TECHNICAL REPORT NO. 10

State of New Mexico
State Engineer Office
Santa Fe, N. Mex.

GROUND-WATER CONDITIONS IN THE NONTHERMAL ARTESIAN-WATER BASIN SOUTH OF HOT SPRINGS, SIERRA COUNTY, NEW MEXICO

By
C. Richard Murray

*Prepared in cooperation with
the United States Geological Survey*

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GROUND-WATER CONDITIONS IN THE NONTHERMAL ARTESIAN-WATER BASIN SOUTH OF HOT SPRINGS, SIERRA COUNTY, NEW MEXICO

By

C. Richard Murray

U. S. Geological Survey

ABSTRACT

A number of flowing artesian wells have been developed on the west side of the Rio Grande south of Hot Springs, N. Mex., in an area extending from Mud Springs Draw, just south of Hot Springs, to Arrey, about 18 miles farther south. Development has been concentrated in three areas; namely, Mud Springs Draw, Animas Creek, and Percha Creek, but there are also a number of wells along the Rio Grande Valley proper. The latter wells are located within 2 miles of the Rio Grande or Caballo Reservoir, but in Animas and Percha Creek valleys flowing wells have been obtained as far as 4 miles from the Rio Grande. The water occurs in sand, gravel, and silt of the poorly consolidated Tertiary or Quaternary deposits that fill the Rio Grande structural depression and dip eastwardly toward the Rio Grande. Artesian conditions are believed to be brought about by confinement of the water in the aquifers by beds of clay. The valley-fill material becomes coarser toward the west and is represented there by fairly well cemented conglomerates. Artesian wells in Mud Springs Draw furnish the municipal water supply for the city of Hot Springs, but most of the wells in the area are used for combined domestic and irrigation purposes. Some of the wells, especially those in Mud Springs Draw, flow a few hundred gallons a minute, but in general flows of only a few tens of gallons a minute are yielded by the wells.

Water is believed to enter the aquifers west of the area of artesian development, to flow through the aquifers toward the Rio Grande, and to be discharged indirectly to the river by upward percolation through imperfectly confining beds to the overlying, shallow-water aquifers and thence to the river.

Nearly 2 second-feet of water is being pumped from a small area near the city wells in Mud Springs Draw. Discharge from these and other wells, which divert water that otherwise would escape to the shallow-water aquifers, is believed to be balanced by a reduction of discharge of ground water to the river. Because the discharge from the artesian aquifers to the river is restricted, the artesian head in some wells close to the river is as much as 60 feet above it.

Water from the artesian wells is of fair quality, in general, but varies considerably from area to area and from well to well. Sodium, calcium, chloride, and bicarbonate are the most abundant cations and anions in the water. The dissolved solids may be as high as 850 parts per million and the hardness 350 parts, but 550 and 200 parts per million, respectively, are about average values.

From a coefficient of transmissibility, determined by pumping tests in the Mud Springs Draw area, of about 11,000 gallons a day per foot, and an easterly slope of the piezometric surface of about 55 feet per mile, it may be calculated that about 1 second-foot of water discharges to the river per mile of its length in the area of nonthermal artesian-water development. This agrees very closely with seepage determinations that have been made on the Rio Grande in this section.

Because of the limited flow from the wells, the small amount of water available, and the limited acreage of irrigable land in the area of artesian flow, no large-scale irrigation development using flowing artesian water is possible. Installation of pumps on the wells may, in certain areas, permit a type of agricultural development better than that involving use of the small natural flow from the wells.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

A number of flowing wells have been obtained in the valley-fill deposits of the Rio Grande depression in an area on the west side of the Rio Grande and Caballo Reservoir from just below Hot Springs to about 18 miles south of Hot Springs. (See pl. 1.) The area of artesian flow averages about 4 miles in width. Development of this artesian basin began about 1938 and has continued until the present. The development has been concentrated in three areas; namely, Mud Springs Draw, Animas Creek, and Percha Creek. In some of the intervening areas, wells have been developed along the valley of the Rio Grande proper. In the Mud Springs Draw area flowing wells yield a few hundred gallons a minute, but in the other areas most wells yield only a few tens of gallons a minute. Most of the wells are used for combined domestic, stock, and irrigation purposes, but those in Mud Springs Draw furnish the municipal water supply for the city of Hot Springs. The drilling near the city wells of additional wells for irrigation and other purposes has caused some concern as to whether the area is being overdeveloped. The northern part of the basin is included in the Hot Springs Artesian Basin, control over which is exercised by the State Engineer of New Mexico. The purpose of the present investigation is to obtain basic hydrologic data on the artesian basin so that optimum development can be made of the limited quantities of water available.

The study of the artesian basin south of Hot Springs, N. Mex., was begun in 1945 by the Ground Water Branch of the United States Geological Survey in cooperation with the State Engineer of New Mexico. The work was carried on under the general supervision of O. E. Meinzer, Geologist in Charge, Ground Water Branch, Water Resources Division of the U.S. Geological Survey, and his successor, A. N. Sayre, and under the immediate supervision of Charles V. Theis, District Geologist.

Field work began in April 1945 when preliminary pumping tests and measurements of artesian pressures were made by C. V. Theis and C. R. Murray, the writer, who collected additional data in October, November, and December, during which time two gravel-packed wells were drilled by the Layne-Texas Co. for the city of Hot Springs. In May 1946 pumping tests were made on the city wells to determine the hydrologic constants of the aquifers, and in June and August 1946 additional field work was carried on. Pumping tests were also made in March 1947 on wells near the mouth of Mud Springs Draw. During the progress of the investigation information was obtained on many water-table and artesian wells in the area, and spirit and barometric levels were run to determine the slope of the water table and the piezometric surface. Exposures of the valley fill were examined throughout the area to determine the influence of the geology on the artesian system. Water samples were collected from a number of wells in the area for chemical analyses.

PREVIOUS INVESTIGATIONS

Several geologic and hydrologic investigations of the general region surrounding the artesian basin had been made previously. One of the most comprehensive was by C. H. Gordon (Lindgren and others, 1910) who was interested primarily in the ore deposits of the area. Early studies of ground water in the Rio Grande Valley and adjacent areas were carried out by Keyes (1905), Slichter (1905), and Lee (1907). The geology of the area was studied at various times by Darton (1928, 1928a) and more recently by Harley (1939). An intensive investigation of the thermal water at Hot Springs was carried on by the Geological Survey in cooperation with the State Engineer of New Mexico under the direction of C. V. Theis (Theis and others, 1941).

GEOGRAPHIC FEATURES OF THE AREA

LOCATION

The area of artesian development extends from Mud Springs Draw, just south of Hot Springs, nearly to Arrey, a small settlement south of Caballo Dam. (See pl. 1.) Flowing wells in the Rio Grande Valley proper are generally less than a mile from the river or Caballo Reservoir, but flowing wells have been developed in the basins of both Animas and Percha Creeks as far as 4 miles away from the Rio Grande. Hot Springs is in the central part of Sierra County, near the center of the southwest quarter of the State. It is on U.S. Highway 85 about 150 miles south of Albuquerque and 120 miles north of El Paso. As the Albuquerque-El Paso branch of the Atchison, Topeka and Santa Fe Railway leaves the Rio Grande Valley at San Marcial, 42 miles above Hot Springs, and does not reenter it again until at Rincon, about the same distance below Hot Springs, the city is without direct railroad connections.

State Highway 52, however, connects Hot Springs with Engle, a station on the railroad about 19 miles to the northeast.

CLIMATE, VEGETATION, AND CULTURE

The climate of the Hot Springs area is semiarid to arid, and the mean annual precipitation at Hot Springs, at an elevation of 4,250 feet, is about 10 inches. At some stations in the nearby mountains, however, the average precipitation is about twice that at Hot Springs. The areal distribution of precipitation in this region is very erratic. Violent thunder showers may fall on one area, whereas an adjoining area may receive little or no precipitation. General and widespread storms are of rare occurrence. The distribution of precipitation from year to year is also erratic. The annual precipitation has varied from as little as 35 percent of the long-time average to 225 percent of the average. Commonly most of the precipitation occurs during the months of July, August, and September, but in any particular year there may be an irregular seasonal distribution. During the winter light snows sometimes fall in the area but quickly disappear.

The mean annual temperature of the Hot Springs area is about 60° F., but there is a great variation from year to year. Daytime temperatures, in general, are high, and a pronounced decline occurs during the night. There is also a distinct seasonal variation. The highest temperature attained in the summer commonly ranges from 90° to 100° F., whereas temperatures as low as 0° F. occur during some winters. Low humidity throughout the year, which averages about 40 to 50 percent, minimizes the discomfort caused by the extremes of temperature. The months from April through October are generally frost-free, and the average growing season slightly exceeds 200 days.

Because of the high temperatures, cloudless days, low humidity, and considerable wind movement, the average annual evaporation for the Hot Springs area is high. It was measured as about 100 inches in a standard Weather Bureau evaporation pan at Elephant Butte. Evaporation for the 6-month period from October through March amounts to only about 30 percent of the annual amount.

Because of the differences in temperature, soil cover, and water supply there is a wide variety of vegetation in the Hot Springs and adjoining mountain areas. Along the river, cottonwood, willow, tornillo, mesquite, tamarisk, and salt grass abound. On the extensive slopes above the flood plain of the river, creosote bush, cactus, greasewood, and yucca (soapweed) occur. Along the arroyo bottoms in the foothills belt grow oak, juniper, and black walnut, and, at still higher altitudes, yellow pine and other species of evergreens. Range grasses grow at varying altitudes where soil conditions are favorable.

Hot Springs, a local spa, is the largest town near the artesian basin. It serves as a distribution point for the surrounding area, where stock raising and mining are the chief industries. As the amount of arable land on the Rio Grande flood plain is small, the population is not highly concentrated along the river, as elsewhere in New Mexico, but Palomas, Caballo, and Arrey are small population centers close to the river. Settlers in increasing numbers are occupying the valleys of the Rio Grande's tributaries. Palomas, Hillsboro, Cuchillo, and Monticello are old established centers of population. Kingston, Chloride, and Winston are mining communities some 25 miles west of the river along the east side of the Black Range. The Rincon and Mesilla Valleys of the Elephant Butte Irrigation District to the south adjoin the area, and Lake Valley, once a thriving mining town, lies a short distance to the southwest. Elephant Butte Reservoir, a few miles above Hot Springs, is a popular recreation center.

TOPOGRAPHY

The Hot Springs area is situated in the Mexican Highlands section of the Basin and Range province of the Intermontane Plateaus (Fenneman and Johnson, 1930). The Colorado Plateau province lies a short distance to the northwest, and the Southern Rocky Mountain province a short distance to the northeast.

The Rio Grande at Hot Springs flows along the eastern edge of a structurally depressed valley or aggraded desert plain lying between narrow mountains that trend north-south. South of Hot Springs the river attains its most westerly position in New Mexico. Here the Sierra Caballos border the river on the east. North of Hot Springs the Fra Cristobal Range similarly borders Elephant Butte Reservoir. The river, whose bottom land averages 2 to 4 miles in width, is separated from the spectacular fault scarps at the base of the mountains to the east by short, steeply sloping pediment surfaces which are cut by sharply incised arroyos. Toward the west pediment surfaces that have a slope of about 50 feet to the mile rise toward the Black Range which forms the Continental Divide and in places exceeds 10,000 feet in altitude. A number of southeastward- or eastward-flowing tributaries of the Rio Grande have eroded broad valleys in this western surface. Because of alternating periods of stability and downcutting by the Rio Grande, a series of pediment surfaces were developed. As the base level was progressively lowered, the older surfaces were incised, and a new series of surfaces were formed at a lower altitude and nearer the river. The most important tributaries of the Rio Grande in this area are the Alamosa, Cuchillo, Mud Springs, Palomas, Seco, Animas, Percha, and Tierra Blanca Creeks. The interstream areas are also cut by a network of small tributaries, some of which are deeply incised, whereas other areas are only slightly dissected. Between the Rio Grande and the Black Range a series of north-south mountain ridges, the Hillsboro, Animas, Palomas, and Cuchillo Mountains, interrupt and temporarily reverse the eastward slope of the land surface. The intermontane basins or bolsons thus formed have been filled with detritus from the Black Range on the west and the Cuchillo-Hillsboro chain on the east. Such bolsons are characterized by talus and fan deposits on their margins, and playa or lacustrine deposits near their centers. The bolsons, which are deeply dissected by the headwaters of tributaries of the Rio Grande, average about 6,000 feet in altitude and connect with the similar but much more extensive Plains of San Augustin to the north, which lie at an altitude of about 6,900 feet. The tributaries of the Rio Grande reach the main valley through gaps cut in the Hillsboro-Cuchillo mountain chain.

The San Mateo Mountains are another prominent topographic feature. They extend to within about 12 miles of Hot Springs on the north and to the Alamosa River on the south. These mountains are of volcanic origin and are characterized by rugged peaks and deep canyons. East of the San Mateo Mountains and Elephant Butte Reservoir an extensive lava flow forms a prominent mesa. Lee (1907, p. 21) believed that this lava flow was instrumental in deflecting the Rio Grande from its former course through the Jornada del Muerto, a desert valley between the Sierra Caballo and Fra Cristobal Ranges on the west and the Organ, San Andres, and Oscura Mountains on the east. The Jornada, which is about 100 miles in length, slopes 4.5 feet to the mile from an altitude of about 4,700 feet at its north end to 4,250 feet at its south end.

GEOLOGY

GEOLOGIC HISTORY

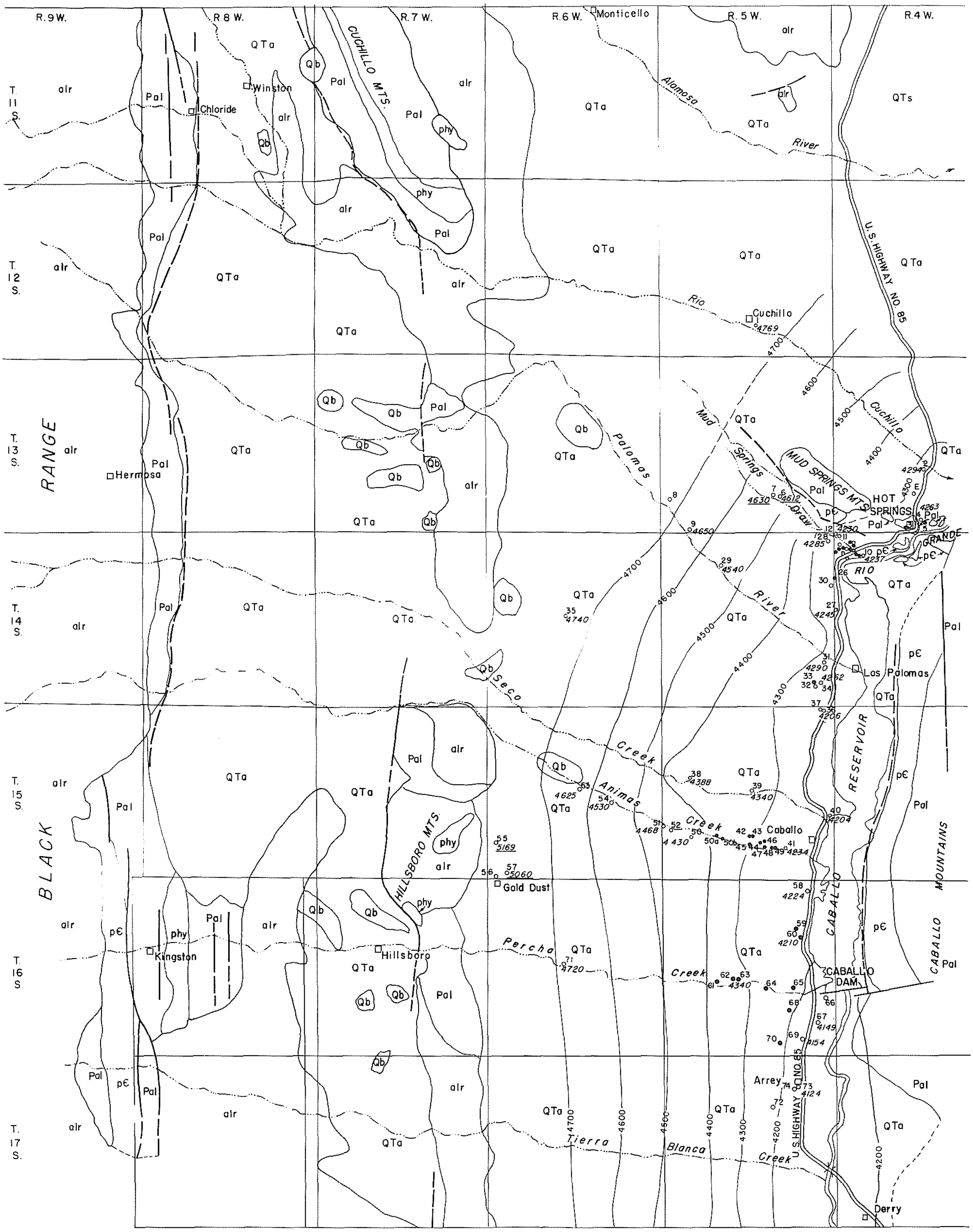
Rocks in the Hot Springs area (pl. 1) range in age from Precambrian to Recent. The rocks that crop out in the area are shown in the section on page 5.

The Precambrian rocks of this area consist largely of granites, gneisses, and schists. Because of their great age, it is difficult to determine the conditions under which they were emplaced, but there were periods of sedimentation, granitic intrusion, and igneous and dynamic metamorphism. A period of erosion that followed the formation of the Precambrian rocks formed a surface on which early Paleozoic rocks were deposited.

All periods of the Paleozoic era, with the possible exception of the Cambrian, are represented in this area by limestones, shales, and sandstones. Marine sedimentation alternating with periods of elevation and erosion are believed to have occurred throughout the Paleozoic era. Continental sedimentation became relatively more important in Permian time. Rocks of Triassic, Jurassic, and Lower Cretaceous age have not been recognized in the Hot Springs area, but during Upper Cretaceous time seas periodically invaded the area, and sandstones, shales, and subordinate limestones were deposited. Lateral compression, as indicated by thrust faulting in the Sierra Caballo, caused general uplift of the area at the end of the Cretaceous period or at the beginning of the Tertiary period. Later in Tertiary time, with the release of the compression, north-south normal faults developed and the Rio Grande depression was formed; detrital material, derived in large part from volcanic rocks in the adjoining highlands and accompanied by some volcanic ash, filled the Rio Grande trough. Adjustment along preexisting fault planes and extrusion of some basalt occurred at this time. Subsequently erosion cut pediment surfaces on the valley fill and older rocks which were graded to the level of the Rio Grande. Alternating periods of stability and downcutting by the Rio Grande produced a series of terraces along the river and its principal tributaries, each one being at a lower level and extending a shorter distance from the river than the one previously cut. In addition to these cut terraces, gravel terraces were formed in some areas by deposition in eroded river channels. Extrusion of basalt lava occurred during and subsequent to the period of pediment formation. Deposition of alluvium along the flood plain of the Rio Grande, accumulation of alluvial-fan material along the bases of the highlands, and accumulation of wind-blown sands along lee slopes are taking place at present.

STRATIGRAPHY

Sedimentary, igneous, and metamorphic rocks are all represented in the Hot Springs area. In age they range from Precambrian to Recent. Only two periods of geologic time, the Triassic and Jurassic, are known not to be represented. Detailed descriptions of the rocks of the area are given by Gordon (Lindgren and others, 1910, p. 225–239) and Darton (1928, p. 319–328).

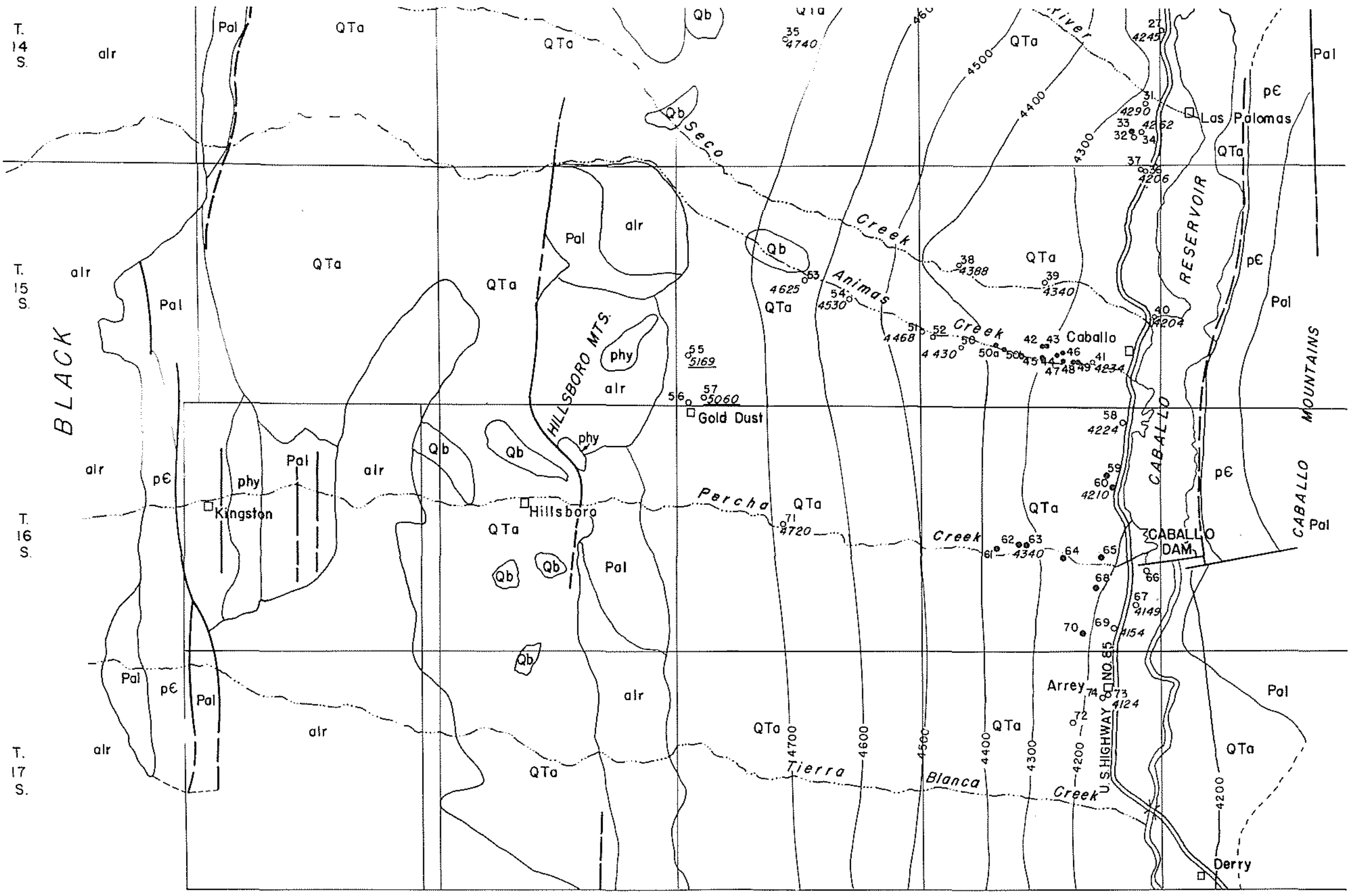


EXPLANATION

SEDIMENTARY ROCKS

IGNEOUS ROCKS

HYDROLOGIC FEATURES



E X P L A N A T I O N

SEDIMENTARY ROCKS

QTa

Alluvium, bolson deposits, terrace gravels, etc. (Includes both the Palomas gravel of Pleistocene age and the Santa Fe formation of upper Miocene and Pliocene age)

TERTIARY AND QUATERNARY

Pal

Paleozoic sedimentary strata, largely limestone with some shale, conglomerate, and sandstone. (Includes San Andres and Yeso formations of Permian age, Abo formation of Permian(?) age, Magdalena group of Permian(?) and Pennsylvanian age, Lake Valley limestone of early Mississippian age, Percha shale and Stevenson's Sly Gap formation of Upper Devonian age, Fusselman limestone of Silurian age, Montoya and El Paso limestones of Ordovician age, and Bliss sandstone of Cambrian(?) age)

CAMBRIAN TO PERMIAN

IGNEOUS ROCKS

Qb

Basalt. (Includes some basalt of Tertiary age)

QUATERNARY

alr

Andesite, latite, rhyolite, tuff, agglomerate, ash, and unclassified igneous rocks, mostly extrusive. (Includes some rocks of Cretaceous age)

phy

Intrusive rocks, mostly porphyries (Stocks, sills, and dikes. Includes some pre-Tertiary rocks)

TERTIARY

IGNEOUS AND METAMORPHIC ROCKS

pЄ

Granite, gneiss, and schist

PRE-CAMBRIAN

HYDROLOGIC FEATURES

○12
Nonflowing well; number refers to field number in well tables

●18
Flowing well

•4269
Altitude, in feet, of water surface in nonflowing well

——4500——
Line showing altitude of water table, Most water-level measurements made in June 1946

○6 4612
Altitude, in feet of water surface in nonflowing well, which is believed to represent a local perched water table

Geology largely after "Geologic Map of New Mexico" by N.H. Darton and "General Geologic Map of Sierra County" by G.T. Harley

Base map after "Sierra County Map" by New Mexico State Highway Department

PLATE I

RECONNAISSANCE GEOLOGIC MAP OF HOT SPRINGS, NEW MEXICO

Showing generalized geology of area, location of selected observation wells, and altitude of the water table in the area surrounding the nonthermal artesian-water development

SCALE
1 0 1 2 3 4 Miles

C R Murray 1947

Generalized section of rocks in Hot Springs area

Era	System	Series	Formation		Commonly reported thickness *(ft)*	Character of rocks
Cenozoic	Quaternary	Recent		Flows and sediments	—	Basalts, terrace gravels, and alluvium
		Pleistocene		Palomas gravel	900	Poorly cemented conglomerate
	Tertiary	Pliocene and Miocene		Santa Fe formation	2,000±	Buff to reddish clays, sands, silts, and gravels
		Oligocene		Eruptives	1,000–4,000	Andesite, latite, and rhyolite
		Oligocene(?) and Eocene		Galisteo(?) sandstone	(?)	Red shale and sandstone
Mesozoic	Cretaceous	Upper Cretaceous		Mancos shale and Mesaverde formation	1,000	Gray shales and sandstones
				Dakota(?) sandstone	100	Cross-bedded sandstone and shale
Paleozoic	Permian and Permian(?)		Manzano group	San Andres formation	500–650	Gray limestone, etc.
				Yeso formation	200–300	Shales and evaporites
				Abo formation	200–800	Red sandstone and shale
	Permian(?) Carboniferous	Permian(?) and Pennsylvanian (upper and middle)	Magdalena group	Madera limestone	400–1,000	Gray limestone, etc.
				Sandia formation	(?)	Limestone, conglomerate, and shale
		Mississippian (middle and lower)		Lake Valley limestone	50–210	Gray limestone, etc.
	Devonian	Upper Devonian		Percha shale and Stevenson's Sly Gap formation	160–250	Dark gray and tan shale
	Silurian			Fusselman limestone	50–200	Gray limestone, etc.
	Ordovician	Upper Ordovician		Montoya limestone	50–400	Gray limestone, etc.
		Lower Ordovician		El Paso limestone	150–400	Gray limestone, etc.
	Cambrian(?)			Bliss sandstone	50–100	Sandstone, quartzite (ferruginous)
	Precambrian				—	Granite, gneiss, schist, etc.

Precambrian rocks

Coarse red granite is the most common Precambrian rock of the Hot Springs area. It occurs in the fault scarps in the west face of the Sierra Caballo and Fra Cristobal Ranges. It underlies the low terrace south of Hot Springs on which the Carrie Tingley Hospital is located, and it is exposed at the south end of the Mud Springs Mountains. Extensive exposures of granite occur on the east slope of the Black Range in the Kingston area. Crystalline schists, granite gneisses, aplite and pegmatite dikes, and occasional basic dikes occur with the granite.

In the artesian basin south of Hot Springs it is probable that the granite occurs at too great a depth, and is too impermeable to hold or transmit significant amounts of water. However, the granite that crops out near the Carrie Tingley Hospital probably forms an impermeable northern boundary for water contained in the valley fill to the south. The granite in the base of the Sierra Caballo and Fra Cristobal Mountains forms a similar impermeable boundary to the east.

Paleozoic strata

Paleozoic sedimentary rocks (pl. 1) are represented in Sierra County by the Bliss, El Paso, Montoya, Fusselman, Percha, Lake Valley, Sandia, Madera, Abo, Yeso, and San Andres formations. The Bliss sandstone, which lies unconformably on the Precambrian, consists largely of quartzite, but contains some shale, and averages about 100 feet in thickness. It is generally believed to be Cambrian in age, but King (1940, p. 153) found evidence which he believed indicated an Ordovician age.

The El Paso limestone, a massively bedded, gray, dolomitic limestone of Lower Ordovician age, averages about 350 feet in thickness. Weathered surfaces of the El Paso limestone are frequently covered with a fine network of brown chert.

The Montoya limestone, a thick-bedded gray limestone of Upper Ordovician age, disconformably overlies the El Paso limestone. It averages about 250 feet in thickness in Sierra County.

The Fusselman limestone, a compact gray limestone which is overlain by hard, dark gray fossiliferous limestone, rests unconformably on the Montoya limestone. It is of lower Silurian (Niagara) age and attains a thickness of 250 feet in places.

The Percha shale, of late Devonian age, was defined by Gordon as consisting of a lower black fissile shale member and an upper member of gray and tan shale containing abundant brachiopods. In the Devonian of the Mud Springs Mountains, *Atrypa devoniana, Schizophoria striatula* var. *australis,* Kindle, and a species of the genus *Pugnax* are common forms. Stevenson (1945) has recently made a study of the Devonian of New Mexico and has subdivided the Percha. He correlates the Devonian of the Mud Springs Mountains with his Sly Gap formation of the San Andres Mountains and states that he found a large number of *Receptaculites,* n. sp., in the Devonian in the Mud Springs Mountains.

The Lake Valley limestone, of Mississippian age, mostly gray in color and massively bedded, exceeds 200 feet in thickness in places but thins toward the north in Sierra County and is entirely absent in the Mud Springs Mountains.

Rocks of the Permian(?) and Pennsylvanian system in New Mexico have commonly been called the Magdalena group. The Magdalena consists of thinly to massively bedded gray cherty limestone with subordinate amounts of shale, sandstone, and conglomerate. Because of its resistance to erosion and its great thickness, in some places exceeding 1,000 feet, the Magdalena group commonly forms the fault-scarp slopes and in some places the dip slopes of the tilted fault-block mountains of New Mexico. Thompson (1942) has subdivided the Pennsylvanian of New Mexico into subordinate stratigraphic units on the basis of detailed lithologic and paleontologic studies, especially of the fusulinid faunas. Four series, beginning with the Derry, at the base, and including the Des Moines, Missouri, and Virgil, are recognized by him. C. B. Read of the Fuels Branch of the U.S. Geological Survey and geologists working under his direction in New Mexico (Read and others, 1944) divide the Magdalena into the Sandia formation at the base and the Madera limestone above. The Sandia is in turn subdivided into an upper clastic member and a lower limestone member. The Madera is subdivided into an upper arkosic limestone member and a lower gray limestone member.

Red beds that overlie the Magdalena group have commonly been referred to as the Abo formation of Permian(?) age. In other areas in New Mexico (Wilpolt and others, 1946) rocks of post-Virgil age but lower in the Wolfcamp series than the Abo formation have been recognized and given formational rank. It is anticipated that similar units will be named in the Hot Springs area after detailed study. The Abo formation in this area consists chiefly of hard slabby reddish-brown sandstone interbedded with red shales and red sandy shales. The Abo is commonly several hundred feet thick in Sierra County.

Above the Abo formation are the beds called by Darton the Chupadera formation, and subdivided by him into the Yeso and San Andres members. The name Chupadera has been abandoned by the Geological Survey and the Yeso and San Andres raised to formation rank.

Paleozoic strata crop out mainly in the mountainous areas near Hot Springs. They form the crests of the Sierra Caballo, Fra Cristobal, and Cuchillo Mountains and crop out at intervals in the Hillsboro-Cuchillo chain of mountains. Paleozoic rocks crop out also in the Kingston-Hermosa-Chloride area at the east base of the Black Range. Along the Rio Grande in Sierra County, Paleozoic rocks are exposed extensively only in the Mud Springs Mountains-Hot Springs area, but they probably underlie much of the area covered by the valley fill and may underlie the volcanic rocks of the San Mateo Mountains.

It is difficult to determine the relation of the Paleozoic strata to the hydrologic system of the nonthermal artesian basin. The Paleozoic rocks are largely impermeable, but along fault zones the rocks may be sufficiently shattered to permit movement of ground water. The outcrops along the base of the Black Range receive considerable recharge both from precipitation and from runoff from the volcanic rocks to the west. These strata dip under the intermontane bolsons to the east. Circulation of water through the Paleozoic strata into the Rio Grande depression would probably be interrupted where the formations are traversed by the fault zone on the west side of the Hillsboro-Cuchillo chain of mountains. Paleozoic strata also dip under alluvial material in the Rio Grande Valley east of the Hillsboro-Cuchillo chain. These strata are again faulted west of the Sierra Caballo and Fra Cristobal Mountains. As granite is brought to the surface at the base of the Caballo and Fra Cristobal Ranges, any eastward circulation of water is almost certainly prevented at this point. The Paleozoic strata appear to be deeply buried on the west side of the Rio Grande Valley south of Hot Springs and probably have little effect on the hydrologic system, at least within depths to which wells are commonly drilled. It would thus appear that the chief effect of the Paleozoic strata on ground water is to direct its movement. In the Hillsboro-Cuchillo chain of mountains, the gaps cut by tributaries of the Rio Grande probably serve as outlets for water in the bolsons to the west, and recharge to the valley fill of the nonthermal water area is undoubtedly concentrated along these gaps. A short distance east of these gaps the streams are no longer perennial. The Paleozoic strata in the Mud Springs Mountains-Hot Springs area, along with the Precambrian granite, form the northern boundary of the valley fill of the nonthermal artesian basin south of Hot Springs, although artesian conditions have been noted in the valley-fill deposits in the northeastern part of the city of Hot Springs (Theis and others, 1941, p. 49).

Mesozoic strata

Rocks of Upper Cretaceous age – the Dakota(?) sandstone, the Mancos shale, and the Mesaverde formation – crop out east of the Sierra Caballo and in the neighborhood of Elephant Butte Dam. They have no apparent relation to the occurrence of the nonthermal artesian water.

Tertiary and Quaternary rocks

Sedimentary strata. At a few places in this area, notably along the east side of Elephant Butte Reservoir, the Galisteo(?) sandstone beds of Oligocene(?) and Eocene age form the base of the Tertiary sequence. These deposits were laid down during the planation that followed the Laramide orogeny. Sandstones, siltstones, and claystones, generally red in color, are the common rock types. Judging from the limited area in which they crop out, deposits of Eocene age are believed to have little effect on the hydrologic system of the nonthermal artesian basin.

Of much wider extent are the valley-fill deposits, which consist of unconsolidated or partly consolidated sand, gravel, and clay and which occupy the Rio Grande depression and the intermontane bolsons to the west. (See fig. 1.) This material was originally classed as Quaternary and named the Palomas gravel by Gordon (Lindgren and others, 1910, p. 237). Harley (1934, p. 29) believes that at least part of the valley-fill deposits are contemporaneous with similar deposits that occur elsewhere in the Rio Grande Valley and are assigned to

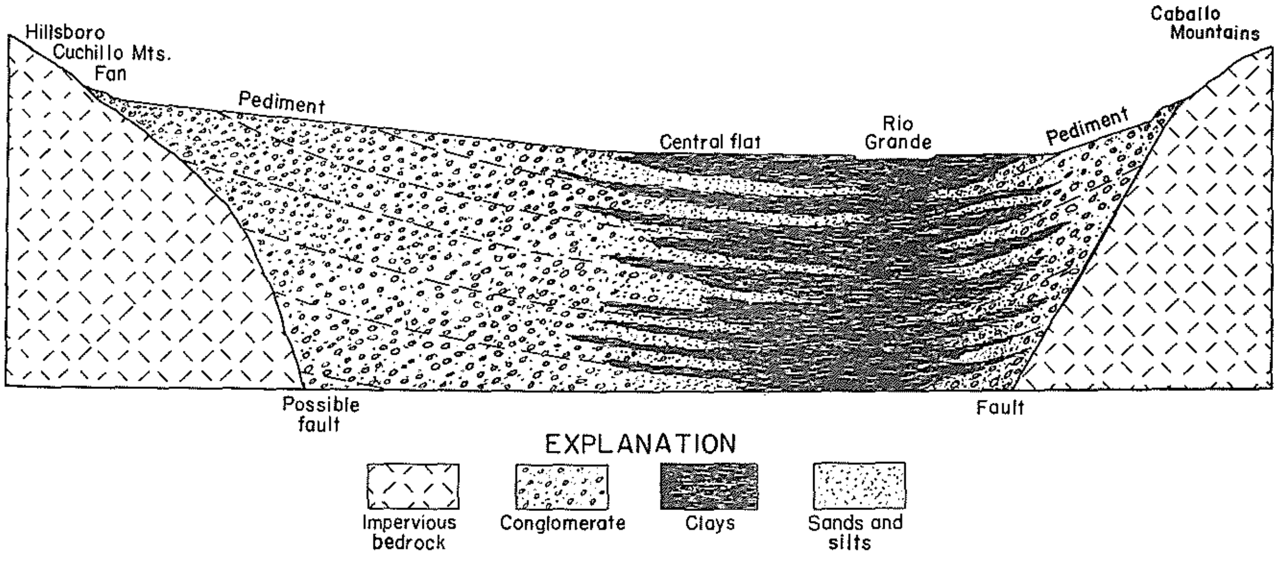


FIGURE 1. Idealized cross section of Rio Grande south of Hot Springs showing postulated relationship of conglomerates to well-bedded fine sediments. Width of section about 15 miles; vertical exaggeration about 10:1.

the Santa Fe formation of late Miocene and Pliocene age. The age of the valley-fill deposits has been determined in the past on the basis of small assemblages of vertebrate faunas, but where such fossils are not available it is difficult to assign a definite age. The valley-fill deposits are well exposed in the steep walls of the tributaries of the Rio Grande both east and west of the river and along bluffs facing the river. Along the river the deposits are rather well sorted and consist of alternating beds of light red or pink clay, and yellowish gray or light brown, medium- to fine-grained, soft sandstone or siltstone. Beds of gravel or conglomerate are interbedded with the clay, sand, and silt at many places, and are especially conspicuous in the bluffs at the mouth of Mud Springs Draw. The strata appear to be nearly horizontal at this location, and the bedded appearance is accentuated because of the removal of soft material from between more resistant layers. Near the mountains the layers of clay and fine sand disappear, and the whole sequence is a poorly sorted conglomerate, the pebbles of which are mainly volcanic rocks. The distance to which the clays extend up the tributaries of the Rio Grande on the west varies widely; in some places it amounts to several miles and in others to only a short distance. It is believed that the beds of clay are responsible for the development of artesian conditions, as they serve as confining layers. In Palomas Creek, sands may replace the clay beds, and above the city wells in Mud Springs Draw where conglomerate occurs at shallow depth flowing wells are not obtained.

Because of the widespread occurrence of the valley-fill deposits and the fact that they are hundreds of feet thick throughout much of the area (more than 2,100 feet at well 33, pl. 1), these deposits are by far the most important strata affecting the hydrology of the nonthermal artesian basin. The lithology of these deposits is shown by the following well logs.

Log of well 13 (city of Hot Springs—Hefferman)

Driller, Geo. Cook

Material	Thickness *(feet)*	Depth *(feet)*
Caliche	25	25
Sand and gravel; water	5	30
Gumbo red clay	100	130
Sand and gravel; water	2	132
Red clay	95	227
Gray lime clay	10	237
Red gumbo clay	40	277

10-inch casing 0-60 feet
Initial flow reported as 340 gpm
Well subsequently deepened to 438 feet

Log of well 15 (Crow)

Driller, Geo. Cook
Well completed prior to Oct. 19, 1940

Material	Thickness *(feet)*	Depth *(feet)*
Dirt	20	20
Rock, clay, and water	5	25
Red gumbo clay	75	100
Black gravel and water	1	101
Common red clay	80	181
Gray lime clay	10	191
Clay and gravel; first flow of water	10	201
Joint clay	20	221
Red clay with gravel; more water	25	246
Gray clay	10	256
Red clay and gravel; more water	16	272
Rotten sandstone and more water	6	278

10-inch casing 0-60 feet
8-inch casing 0-258 feet, 40 feet perforated
Initial flow reported as 140 gpm

Log of well 19 (Dr. Williams)

Driller, Geo. Cook

Material	Thickness *(feet)*	Depth *(feet)*
Rotten sandstone	70	70
Red gumbo clay	100	170
Clay and gravel; water	5	175
Red clay, common	50	225
Red clay, gumbo	2	227
Rotten sandstone; first flow of water	1	228
Red clay, gumbo	10	238
Rotten sandstone; water	2	240
Red clay, common	12	252
Rotten sandstone; water	1	253
Red clay	10	263
Rotten sandstone; water	3	266
Red gumbo clay	14	280
Rotten sandstone; water	1	281
Gray lime clay	10	291
Sand; water	1	292
Red clay	12	304
Gravel and sand; water	2	306
Red clay	10	316
Rotten sandstone; water	1	317
Dark red clay	15	332
Rotten sandstone; water	2	334
Red clay	14	348
Sand; water	1	349
Red clay	12	361
Brown clay	16	377

10-inch casing 0-80 feet
8-inch casing (perforated) 12-362 feet
Temperature, 77.5° F.
Initial flow reported as 640 gpm

Log of well 20 (city well 14a)

Driller, Layne-Texas Co.
Nov. 16, 1945

Material	Thickness (feet)	Depth (feet)	Driller's remarks
Sand, gravel, and boulders	55	55	
Clay	10	65	
Sand, gravel-clay layers	50	115	
Sticky clay	15	130	
Sand and boulders	7	137	
Sand and boulders	4	141	
Clay	26	167	
Clay and sand, gravel layers	17	184	
Sand and gravel, hard	10	194	
Sand	3	197	Cut good
Sand and boulders	14	211	
Clay	2	213	
Sand and gravel, hard	6	219	
Clay	3	222	
Sand and gravel, hard	2	224	
Clay	4	228	
Sand and gravel	3	231	Cut good
Hard sand and boulders	8	239	
Clay	4	243	
Sand and gravel, hard	15	258	Cut good
Clay with layers of sand	7	265	
Sand and gravel, hard	10	275	Cut good
Clay and boulders	7	282	
Hard sand and gravel	12	294	
Clay	3	297	
Sand and gravel	15	312	
Hard sand and gravel	17	329	
Clay	5	334	
Sand and gravel	16	350	Cut fair
Clay	3	353	
Sand, gravel with layers of clay	89	442	

12-inch casing, cemented at 226 feet
7-inch screen, surrounded with gravel pack, diameter 30 inches, to 440 feet
Temperature, 80.6° F.
Flow, 350 gpm, May 25, 1946

Log of well 23 (city well 11a)

Driller, Layne-Texas Co.
September 1946

Material	Thickness (feet)	Depth (feet)	Driller's remarks
Sand and boulders	3	3	
Sand, clay, and gravel layers	17	20	
Hard clay and gravel	10	30	
Sand, gravel, and clay layers	45	75	
Hard sand	5	80	
Clay and gravel	76	156	
Sand	5	161	
Sand, gravel with shale layers	33	194	
Rock	2	196	
Hard clay	1	197	
Rock	1	198	
Hard sand	2	200	
Clay	8	208	
Hard sand and gravel	12	220	
Sand	3	223	Cut good
Sand and clay, hard layers	28	251	
Hard sand	32	283	Cut good
Sand, clay, gravel (hard layers)	29	312	
Sand	5	317	
Rock	2	319	
Sand	2	321	
Rock	1	322	
Clay, with hard layers	10	332	
Sand and gravel	4	336	
Clay and boulders	4	340	
Rock	1	341	
Sand, clay, and boulders	3	344	
Clay	2	346	
Hard sand and gravel	29	375	
Sand, gravel	30	405	Cut good
Clay	5	410	

12-inch casing, cemented at 207 feet
7-inch screen, surrounded with gravel pack, diameter 30 inches, to 410 feet
Temperature, 79.5° F.
Flow, 300 gpm, Oct. 12, 1946

Log of well 24 (Howe)

Driller, Geo. Cook
Completed Sept. 10, 1946

Material	Thickness (feet)	Depth (feet)
Sand and gravel	79	79
Red clay	5	84
Caliche	15	99
Red clay; first flow of water	123	222
Red sandy clay or conglomerate	80	302

10-inch casing 0-80 feet
8-inch casing 0-210 feet
Head, 50 feet
Temperature, 75.6° F., Sept. 26, 1946
Initial flow approximately 400 gpm

Log of well 26 (Slater)

Driller, Geo. Cook

Material	Thickness (feet)	Depth (feet)
Fill (dirt, sand, boulders, gravel)	30	30
Black sea mud; water	5	35
Red clay, gumbo	100	135
Sand and boulders; water	10	145
Red clay	75	220
Gray clay	20	240
Red clay, common	40	280
Rotten sand; struck first flowing water	7	287
Red clay, common	25	312
Rotten sandstone and water	1	313
Red clay, common	30	343
Rotten sandstone and water	1	344
Red clay, common	26	370
Rotten sandstone and water	2	372
Red clay, common	15	387

10-inch casing 0-54 feet
8-inch casing 0-355 feet, 60 feet perforated
Temperature, 77° F., Apr. 14, 1945
Initial flow reported as 140 gpm

Log of well 33 (Iorio)
Driller, Ernest Boardman

Material	Thickness (feet)	Depth (feet)
Surface sand	5	5
Adobe rock	10	15
Loose sand	2	17
Red mud	53	70
Stratified mud	10	80
Sandy mud (water seep)	10	90
Alternate layers, mud and stone	44	134
Running sand (water), loose	6	140
Running sand	45	185
Loose sand and gravel (water)	8	193
Adobe mud, with rock breaks	49	242
Running sand	2	244
Adobe rock	28	272
Running sand	13	285
Red clay	13	298
Sandy clay	7	305
Cavey red shale	5	310
Soft red shale	44	354
Sand and gravel (water)	18	372
Sandy pink shale	8	380
Hard brown shell	2	382
Dark cream clay	25	407
Clay with conglomerate shells	8	415
Pack sand	7	422
Conglomerate fine and hard	26	448
Red clay	3	451
Running sand and gravel	7	458
Hard conglomerate shell	5	463
Clay with hard streaks	7	470
Red clay	35	505
Conglomerate shell	2	507
Red clay	5	512
Hard shell	2	514
White clay with shells	2	516
Pack sand	6	522
Volcanic ash	18	540
Sand and gravel (water)	3	543
Hard-set volcanic ash	35	578
Red clay (sticky)	50	628
Hard conglomerate	2	630
Sandy conglomerate (water)	2	632
Sticky pink clay, with streaks of volcanic ash	53	685
Muddy pack sand (cavey)	10	695
Pink clay (sticky)	12	707
Muddy pack sand	7	714
Sticky pink clay	7	721
Clay and gravel	9	730
Sticky red clay	1	731
Muddy pack sand	4	735
Fine conglomerate	7	742
Pack sand (cavey)	16	758
Soft pink clay	33	791
Loose sand	5	796
Muddy quicksand	6	802
Gray mud	5	807
Pack sand (black bailings)	4	811
Conglomerate rock (clay breaks)	3	814
Soapstone (clay breaks)	10	824
Pack sand, muddy	3	827
Sticky gray clay (sandstone breaks)	25	852
Pack sand	5	857
Pink and gray sticky clay	15	872
Pack sand (gray)	4	876
Muddy sand (gray)	10	886
Sticky clay	6	892
Quicksand, with clay streaks	19	911
Gray clay, with hard streaks	8	919
Muddy sand, gray	20	939
Gray and pink clay	20	959
Sandy clay (gray)	5	964
Sticky pink clay	7	971
Gray sandy clay	4	975
Pink sticky clay	25	1,000
Sandy clay	5	1,005
Sticky red clay, with breaks of volcanic ash; water, increase of water at 1,160	155	1,160
Red sticky clay	5	1,165
Stratified volcanic ash; water increase, rose to 83 feet from surface	5	1,170
Red volcanic ash; started flowing 2 gpm at 1,200	331	1,501
Water sand; started flowing at rate of 25 gpm	13	1,514
Hard volcanic ash	16	1,530
Volcanic ash, with gypsum breaks (hard)	472	2,002
Hard sand; show of gas	2	2,004
Volcanic ash	3	2,007
Hard sand; show of gas	3	2,010
Volcanic ash, with gypsum breaks	90	2,100

The youngest strata in the Hot Springs area are the Recent flood-plain deposits of the Rio Grande. Somewhat older than these are the terrace gravels that border the river in places. The flood-plain and terrace-gravel deposits are limited in areal extent, and are restricted to the vicinity of the river. Their principal effect on the hydrology of the nonthermal artesian-water system is to allow water to discharge through them to the Rio Grande.

Igneous rocks. In early Tertiary time, probably Oligocene, great masses of igneous rocks were extruded in the area west of the Rio Grande in central New Mexico (Harley, 1934, p. 31). Such igneous rocks abound in areas marginal to the plateau country to the west. Westward from the San Mateo Mountains and the Black Range igneous rocks form most of the surface of New Mexico. The first igneous rocks extruded in the Hot Springs area were a thick series of andesitic lavas. During a second period of volcanism that followed, monzonites and latites were intruded into the country rocks, and latites were extruded. The intrusive monzonites and latites are extensively exposed east of Kingston, in the Hillsboro-Gold Dust area, and in the Cuchillo Mountains. Less extensive exposures occur in the Mud Springs and Caballo Mountains.

Such intrusive monzonites may occur under cover over a considerable part of western Sierra County. Extensive erosion followed the volcanic activity and largely removed the andesites and latites, although local faulting favored their preservation in some places. Debris derived from higher levels was deposited at lower levels on the surface of the lavas. Extrusive rhyolites, tuff, and breccias then filled the erosion channels and covered the surface of the older flows and sediments. Erosion has also largely removed the rhyolites, but in the Black Range and the San Mateo Mountains the rhyolite remains over extensive areas. Isolated patches where preservation was favored by faulting are especially abundant in the Hillsboro-Kingston area.

During Quaternary time basalt was extruded in numerous places in the Hot Springs area. These flows appear to be very recent, and at some places they overlie Quaternary pediment gravels. The flow south of San Marcial is the most extensive, but others occur east of Elephant Butte Dam, and both east and west of the Hillsboro-Cuchillo chain of mountains.

Because of the small areal extent and superficial position of the Quaternary basalts, they can have little importance in the hydrology of the nonthermal artesian basin, but the Tertiary intrusive and extrusive rocks are much more important. The Tertiary igneous rocks are too impervious to absorb and transmit much water themselves, but water that falls on them runs off rapidly and is absorbed by the adjacent valley fill. The eastward movement of water in the valley fill from the high-level intermontane bolsons to the Rio Grande Valley proper probably is impeded by the igneous rocks and deflected to the gaps that have been cut through them by the Rio Grande tributaries. The rocks in places undoubtedly form a subsurface platform that restricts the downward movement of water, as in the Gold Dust area where water is obtained by wells at a height about 200 feet above the regional water table.

STRUCTURAL FEATURES

Uplift of the Hot Springs area, after the deposition of marine Cretaceous sediments, was the initial step in the formation of the present structural features of the area. As elsewhere in the Rio Grande Valley in New Mexico, such uplift was accompanied by localized folding and thrust faulting. The Black Range, which is an anticlinal fold with an upthrust granite core, probably originated at this time. Doming of other areas, such as the Sierra Caballo and Fra Cristobal Mountains, may have occurred along with the formation of the high-angle thrust fault that bounds the Sierra Caballo on the north (Theis and others, 1941, fig. 1). The orogenic movements of this time apparently were followed by volcanic activity which gave rise to the San Mateo Mountains, a mass of volcanic rocks, and involved the Black Range, Hillsboro-Cuchillo Mountains area, and other regions to the west. Normal faulting caused the development of the Rio Grande depression and produced the fault scarps on the west faces of the Sierra Caballo, Fra Cristobal, and Hillsboro-Cuchillo Mountains. Transverse faulting, similar to that on the south side of the northward-tilted fault block which forms the Mud Springs Mountains, probably followed. Repeated movements, some of which occurred during or subsequent to the deposition of the valley fill, have taken place, mainly along north-south-trending faults. One such fault is exposed in Cuchillo Creek at the north end of the Mud Springs Mountains below the town of Cuchillo. Minor faults have also been caused by intrusive and extrusive igneous activity.

HYDROLOGY

PRESENT DEVELOPMENT

The area in which flowing wells have been developed (see pl. 1) extends from Mud Springs Draw, just south of the city of Hot Springs, to Arrey, about 18 miles to the south. The zone nowhere exceeds 4 miles in width. Wells are concentrated in three areas, Mud Springs Draw, Animas Creek, and Percha Creek. Wells in interstream areas along the Rio Grande Valley proper are all located within 2 miles of the river or Caballo Reservoir.

Thirteen flowing wells have been drilled in Mud Springs Draw (fig. 2) in sec. 6, T. 14 S., R. 4 W.; however, five of these wells that belong to the city of Hot Springs were plugged and abandoned in December 1945 upon completion of two new, gravel-packed, city supply wells. The new city wells flowed about 300 gallons a minute on completion, had artesian heads of 45 to 50 feet above the land surface, and yielded nearly 7 gallons a minute per foot of drawdown after being pumped for periods of 24 hours at 500 gallons a minute.

In the Animas Creek valley 17 flowing wells have been developed in secs. 27, 28, and 29, T.15 S., R. 5 W. (see pl. 1 and table 1). Most of the wells have yields of only a few gallons a minute and heads of several feet above the land surface. The maximum measured yield was 75 gallons a minute for well 46 (15.5.27.413); this well had a head of about 37 feet.

In the Percha Creek valley nine flowing wells have been developed in secs. 20, 21, 22, and 23, T. 16 S., R. 5 W. (See pl. 1 and table 1.) These wells flow only a few gallons of water a minute and have heads of several feet above the land surface. The largest flow measured in 1946 was 37½ gallons a minute, for well 64 (16.5.22.420). The head was not determinable. The head for well 62 (16.5.21.144) was measured as 12 feet above the land surface. A pump has been operated on a nonflowing artesian well owned by Mrs. J. L. Holden in sec. 20, T. 16 S., R. 5 W., and is reported to produce several hundred gallons a minute. Yields of this magnitude are exceptional in this locality, but there have been few attempts to pump artesian wells. Well 65 (16.5.23.-300), which has recently been completed, flows about 125 gallons a minute and is equipped with a turbine pump. The pump is reported to yield approximately 850 gallons a minute, and after 4 hours of pumping, the water level lowers to about 115 feet below the surface.

Along the west side of the Rio Grande Valley proper, eight flowing wells have been developed. Of these, one is in sec. 7, T. 14 S., R. 4 W.; two are in sec. 11, one in sec. 26, and one in sec. 35, T. 16 S., R. 5 W. (see pl. 1). Although some of these wells are reported to have had fair flows on completion, none of them yielded more than a few gallons a minute in 1946.

In the southern half of T. 14 S. and the northern half of T. 15 S., R. 5 W., from Palomas River to Seco Creek, attempts to develop artesian water have not been successful. Well 33, drilled in sec. 36, T. 14 S., R. 5 W. to a depth of 2,100 feet, obtained only a small flow of water of poor quality. The failure was probably due to the fact that the valley floors of Palomas and Seco Creeks are higher above the valley floor of the Rio Grande than are the valley floors of Animas and Percha Creeks. Near the mouth of Mud Springs Draw, erosion has lowered the land surface below the piezometric surface so that flowing wells can be obtained.

The occurrence of thermal artesian water in the Magdalena limestone at Hot Springs apparently is not closely related to the occurrence of the nonthermal artesian water in the valley fill to the south. Artesian water occurs under similar conditions in the valley fill both in the northeast part of Hot Springs and to the south, but the water is of poor quality in the area northeast of Hot Springs. (See water analysis of well 5, table 2.)

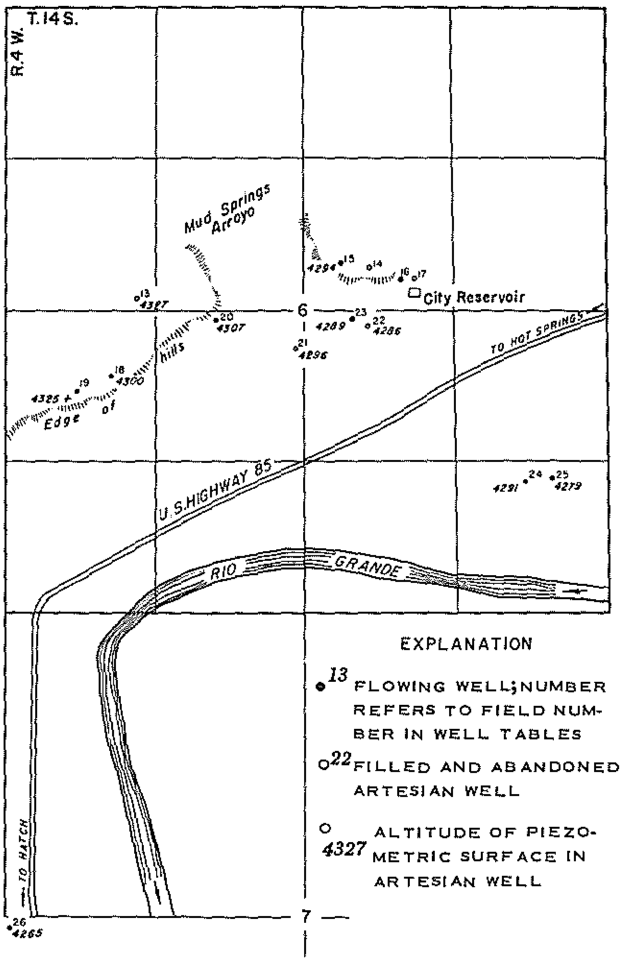


FIGURE 2. Map of Mud Springs Draw area showing location of artesian wells and altitude of piezometric surface in wells. Most of the measurements were made in October 1945.

MODE OF OCCURRENCE OF THE NONTHERMAL ARTESIAN WATER

When an artesian well is drilled, water encountered at successively deeper horizons rises to successively higher levels in the well until, finally, an aquifer is encountered in which the water is under sufficient head to flow at the surface. The depth at which flowing water is obtained varies from well to well. In Mud Springs Draw, well 24 (Howe) first started flowing when water-bearing beds were penetrated at a depth of 222 feet (altitude of land surface 4,237 feet; of aquifer 4,015 feet); well 22 (city well 11) began flowing when beds were penetrated at a depth of 220 feet (altitude of surface 4,242 feet; of aquifer 4,022 feet); and well 21 (city well 14) at 193 feet (altitude of surface 4,248 feet; of aquifer 4,055 feet). This suggests that the horizon at which flowing water is obtained rises at least 20 feet per mile in a northwesterly direction. Flowing water is obtained somewhat closer to the surface in wells increasingly farther up Mud Springs Draw, and also Animas and Palomas Creeks. In Animas Creek, well 50a (Brannon) is reported to have obtained flowing water at a depth of 60 feet

Table 1. Records of selected wells in vicinity of Hot Springs, Sierra County, N. Mex.

EXPLANATION

Field number: asterisk indicates that an analysis of the water from this well is included in table 2.

Topographic situation: A, arroyo; Fp, flood plain; Hs, hillside; P, pediment; R, ridge; T, terrace.

Type of well: Dr, drilled; Du, dug; Dv, driven.

Method of lift: A, air lift; B, bucket; C, centrifugal pump; F, flowing; J, pump jack; P, pressure pump; T, turbine; W, windmill.

Use of water: B, bathing; D, domestic; I, irrigation; In, industrial; M, municipal; S, stock; U, unused.

Lithologic character: A, alluvium; C, caliche; Cl, clay; Cg, conglomerate; G, gravel; L, limestone; S, sand.

Geologic horizon: P, Pennsylvanian; Pl, Pliocene; Ps, Pleistocene; Q, Quaternary; R, Recent.

Discharge: f, flow; p, pumped.

Well		Owner	Altitude above sea level (ft)	Topographic situation	Type of well	Depth of well (ft)	Diameter of well (in)	Depth of casing (ft)	Method of lift	Date completed	Use of water	Water-bearing bed			Water level		Discharge (gpm)	Drawdown (ft)	Date of measurement	Temperature of water (°F)	Remarks
Field number	Location number											Depth (ft)	Lithologic character	Geologic horizon	Above (+) or below (−) land surface datum (ft)	Date of measurement					
1*	12.5.27.300	Adran Garcia	4,795	A	Du	27	48	–	B	–	D	–	A	R	– 26	10/ 4/46	–	–	–	–	Underflow in Rio Cuchillo
2*	13.4.22.330	Andy Faulkner	4,334	A	Dr	100	8	–	W	1937	D,In	–	A	R	– 40	–	–	–	–	–	–
3*	13.4.33.344	James Apts.	4,240	Fp	Dr	105	7	–	C	1924	B	60 to 105	L	P	+ 0.4	9/10/45	1 f	–	2/10/39	114	Thermal water
4	13.4.33.422	Sierra Co. Courthouse	4,292	Hs	Dr	–	6	–	–	–	U	–	A	Pl,Ps	– 29	do.	–	–	–	–	–
5*	13.4.34.310	Mrs. Howard	4,263	T	Dr	120	6	–	–	–	–	–	A	Pl,Ps	+ 6	3/30/39	1 f	–	2/10/39	70	–
6	13.5.26.321	M. W. McCleskey	4,620	A	Du	16	60	–	W	–	D,S	8 to 16	G	R	– 8	–	50 p	7	–	–	Perched water(?). Duration of test 3 hours
7	13.5.27.421	do.	4,658	A	Du	30	60	–	W	–	S	27 to 30	C	R	– 27	–	–	–	–	–	Perched water(?)
8	13.5.30	Walter Doolittle	–	A	Dr	272	8	58	–	1941	U	–	A	Q	– 20	–	–	–	–	–	0–58 feet fill; 58–272 feet cemented gravel
9	13.5.31.444	do.	4,662	A	Du,Dr	42	8	40	C	1942	I	–	A	R	– 15	–	400 p	–	–	–	–
10	14.4. 5.310	Cauthen Packing House	4,245	Fp	Dv	40	6	40	W	1939	U	–	A	R	– 8	6/19/46	–	–	–	–	–
11	14.4. 6.110	Dave Gray	4,323	A	Dr	135	6	–	W	–	D	–	A	Q	– 95	–	–	–	–	–	No flow
12	14.4. 6.110a	do.	4,340	A	Dr	334	10	20	–	1946	–	125 to -	–	Q	– 98	1/22/47	–	–	–	–	Plugged, abandoned Nov. 27, 1945
13	14.4. 6.134	Hot Springs, Hefferman	4,300	A	Dr	438	12	–	–	–	M	–	A	Q	+ 26	10/ 3/45	–	–	–	–	Plugged, abandoned Dec. 10, 1945
14	14.4. 6.233	Hot Springs, city 13	4,251	A	Dr	–	–	–	–	–	–	–	–	–	Flows	–	–	–	–	–	–
15*	14.4. 6.233a	Frank Crow	4,257	T	Dr	278	8	258	–	1940	D,I	–	G	Q	+ 35	10/10/45	70 f	–	4/14/45	–	–
16	14.4. 6.234	Geo. Cook	4,251	A	Dr	230	10	–	–	1936	I	–	–	–	Flows	–	62 f	–	4/ /39	–	–
17	14.4. 6.234a	Hot Springs, city 12	4,251	A	Dr	249	–	–	–	–	M	–	–	–	–	–	–	–	–	–	Plugged, abandoned Dec. 1, 1945
18*	14.4. 6.312	Mr. Creasy	4,266	Hs	Dr	185	12	–	–	–	D,I	–	A	Q	+ 31	10/ 4/45	–	–	–	–	–
19*	14.4. 6.313	T. B. Williams	4,288	T	Dr	385	10	350	–	1940	M	227 to -	S,G	Q	+ 33	8/14/46	250 f	–	8/14/46	77.5	–
20*	14.4. 6.321	Hot Springs, city 14A	4,265	A	Dr	442	13-7	442	F,T	1945	M	See log	G	Q	+ 40	5/29/46	350 f	50	5/25/46	80.6	Duration of test indefinite
21	14.4. 6.322	Hot Springs, city 14	4,248	A	Dr	275	12-10	268	F	1939	M	–	–	Q	+ 48	10/17/45	200 f	–	–	80	Plugged, abandoned Dec. 6, 1945
22	14.4. 6.411	Hot Springs, city 11	4,242	A	Dr	285	12	–	–	1939	M	–	–	Q	+ 44	10/28/45	200 f	–	On completion	79	Plugged, abandoned Dec., 1945
23	14.4. 6.411a	Hot Springs, city 11A	4,247	A	Dr	410	13	410	F,T	1945	M	See log	–	Q	+ 42	5/28/46	400 f	50	10/12/45	80	Duration of test indefinite
24*	14.4. 6.441	Roy Howe	4,237	Fp	Dr	302	10	–	F	1946	D,I,In	222 to -	Cg	Q	+ 58	1/22/47	425 f	–	3/25/47	76	–
25*	14.4. 6.442	Mr. Arnold	4,237	Fp	Dr	305	10	–	F	–	D,I	–	–	Q	+ 42	10/17/46	270 f	–	8/14/46	–	–
26*	14.4. 7.311	J. A. Slater	4,230	Hs	Dr	387	10	355	F	1938	I	280 to 287	S	Q	+ 32	10/ 3/45	18 f	–	10/ 3/45	77	–
27	14.4.18.310	C. Fowler	4,260	Hs	Dr	46	6	40	W	1945	D	–	A	R	– 14	–	–	–	–	–	Salty water at 14 feet

Table 1. Records of selected wells in vicinity of Hot Springs, Sierra County, N. Mex. (continued)

Well		Owner	Altitude above sea level (ft)	Topographic situation	Type of well	Depth of well (ft)	Diameter of well (in)	Depth of casing (ft)	Method of lift	Date completed	Use of water	Water-bearing bed			Water level		Discharge (gpm)	Drawdown (ft)	Date of measurement	Temperature of water (° F)	Remarks
Field number	Location number											Depth (ft)	Lithologic character	Geologic horizon	Above (+) or below (-) land surface datum (ft)	Date of measurement					
28	14.5. 1.223	Walton Gibbons	4,360	A	Dr	95	6	20	W	–	D,S	–	A	Q	– 73	6/18/46	–	–	–	–	–
29	14.5. 8.222	Casamia Baca	4,558	A	Dr	–	8	–	–	1946	–	–	A	Q	– 18	6/19/46	–	–	–	–	Incomplete June 19, 1946
30	14.5.12.244	J. A. Slater	4,265	T	Dr	94	4	40	W,J	1941	D,S	90 to 94	G	Q	– 20	–	–	–	–	–	Water seep at 20 feet; poor quality
31	14.5.25.233	Don Montolla	4,327	A	Dr	55	6	50	–	1945	D	50 to -	G	R	– 37	6/19/46	–	–	–	–	–
32	14.5.36.100	Barney Iorio	–	R	Dr	325	–	–	–	–	–	–	–	Q	–	–	–	–	–	–	Abandoned before completion
33	14.5.36.111	do.	4,350	–	–	2,100	–	–	–	–	–	–	–	–	Flows	–	–	–	–	–	–
34	14.5.36.121	do.	4,380	R	Dr	180	8	180	W,J	1945	In	160 to 180	S, fine	Q	–118	6/19/46	–	–	–	–	Alternating sand and clay
35	14.6.16.440	Ladder Ranch	5,162	P	Dr	–	–	–	W	–	–	–	–	–	–420	–	–	–	–	–	–
36	15.5. 1.214	Jack McGowan	4,280	Hs	Dr	–	4	–	–	–	–	–	–	–	– 74	6/19/46	–	–	–	–	Abandoned
37	15.5. 1.214a	do.	4,280	Hs	Dr	155	8	155	J	1946	In	80 to 155	S	Q	– 40	–	–	–	–	–	–
38*	15.5.18.400	Folcher and Wolf	4,573	A	Dr	272	6	230	W	1945	S	–	Cg	Q	–185	6/20/46	–	–	–	–	–
39	15.5.22.122	John Gordon	4,377	A	Dr	211	6	–	W	1938	S	–	Cl	–	– 37	do.	–	–	–	–	–
40	15.5.24.441	Henry Hopkins	4,244	Hs	Dr	134	12	134	T	1938	D,S	127 to 134	S	Q	– 40	do.	–	–	–	–	Proposed irrigation well
41	15.5.26.334	Gregorio Chavez	4,257	A	Du,Dr	174	–	–	W	–	D,S	–	–	–	– 23	do.	–	–	–	–	–
42	15.5.27.311	Grabiel Miranda	4,312	–	Dr	–	–	–	–	–	–	–	–	–	+ 10	6/13/46	20 f	–	–	74	Three flowing wells at this location
43	15.5.27.311a	John Gordon	4,307	A	Dr	244	6	244	–	1942	D,I	–	–	Q	Flows	–	75 f	–	–	–	Another flowing well at this location
44	15.5.27.324	Ruben Chavez	4,315	–	Dr	–	–	–	–	–	–	–	–	–	+ 13	6/13/46	43 f	–	6/13/46	70	–
45	15.5.27.331	W. E. Cone	–	A	Dr	142	8	–	–	1947	D,I	–	A	Q	Flows	–	–	–	–	–	–
46	15.5.27.413	Oliver Williams	4,300	A	Dr	301	8	–	–	1945	I	–	S	Q	+ 37	6/12/46	75 f	–	6/12/46	72	–
47	15.5.27.433	J. S. Stone	4,300	A	Dr	238	4	130	–	1942	D,S	–	G	Q	+ 7	do.	6 f	–	do.	–	Two wells at this location
48	15.5.27.443	Howard Young	4,276	A	Dr	280	6	110	–	1938-1945	–	–	S	Q	Flows	–	55 f	–	–	70	Sand streaks interbedded with clay
49	15.5.27.443a	Mary Weaver	4,275	A	Dr	309	6	72	–	1945	D	–	S	Q	do.	–	7 f	–	–	–	Do.
50	15.5.29.131	S. P. Crouch	4,440	A	Dr	199	6	199	–	1939	–	–	–	Q	– 12	–	–	–	–	–	150-foot well nearby
50a	15.5.29.243	Robert Eaton	4,390	A	Dr	170	6	107	–	1938	D	60 to -	S	Q	+ 10	6/13/46	2 f	–	6/13/46	–	Two flowing wells at this location
50b	15.5.29.244	Oscar Brannon	4,375	A	Dr	125	6	–	–	–	D	–	–	–	+ 3	do.	3 f	–	–	69	Do.
51	15.5.30.111	John F. Woods	4,478	A	Du	20	–	–	C	–	I	–	–	–	– 10	–	–	–	–	–	Obtains underflow from creek
52*	15.5.30.120	Las Animas Creek Community Spring	4,457	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	61	Spring fed by underflow of creek
53	15.6.15.344	Jack Chatfield	4,632	A	Du	22	–	–	C	–	I	–	–	–	– 6	–	–	–	–	–	Well obtains underflow from creek
54	15.6.23.132	E. A. Watson	4,540	A	Du	20	–	–	C	–	I	–	–	–	– 7	–	–	–	–	–	Do.
55	15.6.30.330	Ladder Ranch	5,252	P	Dr	–	–	–	–	–	S	–	–	–	– 83	–	–	–	–	–	Water perched on intrusive rock
56*	15.6.31.340	M. W. Pague	5,170	A	Dr	193	6	–	J	1943	D,I	–	–	–	–	–	–	–	–	70	Gold Dust, N. Mex., supply well

Table 1. Records of selected wells in vicinity of Hot Springs, Sierra County, N. Mex. (continued)

Well		Owner	Altitude above sea level (*ft*)	Topographic situation	Type of well	Depth of well (*ft*)	Diameter of well (*in*)	Depth of casing(*ft*)	Method of lift	Date completed	Use of water	Water-bearing bed			Water level		Discharge (*gpm*)	Drawdown (*ft*)	Date of measurement	Temperature of water (° *F.*)	Remarks
Field number	Location number											Depth (*ft*)	Lithologic character	Geologic horizon	Above (+) or below (–) land surface datum (*ft*)	Date of measurement					
57	15.6.31.430	John Hallett	5,156	Fp	Dr	200	–	–	–	–	–	–	–	–	– 96	8/20/46	–	–	–	–	Formerly used in placer mining
58	16.5. 1.131	Mrs. Cora Neal	4,309	R	Dr	106	10	–	W	1941	In	–	G	Q	– 85	6/20/46	–	–	–	–	Gravel at 97 and 106 feet
59	16.5.11.433	C. A. Moore	4,305	Hs	Dr	232	6	198	–	1944	D	80 to -	S	Q	+ 16	6/12/46	8 f	–	6/12/46	73	Mostly red clay
60	16.5.11.443	C. W. Maden	4,265	Hs	Dr	110	6	–	W	1939	D	–	–	–	– 55	6/20/46	–	–	–	–	Deepened to 255 feet; flows
61	16.5.20.244	J. L. Holden	4,387	A	Dr	257	–	–	C	1943	I	–	–	–	0	–	–	–	–	74	Two other flowing wells nearby
62	16.5.21.144	H. S. Moore	4,364	A	Dr	154	6	154	–	1942	D,I	80 to -	S	Q	+ 12	6/14/46	16 f	–	6/14/46	75	Water table at 25 feet
63	16.5.21.233	do.	4,360	A	Dr	130	6	130	–	1944	I	–	–	–	Flows	–	–	–	–	–	–
64	16.5.22.420	O. B. Dawson	4,317	A	Dr	216	8	215	–	1944	I	164 to -	S, fine	Q	do.	–	38 f	–	6/13/46	75	Two other flowing wells nearby
65	16.5.23.300	do.	4,285	Hs	Dr	226	18	215	–	1947	I	–	–	–	–	–	850 p	115	–	75	Proposed irrigation well; flow 125 gpm. Duration of test 4 hours
66	16.5.25.211	Bureau of Reclamation	4,199	Fp	Dr	136	6	–	A	1937	–	–	S, fine	Q,R	–	–	–	–	–	–	Used in constructing dam
67	16.5.25.343	A. J. Osborn	4,181	Fp	Dr	152	13	150	T	1946	I	38 to 149	S	Q,R	– 32	6/21/46	–	–	–	–	–
68	16.5.26.143	A. M. Hill	4,275	R	Dr	185	6	–	–	1944	D,I	–	S, fine	Q	+ 37	6/15/46	14 f	–	6/14/46	71	Water table at 40 feet
69	16.5.35.243	Jim Birch	4,208	Hs	Dr	168	6	168	W	1937	D,In	–	–	–	– 54	12/21/45	–	–	–	–	–
70	16.5.35.311	John Gordon	4,265	Hs	Dr	245	8	–	–	–	D,I	120 to -	S	Q	+ 25	6/15/46	25 f	–	6/14/46	72	Two other flowing wells nearby
71	16.6.16.431	Mrs. Sam Clark	4,700	A	Dr	325	6	70	W	–	D,S	25 to -	–	–	– 20	–	–	–	–	–	Three other wells at this location
72	17.5.10.442	A. J. Osborn	4,260	R	Dr	207	–	–	T	1947	–	–	–	–	– 16	4/ /47	–	–	–	–	–
73	17.5.11.211	D. W. Haddock	4,170	Hs	Dr	–	–	–	P	–	D,In	75 to -	–	–	– 46	6/21/46	13 p	–	–	–	–
74	17.5.11.231	do.	–	Hs	Dr	288	8	266	–	1944	–	80 to 125	S	Q	– 60	–	–	–	–	–	No artesian water

Table 2. Analyses of water from wells and springs near Hot Springs, Sierra County, N. Mex.

(See table 1 for location and description of wells.)

Well field number	Owner	Date of collection	Quantities in parts per million														Specific conductance (micromhos at 25° C)	Temperature (° F)	Well field number
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Borate (BO_3)	Dissolved solids	Hardness as $CaCO_3$				
															Total	Noncarbonate			
1	Garcia	8-16-46	-	-	122	11	166	284	74	276	-	15	-	804	350	117	1,480	-	1
2	Faulkner	do.	-	-	173	17	127	218	142	310	-	17	-	893	502	323	1,610	-	2
3	James	2- 9-39	-	0.07	152	18	740	210	74	1,280	2.6	-	-	-	454	-	-	-	3
3	do.	7-19-45	-	-	150	19	756	212	76	1,300	3.2	2.7	-	2,410	452	279	4,410	114	3
3	do.	6- -46	-	-	-	-	-	206	-	1,300	-	-	0.8	-	-	-	4,470	-	3
5	Howard	2- 9-39	18	3.30	460	76	[1]682	152	1,193	1,120	1.6	4.0	-	3,720	1,462	-	-	-	5
5	do.	9-14-45	20	.15	471	100	618	157	1,180	1,110	2.2	1.2	-	3,580	1,590	1,460	5,290	70	5
15	Crow	5-29-46	-	-	64	7.4	[2]130	124	60	216	1.2	1.5	.1	541	190	88	1,020	-	15
16	Cook	2- 9-39	21	2.20	58	5	140	125	52	212	.6	1.0	-	556	166	-	-	-	16
16	do.	7-31-47	28	-	-	-	128	130	56	223	-	3.8	-	-	204	98	1,030'	-	16
18	Creasy	8-15-46	-	-	68	10	117	136	54	210	-	1.5	-	528	210	99	1,000	-	18
19	T. Williams	6-21-46	-	-	75	16	90	140	64	188	.8	1.6	.1	504	253	138	1,030	77.5	19
20	City 14A	8-16-46	-	-	65	9.3	124	130	52	218	-	1.4	-	534	200	94	1,020	80.6	20
23	City 11A	10-16-45	19	.07	67	12	113	122	52	216	.9	.6	-	541	216	116	1,030	80	[3]23
23	do.	6- -46	-	-	-	-	-	124	-	230	-	-	.1	-	-	-	1,050	-	23
24	Howe	9-26-46	-	-	75	12	121	136	52	235	.8	1.2	-	564	236	125	1,070	76	24
25	Arnold	8-16-46	-	-	68	11	121	133	55	220	-	1.2	-	542	214	106	1,040	-	25
26	Slater	6-21-46	-	-	76	14	144	114	51	291	.8	1.6	.1	635	247	154	1,210	77	26
37	McGowan	7-31-47	36	-	81	12	114	236	32	191	.6	2.3	-	585	252	58	1,000	-	37
38	Folcher	6-20-46	-	-	11	3.9	42	126	19	6	.4	2.4	-	147	44	-	216	-	38
41	G. Chavez	7-31-47	-	-	-	-	-	269	-	190	-	-	-	-	-	-	1,070	-	41
42	Miranda	do.	30	-	126	17	146	117	64	380	.2	4.2	-	825	384	288	1,490	-	42
43	Gordon	do.	-	-	-	-	-	164	-	372	-	-	-	-	-	-	1,530	-	43
44	R. Chavez	do.	-	-	-	-	-	138	-	336	-	-	-	-	-	-	1,390	-	44
45	Cone	do.	-	-	-	-	-	207	-	17	-	-	-	-	-	-	381	-	45
46	O. Williams	12-19-45	31	-	105	14	196	96	62	425	.6	1.9	-	883	320	241	1,600	72	[3]46
46	do.	6-13-46	-	-	108	15	189	98	66	418	.4	2.2	-	847	331	250	1,620	-	46
47	Stone	7-31-47	28	-	39	5.7	86	188	26	88	.6	3.3	-	369	121	0	607	-	47
48	Young	do.	21	-	66	7.9	131	122	43	238	.6	.8	-	568	197	97	1,030	-	48
48a	do.	do.	30	-	44	6.7	118	177	32	148	1.0	4.1	-	471	138	0	800	-	48a
50a	Eaton	do.	32	-	71	12	41	329	21	17	.2	.1	-	356	226	0	546	-	50a
50b	Brannon	do.	30	-	28	3.6	65	232	13	15	.8	.4	-	270	85	0	404	-	50b
52	Las Animas Spring	6-14-46	-	-	78	11	28	293	32	18	.4	.6	.0	312	240	-	537	61	52
56	Pague	8-20-46	-	-	63	21	36	242	80	26	1.2	1.2	-	348	244	45	609	70	56
58	Neal	7-31-47	-	-	-	-	-	172	-	15	-	-	-	-	-	-	358	-	58
59	Moore	do.	-	-	-	-	-	182	-	13	-	-	-	-	-	-	338	-	59
60	Maden	do.	-	-	-	-	-	176	-	16	-	-	-	-	-	-	337	-	60
61	Holden	do.	-	-	-	-	-	190	-	8	-	-	-	-	-	-	365	-	61
62	H. S. Moore	do.	-	-	-	-	-	166	-	8	-	-	-	-	-	-	343	-	62

Table 2. Analyses of water from wells and springs near Hot Springs, Sierra County, N. Mex. (continued)

(See table 1 for location and description of wells.)

Well field number	Owner	Date of collection	Quantities in parts per million												Hardness as $CaCO_3$		Specific conductance (micromhos at 25° C)	Temperature (° F.)	Well field number
			Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Borate (BO_3)	Dissolved solids	Total	Noncarbonate			
64	Dawson	6-14-46	-	-	21	4.4	59	169	36	13	1.2	.8	[3] .0	219	70	0	360	75	64
64	do.	6- 7-47	25	-	22	2.5	74	180	58	11	1.0	1.1	-	283	66	-	385	-	64
65	do.	7-31-47	28	-	24	1.6	73	158	52	13	1.2	1.3	-	283	66	0	360	-	65
68	Hill	do.	31	-	37	1.9	69	190	76	10	.6	.7	-	320	100	0	476	-	68
69	Birch	do.	-	-	-	-	-	197	-	8	-	-	-	-	-	-	379	-	69
70	Gordon	do.	29	-	52	2.0	52	199	72	7	.6	.6	-	313	138	0	379	-	70
A	Government	2- 9-39	36	0.10	154	14	[4] 770	215	79	1,300	3.0	10.0	-	2,560	442	-	-	-	A
A	do.	9-15-44	-	-	158	22	748	225	89	1,300	-	1.0	-	2,430	485	300	4,480	-	A
A	do.	6- -46	-	-	-	-	-	216	-	1,330	-	-	1.2	-	-	-	4,560	-	A
B	Van Sant	2- 9-39	26	.76	85	17	[5] 102	272	156	74	.0	.2	-	610	282	-	-	54	B
C	Cuchillo	4- -40	37	.00	109	10	[6] 412	212	79	650	2.4	25.0	-	1,428	314	-	-	85.6	C
D	Myers	7-31-47	-	-	-	-	-	247	-	965	-	-	-	-	-	-	3,630	-	D
E	Bailey-Scott	7-24-47	14	-	452	86	1,150	181	2,110	1,160	1.8	-	-	5,060	1,480	1,330	5,140	-	E

EXPLANATION OF SYMBOLS

A, spring; owned by U.S. Government, managed by city of Hot Springs; temperature 103° – 106° F.; located across street from U.S. Post Office; known as "Government Spring."

B, driven well; diameter 2 inches, depth 4 feet; owned by E. M. Van Sant; located on bank of Rio Grande above Hot Springs.

C, warm spring; located 20 miles northwest of Hot Springs in Cuchillo Canyon, 15 miles west of Cuchillo, N. Mex.

D, drilled irrigation well; diameter 6 inches, depth 60 feet, yield about 30 gpm; owned by W. A. Myers; location No. 14.4.6.340, on flood plain of Rio Grande.

E, drilled oil test well; diameter 4 inches, depth 625 feet; water-bearing formation, limestone [Pennsylvanian and Permian(?)] from 440 to 625 feet; owned by Bailey and Scott; location No. 13.4.28.420.

FOOTNOTES

[1] Includes 21 parts of potassium

[2] Includes 9 parts of potassium

[3] pH = 7.7

[4] Includes 39 parts of potassium

[5] Includes 11 parts of potassium

[6] Includes 26 parts of potassium

(altitude of surface 4,390 feet; of aquifer 4,330 feet), and well 48 (Young) at 110 feet (altitude of surface 4,276 feet; of aquifer 4,166 feet), which suggests that the horizon at which the first flowing water is obtained rises to the northwest at the rate of about 80 feet per mile. This horizon seems to have a similar slope in Percha Creek.

As the coarser sediments in the valley fill are lenticular in nature, it is to be expected that drilling would have to be continued through more clay in one place than in another to penetrate an aquifer that would furnish flowing water. The apparent decrease in depth to the aquifers to the west can be explained by assuming that the strata dip to the east more steeply than the land surface.

The lithology of the aquifers varies considerably. In some wells the aquifer is gravel, in others sand, and in some wells "clay" is the reported water-bearing material. The yield of wells that are finished in the clayey material amounts to only a few gallons a minute. Aquifers in the Mud Springs area appear to be composed of sand and gravel, but those farther south appear to be much finer grained. There also appears to be a general west-to-east gradation from coarse to fine clastics.

The decrease in yield of most wells with time is greater than the normal expected decrease in yield from loss in head. There may be two reasons for this. A limey deposit precipitates from the water and probably tends to seal perforations in the casings; and, as few of the wells are pumped, there is a tendency for the wells to "sand up," especially those in which quicksand is encountered. Sanding up is probably the more important factor.

PIEZOMETRIC SURFACE AND WATER TABLE

The altitude of the piezometric surface at wells where it was possible to measure the hydrostatic head is shown in figure 3. A number of factors affect the accuracy with which the piezometric surface can be determined. The head measured in the well is lower than the static head by the amount of residual drawdown due to previous flow in the well or the drawdown caused by flow from nearby wells. This factor is difficult to evaluate in an area such as Mud Springs Draw, where wells are closely spaced and allowed to flow at irregular intervals. Few artesian wells south of Mud Springs Draw are equipped with valves, and most of them are therefore allowed to flow constantly. It is also difficult in some wells to obtain accurate determinations of the hydrostatic head because many of the artesian wells were poorly constructed and water may rise upward on the outside of the casings.

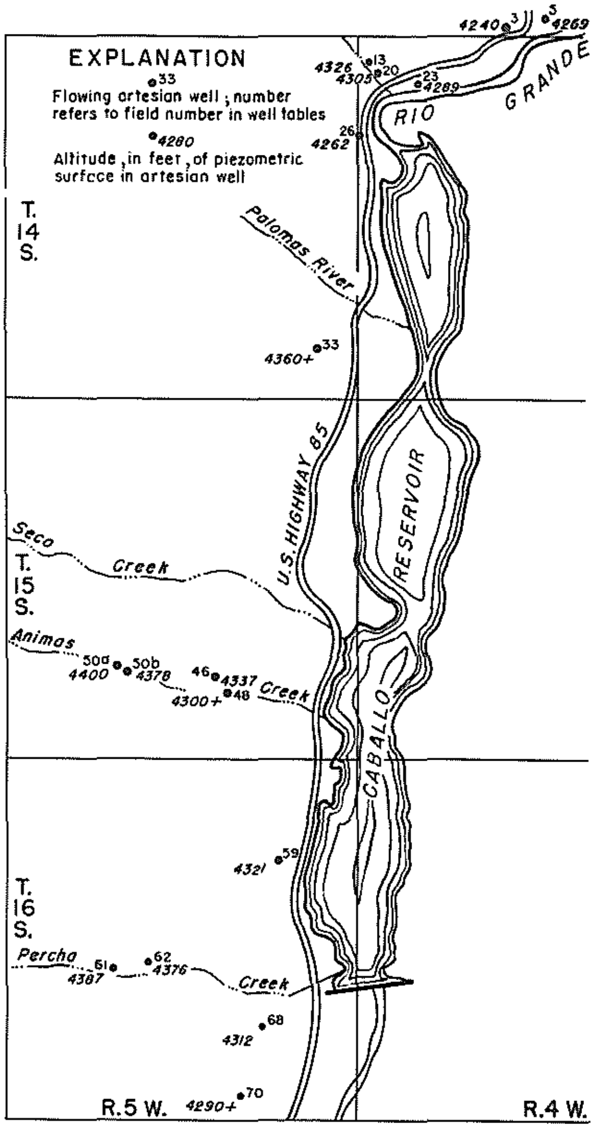


FIGURE 3. Map showing altitude of piezometric surface in selected observation wells. Most of the measurements were made in 1945–46.

Although measurements of head have not been made frequently enough or over a sufficiently long period of time to evaluate daily or seasonal variations of pressure, such variations almost certainly occur. They probably result from fluctuations in artificial and natural discharge. In an area such as Mud Springs Draw where wells are equipped with valves, more water is used during the summer for both city and irrigation purposes. This causes a seasonal decline, which is followed by a period of recovery during the winter months. A similar though smaller variation no doubt occurs daily, as more water is used during the day than the night. Another factor that has an important effect on the artesian pressure in a well is its depth. Artesian pressure commonly increases as progressively deeper aquifers are penetrated. The depth to which the well is drilled will therefore have an important effect on its hydrostatic head.

Because of the above factors and the limited number of places at which the piezometric surface could be determined, accurate contouring of the piezometric surface in the area of the present investigation is impossible. The data obtainable indicate a slope toward the east – that is, toward the river or Caballo Reservoir – of about 30 feet per mile in Percha and Animas Creeks, and from 45 to 70 feet per mile in Mud Springs Draw, depending on the wells used for computing the slope. As only barometrically determined elevations of the water table are available south of well 26 (Slater), the data available are not sufficiently exact or widely spaced to show whether a north-south component to the slope of the piezometric surface exists. As the river has little slope (because of the presence of Caballo Reservoir) through the area of artesian flow, little southerly slope in the piezometric surface is to be expected, on the almost necessary assumption that the river controls the discharge from the artesian system.

Barometrically determined elevations of the water table indicate an easterly slope of about 60 feet per mile for the area south of Caballo (pl. 1). From Caballo to Mud Springs Draw the slope is slightly less and is toward the southeast. A number of altitudes determined for water levels in shallow wells are believed not to represent the position of the main water table. Two wells (Nos. 6 and 7) near the head of Mud Springs Draw, in which the water levels are 4,612 and 4,630 feet, respectively, represent underflow of perched water in the stream channel. Similarly, water is encountered at abnormally high levels in wells along other creek channels. This perched condition is brought about in the majority of cases by impermeable clays, but in the Gold Dust area intrusive rock at shallow depth holds water up near the surface. (See well 57, pl. 1.) On the basis of the measurements that have been made, an easterly slope of about 50 feet per mile is indicated for the water table.

The thermal mineralized water contained in limestone of the Magdalena group at Hot Springs has a lower head than the water in the artesian wells that penetrate the Tertiary and Quaternary rocks both to the south and to the north. (See well 3, fig. 3.) The piezometric surface of the water in wells drilled into limestone of the Magdalena group in Hot Springs is at an altitude of about 4,240 feet, about 25 feet lower than the lowest altitude determined for the artesian wells that penetrate the Tertiary and Quaternary rocks. The piezometric surface of the thermal water is only a few feet above the shallow water table in Hot Springs, whereas the piezometric surface in the nonthermal artesian basin is commonly many feet above the shallow water table. At the mouth of Mud Springs Draw and near the mouth of Percha Creek the piezometric surface is about 60 feet above the shallow water table. Up the draws, the height of the piezometric surface above the shallow water table decreases, and at the western edge of the area of flowing wells it amounts to only a few feet. The altitude of the water levels in wells 38 and 39 in Seco Creek (pl. 1 and fig. 3) is not much lower than the piezometric surface in wells in Animas Creek, a short distance to the south. It thus appears that the reason the water levels are so far below the surface in wells 38 and 39 (187 and 36 feet, respectively) is that the arroyo bottom of Seco Creek is at a relatively high altitude and rises more steeply than that of Animas Creek. A similar explanation seems to account for the absence of flowing wells in Palomas Creek, as the land surface is above the piezometric surface as projected northward from Percha and Animas Creeks. Near the mouth of Mud Springs Draw erosion has cut the land surface down until it is below the piezometric surface, and flowing wells are obtained.

RECHARGE

The eastward slope of the piezometric surface indicates that the nonthermal artesian water in the valley-fill deposits has its source west of the area of flow. Recharge to the aquifers is probably of three kinds: (1) direct rainfall penetration on the edges of the aquifers where they crop out west of the area of flow, (2) infiltration into the outcropping edges of the aquifers from flash floods in the arroyos, and (3) infiltration into the outcropping edges of the aquifers from the perennial streams that occupy the upper reaches of some of the arroyo-like valleys.

Recharge directly from rainfall probably takes place largely in the area between the Hillsboro-Cuchillo Mountains and the area of artesian-water development. Much of this area is underlain by pediment gravels, which would readily receive the rainfall and allow it to percolate into the aquifers which are truncated by these gravels. As the area receives little rainfall, this type of recharge is generally not very important, but during wet periods large amounts of water could be fed to the aquifers.

The amount of recharge from flash floods also is probably not very great. The flash floods in the arroyos occur, in general, at widely separated intervals and are of short duration. The floods have access to only a small area of the aquifers where they crop out in the arroyo bed. If the aquifers were very porous in their outcrop areas it would be possible for a large amount of the flood waters to enter the aquifers after first passing into the channel gravels; however, as the aquifers, in general, are composed of poorly sorted materials they probably would not receive the flood waters very readily.

Recharge from perennial streams, although not large in amount, is the most dependable source of water for the artesian aquifers. Most of the tributary valleys on the west side of the Rio Grande in the Hot Springs area have in their upper reaches small streams which disappear underground after crossing the gaps cut in the bedrock formations of the Hillsboro-Cuchillo Mountains. Part of this underflow is believed to recharge the artesian aquifers and another part the shallow-water aquifers of the area. The recharge takes place in a manner similar to that of the flood waters, but at a much slower rate, so that more time is afforded the aquifers for absorbing the available water. It is probable that some of the ground water in the bolson areas west of the Hillsboro-Cuchillo Mountains discharges into these perennial streams.

The two surface-water reservoirs of the area, Elephant Butte and Caballo, apparently do not have any important bearing on the ground-water recharge in the area of artesian-water development. The bedrock that crops out at Hot Springs probably restricts the circulation of ground water from Elephant Butte Reservoir to the south, and the relatively low altitude of Caballo Reservoir precludes its furnishing water to the system.

Some of the rainfall, especially that occurring during violent thunder showers that produce the flash floods in the arroyos, reaches the Rio Grande directly. Some of it recharges the shallow ground water near the river.

NATURAL DISCHARGE

The water that reaches the shallow-water and artesian aquifers moves in an easterly or southeasterly direction, as shown by elevations of the water table (pl. 1) and the piezometric surface (figs. 2 and 3). As movement to the east of the Rio Grande is prevented or greatly impeded by the rocks of the Sierra Caballo, the Rio Grande is the only apparent discharge area for the ground water. As the head in many artesian wells close to the river is as much as 60 feet above the river, it appears that the artesian aquifers do not discharge directly into the river. It is believed that water from the artesian aquifers escapes vertically through imperfectly confining beds, joins the shallow water body, and moves thence into the river.

Caballo Reservoir has some effect on the ground-water discharge in the artesian area. By maintaining a nearly level water surface in the south-trending Rio Grande throughout most of the area of artesian flow, it reduces the north-south component of the slopes of the water-table and piezometric surfaces, and thereby brings about a more nearly east-west movement of the ground water. Also, by impounding water at an unnaturally high level it raises the water table, and by creating a back pressure on the imperfectly confined artesian water it causes the artesian pressure to increase.

Seeps in the valley-fill materials in the bluffs facing the Rio Grande indicate that some water that enters porous strata flows along the top of the impermeable clay beds until it reaches the outcrop area of the clay in the bluffs facing the river. Similar seeps have been artificially produced by improperly cased artesian wells.

QUALITY OF WATER

The ground waters of the Hot Springs area, analyses of which are given in table 2, can be roughly divided into three groups. (1) Waters with a moderate concentration of sodium and/or calcium cations, and of bicarbonate and/or chloride as the chief anions. About 35 of the water samples shown in the table can be placed in this group. They include most of the nonthermal artesian wells and most of the water-table wells of the Hot Springs area. (2) Waters having a high concentration of sodium and chloride ions, and in which other constituents are present in relatively moderate concentrations. The thermal waters of the area, well 3 and spring A, belong to this group as do also some nonthermal wells near the city of Hot Springs, as indicated by well D. (3) Waters which have, in addition to a high sodium and chloride content, a high calcium, magnesium, and sulfate concentration. This type of water is represented by the analyses for wells 5 and E.

Group 1

The tables of analyses indicate that the nonthermal waters of Mud Springs Draw (samples 15-25) have about 60 to 70 parts per million of calcium; about 120 parts sodium; about 120 parts bicarbonate; about 55 parts sulfate; about 220 parts chloride; about 550 parts dissolved solids; about 225 parts hardness, of which about 100 is noncarbonate hardness; and a specific conductance of about 100. Water from this group of wells is exceptionally uniform in composition for the Hot Springs area.

Other waters listed in the table of analyses show the following comparisons with the nonthermal artesian waters from Mud Springs Draw. Waters from wells 1 and 2 are slightly more concentrated. Water from well B is also more concentrated in calcium, bicarbonate, and sulfate but is lower in chloride content than most wells near Hot Springs, probably as a result of infiltration of low-chloride water from the nearby Rio Grande. The higher sodium chloride content in water from well 26 may be caused by contamination of the artesian water by shallow water entering through breaks in the well casing. Water from well 45, which is on the south side of Animas Creek, differs considerably from the nearby wells (Nos. 42, 43, 44, and 46) on the north side of the creek in having a high bicarbonate content (207) and a low chloride content (17). Its low specific conductance indicates a low total mineral content. Waters from wells 47 and 48a are similar to that from well 45, while water from well 48 is very similar to that from the Mud Springs Draw wells. Calcium bicarbonate waters are also obtained from the following: wells 50a and 50b; spring 52; and wells 56, 58, 59, 60, 61, 62, 64, 65, 68, 69, and 70. These waters are notably low in sodium and chloride content, less than 20 parts per million, and the sulfate content is generally low. The waters are generally softer than the Mud Springs Draw artesian wells.

Group 2

A comparison of waters that belong to the second group, those high in sodium and chloride, with the Mud Springs Draw artesian water (table 2), shows that well 3 is relatively very high in nearly all constituents, sulfate (75) alone being an exception, and is especially high in its sodium (750) and chloride (1,300) content. Water from spring A is almost identical with that from well 3. The water from spring C is similar to that from well 3 and spring A, but has only about half the sodium (386) and chloride (650) concentration.

Group 3

In comparing waters of the third group, those high in both sodium chloride and calcium sulfate, with the artesian waters from Mud Springs Draw, table 2 shows that the water from well 5 is very high in all constituents except bicarbonate (155); it is especially high in sulfate (1,190). Water from well E is similar to that from well 5 but has about twice the sodium (1,150) and sulfate (2,110) content.

Minor constituents

Of the less abundant mineral constituents several facts can be noted from table 2. The silica content in all samples is less than 40 parts per million, and appreciable amounts of iron are found in only two, Nos. 5 and 16. The magnesium content averages about 10 parts per million in the Mud Springs Draw artesian waters but is high in samples 5 and E and low in the most southwesterly wells, Nos. 64 to 70. The fluoride content is sufficiently high to produce mottling of teeth in growing children in only five samples, Nos. 3, 5, A, C, and E. Nitrate content exceeds 5 parts per million in only four samples and these higher values may be the result of surface contamination. Borate exceeds 0.1 part per million in only two of the samples in which it was determined.

Areal pattern of quality of water

The analyses given in table 2 show that there is an areal pattern of quality of water. On the basis of analyses 1 and 2, it appears that water in shallow wells north of Hot Springs is harder and more concentrated, in general, than water in shallow wells to the south. Water from wells near Hot Springs has a high chloride content; this is true not only of water from the limestone of the Magdalena group but also of water from the water-table wells outside the thermal-water area in Hot Springs (Theis and others, 1941, p. 55). It indicates that the thermal water mixes to some extent with the shallow water. Water in the area southwest of Hot Springs, in Seco, Animas, and Percha Creeks, is of good quality, in general, but some marked variations occur among wells close to one another. Water from well 38 in Seco Creek is of exceptionally good quality, having the lowest mineral content of any water sampled. Good water is obtained also from well 45 in Animas Creek. Well 38 is at an altitude of about 4,573 feet, and is in the part of Seco Creek that is dry except for brief periods following flash floods. The well is 272 feet deep, and has a static water level of 187 feet below the surface. Well 45 is located on the south side of Animas Creek and near wells 42, 43, 44, and 46, which are on the north side of the creek and yield water of relatively poor quality. Water from the latter wells is low in bicarbonate but higher in calcium, sodium, and chloride than the nonthermal artesian water in the Mud Springs Draw area. These wells are located in a stretch of Animas Creek where there is a perennial flow from springs.

Artesian wells 61, 62, 64, and 65, in the draw of Percha Creek, yield water considerably better than that from artesian wells in Mud Springs Draw. The water is lower in calcium, sodium, sulfate, and chloride but slightly higher in bicarbonate. Water from wells 58 to 60, along the Rio Grande Valley south of Animas Creek, is similar to that from the wells in Percha Creek. Water from the westernmost artesian wells in Animas Creek, 50a and 50b, and from spring 52 still farther west, are similar to the above waters but higher in either sodium bicarbonate (No. 50b) or calcium bicarbonate. Well 56, located between Animas and Percha Creeks on the flank of the Hillsboro Mountains, also yields a calcium bicarbonate water.

The difference in chemical quality in the waters of the Hot Springs area probably has the following geological significance: the higher calcium, magnesium, chloride, and sulfate concentrations noted in shallow-water samples 1 and 2 probably are due to the presence of Permian strata which are at and near the surface northwest of Hot Springs because of earth movements that produced the fault block that constitutes Mud Springs Mountains. The high sodium chloride content of the thermal water in Hot Springs is believed to be caused by the rising of deep-seated water along a fault zone. The high sodium chloride and calcium sulfate content of well 5 may be caused by the combination of two factors: the high sodium chloride content may have an origin similar to that in the thermal wells, and the calcium sulfate may be derived from Permian strata which lie below the valley fill and which contain soluble minerals. Water from well E, a 625-foot oil test well which obtains its water from bedrock, Pennsylvanian and Permian(?), below 440 feet, is similar to that from well 5 but contains about 500 parts per million more of sodium and 1,000 parts per million more of sulfate. The high chloride in water from wells 42, 43, 44, and 46 may indicate that deep-seated water is rising in the vicinity of these wells. It seems likely that the higher fluoride in wells 3 and 5 and springs A and C, and larger amounts of borate in well 3 and spring A, respectively, are given off as emanations from deep-seated igneous rocks which probably underlie the Hot Springs area. The low mineral content of most of the water southwest of Hot Springs probably indicates that bedrock does not influence the quality of the water and that the aquifers in the valley fill are comparatively free from soluble salts. In the Hillsboro Mountains and in the part of the Black Range southwest of Hot Springs, Pennsylvanian and older rocks, largely limestones, constitute most of the stratified bedrocks whereas Permian rocks, in addition to the Pennsylvanian and older rocks, crop out in the Cuchillo Mountains northwest of Hot Springs. The Permian rocks undoubtedly contain more soluble salts than the limestones and increase to a greater extent the mineral content of waters coming into contact with them.

SPECIFIC CAPACITY OF WELLS

In October and November 1945, during pumping tests on wells 20 and 23 (city wells 14a and 11a), it was possible to determine fairly accurately the specific capacity (the discharge in gallons a minute per foot of drawdown) for these wells. Well 20 was found to have a specific capacity of 6.6 and well 23 a specific capacity of 6.5. These values were determined for discharge in excess of 500 gpm over periods in excess of 24 hours. On March 25 and 26, 1947, well 24 (Howe) discharged nearly 300 gallons a minute for more than 36 hours, with a drawdown of about 43 feet – a specific capacity of nearly 7. Other values obtained by shutting off flowing wells and measuring the recovery in head showed a specific capacity of 2.5 for well 46 (Oliver Williams), 3.5 for well 44 (Chavez), 4.0 for well 15 (Crow), 5.7 for well 25 (Arnold), and 0.7 for well 26 (Slater). The value for well 26 is probably too low because the well casing is leaking. Many of these values for specific capacity are influenced by drawdown effects caused by neighboring wells and by the fact that sufficient time could not be allowed for complete recovery to take place after discharge. It is to be expected, however, that specific capacity will vary, not only from one area to another but even in individual wells in the same general locality, because of variation in the coarseness and degree of sorting of the materials making up the aquifers. However, the data indicate that, in general, the specific capacity in the wells ranges from about 3 to 7. With specific capacities of this magnitude only the better wells could be pumped profitably for irrigation purposes under present pumping costs, once the heads are reduced to where the wells will no longer flow. Most of the wells are of small diameter, but each of the city wells is 12 inches in diameter and has a 7-inch screen surrounded by a gravel envelope 30 inches in diameter.

PUMPING TESTS

A number of pumping tests of short duration have been made on wells in Mud Springs Draw. These tests have been interpreted according to formulas for withdrawal from storage, and although such formulas probably are not strictly applicable to the Hot Springs area where there appears to be considerable upward leakage from the artesian aquifers to the water table, they indicate the order of magnitude of the hydrologic constants of the aquifers. The waterworks system of the city of Hot Springs has very little storage capacity, and therefore the city wells cannot be shut off except for brief periods. It is accordingly impossible to make recovery measurements for very long periods after the wells have ceased pumping. Interpretation of the results of pumping tests is further complicated by irregular and uncontrollable discharge from the numerous wells in the area. Pumping tests made in May 1946 and in March 1947 were the most extensive, and the results are given below.

Tests in May 1946

In May 1946 a series of pumping tests were made in the city well-field area to determine coefficients of transmissibility and storage of the aquifers in this part of Mud Springs Draw. Well 23 was shut off on May 24, and well 20 was allowed to flow 390 gallons a minute until 9:25 a.m. on May 26, so that conditions would become stabilized. The pump on well 20 was then started and yielded 620 gallons a minute. Drawdown effects on the artesian head in wells 15, 18, and 23 were measured until about 12:20 a.m. on May 28, when discharge from well 20 was stopped. Recovery measurements were then made in well 20. Computations were made of the coefficients of transmissibility and storage (T and S) by the following modification of Jacob's formula* in which the drawdown in a single observation well is plotted on a natural scale against the reciprocal of the time elapsed since pumping began on a log scale:

$$T = \frac{264\ Q}{\Delta s_t} \qquad S = \frac{0.3\ T\ (t_e)}{r^2}$$

where

T	is the coefficient of transmissibility; that is, the discharge in gallons a day through each strip 1 foot wide extending the height of the aquifer, under unit hydraulic gradient;
Q	is the discharge (or change in discharge) from the well in gallons a minute;
Δs_t	is the change in drawdown ($s_1 - s_2$) in the observation well over 1 log cycle of 1/t $\left[\log_{10} \frac{\frac{1}{t_1}}{\frac{1}{t_2}} = 1\right]$;
S	is the coefficient of storage; that is, the quantity of water in cubic feet discharged from each vertical prism of the aquifer, with basal area equal to 1 square foot and height equal to that of the aquifer, when the water level falls 1 foot;
r	is the distance in feet between the pumped well and the observation well;
t_e	is the time t in days obtained from the zero-drawdown intercept of the straight-line graph.

The formula (Theis, 1935) used for determining T from the recovery of well 20 when it was shut off is:

$$T = \frac{264\ Q \log_{10} t/t'}{s}$$

where symbols are as above with the following changes and additions:

Q	is the discharge in gallons a minute;
t	is the time in any selected unit since pumping began;
t'	is the time in the same unit as above since pumping stopped;
s	is the residual drawdown in feet.

The following values were obtained:

Well	Values determined by	T	S
23	Drawdown caused by increasing yield of well 20	11,500	0.0002
20	Recovery caused by stopping yield of well 20	12,400	
		Apparent T	
23	Drawdown caused by increasing yield of well 20 after several hours pumping	7,650	
15	Drawdown caused by increasing yield of well 20	8,660	

Tables 3, 4, 5, and 6 give the detailed information from which these values were determined, and figures 4, 5, 6, and 7 show the data graphically.

It will be observed that values determined for T for well 23, computed from drawdown effects caused by increasing the yield of well 20, and for well 20 computed by the recovery of water level in the well, agree closely. The apparent T computed for well 23 after several hours of pumping from well 20 and for well 15 agree rather well. Inasmuch as the apparent T is about 0.7 that of the inferred transmissibility of the aquifer, it suggests partial boundary effects, and the partial boundary of the aquifer appears to be close to well 15. Measurements of the effect on well 18 of changes in the discharge of wells 20 and 23 indicate that there is little connection between well 18 and the city wells, as drawdown or recovery effects produced on it were frequently small and irregular and could not be used for obtaining values of coefficients of transmissibility or storage. This suggests the occurrence of another partial boundary of the aquifer tapped by the city wells.

Values for the coefficient of transmissibility based on the rate of recovery of water levels in well 20 after the pump was stopped on May 28 were determined in two ways: (1) computations were made on the simplified basis that the well started discharging 620 gallons a minute at 9:25 a.m. on May 26, the previous period of flow of 390 gallons a minute beginning at 2:20 p.m. on May 24 being neglected (fig. 6 and table 5); (2) computations were

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*Jacob, C. E., June 1944, *Notes on determining permeability by pumping tests under water-table conditions.* Manuscript report in files of U. S. Geol. Surv., Washington, D. C.

Table 3. Drawdown in well 23 (city well 11a) caused by increasing yield of well 20 (city well 14a)

May 26–28, 1946

Water level in well 23 when pumping began was about 36.6 feet above measuring point. Well 20 had been discharging 390 gpm by natural flow. At 9:25 a.m., May 26, pump was started and yield increased to 620 gpm. Well 23 is 865 feet from well 20.

Time	Water level* (*feet above measuring point*)	Drawdown* (*feet*)	$\frac{1}{t}$ (*days*)
May 26			
9:25 a.m.	Pump on well 20 started		
9:58	36.00	0.60	43.65
10:15	35.70	0.90	28.80
10:40	35.40	1.20	19.20
11:18	34.80	1.80	12.75
11:53	34.40	2.20	9.73
12:17 p.m.	34.10	2.50	8.38
1:22	33.30	3.30	6.08
2:24	32.90	3.70	4.81
3:02	32.70	3.90	4.28
4:02	32.30	4.30	3.63
5:00	32.00	4.60	3.16
6:04	31.70	4.90	2.77
7:38	31.20	5.40	2.35
May 27			
12:05 a.m.	30.00	6.60	1.64
5:38	28.90	7.70	1.19
9:36	28.00	8.60	0.99
12:53 p.m.	27.90	8.70	0.87
6:35	27.30	9.30	0.72
11:18	26.60	10.00	0.63

*Approximations only; no water column readings made on manometer.

$$T = \frac{264 \times 230}{5.3} = 11{,}500 \text{ gpd/ft}$$

$$S = \frac{.3 \times 11{,}500}{(865)^2 \times 23} = 0.0002$$

Table 4. Drawdown in well 15 (Crow) caused by increasing yield of well 20 (city well 14a)

May 26–28, 1946

Water level in well 15 when pumping began was about 20.7 feet above measuring point. Well 20 had been discharging 390 gpm by natural flow. At 9:25 a.m., May 26, pump was started and yield increased to 620 gpm. Well 15 is 1,020 feet from well 20.

Time	Water level (*feet above measuring point*)	Drawdown (*feet*)	$\frac{1}{t}$ (*days*)
May 26			
9:25 a.m.	Pump on well 20 started		
10:49	20.19	0.51	17.14
11:21	19.75	0.95	12.41
11:48	19.73	0.97	10.07
12:20 p.m.	19.29	1.41	8.23
12:33	Well 15 pumped 5 to 10 minutes. Some leakage from shutoff valve		
1:19	18.72	1.98	6.15
2:27	18.68	2.02	4.77
2:57	17.47	3.23	4.34
4:06	17.18	3.52	3.59
5:08	16.89	3.81	3.11
6:15	16.55	4.15	2.72
7:45	16.03	4.67	2.32
11:57	14.91	5.79	1.65
May 27			
5:29 a.m.	14.20	6.50	1.20
9:26	13.06	7.64	1.00
12:45 p.m.	12.78	7.92	0.88
6:30	12.48	8.22	0.73
11:13	13.78	6.92	0.64
May 28			
12:20 a.m.	Pump on well 20 stopped		

$$\text{Apparent } T = \frac{264 \times 230}{7.0} = 8{,}660 \text{ gpd/ft}$$

$$\text{Apparent } S = \frac{0.3 \times 8{,}660}{(1{,}020)^2 \times 10.85} = 0.0002$$

made including both periods of discharge (fig. 7 and table 6), using the following formula:

$$T = \frac{264\ Q_1}{s'} \log \frac{t_1}{t'} \left(\frac{t_2}{t'}\right)^{\frac{Q_2}{Q_1}}$$

where

Q_1 = initial rate of flow in gallons a minute;

Q_2 = increase in rate of flow in gallons a minute caused by pump;

t_1 = time since flow began, expressed in the same unit which is selected for the other periods of time;

t_2 = time since pumping began;

t' = time since discharge stopped;

s' = residual drawdown in feet in the well which has been discharging at a particular point in time governed by above values of t;

T = coefficient of transmissibility as defined above.

The computed value of 12,350 for T, using the simplified procedure, agreed very well with the value of 12,400 determined by solving the above equation, which involved substituting the value of

$$(1/s')\ \log\ (t_1/t')\ (t_2/t')^{\frac{Q_2}{Q_1}}$$

obtained from the slope of the line resulting from a plotting, on semilogarithmic paper, of the above logarithmic factor against residual drawdown for a number of different selected times.

Table 5. Simplified recovery data for well 20 (city well 14a) after pumping ceased, May 28, 1946

(Pump started 9:25 a.m., May 26)

Time	Water level (*in feet above measuring point*)	t (*time since pumping began, in minutes*)	t' (*time since pumping stopped, in minutes*)	$\frac{t}{t'}$
May 28 12:20 a.m.	Stopped pumping	2,335	0	
12:31	13.63	2,346	11	213.20
12:32	14.40	2,347	12	195.00
12:33	14.97	2,348	13	180.50
12:34	15.43	2,349	14	168.70
12:35	15.79	2,350	15	156.60
12:36	16.25	2,351	16	147.00
12:37	16.49	2,352	17	138.40
12:39	17.19	2,354	19	123.90
12:41	17.76	2,356	21	112.20
12:44	18.57	2,359	24	98.30
12:47	19.25	2,362	27	87.50
12:51	20.06	2,366	31	76.30
12:55	20.65	2,370	35	67.70
1:00	21.35	2,375	40	59.40
1:14	23.10	2,389	54	44.25
1:17	23.35	2,392	57	42.00
1:23	23.82	2,398	63	38.10
1:31	24.60	2,406	71	33.88
1:42	25.86	2,417	82	29.48
1:52	26.34	2,427	92	26.40
2:00	26.80	2,435	100	24.35
2:25	28.23	2,460	125	19.68
2:48	29.14	2,483	148	16.78
3:07	29.62	2,502	167	14.97
3:45	30.54	2,540	205	12.40
4:31	31.57	2,586	251	11.40

$$T = \frac{264\ Q}{s} \log_{10} \frac{t}{t'}$$

$$T = \frac{264 \times 620}{13.26} = 12{,}350 \text{ gpd/ft}$$

Tests in March 1947

At 1:29 p.m. on March 25, 1947, well 24 (Howe) was opened and allowed to flow at an average rate of approximately 295 gallons per minute until 2:21 a.m. on March 27 (fig. 8). Measurements were made of the changes in the head in the nearby well 25 during this period (fig. 8 and table 7) and in both wells (figs. 9, 10, and 11, and tables 8 and 9) on shutting off the flow from well 24. Discharge from other nearby wells, particularly that from the city wells 20 and 23, affects the water levels in wells 24 and 25 appreciably, but the following computed values are believed to give an approximation of the transmissibility of the aquifers penetrated by these wells.

Table 6. Recovery of well 20 (city well 14a) following a period of natural flow and a period of pumping, May 24–28, 1946

Static water level about 50 feet above measuring point

Rate of flow = Q_1 = 390 gpm

Increased yield due to pump = Q_2 = 230 gpm

Flow started at 2:20 p.m., May 24
Flow stopped at 12:20 a.m., May 28
Pump started at 9:25 a.m., May 26
Pump stopped at 12:20 a.m., May 28

Time	Head (*in feet above measuring point*)	Drawdown (*in feet*)	Time since flow started (t_1)	Time since pumping started (t_2)	Time since pumping stopped (t')	$\frac{t_1}{t'}\left(\frac{t_2}{t'}\right)^{\frac{Q_2}{Q_1}}$
May 28, 1946 12:35 a.m.	15.79	34.2	4,935	2,350	15	6,490
12:55	20.65	29.4	4,955	2,370	35	1,701
1:23	23.82	26.2	5,043	2,458	63	695
3:45	30.54	19.5	5,125	2,540	205	110

$$T = \frac{264 \times 390}{8.3}$$

$$T = 12{,}400 \text{ gpd/ft}$$

Well	Values determined by	Apparent T
25	Drawdown caused by discharge of well 24	11,500
25	Recovery caused by shutting off well 24	7,100
24	Recovery during 1-hour period caused by shutting off well 24	13,000
24	Recovery after 1 hour caused by shutting off well 24	7,800

As in the results obtained by pumping tests conducted in the city well field, the results of pumping tests conducted on well 24 suggest the presence of a partial boundary to the aquifer in the vicinity of the wells. The effect of these partial boundaries is to cause greater drawdowns than would occur in an areally extensive and uniform aquifer.

In material as variable in texture as the valley fill, values obtained for the coefficient of transmissibility, ranging from 7,100 to 13,000, agree as well as could be expected.

The value for the coefficient of storage appears to be very small but could not be computed with assurance because of the uncertainty of the static water level in the various wells. Large variations in the computed values of this parameter are common

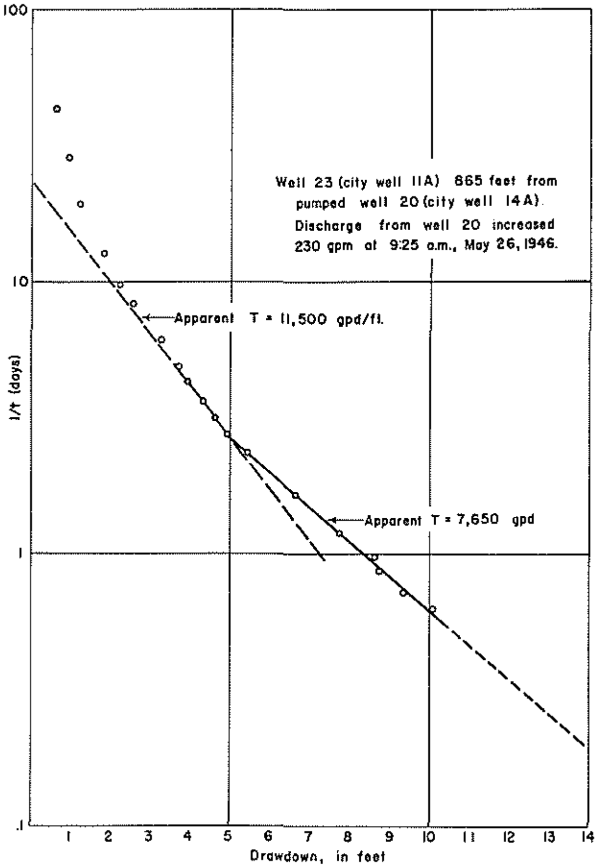


FIGURE 4. Drawdown in well 23 caused by increasing yield of well 20, May 26–28, 1946.

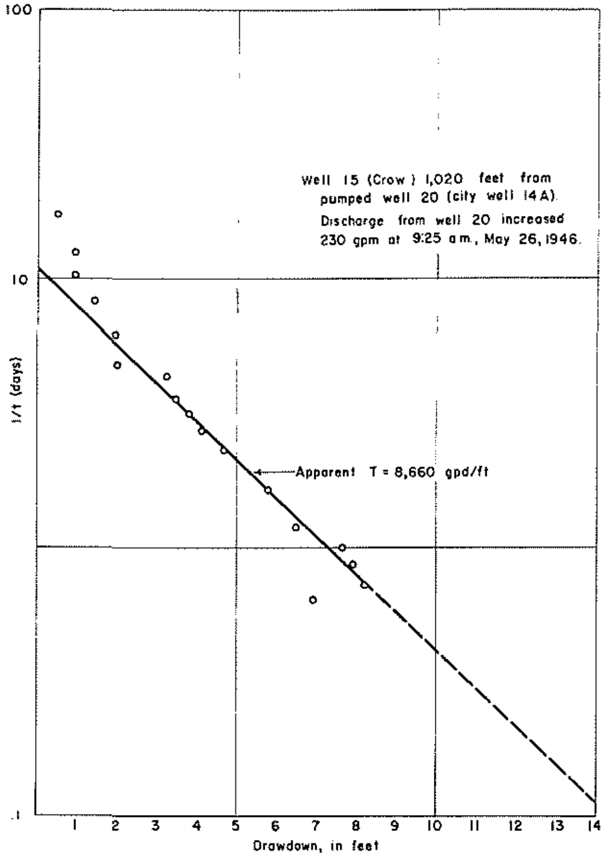


FIGURE 5. Drawdown in well 15 caused by increasing yield of well 20, May 26–28, 1946.

even in formations that seem to be quite uniform in texture. Inasmuch as the computed parameter appears to be quite sensitive to minor variations from the postulated ideal conditions upon which its computation is based, and as in the Hot Springs area the physical conditions depart widely from the ideal conditions, it is probable that the computed coefficient of storage has little significance.

AMOUNT OF FLOW

The amount of water transmitted by an aquifer is a function of the transmissibility of the aquifer and the hydraulic gradient or slope of the water table or piezometric surface. From the values of the coefficient of transmissibility determined by the pumping tests, it may be computed that under a unit gradient 11,000 gallons per day per foot is the maximum rate of transmission of water through the aquifers, and from the slope of about 55 feet per mile, equivalent to a gradient of 0.01 for the Mud Springs Draw area, it is concluded that the part of the aquifer from which the wells derive their water transmits about 600,000 gallons a day, or nearly 1 second-foot per mile of length along the river.

A few seepage studies have been made of the Rio Grande, including the stretch where artesian water development has taken place. Results of two seepage runs are given in the following tabulations.

Results of seepage study of the Rio Grande between Elephant Butte Dam and Leasburg Dam made in November 1928 by E. L. Barrows (1930, p. 22–26) of the State Engineer Office

		Corrected seepage		
		Distance	Gain per mile	
From	To	*(miles)*	*(sec-ft)*	*(gpd)*
Oyster Canyon	Hot Springs	4.50	2.014	1,301,700
Hot Springs	McElvoy Ranch	10.75	1.700	1,098,700
McElvoy Ranch	Percha Creek	11.00	1.885	1,218,300
Percha Creek	Dona Ana-Sierra County line	7.50	0.900	581,700
Oyster Canyon	Leasburg Dam	68.75	1.008	651,500

Results of seepage study of the Rio Grande from Mescal Canyon to south of the Sierra County line made in January and February 1936 under supervision of John H. Bliss of the State Engineer Office

(Data from a memorandum report of February 1936 to T. M. McClure, State Engineer, entitled "Report on investigation of invisible gains and losses in the channel of the Rio Grande from Elephant Butte to El Paso, Tex.")

From	To	Corrected seepage		
		Distance	Gain per mile	
		(miles)	*(sec-ft)*	*(gpd)*
Mescal Canyon	0.7 ± mi. above Hot Springs	3.7	2.14	1,383,100
0.7 ± mi. above Hot Springs	3 ± mi. below Hot Springs	4.2	0.81	523,500
3 ± mi. below Hot Springs	Above Palomas Creek	5.4	0.37	239,100
Above Palomas Creek	Below Palomas Creek	1.1	4.18	2,701,600
Below Palomas Creek	Caballo Post Office	8.0	0.75	484,700
Caballo Post Office	Caballo Dam site	4.6	1.09	704,500
Caballo Dam site	Percha Dam	2.3	1.43	924,200
Percha Dam	Garfield Flume	5.2	0.88	568,800
Garfield Flume	Below County line	5.9	0.95	614,000
Mescal Canyon	Below County line	40.4	1.05	678,600

These measurements indicate that, on the average, about 1 second-foot of water enters the river per mile through the stretch of nonthermal artesian-water development. This value agrees very well with that computed from the determined values of gradient and transmissibility. As the drainage area on the west side of the river is extensive and that east of the river very limited, it seems likely that most of the ground water discharged into the river comes from the west.

NATURAL AND ARTIFICIAL DISCHARGE

From the evidence at hand it appears that the natural discharge from the artesian aquifers in the area south of Hot Springs takes place largely by upward percolation of the artesian water through imperfectly confining beds to the shallow-water aquifers and thence to the river. When water is artificially withdrawn through flowing wells or by pumping from the artesian aquifer, the pressure near the well is reduced, and the water moves toward the well to replace the water being withdrawn (Theis, 1938). Thus, the natural upward percolation of water to the shallow-water aquifers is decreased, and there is a decrease in discharge of water to the river. Equilibrium is established when the amount of water that is prevented from escaping to the shallow-water aquifers equals the discharge from the artesian wells. It seems much more reasonable

Table 7. Drawdown in well 25 (Arnold)
caused by well 24 (Howe)
March 25–27, 1947

(Inferred static water level approximately 46 feet above measuring point)

Time	Water level *(in feet above measuring point)*	Drawdown *(in feet)*	$\frac{1}{t}$ *(days)*	Periods of discharge of city wells
March 25				
11:08 a.m.	42.63			
11:19	42.45			
12:15 p.m.	41.40			
1:23	40.74			
1:29	Opened well 24 (Howe)			
1:51	34.88	11.12	65.45	No record
1:56	34.12	11.88	53.33	
2:01	33.78	12.28	45.00	
2:06	33.36	12.64	38.91	
2:11	33.04	12.96	34.35	
2:16	32.70	13.30	30.63	
2:29	32.14	13.86	24.00	
2:40	31.55	14.45	20.28	
2:50	31.33	14.67	17.77	
3:15	30.78	15.22	13.58	
3:47	30.34	15.66	10.43	On at 4 p.m.
4:36	29.17	16.83	7.70	
5:18	27.47	18.53	6.29	Off at 6 p.m.
6:25	25.95	20.05	4.86	On at 7:45 p.m.
8:30	25.37	20.63	3.42	
9:15	24.46	21.54	3.09	Off at 9:45 p.m.
10:40	24.08	21.92	2.61	
March 26				
12:15 a.m.	24.60	21.40	2.23	
2:10	25.23	20.77	1.89	
4:50	25.65	20.35	1.63	
6:05	25.77	20.23	1.45	
6:29	25.83	20.17	1.41	
7:05	25.85	20.15	1.36	On at 7:15 a.m.
7:58	25.16	20.84	1.30	
8:26	24.37	21.63	1.27	
9:03	23.54	22.46	1.23	
9:51	22.53	23.47	1.18	
10:41	21.71	24.29	1.13	
11:35	21.08	24.92	1.08	
12:45 p.m.	20.50	25.50	1.03	Off at 12:55 p.m.
1:16	20.37	25.63	1.01	On at 1:45 p.m.
2:10	20.82	25.18	.97	
3:10	20.37	25.63	.93	
4:10	19.87	26.13	.90	Off at 4:45 p.m.
5:05	19.74	26.26	.87	
6:25	20.66	25.34	.83	On at 7:45 p.m.
8:10	21.63	24.37	.78	
9:15	20.55	25.45	.75	
10:06	19.88	26.12	.74	Off at 10:20 p.m.
March 27				
12:20 a.m.	20.72	25.28	.69	
1:50	21.64	24.36	.66	
2:21	Howe valve off at 2:21 a.m.			

Apparent T = $\frac{264 \times 295}{6.8}$ = 11,500 gpd/ft to suppose that equilibrium is established by such means than by an increase in the amount of recharge to the aquifers in the outcrop area, or by a decrease in discharge from a nonleaking aquifer connected to the river at some distance from the artesian wells.

As measurements of artesian pressure were not made in this area during its early development, it is impossible to determine the actual loss in head that has occurred, but the rather meager information available appears to indicate that the artesian pressure has not dropped as much as it would have if all water had been taken from storage. Any direct connection between the artesian aquifers and the river is unlikely, as artesian wells close to the river frequently have heads as much as 60 feet above the river.

If the adjustment of pressures were accomplished by the withdrawal of water from the area where the aquifers are under water-table conditions, then considerable lowering of the water table would take place in that area and the artesian pressure would probably be reduced in the area of flow. As water-level measurements are not available for the outcrop area, there is no way of checking how much lowering of the water table might have taken place there as a result of the discharge from the city wells. Because of the supposed proximity of the artesian wells to the discharge area it appears more probable that the withdrawals from the artesian wells will be compensated by reduction in natural discharge rather than by decline of the water table near the outcrop area of the artesian aquifers.

Whether the water discharged by the artesian wells comes from diversion of leakage to the overlying shallow water aquifer, from storage in the artesian aquifer, from diversion of direct flow to the river, or from movement of water from the outcrop area of the artesian aquifer, it will be balanced ultimately by a decrease of seepage into the river. If the artesian discharge is balanced by a loss of upward seepage to the shallow-water aquifers, as appears probable, the interference between wells will be less than would be expected under the other conditions. From the foregoing data it appears that about 600 to 700 acre-feet of water per year per mile length of the river can be removed by wells in the Mud Springs Draw area by lowering the head to the river level. Discharges in excess of this amount will probably cause water to flow from the river back into the shallow aquifers and thence to the pumped artesian wells.

DEVELOPMENT POSSIBILITIES

In Mud Springs Draw approximately 550 acre-feet of water per year is withdrawn from city wells 20 and 23 (fig. 2). Also, a large amount of water, about

Table 8. Recovery of well 24 (Howe)

March 27, 1947

Time	Water level (*in feet above measuring point*)	t (*time since flow began, in minutes*)	t' (*time since flow stopped, in minutes*)	$\frac{t}{t'}$	Remarks
March 25					
1:29 p.m.		0			Flow started
March 27					
2:21 a.m.		2,212	0		Flow stopped
2:22	22.39	2,213	1	2,213	
2:23	22.66	2,214	2	1,107	
2:24	23.23	2,215	3	738	
2:25	23.58	2,216	4	554	
2:26	23.92	2,217	5	443	
2:27	24.16	2,218	6	369	
2:29	24.63	2,220	8	277.5	
2:31	25.08	2,222	10	222.2	
2:33	25.66	2,224	12	185.5	
2:38	26.48	2,229	17	134.7	
2:41	26.75	2,232	20	116.0	
2:44	27.11	2,235	23	102.2	
2:50	27.81	2,241	29	77.3	
2:55	28.17	2,246	34	66.1	
3:00	28.63	2,251	39	57.75	
3:08	29.12	2,259	47	48.05	
3:18	29.74	2,269	57	39.8	
3:28	30.34	2,279	67	34.0	
3:34	30.62	2,285	73	31.3	
3:45	31.23	2,296	84	27.33	
3:55	31.63	2,306	94	24.53	
4:01	31.77	2,312	100	23.12	
4:15	32.40	2,326	114	20.4	
4:33	32.94	2,344	132	17.76	
5:17	34.22	2,388	176	13.57	
5:30					City wells on
5:50	34.91	2,421	209	11.58	
5:59	34.78	2,430	218	11.15	
6:23	34.53	2,454	242	10.14	
6:57	34.14	2,488	276	9.01	
7:41	34.07	2,532	320	7.915	
8:20	34.07	2,571	359	7.16	
9:34	34.03	2,645	433	6.11	
10:18	33.90	2,689	477	5.635	
11:05	33.78	2,736	524	5.225	
12:21 p.m.	36.27	2,812	600	4.685	
1:25	37.43	2,876	664	4.33	
2:20	37.70	2,931	719	4.08	
3:10					City wells off
3:39	38.42	3,010	798	3.774	
4:00					City wells on
5:50	39.06	3,141	929	3.383	
6:00					City wells off
9:05	41.39	3,336	1,124	2.99	
10:25	41.09	3,416	1,204	2.838	
March 28					
2:25 a.m.	45.07	3,656	1,444	2.532	
5:30					City wells on
5:37	47.05	3,848	1,636	2.35	
5:47	47.44	3,858	1,646	2.344	

$$\text{Apparent T during 1-hour recovery period} = \frac{264 \times 295}{6} = 13{,}000 \text{ gpd/ft}$$

$$\text{Apparent T after 1-hour recovery period} = \frac{264 \times 295}{10} = 7{,}800 \text{ gpd/ft}$$

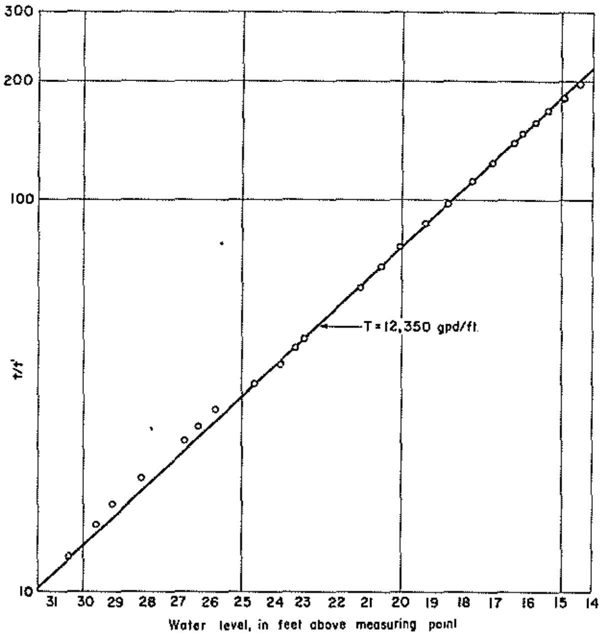
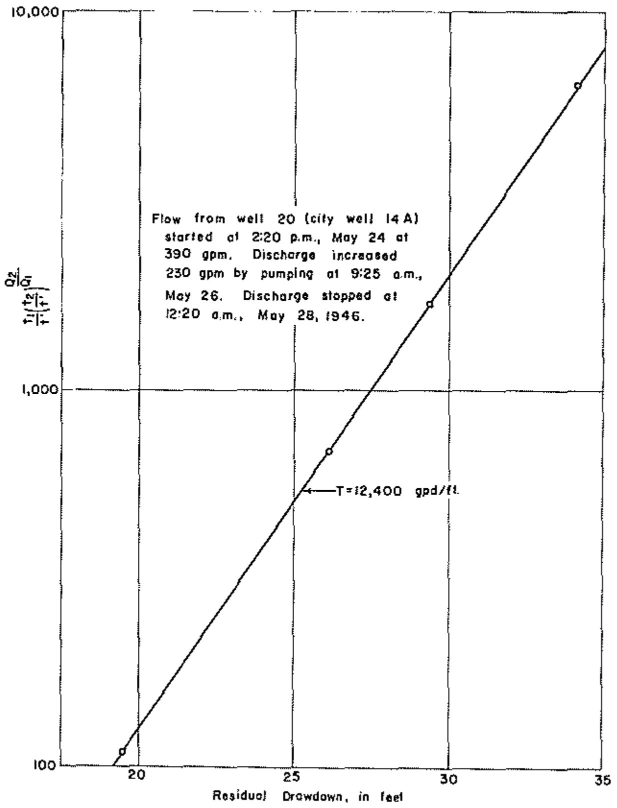


FIGURE 6. Simplified recovery curve for well 20 (city well 14a), May 28, 1946.



Flow from well 20 (city well 14 A) started at 2:20 p.m., May 24 at 390 gpm. Discharge increased 230 gpm by pumping at 9:25 a.m., May 26. Discharge stopped at 12:20 a.m., May 28, 1946.

FIGURE 7. Recovery of well 20 following a period of natural flow and a period of pumping, May 24–28, 1946.

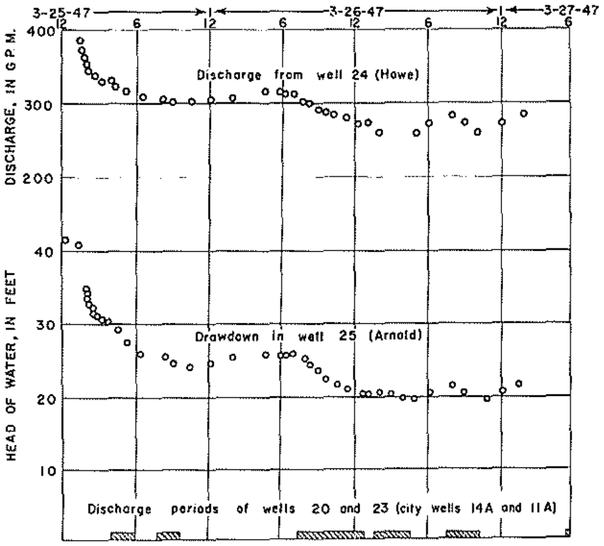


FIGURE 8. Graph showing discharge from well 24, drawdown in well 25, and periods of discharge of wells 20 and 23, March 25–27, 1947.

400 acre-feet, is withdrawn to supply the West Suburban Addition from well 19 that belongs to Dr. Williams. Wells 24 and 25, the Howe and Arnold wells, are capable of producing large amounts of water, but as their use is restricted to small acreages the two combined apparently do not supply more than about 90 acre-feet per year. Wells 15, 16, and 18, the Crow, Cook, and Creasy wells, are used to irrigate only a few acres and the total withdrawal from them probably is not more than 50 acre-feet per year. Well 12 (pl. 1) failed to obtain any flowing water. The above wells, from which a total of about 1,000 acre-feet per year is withdrawn, presumably derive water from the same portion of the aquifer and would need the flow from nearly 2 linear miles of the river to sustain them. As they are concentrated in a relatively narrow area it appears that overdevelopment has occurred in the Mud Springs Draw area and that considerable lowering of the piezometric surface is to be expected. If such decline occurs, the city wells, on which turbine pumps are already installed, will still be able to obtain their required water, but those wells which depend on flow alone at the present time will have to have pumps installed on them. From the rate of decline of the piezometric surface for the period during which measurements have been made it appears that, even with the present development, it will be many years before the present head of 60 to 70 feet above the river will be dissipated and the wells will abstract water from the Rio Grande.

In Animas Creek, well 50a (pl. 1 and fig. 3) is about as far west as flowing water can be expected.

Table 9. Recovery of well 25 (Arnold) on stopping flow of well 24 (Howe), March 27, 1947

Pressure head: 20 feet while city wells and well 24 were flowing;

21.65± feet while well 24 was flowing but city wells were not flowing

Time	Head (in feet above measuring point)	Recovery (in feet)	$\frac{1}{t}$ (days)
March 27			
2:21 a.m.	Shut off Howe well		
2:36	25.73	4.08	96.00
2:47	26.97	5.32	55.38
3:03	28.26	6.61	34.29
3:31	30.03	8.38	21.15
3:58	31.46	9.81	14.85
4:30	32.77	11.12	11.17
5:20	34.50	12.85	8.05
5:53	35.15	13.50	6.79
6:18	35.16	13.51	6.07
6:59	35.06	13.41	5.18
7:40	34.94	13.29	4.51
8:18	34.92	13.27	4.03
9:28	34.84	13.19	3.37
10:30	34.80	13.15	2.95
11:11	34.83	13.18	2.72
12:15 p.m.	34.81	13.16	2.42
1:29	35.63	13.98	2.15
2:15	35.87	14.22	2.02
3:35	36.44	14.79	1.81
5:42	37.48	15.83	1.56
9:00	40.02	18.37	1.29
10:20	39.78	18.13	1.20
March 28			
2:15 a.m.	43.22	21.57	1.00
5:30	45.34	23.69	.88
Nearby pump open			
8:30	44.08	22.43	.80

$$T = \frac{264 \times 295}{10.95} = 7,100 \text{ gpd/ft}$$

There appears to be no basic reason why additional flowing wells cannot be obtained along the 2-mile stretch of the creek between well 49 and Caballo Reservoir. An unusually thick section of clay is reported to have been penetrated by wells drilled in this area, but exploration apparently has not been sufficient to rule out completely the possibility of developing flowing wells in the area.

In Percha Creek, well 61 is at the western limit of the flowing-water area. Until recently, well 64 was the most easterly development in Percha Creek, but the completion of well 65 in May 1947 extended the development to near the mouth of the creek.

Apparently conditions are favorable for developing additional flowing wells in the intertributary areas along the Rio Grande Valley from near the town of Arrey to at least as far north as Animas Creek. There is a chance that flowing wells may not be obtained except near Mud Springs Draw, but additional development appears feasible in the vicinity of well 26. Near the city well area more flowing wells could be obtained but might cause overdevelopment in this area, as discussed above.

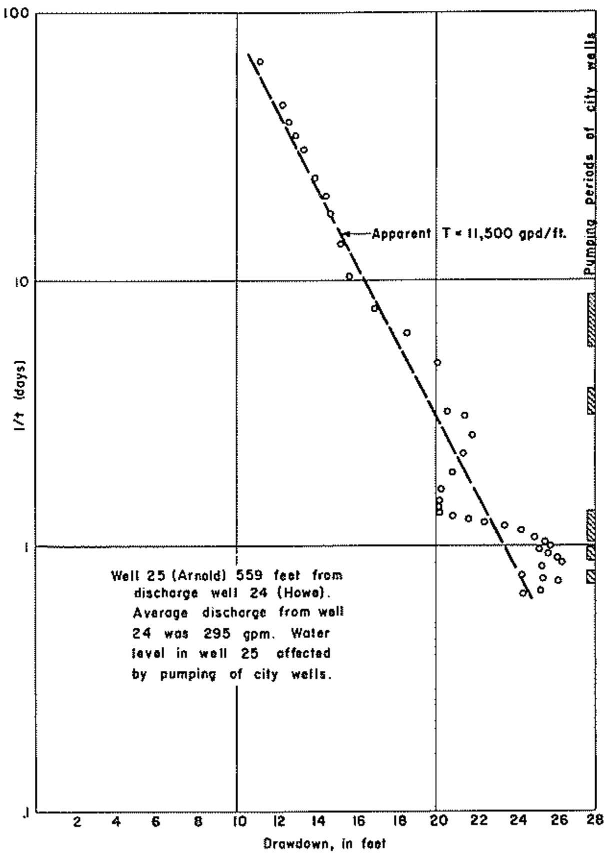


FIGURE 9. Drawdown in well 25 caused principally by discharge from well 24, March 25–27, 1947.

In general it can be said that there is a chance for developing a number of additional wells, mostly in the areas now known to be favorable. However, as the yield of most wells is small and the acreage of arable land is small, and is confined largely to small patches along the arroyo bottoms, no very large development of irrigation with flowing artesian water is possible. Development west of the area of flow is to be considered, as some wells in the latter area might be suitable for irrigation purposes when equipped with pumps. There is little evidence at present, however, to indicate that conditions are suitable for obtaining any large amount of artesian water to the west.

By installing pumps on some of the wells, a much more satisfactory irrigation system could be

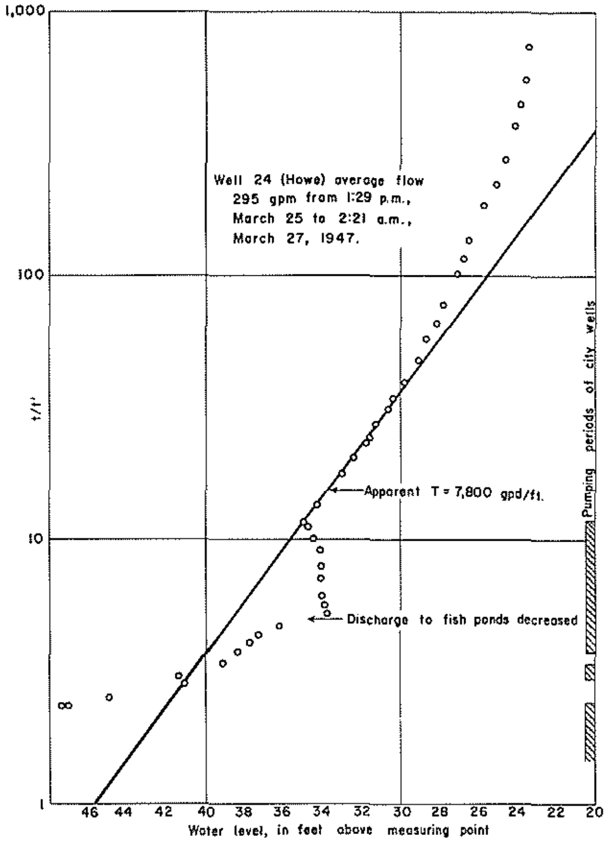


FIGURE 10. Recovery of well 24, March 27, 1947.

developed than is possible with the present system which uses the small natural flows. Well 61 is reported to yield several hundred gallons a minute to a centrifugal pump, and well 65 is reported to yield several hundred gallons a minute when pumped with a turbine pump. Very few other attempts have been made to pump the artesian wells, except the city wells which are equipped with 500-gpm turbine pumps, and the possibilities of such development can only be surmised. From the determinations of specific capacity it is evident that the yield of the

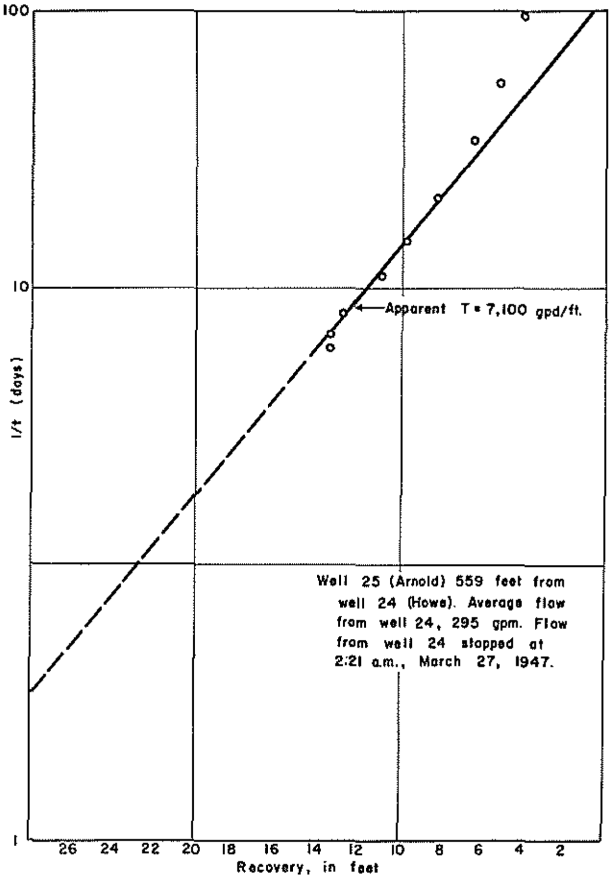


FIGURE 11. Recovery of well 25 on stopping flow from well 24, March 27, 1947.

various wells under pump will vary greatly. This is to be expected when the variable nature of the material encountered by the wells is considered.

There is some use of water along the arroyo bottoms by trees and shrubs, and pumping from wells may lower the water table enough to salvage some of this water, but the largest part of the increased diversions of water to the pumps will be compensated for by lessened discharge to the river.

WELL-NUMBERING SYSTEM

The well-numbering system used in this report conforms to the system used by the Ground Water Branch of the U.S. Geological Survey for numbering wells in New Mexico. The system is based on the common subdivisions adopted by the General Land Office for sectionized land (see example of sectionized township below) and by means of it the well number, in addition to designating the well, locates its position within a 10-acre tract in the land net. The number is divided by periods into four segments, as in the number 16.5.20.244. The first segment denotes the township north or south of the New Mexico base line; the second denotes the range east or west of the New Mexico principal meridian; the third denotes the section; and the fourth, which consists of three digits, denotes the particular 10-acre tract in which the well is situated. For this purpose, the land section is divided into four quarter sections (see diagram of subdivided section below) numbered 1, 2, 3, and 4 in the normal reading order, for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section, which is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus, well 16.5.20.244 in Sierra County is located in the SE¼ SE¼ NE¼ sec. 20, T. 16 S., R. 5 W. Provision is made in the numbering system to add letters after the township and range numbers to indicate whether the well is north or south of the base line and east or west of the meridian in cases where doubt might arise. However, in an area such as Hot Springs, where all wells are on one side of the base line (south) and on one side of the meridian (west), no confusion can arise and the letters are omitted. If a well cannot be located accurately to a 10-acre tract, a zero is used as the third digit of the fourth segment of the well number, and if it cannot be located within a 40-acre tract, zeros are used for both the second and third digits. If a well cannot be located more closely than the section, the fourth segment of the well number is omitted. When more than one well is located in a 10-acre tract, letters a, b, c, etc., are added to the well number for the second, third, fourth, and succeeding wells inventoried in the tract.

Figure 12 shows the system of numbering sections within a township and of numbering the tracts within a section.

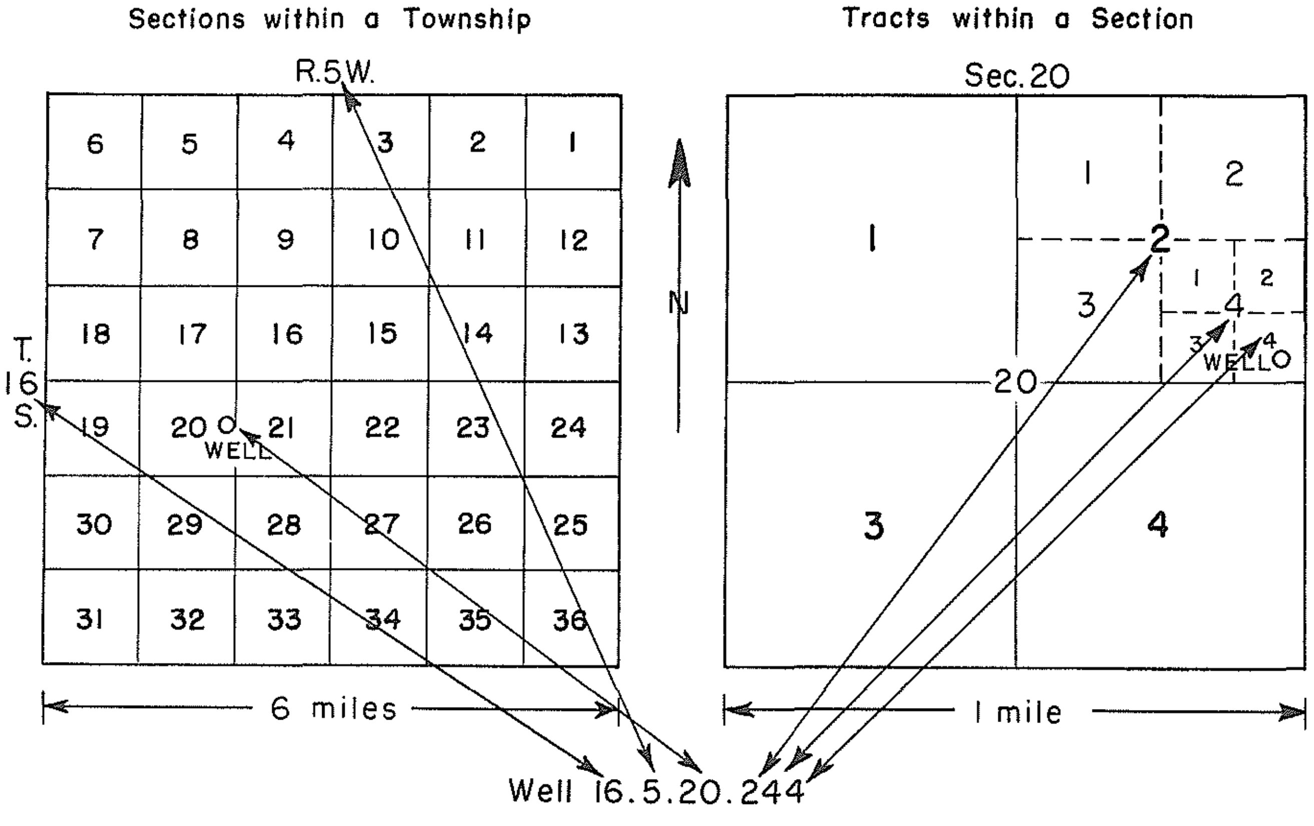


FIGURE 12. Method of numbering sections within a township and tracts within a section.

LITERATURE CITED

Barrows, E. L., 1930, *Seepage study on Rio Grande between Elephant Butte Dam and Leasburg Dam:* N. Mex. State Engineer Ninth Bienn. Rept., p. 22–26.

Darton, N. H., 1928, *"Red beds" and associated formations of New Mexico, with an outline of the geology of the State:* U. S. Geol. Surv. Bull. 794.

————————, 1928a, *Geologic map of New Mexico:* U.S. Geol. Surv., scale 1:500,000.

Fenneman, N. M., and Johnson, D. W., 1930, *Physical divisions of the United States:* U. S. Geol. Surv. Map, scale 1:7,000,000.

Harley, G. T., 1934, *The geology and ore deposits of Sierra County, New Mexico:* N. Mex. Inst. Min. and Technology, State Bur. Mines and Mineral Res. Bull.10.

Keyes, C. R., 1905, *Geology and underground-water conditions of the Jornada del Muerto, New Mexico:* U.S. Geol. Surv. Water-Supply and Irrigation Paper 123.

King, P. B., 1940, *Older rocks of the Van Horn region, Texas:* Am. Assoc. Pet. Geologists Bull., v. 24, no. 1.

Lee, W. T., 1907, *Water resources of the Rio Grande Valley in New Mexico, and their development:* U. S. Geol. Surv. Water-Supply and Irrigation Paper 188.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., 1910, *The ore deposits of New Mexico:* U. S. Geol. Surv. Prof. Paper 68.

Read, C. B., Wilpolt, R. H., Andrews, D. A., Summerson, C. H., and Wood, G. H., 1944, *Geologic map and stratigraphic sections of Permian and Pennsylvanian rocks of parts of San Miguel, Santa Fe, Sandoval, Bernalillo, Torrance, and Valencia Counties, North-Central New Mexico:* U. S. Geol. Surv. Oil and Gas Investigations Prelim. Map 21.

Slichter, C. S., 1905, *Observations on the ground water of Rio Grande Valley:* U. S. Geol. Surv. Water-Supply and Irrigation Paper 141.

Stephenson, F. V., 1945, *Devonian of New Mexico:* Jour. Geol., v. 53, no. 4.

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:* Am. Geophys. Union Trans., 16th Ann. Meeting, p. 519–524.

————————, 1938, *The significance and nature of the cone of depression in ground-water bodies:* Econ. Geol., v. 33, no. 8, p. 889–902.

Theis, C. V., Taylor, G. C., Jr., and Murray, C. R., 1941, *Thermal waters of the Hot Springs artesian basin, Sierra County, New Mexico:* N. Mex. State Engineer, Fourteenth and Fifteenth Bienn. Repts., p. 419–492.

Thompson, M. L., 1942, *Pennsylvanian system in New Mexico:* N. Mex. Inst. Min. and Technology, State Bur. Mines and Mineral Res. Bull. 17.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, G., 1946, *Geologic map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico:* N. Mex. Inst. Min. and Technology, State Bur. Mines and Mineral Res., and U. S. Geol. Surv. Oil and Gas Investigations Prelim. Map 61.

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