franks Ranch well field for the period July 1946-April 1951 are based on average monthly usage, annual precipitation, and the pattern of annual increase in per-capita use. The water year is used to permit comparison with the graph (fig. 13) showing precipitation by water years.

2/ An estimated 50 million gallons was pumped in the period July-September 1946.

3/ The city in 1970 was providing water to an estimated additional 950 persons living outside the city limits, and to the town of Tyrone (est. pop. 830).

Table 8--Monthly pumpage, in gallons, from the Franks Ranch and Woodward Ranch well fields during the calendar years 1965 and 1970

Month	Woodward Ranch wells		Franks Ranch wells		Totals	
	1965	1970	1965	1970	1965	1970
January	11,916,000	21,811,000	6,393,000	7,365,000	18,309,000	29,176,000
February	11,517,000	20,122,000	7,037,000	6,621,000	18,554,000	26,743,000
March	14,016,000	23,450,000	8,757,000	7,276,000	22,773,000	30,726,000
April	19,045,000	31,500,000	12,094,000	10,112,000	31,139,000	41,612,000
May	22,518,000	42,950,000	14,604,000	14,095,000	37,122,000	57,045,000
June	23,538,000	43,858,000	15,379,000	15,737,000	38,917,000	59,595,000
July	17,603,000	38,693,000	11,764,000	14,421,000	29,367,000	53,114,000
August	14,929,000	36,837,000	9,652,000	13,124,000	24,581,000	49,961,000
September	15,253,000	32,757,000	8,975,000	10,301,000	24,228,000	43,058,000
October	18,112,000	25,862,000	9,484,000	7,586,000	27,596,000	33,448,000
November	13,834,000	25,102,000	7,275,000	6,937,000	21,109,000	32,039,000
December	12,732,000	22,916,000	6,439,000	6,604,000	19,171,000	29,520,000
Total	195,013,000	365,858,000	117,853,000	120,179,000	312,866,000	486,037,000
Acre-feet	598	1,120	361	368	959	1,490

water that seeps and trickles into the wells. A few wells have found small amounts of water in fractures and joints in the otherwise solid rock.

The low-capacity wells common to the community were adequate at most times in the past when the per-capita use of water was small, but present-day demands for water have placed a strain on most of the wells. A severe drought would result in acute shortages of water and failure of many wells.

Pollution of ground water is another potential problem in the Pinos Altos area and in other populous areas where domestic wells tap shallow aquifers, and where waste is disposed of through septic tanks, cesspools, and privies. None of these methods of waste disposal can guarantee that bacterial pollution will not move down to the water table and into nearby wells. Assuming that water moving underground will purify itself completely within any specific distance is fallacious, in fact, dangerous.

Waste fluids containing bacterial pollutants introduced into the subsurface can enter a nearby well before being fully purified. Some contaminants as nitrates and chlorides in human waste, toxic chemicals in household waste, and chemical fertilizers and sprays, are not changed or removed from water by percolation through soil and rocks; at best they are only diluted. Some can persist for long periods of time and move great distances before they are rendered harmless by dilution or fixation. Such pollutants can evenbecome concentrated if the water is repeatedly recycled from waste disposal facilities to wells.

NEW WATER SUPPLIES

The problems of finding and developing supplies of water of acceptable quality and quantity for present and future needs can be solved, but not quickly, or easily, or at low cost. Water is becoming more and more a prime commodity and to guarantee a supply for domestic use, cities will have to pay more to obtain water, charge higher rates to curtail unnecessary use, and deny service to industries that require large volumes of water. A greater cost to the city for water for urban supply may result from the need to purchase existing water rights or from the need to bring water from distant points via expensive pumping and transmission systems. For example, water for the urban area of Grant County could be obtained from the alluvial deposits of the Gila Valley and its tributaries; but water rights would have to be purchased and an expensive transmission system, at least 15 miles long, would have to be operated.

Water is available in the Mimbres River Valley, though in lesser quantities than in the Gila River Valley, but a problem of water rights, and the effect of withdrawals on downstream water supplies in the alluvial aquifer would have to be determined.

The upper part of the Gila Conglomerate and the bolson deposits afford at this time the best prospects for obtaining future supplies of water for the urban area as well as for industry. Deposits that can yield up to 1,000 gpm to wells fully penetrating the aquifer lie within 5 to 15 miles of all the points of greatest need (fig. 48).

The lower part of the Gila Conglomerate, a poor aquifer, underlies the area immediately east of Pipe Line Draw, and east of San Vicente Arroyo below the junction with the draw, and south to about the township 19-20 line. Wells tapping the Gila Conglomerate in this area do not produce more than a few gpm.

The upper part of the Gila Conglomerate west of Pipe Line Draw yields up to 500 gpm to wells at the Woodward Ranch well field. Comparable yields can be expected west of the draw and south to the junction with San Vicente Arroyo. Higher yields may be expected in the southeast part of T. 19 S., R. 14 W., in the northeast two thirds of T. 20 S. , R. 14 W.

Well 19. 14. 14. 443 reportedly was test pumped at a rate of 40 gpm for 8 hours. Presumably this output was the capacity of the pump, and not the capacity of the well to yield water. The drawdown apparently was not measured, thus the specific capacity could not be determined. However, the well, which contained about 177 feet of water when visited, is believed not to have fully penetrated the aquifer.

The aquifer in this general area is the upper part of the Gila Conglomerate. It should be as thick (900 feet) as at the Woodward Ranch, and the spacing of the contours on the water-level contour face (fig. 3) indicates that the aquifer should be at least equally, and possibly more permeable than at the Woodward Ranch well field.

The bolson deposits in T. 20 S. , R. 12 to 13 W. , have a good potential for yielding up to 1, 500 gpm. A recovery test made on well 20.12.36.111 indicated a specific capacity of about 15 gallons per foot of drawdown and the aquifer is believed not to have been fully penetrated as the well is only 140 feet deep. Greater penetration probably would result in larger yields per foot of drawdown.

Some of the areas described above are not topographically suited to irrigation agriculture, hence there would be no competition for water from agricultural interests in the immediate vicinity; and only small amounts of water are needed in these areas for domestic and stock use. These needs easily could be supplied without detriment to urban or industrial users. In those areas where the terrain, soil conditions, and depth to water might be favorable for irrigation, agricultural interests probably could not compete economically with industry and the cities for the available water.

The areas described above also are mostly located at distances of 4 to 7 miles from present heavily pumped areas. If developed, the withdrawal of large quantities of water would have little effect on present developments in the foreseeable future (fig. 44).

The east half of T. 19 S. , R. 13 W. , is also an area where large yields of water-500 to 1,000 gpm might be obtained by deep drilling and where the

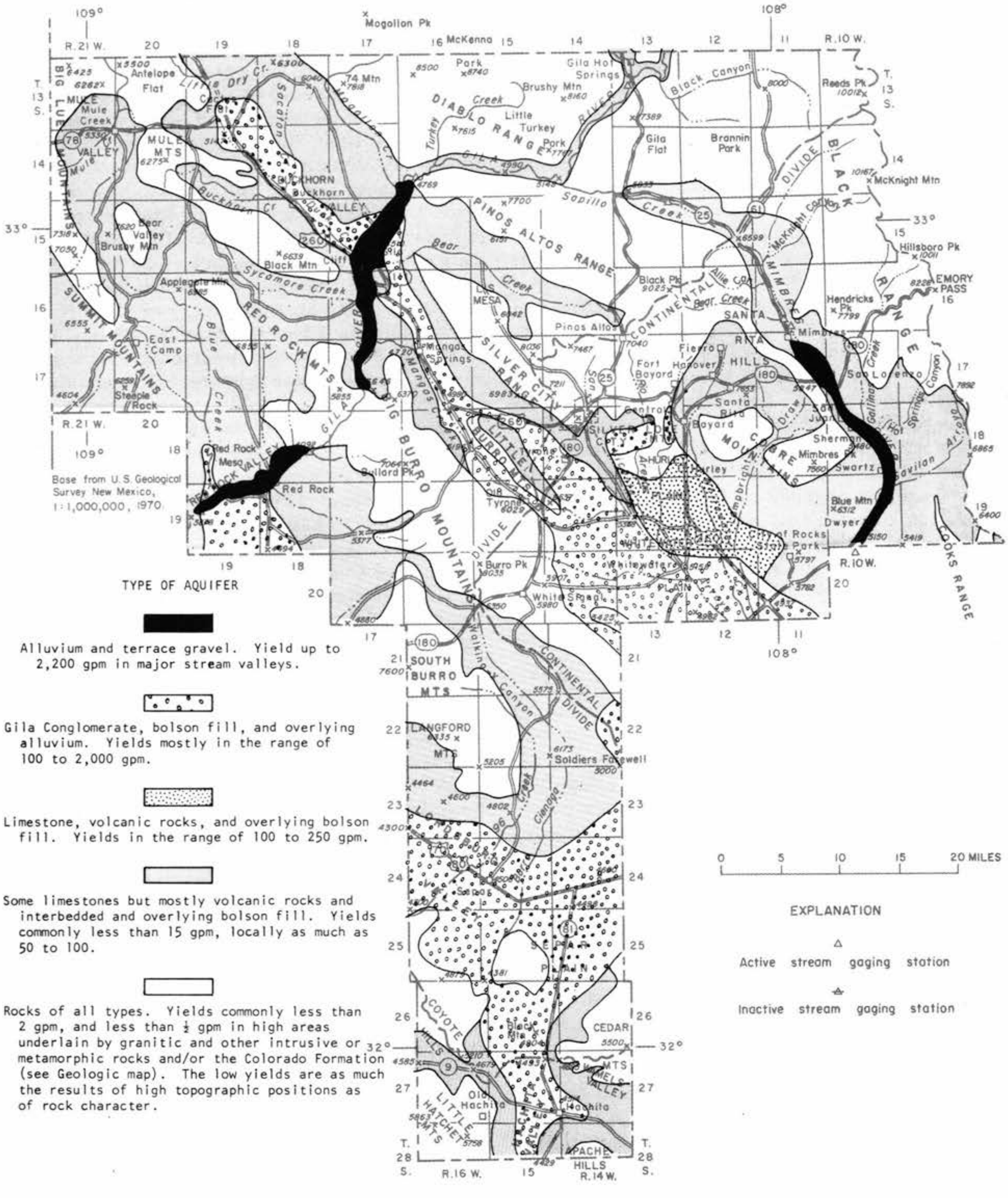


Figure 48– Map showing the availability of ground water in Grant County.

quantities available would sustain long-term development. The surface is underlain by the unproductive lower part of the Gila Conglomerate but limestone rocks of Paleozoic age underlie the Gila. They yield large quantities of water to wells 19.12.19.132, 132a, and 132b at Apache Tejo and to other wells in the vicinity.

Well 19.12. 8. 242, northeast of Apache Tejo, originally produced 1,150 gpm from the overlying fill and underlying limestones of Paleozoic age. The well was 1,542 feet deep, but caved at depth and the yield dropped to about 230 gpm. Apparently most of the water was coming from the limestones in the lower part of the well.

The pattern of exposures of limestone, dip of beds, and information found in well logs, indicate that limestone rocks probably underlie all younger deposits in the area between the Mimbres Valley and a line drawn along the west side of the Silver City Range and down San Vicente Arroyo to at least the T. 19-20 line.

A well (18. 14. 28. 141) drilled in 1970 just east of Pipe Line Draw reportedly was test pumped at rates up to 1,770 gpm; the drawdown at that rate was about 42. 5 feet. No lithologic log is available, but the well is believed to have penetrated the lower Gila and entered the volcanic rocks or limestones where fractured by faulting. If the reported yield is correct, and the principal aquifer is fractured limestone, additional deep drilling tests along the east side of the draw and along a line extended to the Franks Ranch well field might be worthwhile.

Exposures of limestone in the Black Range, Cooks Range, Hatchet Mountains, and on the plains near Separ support the proposition that limestone rocks of Paleozoic age underlie most of the southeast and southern parts of the county. The depth to these rocks ranges from a few hundred feet to more than 4,000 feet. These rocks have not been adequately prospected as sources of large quantities of water.

The bolson fill of the Lordsburg and Hachita Valleys also contains large volumes of water. The great distances of these valleys from the urban areas and points of need of the mining industry probably preclude their development for these purposes in the immediate future. Locally, where the depth to water is less than 100 feet, the water may be developed for irrigation. Possibly sprinkler or underground irrigation could make greater lifts economically feasible as these methods reportedly allow more acreage to be irrigated with a given volume of water.

The valley fill in Mangas Valley also constitutes a potential source of ground water. Yields of 2001, 000 gpm probably could be obtained by fully penetrating the fill between Tyrone (old town) and Mangas Springs. Well 17.16. 9. 343, near Mangas Springs, produced 1,400 gpm with adrawdown of 31 feet. The three wells that once supplied the old town of Tyrone reportedly produced as much as 25 million gallons per month.

Mangas Valley is included in the Gila-San Francisco declared ground-water basin and also is subject to terms of the 1964 decree of the United States Supreme Court in the suit Arizona v. California. Development of ground water in Mangas Valley for urban or industrial use would be dependent upon acquisition of water rights and permits from the State Engineer.

The village of Pinos Altos has a potential source of water available in the many old mines near the townsite. Some of these mines have deep shafts and hundreds of feet of tunnels, many of which are filled with water.

The water in the mines occurs in fractures, joints, and weathered zones of the otherwise dense rocks. The permeability and specific yield of the rocks, mostly granodiorite and diorite porphyry, is low, but networks of joints, faults, and fractures intersect the mine workings. The result is an efficient and extensive water-collecting and storage system that could be utilized.

A well penetrating to the same depth as a mine shaft will intersect comparatively fewer fractures because of its smaller diameter, hence would have a lower yield. However, if the well were drilled into a zone of fractured rock close to one of the water-filled mines, it would draw from the water stored in the mine workings.

One large mine, the Gopher, also known as the Golden Giant, lies at the edge of Pinos Altos, and is mostly in the NE1/4SE1/4, sec. 6, T. 17 S. , R. 14 W. Available data indicate that the shaft is about 520 feet deep and that extensive tunnels were developed on the 400-foot level, and on four other levels (Paige, 1911, p. 120). The position of the water level in the main shaft at 46 feet below land surface on August 17, 1954, indicates that all the workings are full of water.

The southern end of the old Pacific claims and several other nearby claims, all of which had extensive underground workings, are about 1-1/2 miles southwest of Pinos Altos. The Pacific mine was deeper and had more extensive workings than the Gopher, but data concerning water in the Pacific mine are not available.

The combined yield from a number of the large old mines probably would be adequate to supply all the water needed by the present population of Pinos Altos and might prove sufficient for an appreciably greater population.

Storage in the Gopher mine alone would amount to about 160, 000 gallons if the main shaft averages 4 feet on the side, and there are about 1,000 linear feet of tunnels averaging 3 feet wide by 5 feet high.

Modern equipment for treatment of water for public supply could assure that the water from the mines would be satisfactory for domestic use. The use of treated mine water distributed through a municipal system in the Pinos Altos area would eliminate the potential health hazard of using shallow dug wells in close proximity to septic tanks, cesspools, and privies.

Supplies of water adequate for the smaller communities in the Mimbres and Gila River Valleys are available from the alluvium in the respective stream valleys.

Although water is available in the Gila Conglomerate and bolson fill in quantities large enough to meet the needs of the growing cities, getting the water to the cities is another problem. Each of the towns needing more water may seek independently to develop additional supplies. Such action would surely result in competition between the individual cities, and ultimately between the cities and industries, to the detriment of all. Expensive distribution systems would be duplicated and result in unnecessarily high costs to the individual cities. Some smaller communities probably would find themselves financially unable to compete and thus be restricted to subsisting on the meager and unreliable supplies presently available to them.

The integration of the present public supply systems into a metropolitan water-supply district could solve most of the problems of water supply for both the urban and inter-urban area of Grant County. About 15,000 people, 80 percent of the present population of Grant County, live within a radius of 7 miles of the town of Central. Most of these people receive water through municipal or company-operated water-supply systems. But most of the homes in Fierro, Hanover, Vanadium, and Arenas Valley have individual wells and these wells, like those in Pinos Altos, are not always adequate or dependable.

A metropolitan water- supply district that included the cities and principal suburban areas could finance the transportation of water from points too distant for any of the individual cities to manage alone. Such a district would assure an adequate and safe supply of water of good chemical quality to the entire area for the foreseeable future.

QUALITY CONTROL

Solving problems of control of the quality of water is probably more difficult than finding adequate supplies. A single household can contribute bacterial pollutionto an aquifer tapped by many individual wells. An accidental slug of industrial pollution released into a hydrologic system could do damage that would take many years to rectify. Extreme care on the part of industry probably can reduce the danger from industrial pollution to a minimum. However, exercising positive control over hundreds of individual rural homeowner sanitary facilities appears virtually impossible.

A serious contamination problem could develop in the interurban and suburban areas due to the increasing numbers of septic tanks, cesspools, and privies. The areas underlain by the limestone and alluvial aquifers are especially susceptible to such contamination.

Several courses of action are possible to alleviate the danger of pollution of the shallow aquifers that furnish water to the many homes not serviced by municipal water systems. The county authorities could require that all new sanitary facilities be constructed to rigid specifications, and that old facilities be modified to provide equivalent protection. In areas where the population density is high possibly local community sewage treatment facilities could be constructed. A third possibility is the development of community water systems that would provide adequately treated water. Here again a metropolitan water - supply district could provide a broad measure of protection from bacterial and chemical pollution that no other system could equal. A combination of these three alternatives probably could provide reasonably complete protection from contaminated water to most of the population.

IRRIGATION USES

Irrigation is practiced on a moderate scale in Duck Creek Valley, Gila River Valley near Cliff and Gila, Gila River Valley near Redrock, Lordsburg Valley, and in Mimbres Valley from near San Lorenzo to the county line.

Ground water for irrigation is used mainly as a supplement to surface water in most of the irrigated areas of the Gila and Mimbres Valleys in Grant County. Wells supply all the water to some of the irrigated lands in these valleys, but only in Duck Creek and Lordsburg Valleys is ground water used exclusively.

Large-capacity wells supplying water adequate for irrigation have been developed also along San Vicente Arroyo, along Cameron Creek, and near Faywood.

The irrigation wells southeast of Whitewater and some of those along San Vicente Arroyo near Faywood have been acquired, or the water purchased, by Kennecott Copper Corp. for industrial use.

Ground water in Lordsburg Valley has been developed in recent years to irrigate large acreages of grain sorghum. However, only a small part of the Lordsburg Valley declared basin lies in Grant County (fig. 3). Irrigation wells had not been drilled in the Grant County part of the basin when fieldwork was done for this investigation, but a number of wells reportedly have been drilled since 1957. The data in table 1 for these and a few other wells drilled since 1957 were furnished by personnel of the New Mexico State Engineer Office at Deming. Well 24. 16. 31. 122 drilled in April 1957 and visited later that year reportedly was pumped at a rate of 1, 200 gpm.

In general, the depth to water in Lordsburg Valley increases eastward from the Grant - Hidalgo county line as the land surface rises to the Continental Divide. The areas in Grant County where ground water is relatively near the surface have been mostly developed. Whether or not irrigation expands further in the area will depend primarily on farming economics. Cotton does well in the area and, if cotton allotments become available, the irrigated acreage in the Grant County part of Lordsburg Valley may expand appreciably because the crop value could support the cost of pumping from substantial depths.

Wells have been drilled for irrigation in Burro Cienega (21. 15. 28. 234), Thompson Canyon (20. 17.- 22.242), Mangas Valley (18.15.32.234, 17.16.9.343), and Mule Creek Valley (14. 21.1. 111). Yields of these wells range from about 75 gpm to 1,400 gpm. Some of the wells have been used for irrigation, others not at all because the yields were considered too low.

Records of the State Engineer Office show that in recent years about 9,640 acre-feet of water was pumped annually for irrigation use in Grant County (table 9). Irrigation agriculture is the second greatest use of groundwater in the county. Annual pump-age from wells to supplement surface-water irrigation varies greatly from year to year, depending upon the time and quantity of precipitation as well as the availability of surface water. Thus, in some years in the Gila drainage basin, minor amounts of ground water are pumped for supplemental use, whereas in other years the maximum allowed is pumped.

The main problems of irrigating with ground water in Grant County involve availability of water, water rights, and economics. Wells having the capacity to yield from 1,000 to 2,000 gpm have been developed in the alluvium in the valleys of the Gila and Mimbres Rivers and some of their larger tributaries, and in the bolson fill and underlying volcanic and limestone rocks at a few places in both drainage basins. However, most of Grant County lies in either the Gila-San Francisco or Mimbres declared basins and development of any additional wells in these basins is subject to approval by the State Engineer Office. The same is true of part of Lords-burg Valley in Grant County, where irrigation wells tap the bolson fill and produce up to 1, 500 gpm. Large volumes of water probably are available in parts of Lordsburg Valley not included in the declared basin, but in those areas the topography generally is unsuited to preparation for flooding or furrow irrigation. Also, the water lies too deep for economic development at this time. The depth to water commonly is over 220 feet and pumping lifts would be more than 500 feet for yields of no more than 300 gpm.

The combination of comparatively low yields, uneven topography, and high-pumping lifts generally is sufficient for discouraging attempts to irrigate with ground water outside the areas presently developed. However, uneven lands can be irrigated successfully by means of sprinklers, and the method has the added advantage of being able to utilize wells having small to moderate yields.

Information provided by the Extension Engineer, County Extension Service, at New Mexico State University, Las Cruces, indicates that a flow of 10 gpm from a sprinkler is capable, under good manage ment, of furnishing sufficient moisture to the root zone of normal crops on an acre of ground. A well having a capacity as low as 50 gpm can be utilized to irrigate an area up to 5 acres. Experiments and practice have shown that other systems also can be worked out to permit irrigation with wells of small capacity.

Plots of alfalfa totaling about 5 acres were successfully maintained in a small valley on the Dave Woodward Ranch utilizing rainfall, occasional runoff, and the water from two windmills. A concrete-lined reservoir of about 250, 000-gallon capacity stored water from the windmills until a sufficient volume was on hand to irrigate a given plot. A small tractor-driven pump jack was operated on one well when the wind failed for prolonged intervals.

Another type of system for irrigating with low-yield wells involves the use of buried pipe. Subirrigation systems, described in the October 1966 issue of "The Cross Section" (High Plains Underground Water Conservation District No. 1, 1966, p. 3) reportedly can apply 6 inches of moisture to the root zone within a 6-month period, on 30 acres, utilizing a well of 10-gpm capacity. A well of 160-gpm capacity could apply more than 3 inches of irrigation water on 40 acres in 16 days. The system also has the advantage of not requiring level ground.

SOURCES

Ground water pumped for irrigation in the Gila River and Mimbres River Valleys comes primarily from water in transit in the alluvial fill, not from storage, and represents an indirect diversion from the nearby stream. Water levels in irrigation wells in these areas may decline during the period of pumping but generally they recover. quickly and completely with the advent of the rainy season and subsequent increased flow in the rivers.

Water in the bolson fill in Lordsburg Valley, and in the San Vicente embayment comes primarily from storage. Recharge in these areas is slow, thus water levels in areas of heavy pumping can be expected to decline as long as the heavy pumping continues. No annual recovery should be expected. Some rise in the water levels may result from periods of unusually heavy rainfall such as occurred in 1941, but the overall or long-term trend will be down, as indicated by the hydrograph for well 20.11.18. 112, a former irrigation well near Faywood (fig. 44). Part of the decline can be attributed to climatic conditions but a comparison of the hydrograph with one for a nearby industrial well (20. 11. 19. 111) indicates that pumping effects are more significant than climate.

Irrigation wells in Duck Creek Valley, northwest of Cliff, tap water in storage in the upper part of the Gila Conglomerate. The deposits inthis area are of somewhat different character than those in most of the county. Lake beds and other fine-grained deposits are present locally and serve to confine water in the underlying gravel and sand. Several flow-

Table 9--Source of water and the annual water requirement in acre-feet for irrigated areas in Grant County[1/]

Area and year of record	Acres Irrigated: Surface water only	Acres Irrigated: Both surface water and ground water / percent by GW	Acres Irrigated: Ground water only	Number of wells: Full use	Number of wells: Supplemental	Consumptive irrigation requirement / Farm delivery requirement	Acre-feet pumped
Cliff-Gila[2/], 1964	2,084	1,927 / 10	230	10	25	1.6 / 2.9	740
Duck Creek Valley, 1964	4	0	488	15	0	1.6 / 2.9	1,420
Lordsburg Valley, 1966	0	0	1,470	13	0	1.7 / 3.0	4,410
Mangas Valley, 1964	12	0	72	3	0	1.6 / 2.9	210
Mimbres Valley, 1968	877	642 / 20	125	1	29	1.6 / 2.9	814
Mule Creek Valley, 1965	0	31 / 60	0	0	1	1.8 / 3.3	60
Red Rock Valley, 1963	140	1,000 / 50	117	3	19	1.7 / 2.9	1,570
San Vicente-Cameron Creek, 1966		0	109	4	0	1.6 / 2.9	320
Thompson Canyon, 1966	0	0	60	1	0	1.7	180
Total	3,117	3,600 / --	2,671	50	74	--	9,724

1/ From data provided by the State Engineer Office, Deming, N. Mex. 1970.

2/ Irrigated acreage in the Cliff-Gila area will decrease as water acquired by Phelps-Dodge Corp. through purchase of water rights is diverted to mining operations.

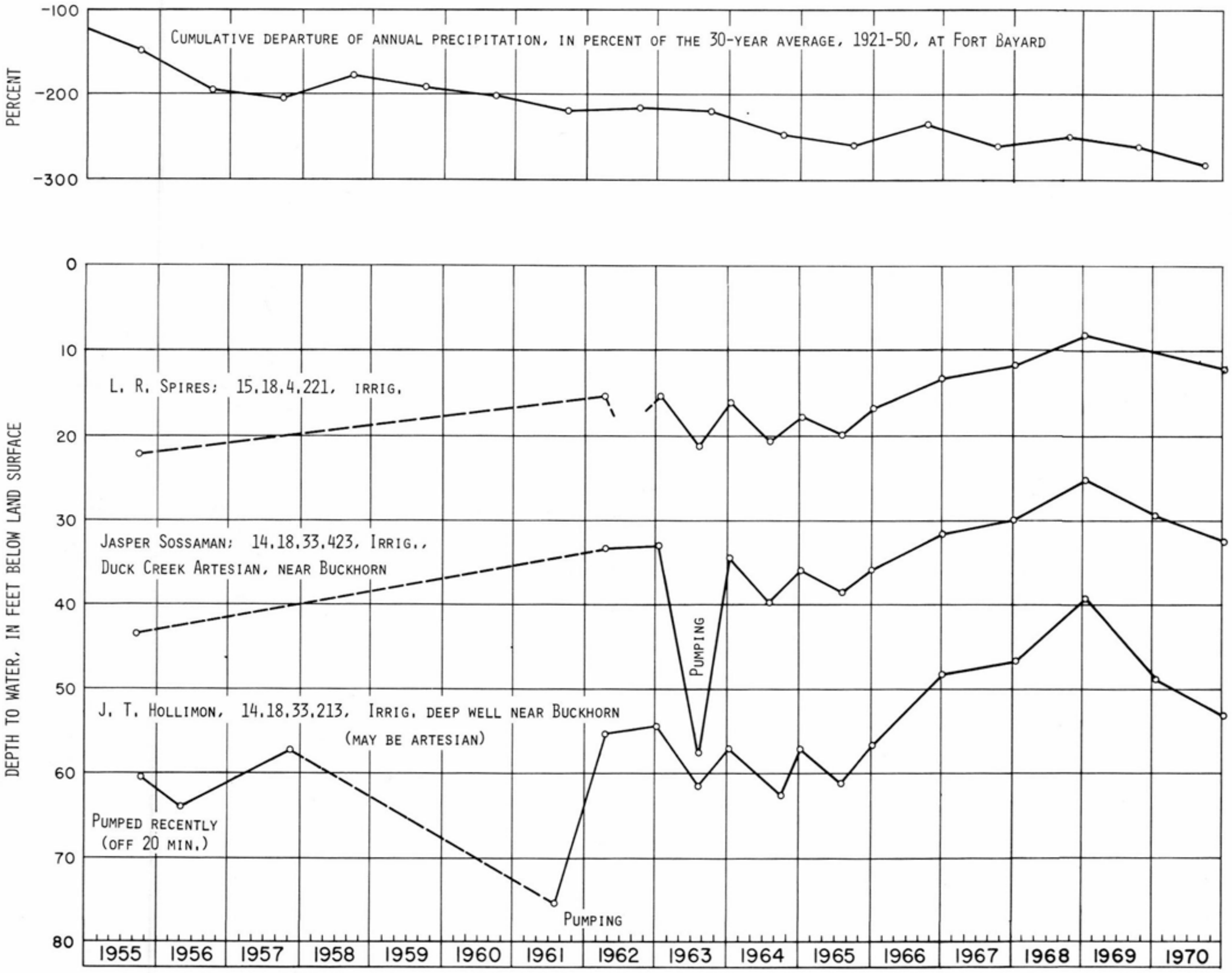


Figure 49—Hydrographs of three wells in Duck Creek Valley, near Buckhorn; at top, cumulative departure in percent of average precipitation.

ing wells have been drilled and others may have some artesian head, but not enough to cause them to flow.

Hydrographs (fig. 49) of two wells in Duck Creek Valley show some anomalous fluctuations that do not correlate with the climatic trend after allowing for fluctuations due to pumping. Water levels rose in the period 1955 to 1962 when the natural trend, due to climatic conditions, should have been down. The low levels of 1955 probably were the result of the combined effect of natural declines and previous years of heavy pumping from storage; and when pumping decreased sharply in the late 1950's the result was a slight but general recovery in the artesian aquifer.

Pumping records are not available for the period prior to about 1962 but pumping reportedly was heavier prior to 1955 than in the period following. Pumping since about 1962 has been minimal and post-1962 water-level fluctuations do correlate with the cumulative departure trends. Apparently water in storage is again in approximate balance with natural recharge and discharge.

RURAL, DOMESTIC, AND STOCK USES

Water for rural, domestic, and stock use in Grant County is provided from wells, from ground tanks that impound surface runoff, and locally from streams and springs. Wells supply all but an insignificant amount of domestic water and much, if not most, of the water for livestock. Some homes are supplied from springs but no domestic supplies are known to be taken directly from rivers or creeks. A few cisterns provide emergency supplies of water but none were found to be in regular use.

Ground tanks are the only source of water for livestock in a few areas, mostly on the higher volcanic terrain, where wells have not been successfully developed. Streams provide dependable sup-

Table 10--Estimated daily rural domestic water requirements in gallons for a family of five[1/]

Activity or appliance and the average or minimum operational requirement to the nearest gallon	Time distribution				[Total]
	AM	Noon	PM	Other or Miscel-laneous	
Toilet, flush: 3 gal. tank capacity, 1 gal. bowl	40	20	20	40	120
Bathing: Tub-15 gal.[2/]	--	--	(75)[3/]	--	--
Shower, soft spray- 5 gal.	--	--	25	--	25
Lavatory: 1 gal.	5	5	5	5	20
Drinking and food preparation: 1 gal. per person per meal	5	5	5	5	20
Dishwashing, manual: 5 gal., wash and rinse[4/]	5	5	5	10	25
Dishwashing, automatic: 13 gal/cycle	13	13	13	--	49
Garbage disposal, electric: variable	4	3	4	--	11
Washing machine, automatic: 18 gal. per cycle with suds-saving device, 35 gal. without (1-2 loads per day)	35	--	--	--	35
Washing machine, non-automatic: 10 gal. per wash and 10 gal. per rinse (1 load per day)	20	--	--	--	20
Miscellaneous household cleaning	10	5	5	--	20
Totals without special / with special	87 / 112	41 / 51	67 / 77	60	250 / 300

1/ Exclusive of use outside the home.
2/ Ten gallons will fill a standard 5-ft. tub to a depth of 3 inches, 15 gallons to 4½ inches.
3/ Not included in total--increase total by 50 gal. if tub is used.
4/ Two gallons will fill one-half of a double sink about half full.

plies of water for livestock only along the Gila and Mimbres Rivers and a few of their tributaries that are perennial in their upper reaches.

Rural domestic use of water generally is less per capita than urban use. Actual water use within the rural and urban dwelling probably is about the same, but most computations to determine urban per-capita use include water used for maintaining extensive home landscaping and for small businesses and industries in the towns.

The average domestic water requirements for a rural family of five in New Mexico is estimated to be about 150 gpd or about 30 gallons per person. The estimate is based on a reported rural population of about 360, 000 (1960 census) and a rural domestic water-use requirement of about 10.0 million gallons per day (Hale, Reiland, and Beverage, 1965, p. 52) in 1960. The estimate is based on statewide conditions of ruralwater use which are in turn influenced by local economic conditions and the regional climate.

Grant County is in the warmer southern part of the state; and the average income of the rural homeowner is greater than the average for the state. Both factors lead to a further assumption that the per-capita rural domestic use of water in Grant County would be greater than the state average. Just how much greater is not known, but, if as much as 50 percent, then the water requirement would be about 45 gpd per person or 225 gpd for a family of five.

Table 10 summarizes theoretical water-use requirements of activities and appliances within a dwelling. The estimates indicate that a water supply if about 200-300 gpd should be adequate for a family of five persons provided there are no special needs requiring large quantities of water. The quantities indicated in table 10 for tub bathing, showering, and dishwashing are less than those cited by Dugan (1966, p. 257), and represent amounts reflecting moderately conservative use of water.

The requirements could be cut appreciably, prob ably well under 200 gpd, with careful water-use management in areas of scarcity. Several communities in southwestern New Mexico report minimum per-capita water requirements ranging from 25 to 50 gpd (Dinwiddie, Mourant, and Basler, 1966), which would indicate that a family of five might manage on no more than 125 gpd. Under conditions of scarcity that restrict a family to no more than 125 gpd, waste of water is intolerable. A leaky faucet dripping at the rate of one drop per second will waste four gallons of water per day, and a leaky toilet bowl may waste 35 gpd or more (Dugan, 1966, p. 257).

Water-use requirements of some common farm animals under various conditions of temperature have been reported by the U. S. Department of Agriculture (1955, p. 17). The [California] State Water Quality Control Board (1963, p. 112) lists requirements for others and discusses permissible limits for concentrations of dissolved solids. In general, any water chemically suitable for people is satisfactory for the usual farm livestock. Table 11 summarizes the data available in the references cited above concerning the water requirements of the kinds of livestock usually kept. The two references give slightly different requirements for some animals; those requirements that seem best suited for conditions in Grant County are given in the table.

The daily water requirements of livestock are determined by the size and maturity of the individual animal, the temperature, humidity, water content of the feed, extent of activity, and the salinity of the water supply.

The water requirements of livestock need particularly to be considered if the stock is to be watered from a domestic well of limited capacity. Family pets, a horse or two, a milk cow, and a flock of chickens may require up to 60 gpd.

The rural, domestic and stock-water requirements cited above do not include use outside the home and barn. Landscaping, an orchard, and a vegetable garden would increase greatly the daily

Table 11--Water requirements of common livestock

Animal	Water requirement in gpd per head, except as noted	Threshold salinity concentrations in mg/l (rounded)
Horses	8-12	6,400
Dairy cattle	10-22	7,200
Jersey cow, fresh	7-12	--
Holstein cow, fresh	8-22	--
Holstein calf, 16 weeks	3- 4	--
Beef cattle	4-12	10,000
Swine	3- 5	4,300
Sheep and goats	1- 4	3,000
Chickens and turkeys	8-15 (per 100 birds)	2,900

requirement. The amount of water needed would depend upon the extent and kind of vegetation grown; the requirements for the more common of these can be estimated.

The U. S. Department of Agriculture reports (1955, p. 466) that, to maintain the average lawn grass, 2 inches of water are needed per week in hot and dry inland regions, and 2. 5 inches of water per week are needed in desert areas during dry summer months. Most lawns in Grant County would not require more than 1/2 inch during each week, April through June. Only occasional supplementary watering would be needed in the period July through October if the seasonal precipitation is normal (table 1) and evenly distributed in time. About 600 gallons of water would be required to apply 1/2 inch of water over a lawn area 30 by 60 feet.

Most trees must receive frequent watering during the first year after planting. Shade trees well adapted to the regional climate generally can thrive with only occasional supplementary watering once they have well established root systems.

Most domestic vegetables, the common garden flowers, and shrubs and woody plants such as roses require at least as much water as do lawn grasses. They may require twice as much to thrive, depending upon the character of the soil and the thickness of the mulch used to retard evaporation losses. Lawn grasses provide their own ground cover to retard drying from the soil surface, but the ground under vegetables, flowers, and shrubs commonly is bare.

PROBLEMS

The availability of water for domestic and stock use is not a major problem for the rural homeowner or stockman in most of Grant County. Ground water is available generally, although it has been necessary to drill wells to depths of more than 500 feet at many places to find an adequate supply. Water is most likely to be deep in the upland areas of the northern part of the county. Trauger (1960, p. 18) found that a well drilled in volcanic rocks in Catron County was dry at the final depth of 925 feet.

The principal rock units supplying water to domestic and stock wells are the alluvium, the bolson deposits, and the Gila Conglomerate. These three units furnish water to about two-thirds of all the domestic and stock wells in the county. Only locally do wells drilled into these rocks fail to yield supplies of water adequate for domestic and stock use.

Most wells that have failed to find water, or failed to develop a supply sufficient for domestic or stock use, have been drilled in rocks of low transmissivity, have not been drilled to the regionalwater table, or have not been drilled to a sufficient depth below the water table. Most of the few areas in which it is difficult to find even the small amounts of water sufficient for domestic and stock use are underlain by granitic and other intrusive or metamorphic rocks, or by the Colorado Formation in which finding water is truly a hit-or-miss matter.

The selection of sites for domestic and stock wells in areas underlain by poor aquifers is, and will remain, a major problem in the development of water supplies for domestic and stock use. Careful study of the geology and topography in the general area usually can yield information helpful to the selection of a site that will provide better chances for developing a water supply than a site selected at random with no thought given to geology and topography.

Except in the areas underlain by the granitic and other intrusive and metamorphic rocks, or the Colorado Formation, a supply of water adequate to supply a home can be developed any place in Grant County, provided the seeker is willing to continue drilling until an adequate supply is found.

In general, a well that will yield as little as 1/2 gpm is sufficient for a minimum rural domestic supply provided adequate storage is available and the pumping equipment is designed for the special problems that low-yield wells present. A well tapping a sandstone bed in the Colorado Formation in Arenas Valley yielded no more than 1/2 gpm, but the well was successfully developed for house use. A pump of low capacity was installed and equipped with an automatic control that would turn the pump off when the water level in the casing dropped to the intake pipe on the pump column; the automatic control would then turn the pump on again when the water level recovered to a predetermined level. The well, by being operated in this manner, could supply up to 700 gpd. This yield would be adequate to supply the normal household needs for a family of four or five persons.

A problem related to low yield is well failure. The cause may be simply a new appliance or sanitary facility that results in a sharp increase in demand for water from a well of limited capacity. Or it may be an actual decline in the ability of the aquifer to yield water. A decline in yield may be the result of drought, dewatering of a limited aquifer, or lowering of the water table.

Many domestic and stock wells are drilled only a few feet below the water table to hold down costs. Such economy may prove more costly in the long run if deepening the well becomes necessary.

The hydrographs of wells 19.15. 10. 324 and 18.15. 32. 234 (fig. 46) and well 15. 17. 35. 134 (fig. 50) show that water levels can fluctuate from 5 to 10 feet, or as much as 30 feet, seasonally or within a few years. A new well that obtained adequate domestic or stock water with shallow penetration of the water table during the wet season could be out of water within a short time, or within a year or two—not because of over pumping, but because of natural declines and fluctuations of the water level.

The danger of a well going dry because of a falling water table cannot be completely avoided but the possibility often can be greatly lessened by drilling the well a few tens of feet deeper at the time of initial drilling. Additional depth is almost always desirable, but is justified especially when yields of the aquifers are known to be low and recharge ap-

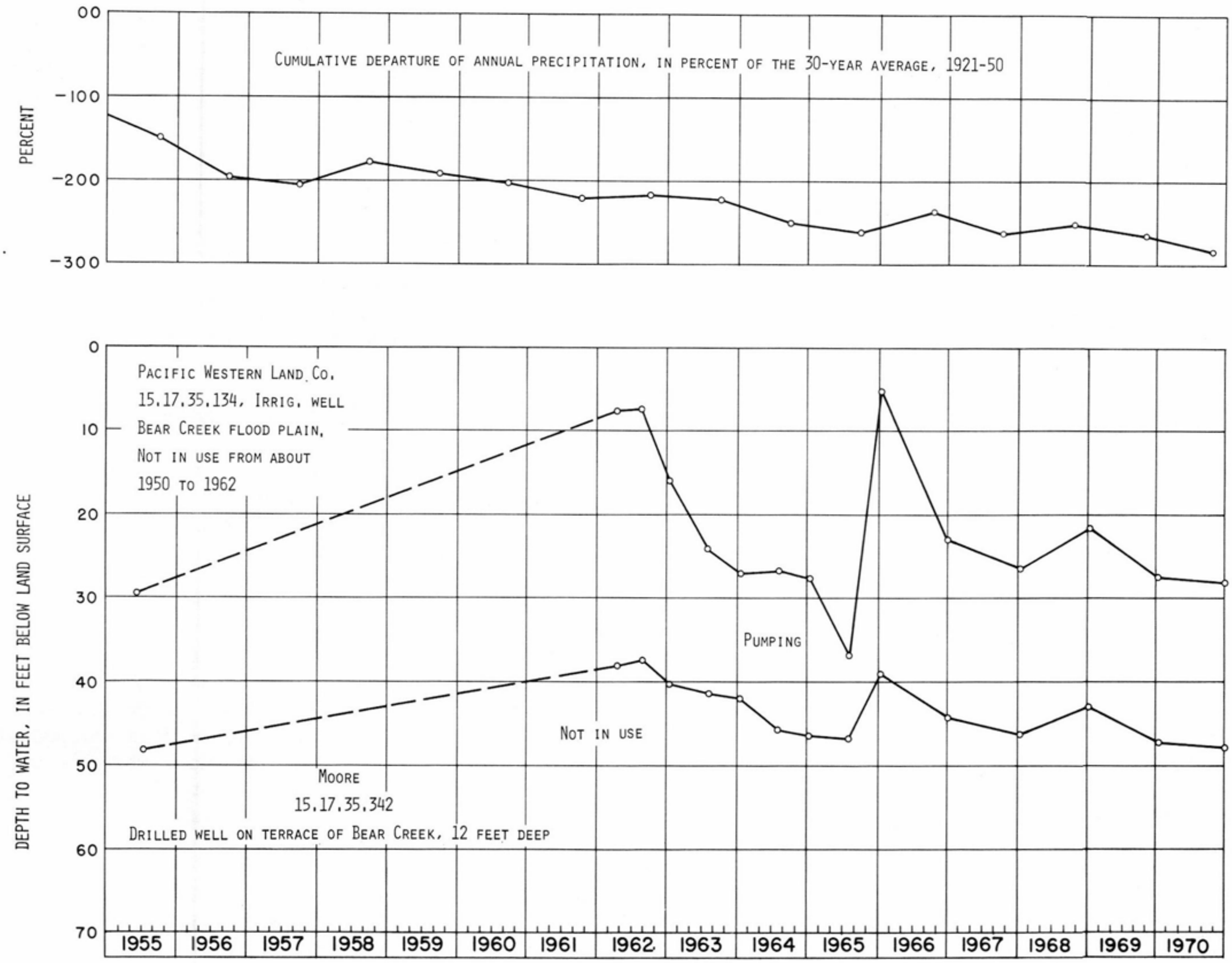


Figure 50–Hydrographs of two wells adjacent to Bear Creek, near Gila; at top, cumulative departure in percent of average precipitation.

pears related to seasonal precipitation or is known to be slow, as in rocks of low permeability.

For those few areas where no ground water, or less than 1/2 gpm, can be developed for domestic use, the principle of the old-time cistern still offers a solution, or partial solution, to the problem of obtaining water for house use. Modern technology has made the collecting reservoir a much more satisfactory method of providing domestic water than it was in past times because the old-time problems of sanitation and the effects of drought can be largely overcome.

Modern filters and economical home-treatment chlorinating units can provide crystal-clear, sanitary water from collected precipitation. Modern tank trucks of large capacity can deliver almost any quantity of water at reasonable prices to any home accessible by automobile when seasonal precipitation fails to maintain adequate supplies.

The principal problems of collecting and storing precipitation are those of providing a satisfactory collecting surface, adequate storage, and proper maintenance; none of these are serious. Sheet plastics and present-day roof coverings can provide excellent low-cost collecting surfaces not available in times past. Modern concrete, steel, or aluminum tanks can provide much larger and more satisfactory storage capacity than was generally practical with underground cisterns. An above-ground, or partly above-ground storage tank offers the added advantage of easy access for cleaning and for supplementary filling during periods of scant precipitation.

Allowing for 20-percent evaporation loss, one inch of precipitation on 100 square feet of collecting surface generally will yield about 50 gallons of water. A 2,000 square-foot roof would thus salvage about 1, 000 gallons of water from one inch of rain. This is equivalent to about 33 gallons per day for a month, an amount which could significantly supplement a weak well. If it were the only source, this supply would be enough water for one, and possibly two persons, provided rigid conservationwere practiced. A supplementary supply would be necessary if monthly precipitation were less than one inch.

The annual precipitation in the Pinos Altos area is about 21 inches (table 1), thus a 2,000 square-foot roof would salvage an average of about 21,000 gallons annually, or an average of 57 gallons per day. The average July precipitation on 2,000 square feet would net about 4.28 x 1,000, or 4,280 gallons for an average of 140 gallons per day—enough, with careful water management, to supply a family of 4 or 5 persons. The main problem in fully utilizing precipitation in this manner would be providing storage to handle salvage from heavy rains of 2 inches or more.

Larger collecting surfaces could be easily and economically constructed, thus increasing the yield to provide for adequate water during much of the year. Some haulage might be necessary during the drier months of April, May, and June. A large reservoir would permit carryover from normally heavy July-September precipitation to help meet needs in the drier month of November.

SALVAGE FROM LIGHT PRECIPITATION

The problem of supplying stock water in areas where no ground water is available was long ago alleviated, if not solved completely, by extensive development of ground tanks. Some improvements might yet be made in the system by applying the principles just discussed.

Surface runoff from light showers that normally would only dampen the ground can be obtained by coating cleared areas of ground with inexpensive, impermeable materials commercially available.

Experiments on the White Sands Missile Range (Ballance and Basler, 1969, p. 110-112) have shown that a rainfall of 0. 22 inch in 225 minutes resulted in a runoff yield of 60 percent from a prepared area of 9. 10 acres. Another rainfall of 0.22 inch fell in 6 minutes and the runoff amounted to 80 percent. One inch of rain fell in 292 minutes and the runoff was 77 percent, or about 190,000 gallons.

One inch of rain on one acre of paved ground would yield 21, 000 gallons at the rate of 77 percent runoff. A quarter of an inch of rain and 60 percent runoff would yield about 4,000 gallons, and an 80 percent runoff would yield 5,400 gallons.

In the experiment at White Sands the cost of salvaged water amounted to about 50 cents per 1, 000 gallons. The efficiency of the system increases and the unit cost of water salvaged decreases, as the annual average precipitation increases. The annual precipitation at the White Sands project site averages about 10 inches, but was only 7. 26 inches in the test period May 1964 through February 1966 when the average shower amounted to 0.20 inch. At these low rates the collection efficiency was only 62 percent. The average annual precipitation at Fort Bayard is about 15 inches (table 1) and 21 inches at Pinos Altos.

The technique is not necessarily limited to small areas and small quantities of water. Ballance and Basler (1969, p. 112) point out that, assuming a collection efficiency of only 62 percent: "An area of 5. 5 square miles, treated with an impervious material and receiving 15 inches of annual rainfall would collect 2,774 acre-feet of water each year." In 1965 the communities of Bayard, Central, Hurley, North Hurley, Santa Rita, and Silver City used a total of 1, 518 acre-feet (table 6). Data presented by Koopman and others (1969, p. 9-12) indicate the water needs of these communities will amount to about 4,600 acre-feet by 1980. Annual precipitation in the foothill areas immediately north of these communities averages between 17 and 21 inches, thus a 5-square mile paved tract probably would supply the additional water needs for the next 10 years.

RECREATION USES

The utilization of ground water for purely recreational purposes in the southwest has been limited in the past mainly to swimming pools and turf playing fields. However, the increasingly large sums of money that people are willing to spend for recreation may make greater use of water for such purposes a major objective.

Fishing, boating, and related pastimes generally require larger quantities of water than are available at most places in the southwest. However, some development along these lines has been accomplished and a considerable potential for increased development exists in parts of Grant County.

The New Mexico Department of Game and Fish successfully developed, as recreational facilities, Lake Roberts on Sapillo Creek and Bill Evans Lake near the junction of Mangas Creek and the Gila River. The Bill Evans Lake development is a noteworthy example of cooperation between industry and a state agency to make full use of a limited supply of water. Another similar facility might be developed on Mangas Creek a few miles below Mangas Springs, and at a number of places on Bear Creek above sec. 29, T. 15 S. , R. 16 W. The base flow of both Mangas Creek (table 2) and Bear Creek (near Cliff and Gila) probably could support lakes comparable in size to Lake Roberts.

No records of base flow are available for Bear Creek north and west of Pinos Altos but in November of 1953, a year of about normal precipitation (fig. 13), an estimated flow of 2 to 3 cfs was observed in the channel in sec. 25, T. 15 S. , R. 16 W. A comparable amount could be presumed moving down the channel as underflow.

Developments of the type at Lake Roberts and Bill Evans Lake could utilize surface water at this potential recreational site not now being utilized fully for other purposes. However, such recreational development would be in direct competition with other water uses. Acquiring rights to water to offset consumptive use (mainly losses due to evaporation) might be feasible.

Float trips utilizing various types of craft have attempted on the Gila River with varying degrees of success. Experience has shown that rigid boats are not satisfactory, and that the river discharge should be at least 120 cfs (table 2) to minimize portaging through shallow waters.

The principal problem in developing surface water for recreation is water rights. Water lost by evaporation from an artificial lake surface exceeds the loss under natural pre-lake conditions. Rights must be acquired to compensate for greater loss due to increased evaporation. Use of paving to salvage water from precipitation that otherwise would be lost through evaporation could solve the problem of making up evaporation losses from a lake surface. The paving for salvage purposes might be combined with paving for recreational facilities, such as parking areas.

Water for some recreational use such as golf courses and small ponds for fishing can be obtained also by development of ground water. Ground water is particularly feasible for facilities using relatively small amounts of water.

A third potential source of water for recreation use is water that has been once used and then discarded, and which could be reclaimed. The principal source of such water at this time in Grant County is the effluent from municipal water- supply systems. An appreciable part of Silver City's effluent water is being used, but the balance, some 240 acre-feet annually, is returned to the aquifer.

Some method may be found to make use of the lost effluent; the losses will increase as the per-capita use of water increases. The economic gains can be appreciable if water can be made to serve two uses instead of one, and, conceivably, adequately treated effluent could be utilized three or four times. The water used at Kennecott's various operations is recycled until it literally is "used up." The company has achieved an extremely high efficiency in handling its water supplies—an accomplishment that well could be followed by all municipal water distributors.

Conservation of Eater

Water salvage and artificial recharge canbe economically worthwhile under some conditions. They, of course, are not practical if costs exceed the value of the good derived. Careful study should be made of all circumstances where either salvage or recharge, or both, might be practiced to advantage. Not all the benefits can be measured in dollars. Some intangible benefits may make practical an otherwise impractical salvage or recharge effort.

Perhaps the grossest waste of water that offers worthwhile possibilities for salvage is the effluent discharged by the various public-disposal systems. Silver City utilizes some of its effluent, but the balance, about 240 acre-feet annually (equivalent to a steady flow of about 150 gpm) is no small amount of water in an arid to semiarid environment. That water could be salvaged and offered to an industry as inducement to locate in the area, or perhaps sold at nominal cost to some present industry in need of more water. At 10 cents a 1,000 gallons, the waste water would be worth about $5, 700 annually. It also could be fully instead of partially utilized for recreation. It might, perhaps, be discharged to the drainage system of the Gila-San Francisco rivers in exchange for additional right to prime water from that system for urban use, or for recreational use, such as make-up for evaporation losses from a lake on Mangas or Bear Creek.

In like manner, the effluent water from the urban area of Central, Bayard, Fort Bayard, and Hurley could be salvaged and utilized. The time will certainly come when that water will be needed. Too often aesthetic reasons alone prevent the treatment and reuse of effluent by cities. Prime water presently used in industrial processes could easily be replaced by treated effluent.

Some mine operators that have little or no need for water are wasting water to creek channels where much is lost by evaporation. Most of the mine, mill, and smelter operators that require large quantities of water fully utilize that which they have. Ingenuity has been used to devise methods to get the most use from limited supplies. Nevertheless, more water could be salvaged by these large users. Gilkey and Stotelmeyer (1965, p. 43) indicate that losses from Kennecott's milling system by evaporation and by infiltration into the tailing dump at the Hurley smelter amount to a steady flow of about 3,200 gpm. Most of the 1,450 gpm lost by infiltration could be salvaged by installation of a sealcoat, thin gravel bed, and drains under the tailing as the dump is extended.

Kennecott in 1962 was experimenting with reducing evaporation losses (about 1,750 gpm from 384 acres) by applying cetyl alcohol to 42 acres of pond surface, but at that time the results were not conclusive (Gilkey and Stotelmeyer, 1965, p. 43). The experiments were later judged to be successful enough to warrant continued use, and in 1971 applications of evaporation retardants still were being made on a regular basis to selected pond areas.

Precipitation collected and stored in reservoirs could conserve water for the mining industry, however, permits from the State Engineer would be required before retention structures could be built. Dependency on rainfall of sufficient intensity to result in runoff made such systems impractical in the past, but the experiments with paved or surfaced areas previously mentioned call for reappraisal of the method by users of large quantities of water. The water collected would be generally free of sediments and suitable for most industrial needs in the county.

The elimination of phreatophytes along stream channels might salvage water by reducing evapotranspiration. Conover (1954, p. 78) estimated that native vegetation in the Rincon and Mesilla Valleys transpired about 40,000 acre-feet per year. However, it was estimated also that the amount of water that could be salvaged by eradication of non-beneficial vegetation would be much less than the amount consumed. The previously consumed water would remain in the river channel where much of it still would be lost by evaporation before recovered for beneficial use.

Another question and problem is posed by any proposal to eliminate phreatophytes to salvage water. The role of willows and salt cedar as water-stealing villains is well-known but many people would object to seeing the villains "done in." Further, not many people would approve the total destruction of the cottonwoods that make such pleasing vistas along the river valleys. Even the salt cedar and willows serve a useful purpose in providing a place where game birds and other wildlife nest and rear their young. Trees also have a real value in dollars by providing scenery and natural beautyto attract tourists.

The question also has been raised as to whether or not the amount of water salvaged by eradicating phreatophytes would be worth the cost. The water salvaged might be stored in the alluvial aquifer, or be returned to the channel, but a large part of it still would be lost byevapotranspiration, and the net gain might be small. The problem becomes more complex the more it is considered and there would seem to be no simple solution that would please everyone.

The argument has been advanced that many small dams on upland reaches of streams and washes would salvage water by increasing recharge. Such dams are beneficial in some respects. They provide water for livestock and game, and they may retard erosion, but they will aid recharge only if the rock formation under the reservoir can absorb and transmit water. And such recharge is a practical operation only if enough of the water can be recovered to justify the cost.

The presence of tritium (table 3) in water from Silver City's No. 5 Franks Ranch well shows that the aquifer tapped by the city wells is recharged by natural runoff on the watershed, and that the recharge occurs within a relatively short time of the runoff. Artificial recharge to retard depletion in the Franks Ranch well field could be accomplished by the construction of retention dams upstream on the two broad sandy-bottomed water courses that converge in the vicinity of the well field. Runoff occurs annually in these water courses and thus some additional recharge would be induced annually. Possibly recharge structures in the area of the Franks Ranch well field would be economically feasible. However, in all matters of development of water resources in the Gila drainage, provisions of the U. S. Supreme Court decree in Arizona v. California must be considered.

Artificial recharge to the aquifer underlying Silver City's Woodward Ranch well field presently is being accomplished, though unintentionally, as a result of construction of ground tanks to provide stock water. The tanks are located in the same drainage system as the well field, mostly up the hydraulic gradient from the well field, and some tanks are adjacent to city wells.

The larger tanks are relatively new and in 1968 none of them were fully sealed. Consequently, runoff caught in the tanks was retained no longer than 6 to 8 weeks except in the lower part of some of the tanks. The rock formation underlying the tanks, the upper part of the Gila Conglomerate, is permeable enough to permit rapid infiltration of water. Data from a neutron log run on well 18. 14. 30. 432 May 23, 1966 show moisture penetration to a depth of about 97 feet, probably a consequence of heavy precipitation and above-average runoff during the preceding year.

Data furnished by Dave Woodward, owner of the property, show that in 1965 six tanks above the well field caught about 24 acre-feet of runoff. Most of the tanks were dry within 4 to 6 weeks after receiving water. An estimated 4 acre-feet was lost by evaporation, and an estimated 5 acre-feet was retained beyond two months. Roughly 15 acre-feet, or about 60 percent of the captured runoff, can be assumed to have recharged the aquifer at points where much of the recharge water would be recovered through the city wells.

An effort to promote infiltration by keeping the bottoms of the ground tanks broken and unsealed could result in more rapid infiltration, less evaporation loss, and a salvage rate estimated at 85 to 90 percent of runoff. Paving of areas immediately upstream from the larger tanks would greatly increase runoff, and also recharge the aquifers at the points where pumping has lowered water levels the most. The use of paved surfaces to assure some runoff to the tanks from even light showers could increase annual recharge.

The average precipitation in the vicinity of the Woodward Ranch well field is about 15 inches annually. Recovery of 80 percent of the precipitation as runoff, and an infiltration rate of 80 percent of the runoff would yield 8 acre-feet (or about 260, 000 gallons of water) per paved acre in a year of average precipitation. At that rate, 1 square mile of surfaced ground would supply about 510 acre-feet, an amount equal to all the water used by the towns of Bayard, Central, Hurley and North Hurley in 1965, or one-half that used by Silver City.

A depleted aquifer can be recharged directly through wells, but the success of the operation is dependent upon a number of factors difficult to control. The requirements ingeneral are: 1) sufficient volume of water available to maintain an input at least equal to the capability of the well to produce—this to assure that water can be introduced under full column head to prevent undue roiling and air entrapment; 2) water sufficiently sediment-free to preclude possibility of plugging the aquifer; 3) water of a quality compatible with that of the aquifer to preclude adverse chemical reaction that would damage the aquifer; and 4) water introduced free of bacteriological and other organic matter that might adversely affect the aquifer or the quality of the water already contained.

Apparently at this time water available in Grant County could not meet all these requirements.

Some surface water used for irrigation in the Gila and Mimbres River Valleys is wasted because of unnecessarily high evaporation and transpiration resulting from over-application of water. Flood irrigation commonly results in high evaporation and seepage losses, and applying excessive water simply increases those losses. Most of the excess water infiltrates to the shallow water table, thence back to the river. Generally some of that ground water is transpired by non-beneficial vegetation and wasted. Applying the proper amount of water could reduce such unnecessary losses.

Lining ditches also would conserve that part of seepage water consumed by non-beneficial vegetation. Seepage water that returns to the water table may not be truly lost because it can be recovered elsewhere in the system; but certainly it is lost to the irrigator at that place. If ground water is being pumped for irrigation the economic advantage in having lined ditches can be great because of the high initial cost of producing the water, and consequent greater worth of the wasted water.

Evaporation losses from sprinkler irrigation systems are also large, especially when the humidity is low and wind velocity high. However, these evaporation losses are offset by savings due to reduction of seepage losses. In general, sprinkler irrigation is considered more efficient than open ditch, furrow, or flood irrigation. A great many factors, especially those concerning soil conditions, determine irrigation efficiency. The Bureau of Reclamation (A. E. Gibbs, personal communication) reports that for rule - of - thumb estimates, where good irrigation practices are followed and soil conditions are comparable, sprinkler irrigation provides 75 percent efficiency and furrow irrigation 65 percent efficiency.

Irrigation by buried porous pipe, as previously described, is still in the experimental stage, and not much is known concerning problems that might develop with long-term use. The method would seem to be the most efficient way to apply irrigation water.

Summary

Streamflow records for the Gila and Mimbres Rivers, considered with estimates of evapotranspiration losses from their channels and flood plains, indicate that both rivers gain flow from ground-water discharge along most of their courses through the county. However, evapotranspiration losses commonly exceed ground-water inflow so that the channels of the rivers are dry at times.

Evapotranspiration losses due to non-beneficial vegetation are great, but the wide dispersal of the growth, poor accessibility, and the cost of materials and labor would make eradication infeasible at this time. Without control, non-beneficial vegetation can be expected to increase, and at some future time eradication may become economically and ecologically practical.

Ground-water irrigation of the flood plains of the Gila and Mimbres Rivers decreases the streamflow by an amount equal to the consumptive use of the water applied. Some, but not all, of the decrease will be in base flow. Water pumped from the flood plains for use at appreciable distance from the river will decrease the river flow by the full amount of the water pumped. The pumping will decrease spring runoff more than it will affect base flow because spring runoff in the river will move from the channels to replace the water removed by pre-runoff pumping.

The ultimate effect of pumping groundwater from aquifers contributing to base flow, other than the alluvium in the river valleys, will be to reduce ground-water discharge to the river, and thus reduce base flow by the amount of pumpage. Because most pumping is at considerable distance from the rivers, the total effects of pumping on the base flow may not occur for many years. In all probability, pumping effects would not be detectable by ordinary procedures, or be separable from variations in flow due to seasonal and climatic trends.

The principal aquifers furnishing ground water for domestic, stock, irrigation, municipal, and industrial use in Grant County are the stream-valley alluvium and bolson fill of Quaternary age, and the Gila Conglomerate of Quaternary and Tertiary age.

Other rocks in the county, for the most part, furnish very small to small quantities of water to wells. The granitic and metamorphic rocks, ranging from Precambrian to Tertiary age, are nearly everywhere poor aquifers. A few wells drilled in deeply weathered and (or) fractured zones yield more than 10 gpm.

Marine and continental deposits of Paleozoic and Mesozoic ages, mostly limestones and shales, underlie much of the more populated part of the county where the demand for water is great, yet these rocks are mostly poor aquifers. However, in those localities where the limestones are below the water table and are fractured by faulting, they locally yield large supplies of water to mines and wells.

Rocks of volcanic origin extend over an area of about 1, 400 square miles in Grant County; these rocks generally do not yield more than a few gallons per minute to wells. The flow rocks are mostly dense and relatively free of joints and fractures that could store water. The pyroclastic rocks and pumiceous tuffs are mostly massive, and are either so poorly sorted or so fine-grained as to be virtually non-water bearing. So, also are the occasional interbeds of sandstone which generally contain large proportions of pumiceous material.

A contributing cause to the scarcity of ground water in much of the area underlain by the volcanic rocks is the deep dissection of the terrain. Water that might otherwise accumulate in inter-flow rubble zones, joints, and fractures tends to drain to the level of the floor of the nearest major canyon which may be as much as 1,000 feet below the general level of the upland.

The sequence of rocks commonly called, the Gila Conglomerate can be divided into upper and lower members in Grant County. The members easily can be distinguished in some outcrops, and in some well cuttings, but they cannot be mapped over any appreciable distance without careful study. The lower member is firmly consolidated and locally is much deformed, whereas the upper member is poorly consolidated and in general is only slightly deformed. The uppermost part of the upper member is unconsolidated and undeformed. The lower member may exceed 2, 000 feet in thickness, whereas the upper member generally is less than 1, 000 feet. The lower member yields virtually no water to wells because of its low permeability. The upper member yields moderate to large quantities of water and is the aquifer from which Silver City obtains its water supply.

The alluvium of the river valleys, primarily those of the Gila and Mimbres, and the bolson fill are the most productive aquifers in the county, both in yield to individual wells and in total volume of water pumped. Ground water in the alluvium of the major river valleys is in transit, and water removed by pumping is soon replaced by induced infiltration from the river; recharge commonly is complete seasonally and water levels fluctuate within relatively narrow limits. Ground water pumped from the bolson fill comes mainly from storage, and water levels in the bolson are declining annually in some areas of large withdrawals.

Ground water in nearly all of Grant County is suitable for domestic, livestock, irrigation, and most industrial uses. Water obtained from valley fill of Tertiary and Quaternary age generally is hard to moderately hard. It contains from 200 to 400 ppm

(parts per million) of dissolved solids in the northern and central part of the county, and from 300 to 800 ppm in the southern part. Water obtained from the rocks of Paleozoic and Mesozoic age, mostly limestones and shales in the Fierro-Hanover-Santa Rita district and the area north and east of Silver City, is generally hard to very hard. Water from rocks of volcanic origin is generally of good quality, but in the vicinity of some of the mining districts acid waters with high sulfate content occur locally.

Highly mineralized water occurs locally in alluvial deposits in Duck Creek Valley, but in general the ground waters there are of good quality.

Analyses of water from the principal hot springs indicate that the fluoride content of some of the spring waters is somewhat higher than is considered optimum for domestic use.

Surface waters generally contain slightly more dissolved solids than do the ground waters. In addition, the streams carry some sediment, even at low flow. None of the perennial streams carry large sediment loads, percentage-wise, even during periods of flood.

The mining, milling, and smelting industry is at present, and probably will be for the foreseeable future, the largest user of ground water in Grant County. Irrigation agriculture is the second greatest user of ground water, and municipalities are the third greatest users. Data for the period 1960-65 show that the mining-milling-smelting industry annually used about 11,000 acre-feet of water, agriculture used about 9,500 acre-feet (for irrigation), and the cities used about 1,500 acre-feet.

Use of ground water by the mining industry will increase when the Phelps-Dodge Corp. completes development activity at their Tyrone mine. However, data concerning what percent of the water for Tyrone will come from ground water and what percent from surface water are not available. Construction of a local smelter would result in a need for additional large quantities of water. Some ground water previously used for irrigation in the Duck Creek Valley-Cliff-Gila area probably will be utilized at the Tyrone mine and mill. Most of the water to be used at Tyrone will be surface water diverted directly from the Gila River, or indirectly through wells tapping the channel and floodplain deposits in the Gila River Valley.

No appreciable increase in irrigation in Grant County is expected because the most suitable areas are presently developed and are included in declared ground-water basins. This investigation did not reveal any extensive new areas where ground water for irrigation could be developed under present economic conditions.

Some expansion of irrigation may take place in the Lordsburg Valley segment of Grant County, and in the San Vicente basin near the county line. The land in these areas is suitable generally, for agriculture; wells with large yields could be developed, but the depths to water are mostly too great to permit economical pumping under present conditions.

Relatively small acreages outside the Lordsburg Valley may be developed from time to time for irrigation with ground water. However, the total acreage that might be under irrigation at any one time from local sources of ground water probably will not amount to more than 500 acres in the predictable future.

Per-capita use of water in Grant County has increased sharply in the past 10 years in all but one community. Per-capita use will continue to increase as long as the supplies of water are available to meet the demands. All communities should plan to meet continually increasing needs for water.

Supplies of surface water in the Gila River and Mimbres River drainage basins in Grant County are considered by the courts and the New Mexico State Engineer to be fully appropriated and not available for development in excess of current use. Any new development utilizing surface water must depend upon transfer of surface-water rights, subject to approval by regulatory authority.

Ground water to provide the needs of industry and the cities is available in the upper part of the Gila Conglomerate and in the bolson fill in the San Vicente basin but appropriation is subject to approval by the State Engineer.

References

American Geological Institute, 1960, Glossary of geology and related sciences, with supplement: Washington, D. C., Am. Geol. Inst. , 2d ed. , 397 p. (325 p. , supp. 72 p.).

American Society of Civil Engineers, 1962, Nomenclature for hydraulics: ASCE manuals and reports on engineering practice, no. 43, 501 p.

Ballance, W. C., 1962, Ground- water levels in New Mexico, 1961: New Mexico State Engineer Basic Data Rept. , 130 p. , 20 figs.

1963, Ground-water levels in New Mexico, 1962: New Mexico State Engineer Basic Data Rept., 126 p., 20 figs.

1965, Ground-water levels in New Mexico, 1963: New Mexico State Engineer Basic Data Rept., 143 p., 27 figs.

Ballance, W. C. , and Basler, J. A. , 1969, Treated watershed yields improved water harvest: Environmental Sci. and Technology, v. 3, no. 2, February 1969, p. 110-112.

Ballance, W. C. , and others, 1962, Ground-water levels in New Mexico, 1960: New Mexico State Engineer Tech. Rept. 27, 215 p. , 33 figs.

Ballmann, D. L. , 1960, Geology of the Knight Peak area, Grant County, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull 70, 39 p., 1 pl., 10 figs.

Bieberman, R. A. , and Crespin, F. B. , 1955, Index to samples from oil and gas well tests in library at Socorro, New Mexico: New Mexico State Bur. Mines Mineral Resources, Circ. 30, 24 p.

Blaney, H. F. , and Criddle, W. D. , 1962, Determining consumptive use and irrigation water requirements: U. S. Dept. Agriculture, Agr. Research Service Tech. Bull. 1275, 59 p.

Blaney, H. F. , and Hanson, E. G. , 1965, Consumptive use and water requirements in New Mexico: New Mexico State Engineer Tech. Rept. 32, 82 p., 6 figs., 3 apps.

Bodvarsson, Gunnar, 1966, Energy and power of geothermal resources: Ore Bin, v. 28, no. 7, 8 p., 1 fig.

Bowen, R. G., 1971, Electricity from geothermal, nuclear, coal sources-An environmental impact comparison: Ore Bin, v. 33, no. 11, 13 p., 5 figs.

Bromfield, C. S. , and Wrucke, C. T. , 1961, Reconnaissance geologic map of the Cedar Mountains, Grant and Luna Counties, New Mexico: U. S. Geol. Survey Mineral Inv. Field Studies Map MF-159.

Busch, F. E. , 1966, Ground-water levels in New Mexico, 1964: New Mexico State Engineer Basic Data Rept. , 130 p.

Busch, F. E. , and Hudson, J. D. , 1967, Ground-water levels in New Mexico, 1965: New Mexico State Engineer Tech. Rept. 34, 124 p. , 44 figs.

1968, Ground-water levels in New Mexico, 1966: New Mexico State Engineer Basic Data Rept. , 71 p. , 29 figs.

1969, Ground-water levels in New Mexico, 1967: New Mexico State Engineer Basic Data Rept. , 74 p., 30 figs.

__________ 1970, Ground-water levels in New Mexico, 1968: New Mexico State Engineer Basic Data Rept. , 77 p. , 31 figs.

Bushman, F. X., 1955, Ground-water data for Dwyer quadrangle, Grant and Luna Counties, New Mexico; New Mexico State Bur. Mines Mineral Resources, Circ. 37, 18 p. , 1 map.

[California] State Water Quality Control Board, 1963: Water Quality Criteria, 2d ed. , [California] State Water Quality Control Board Pub. 3, 548 p., 4 figs., 18 apps.

Christiansen, P. W. , 1965, New Mexico's Southwest, in New Mexico Geol. Soc. Guidebook, 16th Field Conf. , Southwestern New Mexico II, 1965, p. 230-233.

Conover, C. S. , 1954, Ground-water conditions in the Rincon and Mesilla Valleys and adjacent areas in New Mexico: U. S. Geol. Survey Water-Supply Paper 1230, 200 p. , 9 pls. , 15 figs.

Conover, C. S., and Akin, P. D., 1942, Progress report on the ground-water supply of the Mimbres Valley, New Mexico, in Fourteenth and Fifteenth Bienn. Repts. of the State Engineer of New Mexico, 1938-42, p. 237-282, 12 figs.

Cooper, H. H., Jr., and Jacob, C. E., 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history: American Geophys. Union Trans. , v. 27, no. 4, p. 526534.

Dane, C. H., and Bachman, G. 0., 1965, Geologic map of New Mexico: U. S. Geol. Survey (2 sheets), scale 1:500, 000.

Darton, N. H., 1928a, "Red Beds" and associated formations in New Mexico, with an outline of the geology of the State: U.S. Geol. Survey Bull. 794, 356 p., 62 pls. , 173 figs. [1929].

1928b, Geologic map of New Mexico: U. S. Geol. Survey, scale 1:500, 000.

Davis, S. N. , and Turk, L. J. , 1964, Optimum depth of wells in crystalline rocks: Ground Water, v. 2, no. 2, p. 6-11.

Dinwiddie, G. A., Mourant, W. A., and Basler, J. A. , 1966, Municipal water supplies and uses, northwestern New Mexico: New Mexico State Engineer Tech. Rept. 29-C, 197 p. , 24 figs.

1966a, Municipal water supplies and uses, southwestern New Mexico: New Mexico State Engineer Tech. Rept. 29-D, 98 p. , 18 figs.

Dixon, G. H., Baltz, D. H. , Stipp, T. E., and Bieberman, R. A. , 1954, Records of wells drilled for oil and gas in New Mexico: U. S. Geol. Survey Circ. 333, 79 p., 1 pl.

Dorroh, J. H., Jr., 1946, Certain hydrologic and climatic characteristics of the southwest: Univ. New Mexico, Pub. in Eng. no. 1, 64 p., 3 pls., 2 figs.

Doty, G. C. , 1960, Reconnaissance of ground water in Playas Valley, Hidalgo County, New Mexico: New Mexico State Engineer Tech. Rept. 15, 40 p. , 1 pl. , 9 figs.

Dugan, James, 1966, Nor any drop to drink: Playboy, v. 13, no. 9, HMH Pub. Co., Inc., Chicago, U. S. A.,

p. 150-152, 257-270.

Eckis, Rollin, 1934, Geology and ground water storage capacity of valley fill: California Div. Water Resources Bull. 45, p. 91-246.

Elston, W. E., 1957, Geology and mineral resources of Dwyer quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull. 38, 86 p. , 8 pls. , 8 figs.

– 1958, Some aspects of volcanism and mineralization in southwestern New Mexico, in Guidebook Roswell Geol. Soc. of Southwestern New Mexico: 11th Field Conf., Hatchet Mountains and the Cooks Range-Florida Mountains areas, Grant, Hidalgo, and Luna Counties, p. 57-59.

– 1960, Reconnaissance geologic map of Virden thirty- minute quadrangle: New Mexico State Bur. Mines Mineral Resources, Geol. Map 15.

1965a, The Mogollon Plateau volcanic province: Possible connection with ring - dike complexes and lunar craters, [abstract]; in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, p. 239.

1965b, Volcanic rocks of the Mimbres and upper Gila drainages, New Mexico, in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, p. 167-174.

1968, Terminology and distribution of ash flows of the Mogollon - Silver City - Lordsburg region, New Mexico, in Arizona Geol. Soc. Guidebook III, southern Arizona, p. 231-240.

Elston, W. E. , and Damon, P. E. , 1970, Significance of four new K-Ar dates from the Mogollon Plateau volcanic province, southwestern New Mexico, in Correlation and chronology of ore deposits and volcanic rocks, U.S. AEC Ann. Prog. Rept. no. C00-689-130, AT (11-1)-689, Geochronology Labs., Univ. Arizona, p. AVI- 1-AVI- 9.

Elston, W. E., and Netelbeck, T. A., 1965, Road log from Mimbres Valley to Silver City, in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, p. 36-43.

Elston, W. E., Weber, R. H., and Trauger, F. D., 1965, Road log from Silver City to junction of New Mexico Highways 61 and 90 [via Pinos Altos, Sapillo Creek, Gila Cliff Dwellings National Monument, and Mimbres Valley], in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, 1965, p. 45-62.

Fenneman, Nevin B. , 1931, Physiography of western United States: McGraw-Hill Book Co., Inc. , New York, 534 p.

Ferguson, H. G., 1927, Geology and ore deposits of the Mogollon mining district, New Mexico: U. S. Geol. Survey Bull. 787, 100 p. , 25 pls. , 5 figs.

Feth, J. H., 1964, Hidden recharge, in Ground Water, Natl. Water Well Assoc. , v. 2, no. 4, p. 14-17, 2 figs.

Fishel, V. C., 1956, Long-term trends of ground-water levels in the United States: AmericanGeophys. Union Trans. , v. 37, p. 429-435.

Gatewood, J. S., Robinson, T. W. , Colby, B. R. , and others, 1950, Use of water by bottom-land vegetation in lower Safford Valley, Arizona: U. S. Geol. Survey Water-Supply Paper 1103, 210 p. , 5 pls. , 45 figs.

Gilbert, G. K., 1875, Report on the geology of portions of New Mexico and Arizona: U. S. Geog. and Geol. Survey West of 100th Meridian (Wheeler), v. 3, p. 501-567.

Gilkey, M. M. , and Stotelmeyer, R. B., 1965, Water requirements and uses in New Mexico mineral industries: U. S. Bur. Mines Inf. Circ. 8276, 113 p. , 59 figs.

Gillerman, Elliot, 1952, Fluorspar deposits of Burro Mountains and vicinity, New Mexico: U. S. Geol. Survey Bull. 973-F, p. 261-289.

– 1964, Mineral deposits of western Grant County, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull. 83, 213 p. , 11 pls. , 34 figs.

Gillerman, Elliot, and Whitebread, D. H., 1956, Uranium - bearing nickel- cobalt- native silver deposits, Black Hawk district, Grant County, New Mexico: U. S. Geol. Survey Bull. 1009-K, p. 283-313.

Gillerman, Elliot, Whitebread, D. H., Swinney, M. C., and Crowley, R., 1953, Generalized geologic map of a portion of the White Signal district, Grant County, New Mexico, in Guidebook of New Mexico Geol. Soc., 4th Field Conf. , Southwestern New Mexico: p. 135.

Gratton, L. C. , Lindgren, Waldemar, and Hill, J. M., 1910, Grant County, in Lindgren, Gratton, and Gordon, The ore-deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 295-347, 3 figs.

Hale, W. E. , Reiland, L. J. , and Beverage, J. P., 1965, Characteristics of the water supply in New Mexico: New Mexico State Engineer Tech. Rept. 31, 131 p. , 3 pls. , 27 figs.

Hantush, M. S. , 1957, Preliminary quantitative study of the Roswell ground-water reservoir, New Mexico: New Mexico State Bur. Mines Mineral Resources, rept. undesignated ser. , 118 p., 22 figs.

Hastings, J. R., and Turner, R. M., 1966, The changing mile: Univ. Arizona Press, Tucson, Arizona, 317 p. , 96 pls. , 14 figs.

Hayes, P. T., 1970, Cretaceous paleogeography of Southeastern Arizona and adjacent areas: U. S. Geol. Survey Prof. Paper 6588, 42 p., 6 figs.

Heindl, L. A., 1965, Groundwater in the Southwest-A perspective, in Ecology of groundwater in the southwestern United States: Arizona State Univ. Bur. Publications, p. 4-26, 3 figs.

Hem, J. D., 1959, Study and interpretation of the chemical characteristics of natural water: U. S. Geol. Survey Water-Supply Paper 1473, 269 p. , 2 pls. , 40 figs.

Hernon, R. M., Jones, W. R., and Moore, S. L., 1953, Some geological features of the Santa Rita quadrangle, New Mexico, in New Mexico Geol. Soc. Guidebook, 4th Field Conf. , Southwestern New Mexico, p. 117130.

– 1964, Geology of the Santa Rita quadrangle, New Mexico: U. S. Geol. Survey Geol. Quad. Map GQ-306.

Hewitt, C. H., 1959, Geology and mineral deposits of the northern Big Burro Mountains - Redrock area, Grant County, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull. 60, 151 p., 13 pls., 3 figs.

High Plains Underground Water Conservation District No. 1: 1966, The Cross Section, Lubbock, Texas, v. 13, no. 5, 4 p.

Hutchins, W. A., 1955, New Mexico law of water rights: New Mexico State Engineer Tech. Rept. 4, 61 p.

Jacob, C. E., 1950, Flow of ground water, chap. 5 in Rouse, Hunter, Engineering hydraulics: New York, John Wiley & Sons.

Jicha, H. L. , 1954, Geology and mineral deposits of Lake Valley quadrangle, Grant, Luna, and Sierra Counties, New Mexico: New Mexico State Bur. Mines Mineral Resources, 93 p. , 5 pls. , 13 figs.

Johnson, A. I., 1966, Compilation of specific yields for various materials: U. S. Geol. Survey open-file report, Bull. 37, 119 p. , 19 figs.

Jones, W. R. , 1953, Road log, Silver City to Hanover and Santa Rita, in New Mexico Geol. Soc. Guidebook, 4th Field Conf., Southwestern New Mexico, p. 66-82.

Jones, W. R. , Case, J. E. , and Pratt, W. P. , 1964, Aeromagnetic and geologic map of part of the Silver City mining region, Grant County, New Mexico: U. S. Geol. Survey Geophys. Inv. Map GP-424.

Jones, W. R. , Moore, S. L. , Brew, D. A. , and Koch, G. S. , Jr. , 1963, Preliminary geologic map of Fort Bayard quadrangle, Grant County, New Mexico: U. S. Geol. Survey open-file rept.

Jones, W. R., Hernon, R. M., and Moore, S. L., 1967, General geology of Santa Rita quadrangle, Grant County, New Mexico: U. S. Geol. Survey Prof. Paper 555, 144 p. , 3 pls. , 44 figs.

Kelley, V. C., 1955, Regional tectonics of the Colorado Plateau and relationship to the origin and distribution of uranium: Univ. New Mexico Press, Pubs. in Geol. , no. 5, 120 p. , 8 pls. , 17 figs.

Kiersch, G. A. , 1964, Geothermal steam; origin, occurrence, characteristics, and exploitation: U. S. Dept. Commerce, Natl. Bur. Standards, Inst. Appl. Tech. , 107 p. , 25 figs. , 9 apps. , 96 p.

Kohler, M. A. , Nordenson, T. J. , and Baker, D. R. , 1959, Evaporation maps for the United States: U. S. Weather Bur. Tech. Paper no. 37, 13 p. , 5 pls. , 6 figs.

Koopman, F. C. , Trauger, F. D. , and Basler, J. A. , 1969, Water resources appraisal of the Silver City area, Grant County, New Mexico: New Mexico State Engineer Tech. Rept. 36, 50 p., 1 pl. , 11 figs.

Kuellmer, F. J. , 1954, Geologic section of the Black Range at Kingston, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull. 33, 100 p. , 3 pls. , 28 figs.

1956, Geologic map of Hillsboro Peak thirty-minute quadrangle: New Mexico State Bur. Mines Mineral Resources, Geol. Map 1.

Langbein, W. B. , and Iseri, K. T. , 1960, General introduction and hydrologic definitions; Manual of hydrology: Part 1, General surface-water techniques: U. S. Geol. Survey Water-Supply Paper 1541-A, 29 p.

Lasky, S. G., 1936, Geology and ore deposits of the Bayard area, Central mining district, New Mexico: U.S. Geol. Survey Bull. 870, 144 p., 17 pls., 21 figs.

1947, Geology and ore deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico: U. S. Geol. Survey Prof. Paper 208, 101 p., 27 pls. , 18 figs.

Leopold, L. B. , 1951, Rainfall frequency; an aspect of climatic variation: AmericanGeophys. Union Trans., v. 32, p. 347-357.

Leopold, L. B., and Snyder, C. T., 1951, Alluvial fills near Gallup, New Mexico: U. S. Geol. Survey Water-Supply Paper 1110-A, p. 1-18, 8 figs.

Lohman, S. W. , and others, 1972, Definitions of selected ground-water terms-revisions and conceptual refinements: U. S. Geol. Survey Water-Supply Paper 1988, 21 p.

Lovering, T. G., 1956, Radioactive deposits in New Mexico: U. S. Geol. Survey Bull. 1009-L, p. 315-390, pls. 17-23, figs. 49-57.

Meinzer, 0. E. , 1923a, The occurrence of ground water in the United States, with a discussion of principles: U. S. Geol. Survey Water-Supply Paper 489, 321 p. , 31 pls. , 110 figs.

1923b, Outline of ground- water hydrology, with definitions: U. S. Geol. Survey Water-Supply Paper 494, 71 p. , 35 figs.

Meyers, J. S. , 1962, Evaporation from the 17 Western States, with a section on Evaporation rates, by T. J. Nordenson, U. S. Weather Bur. : U. S. Geol. Survey Prof. Paper 272-D, p. 71-100, 1 pl., 5 figs.

Morrison, R. B., 1965, Geologic map of the Duncan and Canador Peak quadrangles, Arizona and New Mexico: U. S. Geol. Survey Misc. Geol. Inv. Map 1-442.

New Mexico Legislature, 1968, New Mexico Statutes, 1953, annotated: Allen R. Smith, chap. 75, 708 p.

New Mexico State Engineer, 1953, Manual of rules and regulations governing the appropriation and use of surface waters of the State of New Mexico: New Mexico State Engineer, Manual, 39 p.

1956a, Climatological summary New Mexico, temperature, 1850-1954, frost, 1850-1954, evaporation, 1912-1954: New Mexico State Engineer Tech. Rept. 5, 227 p. , 5 exhibits.

1956b, Climatological summary New Mexico, precipitation, 1849-1954: New Mexico State Engineer Tech. Rept. 6, 407 p., 5 exhibits.

1962, Twenty-fifth biennial report of the State Engineer of New Mexico, for the 49th and 50th fiscal years, July 1, 1960 to June 30, 1962, 162 p. , 7 figs.

1966, Rules and regulations governing drilling of wells and appropriation and use of ground water in New Mexico, 124 p.

Ordonez, Gearges, Baltosser, W. W. , and Martin, Keith, 1955, Geologic structures surrounding the Santa Rita intrusive, New Mexico: Econ. Geology, v. 50, no. 1, p. 9-21.

Paige, Sidney, 1910, The ore deposits near Pinos Altos, New Mexico, in Contributions to economic geology, 1910, Pt. I, Metals and nonmetals except fuels: U. S. Geol. Survey Bull. 470, p. 109-125.

1916, Description of the Silver City quadrangle, New Mexico: U.S. Geol. Survey Geol. Atlas, Folio 199, 19 p.

1922, Copper deposits of the Tyrone district, New Mexico: U. S. Geol. Survey Prof. Paper 122, 53 p. , 10 pls. , 29 figs.

Reeder, H. 0. , 1957, Ground water in Animas Valley, Hidalgo County, New Mexico: New Mexico State Engineer Tech. Rept. 11, 101 p., 4 pls., 39 figs. [1958].

Reeder, H. 0. , and others, 1962, Ground-water levels in New Mexico, 1958: New Mexico State Engineer Tech. Rept. 23, 288 p. , 20 figs.

1962a, Ground-water levels in New Mexico, 1959: New Mexico State Engineer Tech. Rept. 24, 125 p. , 21 figs.

Schulman, Edmund, 1956, Dendroclimatic changes in semiarid America: Univ. Arizona Press, 142 p. , 42 figs.

Schwennesen, A. T. , and Hare, R. F. , 1918, Ground water in the Animas, Playas, Hachita, and San Luis basins, New Mexico: U. S. Geol. Survey Water-Supply Paper 422, 152 p. , 9 pls. , 17 figs.

Spencer, A. C. , and Paige, Sidney, 1935, Geology of the Santa Rita Mining area, New Mexico: U. S. Geol. Survey Bull. 859, 78 p. , 6 pls. , 1 fig.

Stearns, N. D., 1927, Laboratory tests on physical properties of water-bearing materials: U. S. Geol. Survey Water-Supply Paper 596-F, p. 121-176.

Theis, C. V. , 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using ground-water storage: American Geophys. Union Trans.. v. 16, pt. 2, p. 519- 524.

Thomas, H. E., 1962, The meteorologic phenomenon of drought in the Southwest: U. S. Geol. Survey Prof. Paper 372-A, p. A1-A43, 1 pl. , 20 figs.

Tolman, C. F. , 1937, Ground water: [New York and London] McGraw-Hill, 593 p.

Trauger, F. D. , 1960, Availability of ground water at proposed well sites in Gila National Forest, Sierra and Catron Counties, New Mexico: New Mexico State Engineer Tech. Rept. 18, 20 p. , 3 pls. , 2 figs.

– 1965, Geologic structure pattern of Grant County, New Mexico, in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, p. 184-187, 1 fig.

Trauger, F. D., and Doty, G. C., 1965, Ground water - Its occurrence and relation to the economy and geology of southwestern New Mexico, in New Mexico Geol. Soc. Guidebook, 16th Field Conf., Southwestern New Mexico II, p. 215-227, 2 figs.

Trauger, F. D., and Herrick, E. H., 1962, Ground water in central Hachita Valley northeast of the Big Hatchet Mountains, Hidalgo County, New Mexico: New Mexico State Engineer Tech. Rept. 26, 21 p., 1 pl. , 2 figs.

Trewartha, G. T. , 1937, An introduction to weather and climate: [New York] McGraw-Hill, 373 p.

Tuan, Yi-Fu, and Everard, C. E., 1964, New Mexico's climate: The appreciation of a resource: Natural• Resources Jour., v. 4, no. 2, p. 268-308, 9 figs.

Turner, G. L. , 1962, The Deming axis, southeastern Arizona, New Mexico, and Trans-Pecos Texas, in New Mexico Geol. Soc. Guidebook, 13th Field Conf. , Mogollon Rim Region, east-central Arizona, p. 59-71, 9 figs.

U. S. Bureau of the Census, 1970, U. S. Census of population 1970, number of inhabitants, New Mexico: U. S. Govt. Printing Office, Washington, D. C.

U. S. Bureau of Reclamation, 1930, Report on Upper Gila River Investigations, 1929-30, in Eleventh Bienn. Rept. of the State Engineer of New Mexico, 1932-34, P. 183-239.

U. S. Department of Agriculture, 1955, Water - The yearbook of agriculture: U. S. Govt. Printing Office, Washington, D. C. , 751 p.

U. S. Department of the Interior, 1951, The drought in southwestern United States as of October 1951: U. S. Govt. Printing Office, Washington, D. C. , 65 p. , 7 figs.

U. S. Geological Survey, 1954a, Water-loss investigations: Lake Hefner studies, Tech. Rept.: U. S. Geol. Survey Prof. Paper 269, 158 p., 101 figs.

– 1954b, Compilation of records of surface waters of the United States through September 1950, Pt. 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1313, 749 p.

–1954c, Surface water supply of the United States, 1954, Pt. 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1343, 481 p.

–1955, Surface water supply of the United States, 1955, Pt. 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1393, 492 p.

–1956, Surface water supply of the United States, 1956, Pt. 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1443, 466 p.

– 1960, Compilation of records of surface waters of the United States through September 1950, Pt. 8, Western Gulf of Mexico Basins: U. S. Geol. Survey Water-Supply Paper 1312, 633 p.

1962, Surface water records of New Mexico, 1962: U. S. Geol. Survey, 206 p.

– 1964a, Compilation of records of surface waters of the United States, October 1950 to September 1960, Pt. 8, Western Gulf of Mexico Basins: U. S. Geol. Survey Water-Supply Paper 1732, 574 p.

1964b, Compilation of records of surface waters of the United States, October 1950 to September 1960, Pt. 9, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1733, 586 p.

1964c, Quality of surface waters of the United States, 1959: U.S. Geol. Survey Water-Supply Paper 1645, 524 p.

1964d, Water qualityrecords in New Mexico, 1964: U. S. Geol. Survey, 166 p.

1965, Surface water records of New Mexico, 1965, Pt. 1: U. S. Geol. Survey, 240 p.

– 1966, Surface water records of New Mexico, 1966, Pt. 1: U. S. Geol. Survey, 262 p.

1967, Surface water records of New Mexico, 1967, Pt. 1: U. S. Geol. Survey, 249 p.

1968, Surface water records of New Mexico, 1968, Pt. 1: U. S. Geol. Survey, 271 p.

– 1969, Surface water records of New Mexico, 1969, Pt. 1: U. S. Geol. Survey, 242 p.

– 1970a, Surface water supply of the United States, 1961-65, Pt. 8, Western Gulf of Mexico Basins: U. S. Geol. Survey Water-Supply Paper 1923, 786 p.

1970b, Surface water supply of the United States, 1961-65, Pt. 8, Colorado River Basin: U. S. Geol. Survey Water-Supply Paper 1926, 571 p.

U. S. Public Health Service, 1962, Public Health Service drinking water standards - 1962: Public Health Service Pub. no. 956, 61 p.

U.S. Weather Service, 1955-70, Climatological data; monthly and annual summaries, New Mexico: U. S. Weather Service.

von Buttlar, Haro, 1959, Ground-water studies in New Mexico using tritium as a tracer, II: Jour. Geophys. Research, v. 64, no. 8, p. 1031-1038.

von Buttlar, Haro, and Wendt, Immo, 1958, Groundwater studies in New Mexico using tritium as a tracer: American Geophys. Union Trans., v. 39, p. 660-668.

Von Eschen, G. F., 1961, The climate of New Mexico: New Mexico Univ. , Bur. Business Research, Albuquerque, New Mexico, 72 p.

Wahrhaftig, Clyde, 1965, Stepped topography of the southern Sierra Nevada, California: Geol. Soc. America Bull. , v. 76, p. 1165-1190, 2 pls. , 19 figs.

Weber, R. H., and Willard, M. E., 1959a, Reconnaissance geologic map of Mogollon thirty-minute quadrangle: New Mexico State Bur. Mines Mineral Resources, Geol. Map 10.

Weber, R. H., and Willard, M. E., 1959b, Reconnaissance geologic map of Reserve thirty-minute quadrangle: New Mexico State Bur. Mines Mineral Resources, Geol. Map 12.

Wenzel, L. K. , 1942, Methods for determining permeability of water-bearing materials, with special reference to discharging-well methods, with a section on Direct laboratory methods and Bibliography on permeability and laminar flow, by V. C. Fishel: U. S. Geol. Survey Water-Supply Paper 887, 192 p.

West Texas Geological Society and Southwestern New Mexico Section, American Inst. Mining Metall. Engineers, 1949, Geology and ore deposits of Silver City region, New Mexico, Guidebook, Field Trip no. 3, 1949, 45 p.

White, W. N., 1930, Ground-water supplies of Mimbres Valley, New Mexico: U. S. Geol. Survey Water-Supply Paper 637-B, p. 69-90, 1 pl.

Wilson, W. W., 1965, Pumping tests in Colorado: Colorado Water Conserv. Board, Circ. 11, Ground-water series, 361 p. , 1 pl.

Winchester, D. E., 1920, Geology of Alamosa Creek Valley, Socorro County, New Mexico, with special reference to the occurrence of oil and gas, in contr. to Econ. Geology, Pt. II, Mineral Fuels: U. S. Geol. Survey Bull. 716, p. 1-15, 5 pls.

Wisler, C. 0. , and Brater, E. F. , 1949, Hydrology: [New York] John Wiley & Sons, Inc. , 419 p.

Zeller, Robert A. , Jr. , 1970, Geology of the Little Hatchet Mountains Hidalgo and Grant counties, New Mexico: New Mexico State Bur. Mines Mineral Resources, Bull. 96, 23 p. , 2 pls.

Glossary of Hydrogeologic Terms

The basic definitions that follow were taken in part from Meinzer and Tolman, from the Glossary of Geology and Related Science (American Geological Institute, 1960), from Nomenclature for hydraulics (American Society of Civil Engineers, 1962), from Langbein and Iseri (1960) and from Lohman and others (1972); some definitions have been abridged and (or) modified to meet the particular needs of this report.

Acre-foot. —The amount of water (325,851 gal) that will cover one acre to a depth of 1 foot.

Aquifer. —A rock formation, group of formations, or a part of a formation containing water that can be recovered through wells. An aquifer may be called also a water-bearing bed, formation, or zone. Alluvium and bolson fill are the most widespread aquifers in Grant County.

Artesian water. —Ground water that rises above the level at which it is encountered by a well, but which does not necessarily rise to or above the surface of the ground—also called confined water. The rock in which artesian water is found may be called an artesian aquifer, and the well an artesian well, especially if water flows at the surface. Water that is semiconfined is also artesian. A semiconfined aquifer is one that is confined by beds that do not form a perfect seal, thus permitting leakage into or out of the aquifer, depending upon the head relative to the head in overlying and underlying beds.

Bank storage. —Water absorbed and stored in the banks of a stream, lake, or reservoir when the stages rise above the water table in the bank formations. Bank storage may be returned in whole or in part as seepage back to the river when the level of the surface water returns to a lower stage.

Base flow. —Sustained or fair-weather runoff—generally that portion of the streamflow derived from discharging groundwater or other delayed sources such as lakes, snow fields, and glaciers—also base runoff. Under some circumstances the controlled release or natural flow from reservoirs may be considered to be base flow.

Basement rock. —Name commonly applied to metamorphic and igneous rocks, generally of Precambrian age, that underlie a predominantly sedimentary sequence of rocks.

Bedrock. —Any solid rock underlying soil, sand, clay, bolson fill or any unconsolidated combination of these.

Bolson. —An alluvium - floored basin, depression, or wide valley, mostly surrounded by mountains, drained by a system that has no outlet to the sea. Bolson fill is the alluvial detritus that fills a bolson—also commonly called bolson deposits.

Capillary fringe. —Zone immediately above the water table in which some or all of the interstices are filled with water that is held in the pore space by surface tension at less than atmospheric pressure. The capillary fringe commonly is thin where the pore spaces are large, thicker where they are small.

Cfs. —Abbreviation for cubic feet per second. One cfs equals a steady flow of 449 gpm (gallons per minute).

Cone of depression. —The depression produced in a water table or potentiometric surface by pumping (or artesian flow). A huge cone of depression has developed in the vicinity of Santa Rita as a consequence of the dewatering caused by mining operations.

Confined water. —The same as artesian water.

Confining bed. —A rock formation that will not transmit water readily and which retards or stops the free movement of water underground. Confining beds have also been called aquicludes, aquitards, or semiconfining beds.

Few rocks are completely impermeable—most will transmit some water, though slowly, hence "aquifer" and "confining bed" are relative terms. A rock formation with a low capacity to transmit water may abut or overlie a very permeable formation, in which case it might act as a dam or as a confining bed. Elsewhere that same formation might provide a small, reliable supply of water to wells, in which case it would be considered an aquifer. Both the Gila Conglomerate and the Colorado Shale formations are examples of rocks that locally may be confining beds, and elsewhere, aquifers.

Discharge. —Rate of flow at a given instant in terms of volume per unit of time: pumping discharge equals pumping rate, usually given in gallons per minute; stream discharge, usually given in cubic feet per second. In ground water use: the movement of water out of an aquifer.

Discharge may be natural, as from springs, as by seepage, or by evapotranspiration, or it may be artificial as by constructed drains, or from wells.

Drawdown. —The lowering of the water table or potentiometric surface caused by pumping (or artesian flow).

Knowledge of the amount of drawdown at a given pumping rate, over a specified length of time, is necessary to estimate the probable long-term effect on the water table of pumping from the aquifer.

Dry hole. —Common expression applied to any newly drilled well that does not develop enough water to meet the needs for which it was drilled.

A well drilled for irrigation supply may be considered "dry" yet yield an adequate supply of Water for domestic or stock well. A "dry hole" may contain water that stands within a few feet of land surface but will not sustain a yield sufficient to justify installing a pump. Holes have been drilled that reportedly found no water, yet were found to contain water when examined later. The water may result from slow seepage that was not detected at the time of drilling or it may result from inflow of rain water at the ground surface.

Effective porosity. —See Porosity.

Ephemeral stream. —A stream or portion of a stream which flows only in direct response to precipitation. Such flow is usually of short duration. Most of the dry washes of the region may be classified as ephemeral streams.

Evapotranspiration. —The process by which water is returned to the air through direct evaporation or by transpiration of vegetation, no attempt being made to distinguish between the two.

Floodflow. —The discharge of a stream during periods of flood—commonly recognized as a rapid accumulation of water markedly in excess of the normal flow for that time of the year, and generally of a magnitude that could cause damage to property and lands.

Flow line. —As applied to the movement of ground water, the path that a particle of water follows as it moves down the hydraulic gradient.

Gaining stream. —A river, or reach of a stream or river, that gains flow from ground-water seepage or from springs in, or alongside, the channel—sometimes called an effluent stream.

The Gila River is gaining through much of its course in Grant County, and the Mimbres is gaining from about McKnight Canyon to San Lorenzo.

Gpm. —Abbreviation for the term "gallons per minute."

Ground water. —Water found beneath the land surface, in the zone of saturation below the water table.

Ground-water cascade. —Ground water that spills over a ground-water dam, or descends on a steep hydraulic gradient to a lower and flatter water-table slope. Presence of a ground-water cascade is indicated by local steepening of water - table contours east and southeast of White Signal.

Ground-water dam.—A body of material, natural or artificial, below the land surface, which is impermeable, or nearly so, and which impedes the horizontal movement of ground water. The result commonly is a pronounced difference in the level of the water table on opposite sides of the dam.

A concealed ridge or mass of impermeable rock under a stream channel may cause underflow in the subsurface part of the channel to rise to the surface, where it appears as surface flow; the water may then sink back beneath the channel bed once it has crossed over the impermeable rock.

Ground-water divide. —A line on a water-table or potentiometric surface on each side of which the hydraulic gradient slopes downward in a direction away from the line.

Meinzer (1923b, p. 34) explains further: "It is analogous to a divide between two drainage basins on a land surface. The water moves in the direction of the slope—that is, in opposite directions on opposite sides of the divide. Generally a ground-water divide is found nearly below a surface-drainage divide, but in many localities there is no relation between the two." The principal ground - water divide in Grant County lies nearly under the Continental Divide which separates the Gila-Mimbres and Mimbres-Animas surface-drainage basins.

Ground-water mound or ridge.— Mound- shaped or ridge-shaped rise in the water table, built up by influent seepage.

Ground-water trench or valley. —An elongated depression of the potentiometric surface caused by movement of ground water outward, or downgradient, at a more rapid rate than under adjacent areas, generally because of more permeable rock.

Hydraulic gradient.—The gradient of the potentiometric surface or water table, in the direction of the steepest slope, generallyexpressed in feet per foot or feet per mile. May also be stated as the change in static head per unit of distance in a given direction.

Hydrograph. —Graph showing the stage, flow, velocity or other property of water with respect to time. Hydrographs of wells show the changes in water levels during the period of observation.

Hydrologic boundary. —Any change in the lithology, structure, or other conditions that impedes or results in a complete blockage of the flow of ground water in one direction, or results in the establishment of a constant recharging head within the aquifer.

A boundary such as an intrusive dike (or another pumping well) that blocks or cuts off the flow toward a pumping well is called a discharging boundary because it has the same effect as if a second pumping well were removing water that would otherwise flow to the first well. A boundary such as a perennial stream or lake that provides a constant head and a source of steady flow toward a well is called a "recharging" boundary because it seems to add water that otherwise would not enter the aquifer.

Hydrologic cycle. —The circulation of water from the sea, through the atmosphere, to the land, and ultimately back to the sea byway of surface streams, or by indirect routes that may involve long delays in underground storage, or numerous passages between the land and the atmosphere before the return to the sea. Sometimes called the "water cycle."

Hydrologic system. —Any relatively large area, or sequence of geologic rock units, within which the hydrologic characteristics are closely related and which can be isolated, or nearly so, from other areas or units for consideration of causes and effects pertaining to water.

Hydrology.—The science that relates to the water of the earth.

Impermeable. —Not capable of transmitting fluids or gasses in appreciable quantities. Few rocks are completely impermeable, but some, such as unweathered granite, dense basalt, welded tuff, dense limestone, and well cemented conglomerate may be so considered for practical purposes.

Infiltration. —Movement of water through the soil surface into the ground. Infiltration takes place above the water table, as distinguished from percolation which is the more or less horizontal movement of water in saturated material, below the water table.

Intermittent stream. —A stream which flows for only a part of the time. Flow generally occurs for several weeks or months during or after seasonal precipitation, due to ground-water discharge, in contrast to the ephemeral stream that flows but a few hours or days following a single storm.

Interrupted stream.—A stream which is perennial along parts of its course and intermittent or ephemeral along intervening parts.

Interstices. —Openings or pore spaces in rocks, sometimes called voids. If connected, they serve as passageways for water seeping down to the water table;

and if below the water table, they constitute the reservoir which makes the rock an aquifer and through which the water moves.

Losing stream. —A stream that loses water by infiltration through the bed and bank—sometimes called influent stream.

Milligrams per liter (mg/1).—A measure of the concentration of a substance in a solution. A milligram per liter is one thousandth of a gram (0. 001 gram) of a substance in one liter (about 1,000 cubic centimeters) of solution. A milligram per liter (mg/1) is equivalent to 1 part per million (ppm) for concentrations of about 7, 000 ppm or less.

Mineralized zone. —Mineral-bearing belt or area extending through a district; its width and areal extent distinguish it from a vein or lode. In this report, restricted to include only those areas where ore minerals and associated gangue minerals are common and widely distributed.

Parts per million (ppm). —(See milligrams per liter.)

Perched water. —Ground water held or detained above the regional water table by a layer or bed of impermeable or semipermeable rock.

By inference, a zone of unsaturated rock lies between the perched water and the water table, and there may be two or more bodies of perched water at different levels. Perched-water bodies may be of small or large areal extent; they are relatively common in bedded rocks in upland areas. The supporting bed can be any type of impermeable rock (fig. 21).

Recognition of perched water is difficult at the time of drilling. The amount of water found may be adequate to sustain drilling operations and supply a well having a small water demand, but later, if moderate to large amounts are pumped, the supply may be exhausted in a relatively short time. Also, perched water may leak downward into the underlying unsaturated rocks if the supporting bed is fully penetrated by the drill.

A well may be suspected of tapping a body of perched water if the water level declines slowly after drilling and the well eventually goes dry or stabilizes at a lower yield. Well 17.14. 32. 233, drilled in carbonate rocks, had a yield of about 1-1/2 gpm when it was first drilled; within a year the yield gradually dropped to less than 1/2 gpm. The log (table 5) indicates three water-bearing zones and it is probable that at least the upper two were perched and were eventually drained.

Percolation. —(See "infiltration. ")

Porosity. —The ratio of the total volume of pore space (voids in a rock or soil to its total volume) usually stated as a percentage. Effective porosity is the ratio of the total volume of interconnected voids to the total volume. Unconnected voids contribute to total porosity, but are ineffective in transmitting water through the rock.

Potentiometric surface.—The surface which represents the static head, especially in those aquifers in which water is confined under some hydrostatic pressure. As related to an aquifer, it is determined by the levels to which water will rise in tightly cased wells. The water table is a particular potentiometric surface, all points on which are at zero hydrostatic pressure.

Pump test. —Term commonly (though improperly) used to describe the testing of a well to determine the potential yield; the term "aquifer test" is more appropriate as it is the aquifer, not the pump, that is being tested.

Pumping level. —Level of water in a well during pumping. (See "water level. ")

Recharge. —Process by which water infiltrates and is added to an aquifer, either directly into the aquifer, or indirectly by way of another rock formation; also, the water itself.

Recharge may be natural, as when precipitation infiltrates to the water table, or artificial, when water is injected through wells or spread over permeable surfaces for the purpose of recharging an aquifer.

Residual seepage. --Water returned to the channel after temporary storage in stream bank or bed, or in soil zone or bedrock after a flood crest has passed.

Semiconfined aquifer. —(See "artesian water. ")

Sheet wate r. — Commonly-used term that implies a small supply of water found at a particular depth. Sheet water occurs in thin zones, from a few inches to a foot or so thick, of permeable and saturated rock overlying an impermeable, or nearly impermeable, rock. Some sheet water may be perched. The thin saturated zones at the base of the alluvium and soil overlying granitic rocks are good examples of sheet water. Occurrences of sheet water are common in areas of scant rainfall where a relatively thin cover of alluvium and surface or slope wash lies on relatively impermeable rock. Small amounts of water move down through the alluvial cover to the dense "bedrock, " then move laterally over the surface of the rock.

Soil moisture. —Moisture held in the soil zone.

Most precipitation that falls in arid and semiarid lands either evaporates immediately or is held for a relatively short time in the soil zone where, if it is not used byplants, it ultimately is evaporated. Some soil moisture generally is held so tightly by capillary attraction that it is not available to plants and is not evaporated at normal temperatures.

Specific capacity. —Yield of a well in gallons per minute per foot of drawdown after a specified period of pumping.

A well yielding 20 gallons per minute with a drawdown of 5 feet has a specific capacity of 4 gpm per foot at that time, at that particular rate of pumping, and at that pumping level. The specific capacity may change with time. It may increase as the formation is opened up by removal of fine material, or it may decrease. Decreases are to be expected more commonly than increases as the aquifer is dewatered and as perforations in the casing or screen or voids in the aquifer become clogged for one reason or another.

Specific yield. —Ratio of (1), the volume of water a saturated rock will yield by gravity, to (2), its own volume, expressed as a ratio or percentage. If the time the material is allowed to drain is known, it should be stated.

If 40 cubic feet of saturated rock yields 3 cubic feet of water by gravity drainage, its specific yield is 3/40 or 0. 075 or 7.5 percent.

Static water level. —The level at which water stands in a nonpumping well—the prepumping level. Also, the level to which water eventually will return after pumping has stopped, sometimes called the recovery level.

The recovery level may not stand as high as the original or first static level if the water pumped has come from storage and is not replaced by recharge. (See "water level. ")

Storage coefficient.—Volume of water released or taken into storage in an aquifer per square foot of surface area per foot of vertical change in the head. The storage coefficient is approximately equal to the specific yield for nonartesian (unconfined) aquifers. It is much less for confined aquifers because in a confined aquifer it represents the change due to the combined compressibility of the aquifer and water, which is very slight.

Transmissivity. —Ability of a rock to transmit water under hydraulic head. The transmissivity is the rate of flow of water at the prevailing temperature, through a vertical unit-wide strip of the aquifer, extending the full height of saturation, under unit hydraulic gradient (1 unit of head per unit of flow distance). In this report the units used are feet. Transmissivity in recent years has been used instead of "transmissibility" with which it is synonymous.

Unconfined water. —Ground water not under artesian conditions. Generally used to describe water that does not rise above the point at which it is first found, at the time it is found. Seasonal changes in both unconfined and confined water levels may take place as a result of variations in recharge and discharge.

Unde rflow. —Wate r moving parallel to the stream course through the alluvium beneath the streambed.

Voids. —(See interstices.)

Water level.—The surface of still water; the altitude or level of a water surface above or below a given datum. In this report it is shown in fig. 2 as the altitude in feet above mean sea level, and is given in tables as feet below land surface at the well or shaft. Water levels in wells fluctuate in response to natural causes and to activities of man. Some fluctuations of water levels can be correlated with variations in atmospheric pressure. Seasonal changes in water levels can result from variations in rates of recharge and discharge. Increased precipitation, death of seasonal vegetation, or reduced pumping can result in a rise in water levels; declines generally begin during and after periods of drought, heavy pumping, reactivated growth of vegetation, or upstream diversion of surface flow.

Fluctuations of water levels must be measured over definite periods of time to determine their causes, to aid in understanding of the occurrence and behavior of ground water in an area, and to help determine action for development or conservation of supplies of water.

Water table. —Upper surface of the zone of saturation where that surface is not confined and is at atmospheric pressure. Where water is confined in an aquifer, different terminology is used—see "potentiometric surface. "

Saturation usually occurs some distance above the water table within the capillary fringe. The position of the water table below the land surface can be determined by measuring the depth to water in wells.

Water year. —The period October 1 through September 30 of any two successive years, as October 1967 through September 1968.

A period based on the seasonal cycles of rainfall, runoff, and plant growth. Fall and winter precipitation greatly affects the following year's early growth of vegetation because it is stored as soil moisture and snowpack. For realistic consideration of the relation of precipitation to plant growth, as with tree growth-ring analysis or crop and range predictions, the October through December precipitation must be considered with that falling during the successive spring and summer growing months.

Zone of aeration. —Zone in which the connected interstices or voids in a permeable rock are not filled with water and there can be movement of air. Generally, the zone between the land surface and the water table, but a zone of aeration can exist below an artesian aquifer, and below a perched water body.

Zone of saturation.—Zone in which all the connected interstices or voids in a permeable rock are filled with water under pressure equal to, or greater than, atmospheric pressure. The water table commonly is considered to be at the top of the zone of saturation.