GROUND-WATER REPORT 7

Geology and Ground-Water Conditions in Eastern Valencia County, New Mexico

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STATES GEOLOGICAL SURVEY

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Abstract

Eastern Valencia County contains a part of the wide Rio Grande graben; part of the Lucero uplift, which bounds the graben on the west; and a small part of the Manzano Mountains, which bound the graben on the east. The graben contains several thousand feet of poorly consolidated sediments of the Santa Fe Group of middle (?) Miocene to Pleistocene (?) age. The Rio Grande occupies a valley entrenched into the Santa Fe in the central part of the graben. The 2- to 4-mile-wide flood plain of the river is underlain by river-deposited alluvium of Recent age that is as much as 120 feet thick in places. East of the Rio Grande valley in Valencia County are several terraces that represent successive stages of downcutting of the ancient Rio Grande from a high of about 340 feet above present river level. The lowermost two terrace levels, 160 and 120 feet above river level, respectively, are underlain by unconsolidated alluvial deposits that probably facilitate ground-water recharge.

The most extensive and thickest aquifer system in the area is in the sediments of the Santa Fe Group. The ground water occurs in the system under water-table conditions. A few wells near the Rio Grande valley yield as much as 1000 gpm (gallons per minute) from this aquifer system. However, most of the wells completed in the Santa Fe are stock wells that are designed to pump only a few gallons per minute. The potential discharge rates for the Santa Fe in most of eastern Valencia County thus have not been determined; it is probable that yields of at least 100 gpm can be obtained wherever the Santa Fe is thick, allowing deep well penetration below the water table.

Most of the large-capacity wells in eastern Valencia County are completed in the alluvial aquifer in the Rio Grande valley. Reported discharges from these wells are as much as 2500 gpm. The highest discharge measured during this study was 1840 gpm. Most of the wells are used to supply irrigation water to supplement the surface-water supply.

The alluvial aquifer is effluent in some places and influent in other places in the valley. Sources of recharge are irrigation water supplied in excess of the moisture-holding capacity of soils, infiltration losses from irrigation ditches and the river, and precipitation. Ground water is discharged by drainage ditches and evapotranspiration. The several recharging and discharging functions interact, and the result is a tendency toward a controlled water table in which seasonal and longer period water-level fluctuations are reduced or eliminated.

East of the Rio Grande valley the water table slopes toward the Rio Grande. West of the valley the water table also slopes generally toward the Rio Grande except along a water-table trough that enters the county from the north between the Rio Puerco and the Rio Grande. The trough joins the alignment of the Rio Grande in the vicinity of Belen. The

slope of the water table is much steeper near the margins of the graben than in the central part.

The average depth to water under the Rio Grande flood plain is seven to nine feet. On both sides of the valley, the depth to water increases owing to the sharp topographic rise of the valley walls. Eastward toward the Ojuelos fault and westward toward the Lucero uplift, the depth to water ranges from 100 to several hundred feet. Springs discharge along the Ojuelos fault and the fault zone bounding the Lucero uplift. Ground water descends from land surface to depths several hundred feet below land surface as it crosses the Ojuelos fault.

The amount of dissolved solids in ground water east of the axis of the water-table trough is low, and the water from this part of the area is potable. Westward from the axis of the trough, the dissolved solids increase as a result of recharge of very saline water from the Lucero uplift. Here the ground water is generally impotable. In the Rio San Jose valley in the northwestern part of the area, however, some potable water is obtained from the alluvium.

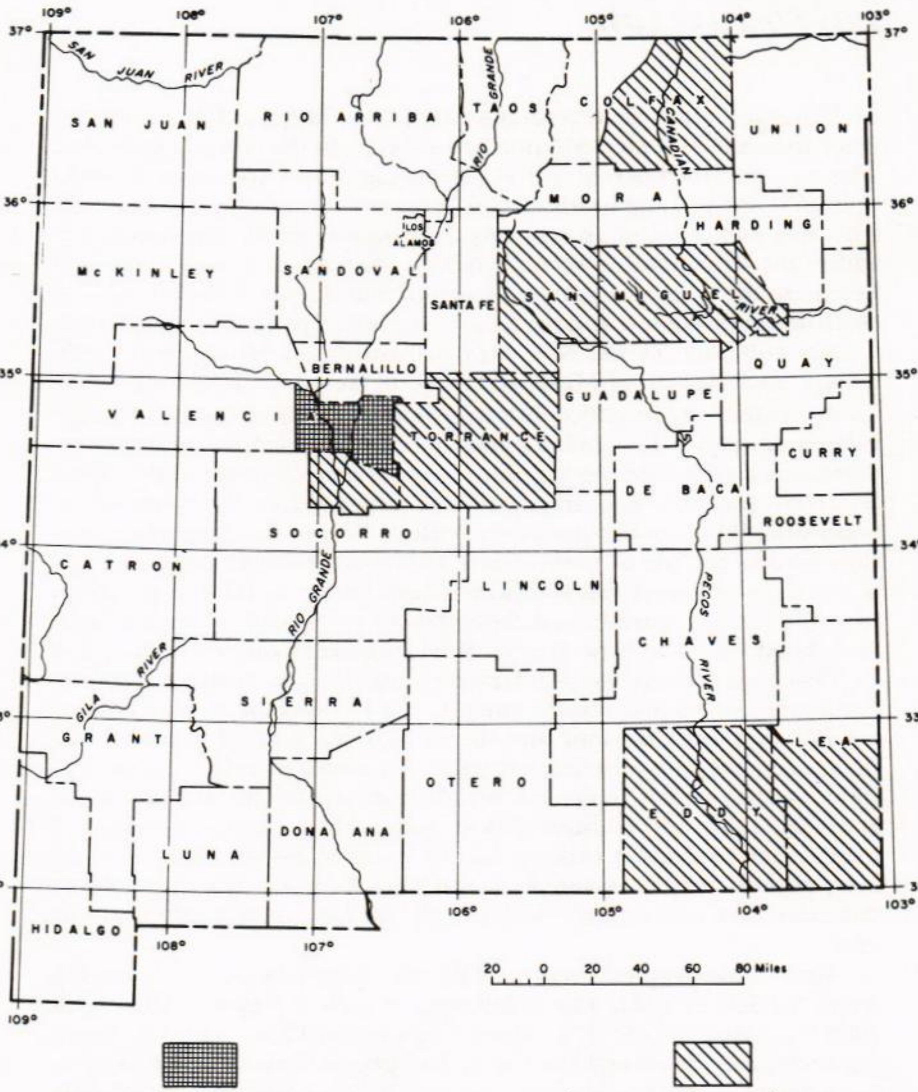
Introduction

Valencia County is in central-western New Mexico. The county extends from the Manzano Mountains westward to the Arizona state line. The area described herein is that part of the county lying east of longitude 107° 15' W., and south of U.S. Highway 66 and the Rio San Jose. The area comprises approximately 1100 square miles and lies mostly within the Rio Grande structural trough. The towns of Los Lunas and Belen are the principal centers of population. Figure 1 shows the area described in this report and the areas described in previous ground-water reports published by the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources Division.

Agriculture by irrigation historically is the basis of the Rio Grande valley's economy. The Indians irrigated land by simple surface-water diversions long before the Spanish explorers arrived in the early 1500's. Irrigation practices were improved and expanded by the Spanish colonists and, later, by the American settlers. Present-day irrigation practices involve the use of both surface and ground water. Ground water is the source of most drinking-water supplies for cattle and sheep on the range lands. Unrestricted development of ground water has been prohibited since the New Mexico State Engineer's order of November 29, 1956, that declared the Rio Grande Underground Water Basin. The declaration stated that surface waters of the Rio Grande in New Mexico are fully appropriated and that the surface and ground waters in the basin are intimately interrelated parts of a single supply. The ground water in the basin is under the jurisdiction and administration of the State Engineer, and additional development is permitted only to the extent that equivalent existing surface-water rights are retired. However, permits may be granted for watering livestock, for irrigation of not more than one acre for domestic use, and for certain other specific uses.

Most of the people in eastern Valencia County live in the inner valley of the Rio Grande. The population of eastern Valencia County in 1960 was about 16,100 (U.S. Bureau of Census, 1960). The two incorporated towns, Belen and Los Lunas, had populations of 5031 and 1186, respectively. The rest of the population is in small, unincorporated communities and on the many farmsteads in the valley. Los Lunas is the county seat.

Farming is restricted for the most part to the flood plain of the Rio Grande because of the ease of obtaining water for irrigation. According to an estimate by John R. Justice of the Bureau of Reclamation (oral communication, 1958), about 22,600 acres was farmed in 1956 in the valley between the south line of the Isleta Pueblo Grant and Bernardo, nine miles south of Valencia County. About half the agricultural pro-



Area covered by this report

Areas covered by previous reports

Figure 1

Areas in New Mexico described in ground-water reports published by the New Mexico Institute of Mining and Technology, State Bureau of Mines and Mineral Resources Division, in cooperation with the U.S. Geological Survey and the New Mexico State Engineer duction is alfalfa; the rest is mostly wheat, corn, pasturage, and silage. The average value of crops was about $98 an acre in 1956 (U.S. Bureau of Reclamation, 1957).

The Middle Rio Grande Conservancy District maintains and operates a system of diversion dams and ditches that supply surface water to most of the farms in the valley in Sandoval, Bernalillo, Valencia, and Socorro counties. The U.S. Bureau of Reclamation has estimated (1947) that production of an average annual yield of alfalfa (about 4 tons an acre) requires 52 inches of water. The weighted average requirement of water for all crops is 43 inches a year. Most of the water supplied by the Conservancy District is diverted from the Rio Grande; thus, low flows in the river during the irrigation season result in shortages. The Middle Rio Grande Conservancy District also maintains a system of drainage ditches, or "drains," in the flood plain of the river to prevent waterlogging of the farm land.

Between 1945 and 1957 many wells were drilled by farmers to supplement or replace the surface-water supply for irrigation. More than 80 irrigation wells were in use in the Rio Grande valley in Valencia County in 1957. Irrigating with water from wells is advantageous because the water supply is not dependent upon seasonal precipitation and because weed seeds are not brought into the fields as with surface water. Irrigating with ground water, however, requires that the farmer bear the expense of drilling, maintaining, and pumping a well.

This study of the ground-water resources in eastern Valencia County, New Mexico, was made by the U.S. Geological Survey in cooperation with the State Bureau of Mines and Mineral Resources Division of the New Mexico Institute of Mining and Technology, and the New Mexico State Engineer. The purpose of the study was to determine the general availability and chemical quality of ground water, to investigate the relationship between geology and the occurrence of ground water, and to determine the effect of present water usage on the hydrology of the Rio Grande valley. General areas of recharge and discharge were determined, information on the quantity and types of ground-water use in the area was obtained, and factors influencing ground-water movement were studied.

The field work upon which this report is based was started in February 1956 and continued, with occasional interruptions through December 1957. The investigation included locating and describing all irrigation, municipal, industrial, and stock wells in the area and measuring water levels in these wells where possible. A few domestic wells were also investigated in localities where supplemental information was needed. Samples of water from selected wells throughout the area were collected for chemical analysis. Geologic maps were spot-checked in the field. The geologic map accompanying this report is largely a compilation of these maps. Special attention was given to the geology of the

Santa Fe Group and the alluvium of Quaternary age in the field because of their importance as aquifers.

Fundamental data from wells are included in Appendixes A and B; data from springs are included in Appendix C. Chemical analyses of ground water and surface water are recorded respectively in appendixes D and E.

Topographic maps prepared by the U.S. Geological Survey on a scale of 1:24,000 are available for all but the western part of the area. These maps have been published since 1951. Recent topographic maps on a scale of 1:62,500 are available for the western part of the area.

The earliest publication on the geology and ground-water resources of the Rio Grande valley was written by W. T. Lee (1907). A report by Darton (1928) described the geologic structure and stratigraphy in the vicinity of the Rio Grande. Various aspects of the geology of the area have since been described by Bryan and McCann, Read et al., Kelley and Wood, Parry Reiche, and J. T. Stark. The results of a reconnaissance of the water resources of the upper Rio Grande, which includes the reach of the river in Valencia County, were reported in the Rio Grande Joint Investigation, released by the National Resources Committee in 1938. The section of that report on ground water in the middle Rio Grande valley was prepared by C. V. Theis.

Officials of the U.S. Bureau of Reclamation, the United Pueblos

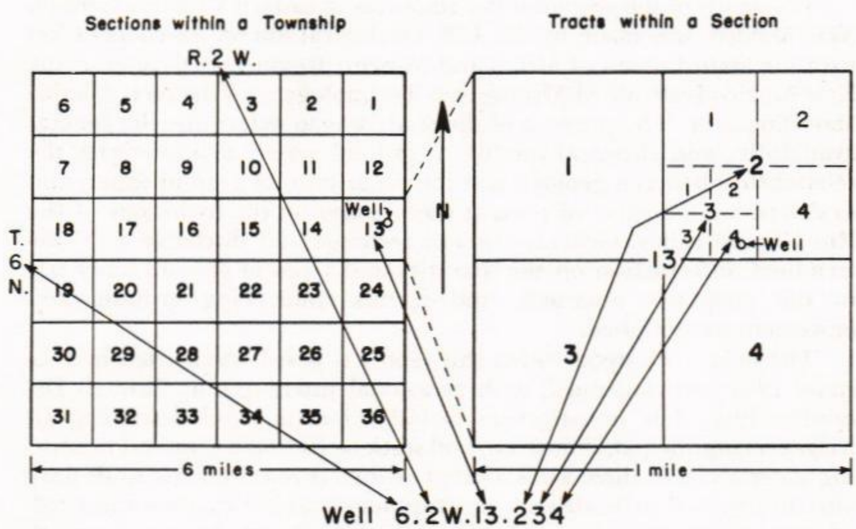


Figure 2

SYSTEM USED BY THE U.S. GEOLOGICAL SURVEY TO NUMBER WATER WELLS AND SPRINGS IN NEW MEXICO

Agency of the U.S. Bureau of Indian Affairs, and the Soil Conservation Service supplied well logs, water-level measurements, and data on irrigation in the Rio Grande valley. Their cooperation is gratefully acknowledged. Mr. Arthur Bibo, Valencia County rancher, supplied much interesting and valuable historical information on the ranching country west of the Rio Puerco. Special thanks are extended to the many farmers, ranchers, and well drillers who supplied information on wells in the area.

WELL-NUMBERING SYSTEM

The system of numbering wells and springs in this report is that used by the U.S. Geological Survey for numbering water wells in New Mexico; it is based on the common subdivisions in sectionized land. The system is illustrated in Figure 2. Each well and spring is assigned a number that is divided into four segments separated by periods. The first segment denotes the township north of the New Mexico base line, the second segment denotes the range cast or west of the New Mexico principal meridian, and the third segment denotes the section. The letter "W" is added to the second segment of the number if the well is west of the New Mexico principal meridian; no letter is used if the well is east of the principal meridian.

The fourth segment of the well number consists of three digits which denote the particular 10-acre tract in which the well is located within the section. The section is quartered, and the quarters are numbered in normal reading order. The first digit locates the well within one of these quarters. The procedure is then repeated within the 160-acre tract to obtain the second digit. The second digit locates the well in the proper 40-acre tract. The process is repeated once more to determine the third digit, which indicates the 10-acre tract containing the well. Where more than one well occurs in a 10-acre tract, second and subsequent wells are identified by adding "a", "b", etc. to the well number. If the actual location of the well cannot be determined to within a 10-acre tract, a zero is used for the third digit; similarly, if it cannot be determined to within a 40-acre tract, a zero is used for the second digit.

Less than half the area investigated has been sectionized. To locate wells by the numbering system described and to facilitate the location of other features, section lines were projected from the sectionized part of the area into the un-sectionized part. The projected lines are shown by dashes on maps accompanying this report.

Physiography

The Manzano Mountains on the east and the Lucero uplift on the west bound a physiographic trough more than 35 miles wide in eastern Valencia County (fig. 3). Fenneman (1931) assigned the trough

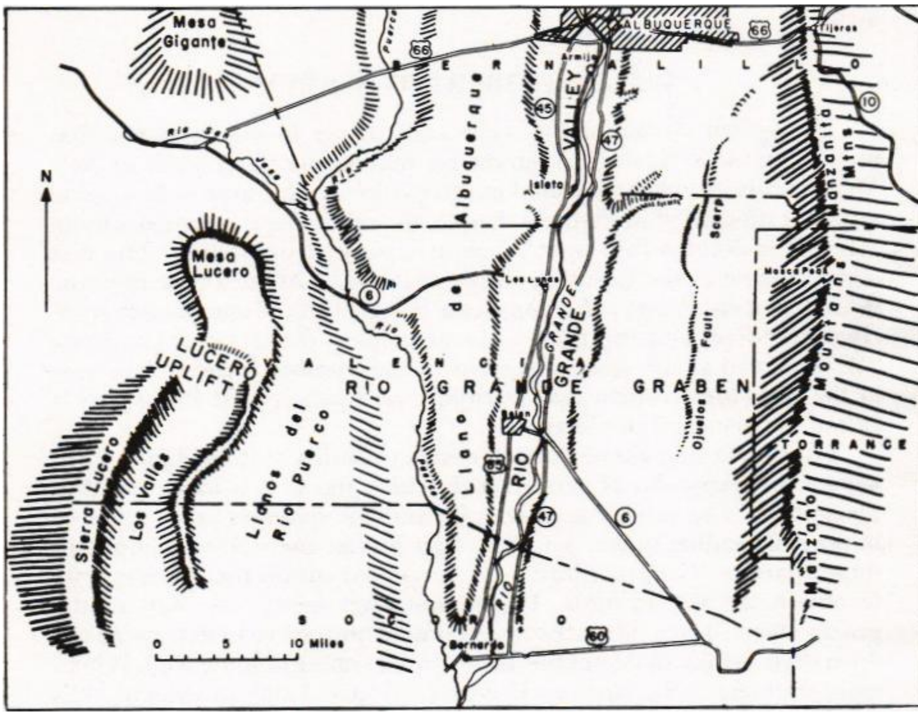


Figure 3

PHYSIOGRAPHIC DIAGRAM OF EASTERN VALENCIA COUNTY AND VICINITY

and the bordering Manzano Mountains to the Mexican Highland section of the Basin and Range province. The Lucero uplift he assigned to the Datil section of the Colorado Plateau province. On the east side of the trough the land surface slopes downward from the foot of the mountains to the incised inner valley of the Rio Grande. Similarly, on the west side of the trough the land surface slopes toward the incised inner valley of the Rio Puerco. The Rio Grande and the Rio Puerco are separated by the gently rolling, steep-sided upland of the Llano de Albuquerque. Throughout this report the names "Rio Grande valley" and "Rio Puerco valley" are used in a restricted sense to identify only the incised inner valleys of these streams.

The rugged west face of the Manzano Mountains has a topographic relief of about 4000 feet. The bajada at the foot of the mountains consists of well-developed, coalescing, alluvial fans. The heads of many of the fans have been somewhat dissected by erosion, probably as the stream channels within the mountains approached a graded profile. *(See* Blissenbach, 1954.) A mile or more away from the foot of the mountains, deposition on the bajada has resulted in a nearly featureless slope. However, five to seven miles west of the mountain front, the scarp of the Ojuelos fault locally forms a prominent break in the slope (pl. 1). An old erosion surface is preserved on the top of the uplifted block. Erosion in arroyos has worked head ward into the uplifted block only one to one and a half miles.

West of the Ojuelos fault the land surface slopes smoothly downward for about four miles. The few small stream channels on the slope are braided and are not incised below the general land surface. The channels become smaller to the west and ultimately disappear. Locally, gravel caps east-west, elongate, general rises that are as much as 20 yards wide and a foot or more high. These are old stream channels that stand above the general land surface because of the protection afforded by the gravel from erosion by wind and sheet wash.

The land surface immediately east of the Rio Grande valley, in a strip several miles wide, is gently rolling and has slight relief. The topography consists of wide, very shallow valleys with a general north-south alignment; large, shallow, closed depressions; and wide, poorly defined terraces. Caliche, a soil or sediment layer cemented by calcium carbonate, underlies much of the surface soil and the local cover of fixed sand dunes. These features are probably remnants of channels that once contained the river and are evidence that the ancestral Rio Grande occupied this part of the physiographic trough. Several levels of terrace remnants are recognized (fig. 4).

The flat upper surface of each terrace is the area designated in Figure 4. The slopes between the terraces are not patterned. The highest terrace preserved in Valencia County is 340 feet above the present level of the Rio Grande. A 370-foot remnant is preserved east of the river in southern Bernalillo County. The river gradient during establishment of at least the lowermost four terraces was about the same as that of the river at present.

The two lowest terraces (120 feet and 160 feet above the present level of the river) are underlain by deposits of river-laid alluvium. No evidence is present to indicate that the higher terraces ever had more than a veneer of alluvium over the older sediments. The alluvium under the 160-foot terrace is at least a few tens of feet thick. The alluvium under the 120-foot terrace is, at least locally, more than 130 feet thick.

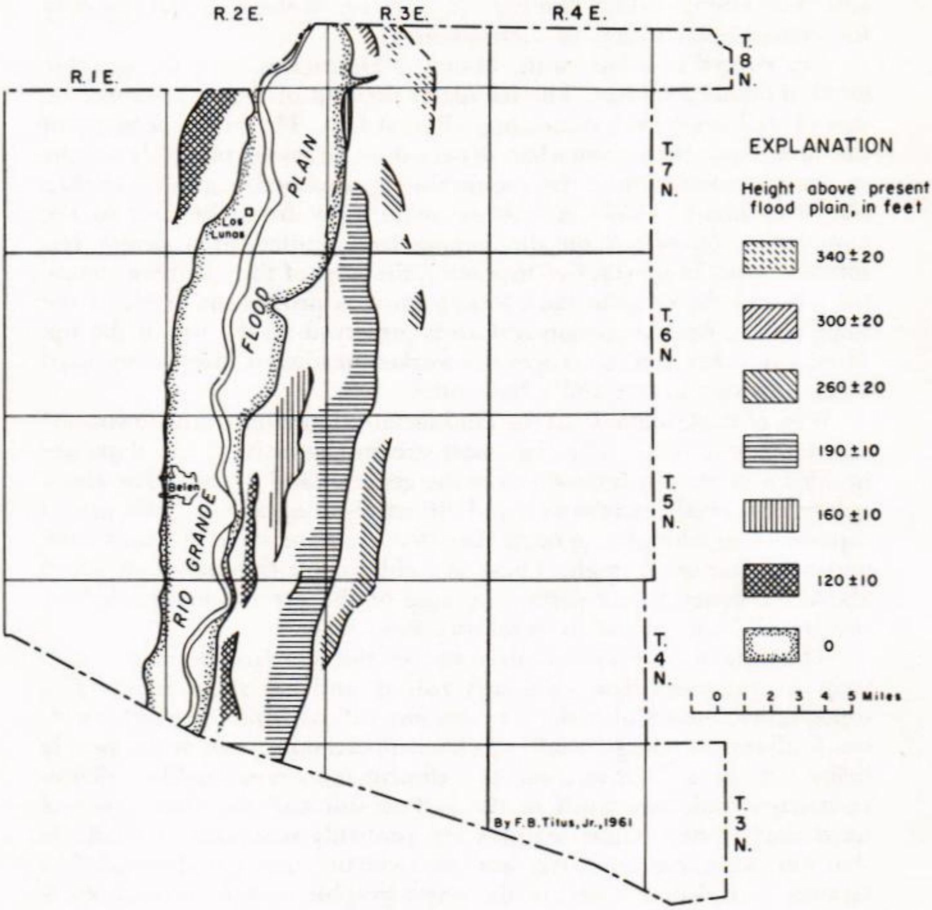


Figure 4
TERRACE LEVELS REPRESENTING PROBABLE CHANNEL REMNANTS OF THE ANCIENT RIO GRANDE IN VALENCIA COUNTY, N. MEX

The present flood plain of the Rio Grande is underlain by more than 100 feet of alluvium. The thickness of the alluvium underlying the present Rio Grande flood plain and of the alluvium of the two lower terraces is obviously greater than could be scoured and filled during even maximum floods. It is therefore concluded that in establishing each of the three latest channel stages, the river cut well below the channel level now recognized and then partly refilled the valley with alluvium.

Bryan stated in 1938 (p.218) that the present Rio Grande channel and flood plain had ". . . been rising in the last few years. . . ." Happ (1948) found that the Rio Grande floodway between Cochiti (40 miles north of Albuquerque) and San Antonio (10 miles south of Socorro) aggraded at a rate of about one foot in 10 to 12 years in the period between 1917-18 and 1941. It should not be concluded, however, that the entire thickness of alluvium in the present valley has been deposited at a rate of one foot in 10 to 12 years. This rate is probably much higher than the long-term average. It would indicate that when Coronado was exploring this part of the Rio Grande valley in 1540 the flood plain was 35 to 40 feet lower than at present—a condition not supported by archaeological evidence. The aggradation possibly may be related to extreme erosion of arroyos in the southwest that began about a hundred years ago. *(See* Happ, 1948; Bryan, 1928.) The rate of aggradation in the floodway between the levees may be greater than it would be if the river were free to aggrade the entire natural flood plain beyond the levees.

Hell Canyon Wash near the Bernalillo County line is the only arroyo in Valencia County that extends from the Manzano—Manzanita mountain front to the inner valley of the Rio Grande. Other arroyos draining the west side of the mountains disappear on the slope between the mountain front and the valley. The Hell Canyon drainage area in the Manzanitas in Bernalillo County is larger than that of any of the other arroyos.

The Llano de Albuquerque, a long, narrow upland west of the river, separates the valleys of the Rio Grande and the Rio Puerco in Valencia and Bernalillo counties. The surface of the Llano is about 400 feet above the level of the flood plain of the Rio Grande at the south boundary of Valencia County, and north of El Cerro de Los Lunas it is about 450 feet above the flood plain.

The Llano de Albuquerque has a persistent caliche cap two to four feet thick that tends to protect the surface from erosion. Wind-blown sand covers large parts of the Llano and has been distributed across it in streaks and bands by strong southwest winds. A north-south line of recent cinder cones several miles long lies across the Valencia—Bernalillo county line on the Llano. Basalt flows associated with the cones cover an area of about ten square miles in Valencia County and an equal area in Bernalillo County.

The margins of the Llano in most places are cut by steep-walled gullies. The gullies and intervening spurs along most of the margin are not oriented parallel to the general slope off the Llano as would be expected; they have a strong preferred orientation to the southwest on both the east and west sides of the Llano. The southwest lineation of the spurs parallels the lineation of the streaks of wind-blown sand. The southwest winds have evidently influenced the direction of development of the gullies. Drainage of surface water off the Llano in Valencia

County is insignificant except in a minor tributary arroyo to the Rio Puerco in T. 7 N., R. 1 W. Most of the precipitation on the Llano is absorbed by the soil. Heavy rainfall may produce local sheet wash, but only occasionally does water collect in topographic depressions.

The surface of the Llano de Albuquerque, the Ortiz erosion surface, developed in late Pliocene to Pleistocene time according to Bryan and McCann (1936). Elongate depressions and shallow valleys that are preserved on the erosion surface in Valencia County suggest that at the time the surface was established the local drainage was southward.

The Rio Puerco, one of the principal western tributaries of the Rio Grande, flows generally southward across Valencia County and joins the south-southeastward flowing Rio Grande in Socorro County about 12 miles south of Valencia County.

The Rio Puerco valley in eastern Valencia County has a broad flat floor into which the Rio Puerco was incised 40 feet or more in the latter part of the seventeenth century. The interesting historic evidence of changes in the channel of the Rio Puerco has been described by Kirk Bryan (1928). The deep erosion has not exposed the base of the valley alluvium. Alluvium deposited by the Rio Puerco before the recent down cutting is well exposed in the near-vertical walls of the channel.

The east side of the Rio Puerco valley rises sharply to a break in slope at the edge of the Llano de Albuquerque known as the Ceja del Rio Puerco. The slope of the west side of the valley is not so steep as the slope of the east side.

West of the Rio Puerco valley the land surface slopes upward toward the Lucero uplift. In the southern part of Valencia County and in the adjacent part of Socorro County, the slope is gentle and nearly constant for many miles. This sloping plain has been called the Llanos del Rio Puerco. Several arroyos drain toward the Rio Puerco across this surface, and some, such as Arroyo Comanche, have cut valleys several tens of feet below the general surface.

H. E. Wright (1946) has mapped remnants of several erosion surfaces in this area. He recognized three surfaces in the Llanos del Rio Puerco. These are 60 feet, 175 feet, and 400 to 500 feet above the present grade of the major drainage.

An area of badlands topography comprising more than ten square miles is roughly centered in sec. 36, T. 6 N., R. 2 W., on the southwest flank of the Gabaldon anticline. This is the "Gabaldon Badlands" described by Wright. Here a thick section of evenly bedded sediments of the Santa Fe Group dipping 10 to 15 degrees to the west is exposed. The strata have generally weathered to rounded forms, with the more resistant beds leaving slabby blocks.

Two prominent masses of volcanic rock form hills which are about a mile apart and which lie mainly in the northeast part of T. 6 N., R. 2 W. The hills consist of basaltic sills and flows interbedded in the Santa Fe Group (Wright).

The west margin of the Rio Grande physiographic trough in T. 6 and 7 N. coincides with a fault zone that approximately follows the west side of R. 2 W. The margin of the uplifted block west of the fault is marked by extremely rugged topography and high relief. The land surface rises more than 1200 feet in two to three miles from the surface of the trough to the flat top of basalt-capped Mesa Lucero. The slope has been deeply dissected by erosion.

Farther south, at Gray Mesa, the trace of the fault zone swings southwest across T. 5 N., R. 3 W., then turns south again in secs. 6 and 7, T. 4 N., R. 3 W. near the Socorro County line. Here the uplifted block forms a large, west-dipping hogback. West of the hogback differential erosion of shale has formed the north-northeast-trending Los Valles. Los Valles is an elongate valley which is roughly divided into an eastern and a western section by low cuestas formed from sandstone beds interlayered with the shale. The sheer face of Sierra Lucero, a spectacular wall 1000 to 1500 feet high, forms the west side of Los Valles. Nearly flat lying beds of sedimentary rocks crop out in the east face of the Sierra and basalt flows cap the higher parts.

Mesa Lucero, at the north end of Sierra Lucero, occupies an area of a little more than 13 square miles in T. 7 N., R. 3 W. The flat top of the mesa is capped by a basaltic lava flow. Large landslide blocks of basalt cover the north and west slopes, and slides consisting of long, thin slivers of basalt are particularly well developed on the west slope of the mesa.

In summary, the physiographic trough of the Rio Grande in eastern Valencia County is subject to an interesting combination of erosional and depositional conditions. The surface of the Llano de Albuquerque is protected from erosion by a resistant cap of caliche and from inundation with additional sediment by the position of the valleys of the Rio Grande and the Rio Puerco. The terraces east of the Rio Grande and west of the Rio Puerco signify downcutting of the rivers in stages. Most of the terraces are underlain by layers of caliche which formed during one or more periods. The Manzano and Manzanita mountains and the Sierra Lucero continue to contribute sediment to the trough. Sediment that originates west of the Rio Puerco is transported to the Rio Puerco and thence southward out of Valencia County. East of the Rio Grande, however, the only stream course in the county that extends from the mountains to the Rio Grande is Hell Canyon Wash. The sediment that is contributed to the trough from the Manzano and Manzanita mountains, except that being transported down Hell Canyon Wash and into the Rio Grande, comes to rest between the foot of the mountains and the ancient channel remnants east of the river.

General Geology

Eastern Valencia County is dominated structurally by the Rio Grande graben, a broad, down-faulted trough that is roughly coextensive with the physiographic trough. Complex faulting in Laramide time, in late Tertiary time, and continuing into Recent time, has lifted the Manzano Mountains on the east and the Lucero region on the west. The intervening Rio Grande graben has been depressed and probably intensely faulted and then covered with several thousand feet of terrestrial sediment. The terrestrial sediment has been subjected locally to volcanic activity and minor folding and faulting.

The rocks that crop out in the uplifted blocks on each side of the graben are of igneous, metamorphic, and sedimentary origin and mostly range in age from Precambrian to Cretaceous (pl. 1). A small area on top of Sierra Lucero is capped by basalt of Tertiary age; basalt of Quaternary age covers Mesa Lucero and part of the valley of the Rio San Jose northwest of Mesa Lucero. Each of the major rock classes has significance in the geologic control of ground water in the area.

The sediment in the structural trough consists mainly of clastic material that has been transported into the trough from bordering highlands. Most of this material was deposited during two periods of sedimentation in Tertiary time; material also was deposited in Quaternary time. The most recent deposition has been in the valleys of the Rio Grande and the Rio Puerco, which are underlain by alluvium of Quaternary age that in places is more than 100 feet thick. The main tributaries of these streams also have alluvium in their channels.

STRUCTURE

The principal deformation exposed in eastern Valencia County is in the margins of the uplifts that bound the Rio Grande graben. Here major faults and folds of more than one age roughly parallel the edge of the graben. Only a few faults and folds occur in sediments of Tertiary and Quaternary age within the graben. Rocks of pre-Tertiary age in the down dropped block of the graben are likely to be complexly faulted and folded; if so, the folds and faults are, of course, concealed by the thick cover of younger sediment.

The complex structure of the Manzano Mountains will not be described in detail in this paper. For such a description the reader is referred to publications by Read et al. (1944), Reiche (1949), and Stark (1956).

A normal fault of great magnitude lies along the west side of the Manzano Mountains, probably near their foot. This fault has been inferred by all previous geologic investigators, although it is nowhere exposed. Reiche (1949, p. 1203) stated that the fault is ". . . unmistakably implied by a battered fault scarp 1,000 feet high . . ." along the north Manzano Mountains. He thought that this inferred fault might connect to the north with a fault in secs. 20, 29, and 32, T. 8 N., R. 5 E. (pl. I), which bounds the Manzanita Mountains. According to Stark, a vertical displacement of 7400 feet at the mountain front is possible, based on the stratigraphic relief between the Paleozoic sedimentary rocks that crop out a few miles west of the mountain front and those that crop out on top of the mountain.

A second normal fault having a large displacement lies three to six miles west of the front of the mountains. This is the Ojuelos fault named by Reiche for the three springs called Los Ojuelos that lie on the fault in sec. 20, T. 6 N., R. 4 E. This fault is best exposed in the Los Ojuelos district in T. 5 and 6 N., R. 4 E., where it is marked by a west-facing scarp about 120 feet high. Sedimentary rocks of Permian and Triassic age crop out along the scarp and on the uplifted block east of the scarp. The maximum width of the outcrop belt is about two miles. East of this belt these rocks are covered by a wedge of Cenozoic sediment which thickens toward the mountains. Data reported by the U.S. Bureau of Indian Affairs for a water well in the NE v_iNW1/4 sec. 5, T. 7 N., R. 5 E. (only a few hundred feet outside of Valencia County) indicate that at this location, a mile west of the mountain front, the sediment wedge is about 300 feet thick.

The latest movement on the fault in the Los Ojuelos district was about 25 feet, which is indicated on the uplifted block by the height of flat valley floors that as yet are little entrenched (Reiche). An erosional bench or terrace preserved locally about 60 feet above the surface of the downthrown block and another bench 120 to 140 feet above the down-thrown block indicate two earlier periods of uplift. The youthfulness of the dissection of the scarp would suggest that movement has taken place in Recent geologic time (Reiche).

Several long, narrow mesas project westward for one to more than three miles from the mountain front in the northeast and central parts of T. 5 N., R. 4 E. The mesas consist of Cenozoic terrestrial sediments similar to those deposited along the entire mountain front. Their upper surface, 100 to 200 feet above the bajada, is smooth and slopes downward to the west at an angle somewhat greater than the general slope of the bajada.

For several miles south of the mesas, and south of the end of the Ojuelos fault scarp, the arroyos at the heads of the alluvial fans appear to be somewhat more deeply incised than do arroyos to the north and south.

The fingerlike mesas and the incised arroyos suggest that in the vicinity of the south end of the Ojuelos fault scarp the bajada was uplifted and tilted to the west concomitant with recent movement on the Ojuelos fault. The mesas are remnants of the uplifted surface that have not yet been removed by the erosion which has produced the present surface. The general westward migration of the successive stages of the ancient Rio Grande shown on Figure 4 suggest that tilting of the land surface was not restricted to the south end of the Ojuelos fault scarp, but affected at least the east half of the Rio Grande trough in eastern Valencia County.

North of the vicinity of sec. 8, T. 6 N., R. 4 E., the trace of the Ojuelos fault is indistinct in Valencia County. Its location is probably marked by a slight break or increase in slope that follows a somewhat sinuous path northward (pl. 1). Two branches of the fault are poorly exposed in the walls of Hell Canyon Wash. Just north of Valencia County, strata of Permian age crop out in the uplifted eastern block of the fault, as in the Los Ojuelos district to the south.

The total displacement on the Ojuelos fault is not known. An oil-test hole, the Grober No. 1 Fuqua, was drilled in 1940 to a depth of 6300 feet in the NE1/4 NWIANE1/4 sec. 19, T. 5 N., R. 3 E., about six miles west of the trace of the Ojuelos fault. (A log of the hole is on file at the State Bureau of Mines and Mineral Resources Division of the New Mexico Institute of Mining and Technology.) At least the upper 4550 feet of this hole are in sediments of Tertiary age (R. L. Bates *in* Reiche, 1949). If the Tertiary strata are nearly flat-lying between the fault and the test hole, displacement on the fault is at least a few thousand feet.

Deformation of rocks of the Santa Fe Group within the Rio Grande graben in most of eastern Valencia County has not been great. Where dips can be measured on the Santa Fe between the Rio Grande and the Ojuelos fault, the beds are flat-lying or dip to the west at angles of only a few degrees. Under the Llano de Albuquerque the strata of the Santa Fe Group are in most places nearly flat. An exception is on the west flank of El Cerro de Los Lunas, where the strata clip away from the volcano as much as 20 degrees. A little more than a mile to the west of the volcano the dip is almost horizontal.

A small north-northeast-trending structural feature is poorly exposed east of Isleta Pueblo in sec. 19, T. 8 N., R. 3 E., partly in Valencia County and partly in Bernalillo County. The structure is indicated by a thin, calcareous sandstone which caps a low ridge about three quarters of a mile long. The sandstone dips to the east at about 10 degrees near the north end of the ridge and 15 degrees at the south end. The southern end of the feature has been truncated by erosion. The deformation is probably related to the volcanism to the northwest in Bernalillo County.

The Gabaldon anticline, in which strata of the Santa Fe Group have been deformed, has been described in detail by H. E. Wright. According to him, the anticline trends northwest from sec. 32, T. 6 N., R. 1 W. to sec. 11, T. 6 N., R. 2 W., and plunges gently to the northwest. The structure is asymmetric, with dips as great as 35 degrees on the northeast flank and 10 to 15 degrees on the southwest flank. On the southwest flank of the anticline, 4800 feet of Santa Fe sediment are exposed, according to Wright. Most of the northeast flank is buried under the alluvium of the Rio Puerco valley. The anticline is cut by several faults, most of which are transverse to the alignment of the anticlinal axis. Wright stated that on the largest fault, which is in sec. 35, T. 6 N., R. 2 W., the southeast block has been dropped down 1500 feet relative to the northwest block.

The following description of the geologic structure of the Lucero region was drawn mostly from Kelley and Wood (1946).

The zone of deformation that bounds the Lucero uplift and extends beyond it to the north and south was named the Rio Puerco fault zone by Kelley and Wood. In the southern part of Valencia County, the east edge of the Lucero uplift is marked by a major thrust from the west which Kelley and Wood named the Comanche thrust fault. In the northern part of the county, the margin of the uplift is marked by normal faults. The thrust faults and the normal faults were superimposed on, and have cut the east limb of, the Lucero anticline, which trends generally north-northeast. Dips on the west limb of the anticline range from 2 degrees to about 10 degrees.

The sinuous trace of the Comanche thrust fault is probably due to undulations in the fault plane. Kelley and Wood thought that the dip of the thrust plane in general may be flatter than they could observe in exposures. Movement on the Comanche fault in Valencia County may have been a few thousand to several thousand feet. The Madera Limestone is the lowermost sedimentary unit that is exposed on the thrust block in most places (fig. 5). Extensive deposits of travertine cover most of the trace of the Comanche thrust fault in T. 4 and 5 N. and locally extend more than a mile east of the fault. In T. 6 N., where the outcrops are not covered by travertine, the Madera can be seen lying on the upper part of the Yeso Formation.

In T. 7 and 8 N., several normal faults cut the Paleozoic and Mesozoic strata along the east side of the Lucero uplift. The faults generally trend northward. In T. 7 N., travertine covers many of the fault traces. The normal faults, which are mostly younger than the thrust, may have originated during a period of relaxation after the thrusting. Renewed movement on the normal faults in middle Miocene time, during formation of the Rio Grande graben, probably caused most of the displacement now evident. The faults west of the Sierra Lucero and in Los Valles may be of the same age as the normal faults on the margin of the Lucero uplift.

The Santa Fe fault, which trends northward through the western part of T. 7 N., R. 2 W., is post-Santa Fe in age. Rocks of the Santa Fe Group east of this fault have been dropped down relative to the pre-Tertiary rocks west of the fault. Minor folding in the rocks of the Santa Fe Group near the fault is associated with displacement on the fault. The post-Santa Fe displacement on the Santa Fe fault may be due to rejuvenation and possibly reversal of movement on an older buried fault plane (Kelley and Wood).

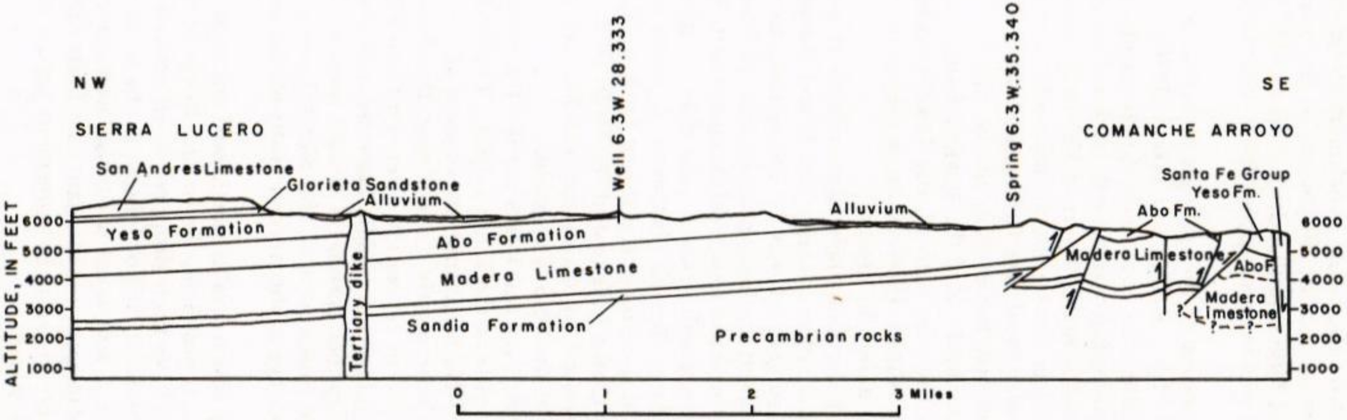


Figure 5

GENERALIZED SECTION ACROSS THE LUCERO UPLIFT IN VALENCIA COUNTY, N. MEX.

Well and spring locations projected to line of section. Modified from Kelley and Wood (1946, section E-E′).

The deformation within and bounding the Rio Grande graben probably took place during several distinct time intervals. During the Laramide revolution the Lucero anticline developed and was broken on the east by the Comanche thrust fault. Also during the Laramide, thrusting to the east occurred in the present locality of the Manzano Mountains. Normal faults developed in the Lucero area, probably during the period of relaxation after thrusting. Commencing in middle Miocene time, the normal faults along the margin of the Lucero uplift were rejuvenated and new faults were formed that dropped down the west side of the Rio Grande graben. The east side of the graben was dropped along faults ". . . near, or within a few miles to the west of, the present Ojuelos fault . ." (Reiche, p. 1210); presumably this faulting also commenced in middle Miocene time. Later, probably in Pliocene time, the inferred normal fault west of the Manzano Mountains developed, uplifting the mountains relative to the Rio Grande graben (Reiche). The Ojuelos fault also developed in Pliocene time. Contemporaneous movement may have taken place along the west side of the graben. Toward the end of deposition of the Santa Fe Group, compressional forces formed the Gabaldon anticline, and minor folds were developed in the center of the Rio Grande graben. Deformation of strata of the Santa Fe Group in the center of the graben was associated with volcanism. The scarp of the Ojuelos fault indicates renewed movement on the fault in Recent time.

ROCKS AND THEIR WATER-BEARING PROPERTIES

Rocks exposed in eastern Valencia County range in age from Precambrian to Recent. All major geologic time intervals are represented except for the Cambrian through the Mississippian periods. The rocks of Precambrian age are igneous and metamorphic. Rocks of late Paleozoic, Mesozoic, and Cenozoic ages are mostly sedimentary. Outcrops of rocks of pre-Cenozoic age are restricted to the uplifts that bound the Rio Grande graben and to the scarp of the Ojuelos fault. Rocks of Cenozoic age are restricted for the most part to the Rio Grande graben. In general these sediments are unconsolidated or poorly lithified. They are more permeable than the older rocks and constitute the most important aquifer system in the area. The older rocks which crop out on both sides of the graben are, in general, not highly productive aquifers. Hydrologically they are noteworthy, however, because they are important sources of recharge and as such affect the quantity and the chemical quality of ground water in sediments of Cenozoic age in the trough.

PRECAMBRIAN ERA

Rocks of Precambrian age crop out over most of the west face of the Manzano Mountains. They consist principally of granitic igneous rocks and metamorphosed sedimentary rocks that are now schist, gneiss, and quartzite. *(See* Reiche, 1949, and Stark, 1956.) The rocks are not differentiated on the geologic map (pl. 1). All these rocks, whether they be igneous or metamorphic, arc relatively impermeable, and ground water can move only through fractures and openings produced by weathering. Granitic rocks are particularly susceptible to relatively deep weathering. In the weathered zone chemical erosion has removed some of the rock material, forming small cavities and fissures between grains of more resistant material, and thus has increased the permeability.

Several small springs in rocks of Precambrian age, along the west side of the Manzano Mountains, bring ground water to the surface. Bustamonte Spring (3.4.11.144) is on the north side of a small, alluvium-filled re-entrant. The spring is at the contact between quartzite and granite and the alluvium. Water issues from a pit that has been dug into the alluvium, but the source of the water is probably from fractures in the granite and quartzite. No wells are known to produce water from the rocks of Precambrian age in eastern Valencia County.

One small outcrop of Precambrian granite occurs on the Comanche thrust fault in the Rio Puerco fault zone in secs. 13 and 24, T. 5 N., R. 3 W. The size of the granitic body probably increases with depth.

PENNSYLVANIAN SYSTEM

Sandia Formation

The oldest sedimentary rocks that have been described in eastern Valencia County belong to the upper clastic member of the Sandia Formation of Early Pennsylvanian age. The Sandia Formation consists characteristically of alternating irregularly bedded sandstone, coal, carbonaceous shale, and occasional impure beds of limestone, divided into a discontinuous lower limestone member and an upper clastic member (New Mexico Geological Society, 1952, p. 107-108). In the Rio Grande graben south of Valencia County, the Sandia Formation is as much as 370 feet thick. The clastic member crops out in small areas on each side of the Rio Grande trough. In the southeastern part of the county the clastic member crops out under the lowermost unit of the Madera Limestone (Wilpolt et al., 1946). In the Lucero area about 100 feet of coarse-grained sandstone, assigned by Kelley and Wood to the Sandia Formation, crops out above Precambrian rocks in secs. 13 and 24, T. 5 N., R. 3 W. The formation has not been utilized as an aquifer in eastern Valencia County. It would probably yield water to wells in most places where it occurs in the subsurface. Here, however, it is commonly overlain by a thick sequence of Madera Limestone from which small quantities of water usually may be obtained.

Madera Limestone

The marine limestone and interbedded clastic rocks of the Madera Limestone crop out extensively on both sides of the Rio Grande graben.

The formation caps the Manzano and Manzanita mountains and forms the dip slope on the east side of the mountains. On the west side of the graben in Valencia County, the Madera crops out along the Rio Puerco fault zone from the Socorro county line northward for about 15 miles. The prominent hogback along the Comanche thrust fault, which forms the east wall of Los Valles, is composed of Madera Limestone. The formation is of Middle and Late Pennsylvanian age.

East of the Rio Grande graben the Madera Limestone has been divided into two members: the lower gray limestone member, which is as much as 850 feet thick, and the upper arkosic limestone member, which is as much as 1200 feet thick (New Mexico Geological Society, p. 108). West of the graben the formation consists of three members. In ascending order these are the Gray Mesa Member, as much as 900 feet thick; the Atrasado Member, as much as 800 feet thick; and the Red Tanks Member, as much as 300 feet thick (New Mexico Geological Society, p. 115). The lower and upper members of the Madera in the Manzano Mountains are approximately correlative to the Gray Mesa and Atrasado members in the Lucero area (New Mexico Geological Society). The Red Tanks Member is transitional between the marine limestone of the Madera and the terrestrial red shale and siltstones of the overlying Abo Formation. It occupies a position equivalent to that of the Bursum Formation, which occurs east of the graben.

The lowermost member of the Madera Limestone consists of thin-bedded to massive, gray, cherty limestone, containing minor amounts of interbedded calcareous shale. The upper member of the Madera (the Atrasado Member in the Lucero area) consists of thin- to medium-bedded gray limestone, containing less chert than the underlying member and more interbedded shale and sandstone. In the Manzano Mountains the upper member of the Madera is arkosic.

The Madera Limestone yields small amounts of water to a few wells and springs in eastern Valencia County. Movement of ground water is inferred to be through fractures, joints, and openings along the bedding plains inasmuch as little movement could occur in the dense limestone, tight shale, and well-cemented sandstone.

One spring (3.5.30.100) discharges very small amounts of water from the Madera in the southeastern part of the county. Other wells and springs that yield water from the Madera in eastern Valencia County are on the west side of the graben in Los Valles and along the Comanche thrust fault. In Los Valles two wells (5.3W.20.232 and 5.3W.20.333) yield small amounts of water from the Madera Limestone. On the south end of Gray Mesa, well 5.3W.28.143 also yields water from the Madera. Several water gaps breach the hogback that separates Los Valles from the Rio Grande physiographic trough. In each water gap there is a spring or a large salt flat. *(See* springs 4.3W.6.444, 5.3W.29.441, and 6.3W.35.340.) The discharge from spring 6.3W.35.340 has been estimated to be 30 gpm. Ground water discharging from these springs comes from the west and moves up dip through the Madera.

PERMIAN SYSTEM

Bursum Formation

The Bursum Formation of Permian age crops out in the extreme southeastern part of Valencia County. Here it is 130 feet thick and consists of thick beds of dark-purplish-red and green shale separated by thinner beds of arkosic conglomerate and gray limestone (New Mexico Geological Society, p. 50, 111-112). The Bursum is a transitional sequence of sedimentary rocks between the underlying marine limestone of the Madera and the terrestrial red beds of the overlying Abo Formation. The top of the Bursum is the top of the uppermost marine limestone in the sequence.

Stratigraphically the Bursum Formation occupies the same relative position as the Red Tanks Member of the Madera Limestone in the Lucero uplift. The Bursum, however, is of Permian age and thus is younger than the Red Tanks. These marine—terrestrial transitional strata evidently are older to the west and north and younger to the south and east.

A few wells yield small amounts of ground water from the Bursum Formation in eastern Valencia County. According to Spiegel (1955), ground water occurs in the limestone and sandstone interbedded with the shale of the Bursum. The water may be perched or may be under artesian pressure. Water from the Bursum is usually soft, but it may be objectionably high in sodium and carbonate, such as in well 3.5.32.210 (Spiegel).

Abo Formation

The Abo Formation crops out on both sides of the Rio Grande graben. It rests conformably on, and intertongues with, strata of the Bursum Formation in the southeastern part of the county and with the Red Tanks Member of the Madera Limestone in the Lucero uplift (New Mexico Geological Society). It is also exposed on the uplifted block of the Ojuelos fault in T. 5 and 6 N., R. 4 E. In the type locality of the Abo Formation (in Abo Canyon, Torrance and Socorro counties, just outside the southeast corner of Valencia County), the unit is 810 feet thick (Bates et al., 1947). Here it consists of about 60 percent red shale, about 40 per cent sandstone, and some arkose and conglomerate (Smith, 1957). The dark red to maroon color of the Abo is distinctive. A continental origin of the formation is indicated by color, mud cracks, current ripple marks, cross-bedding, tracks of land vertebrates, plant impressions, and the lenticular character of the sandstone beds. Fossil plants that were collected from the upper part of the Abo and identified by

C. B. Read suggest that this part of the formation is Leonard in age (New Mexico Geological Society, p. 12).

Reiche (p. 1199) mentioned ". . . nearly 1,400 feet of dark-red clays, siltstones, and sandstones, many of which are flaggy and ripple-marked . . ." east of the Ojuelos fault a few miles north of Valencia County. These rocks he assigned to the Abo Formation. They rest on a dark-gray limestone. Although the Abo does not crop out on the eastern block of the Ojuelos fault in Valencia County, it probably occurs in the subsurface.

West of the graben, in Los Valles, the thickness of the Abo Formation ranges from 870 to 900 feet (New Mexico Geological Society, p. 1160). Here the Abo can be divided into a lower unit, consisting of soft, red-brown shale and occasional beds of thin, fresh-water limestone, and an upper unit of red-brown, cross-bedded, massive sandstone alternating with shale. The cross-bedded sandstone forms a line of low cuestas in the center of Los Valles (Kelley and Wood).

Small amounts of ground water are obtained from a few wells that tap the Abo Formation in eastern Valencia County. The ground water probably comes from the fine- to coarse-grained, well-cemented sandstone in the formation. The permeability of the sandstone is usually low. Well 3.5.28.444 in the southeastern part of the county yields potable water from the Abo Formation (Spiegel). Three wells in Los Valles (5.3W. 19.111, 5.4W.26.411, and 6.8W.28.333) yield ground water from the Abo Formation.

Yeso Formation

Rocks of the Yeso Formation crop out west of the Rio Grande graben in the Lucero uplift and on the uplifted block of the Ojuelos fault in T. 5 and 6 N., R. 4 E. The Yeso also crops out on the east side of the Ojuelos fault a few miles north of Valencia County. In this area the Yeso is about 1200 feet thick and consists of orange-red siltstone and sandstone and minor white sandstone. A few thin beds of limestone are present in the upper part (Reiche). Only part of the Yeso Formation is exposed along the Ojuelos fault in Valencia County.

In the Lucero area two members of the Yeso Formation are recognized. The lower is the Meseta Blanca Sandstone Member and the upper is the Los Vallos Member. The Meseta Blanca Sandstone Member is about 250 feet thick. It crops out with the sandstones of the upper part of the Abo Formation. The Los Vallos Member, named by Kelley and Wood from strata cropping out in the vicinity of Los Valles, constitutes the bulk of the Yeso Formation and is probably correlative with the Torres, Canas, Gypsum, and Joyita Sandstone members in the Joyita Hills, Los Pinos Mountains, and Oscura Mountains (New Mexico Geological Society, p. 116). It underlies the western part of Los Valles and forms the lower slopes in the east face of Sierra Lucero. The large outcrop of rocks of Permian age in the southeastern part of T. 7 N., R. 3 W. is mostly the Los Vallos Member. According to Kelley and Wood, the lower part of the member is dominantly a elastic unit, but contains several persistent thin limestone and thicker gypsum beds. In the upper part of the Los Vallos Member, gypsum makes up about 50 percent of the section.

One well (6.3W.10.233) in eastern Valencia County probably obtains water from the Yeso Formation. This well is at the north end of Los Valles.

Glorieta Sandstone

The Glorieta Sandstone crops out on the uplifted block of the Ojuelos fault and on the sheer face of Sierra Lucero. In the Los Ojuelos district the Glorieta is ". . . about 125 feet thick and consists of yellow and buff, well-bedded friable sandstone; it commonly has low-angle cross-bedding . . ." (Reiche, p. 1199).

In the Lucero area the Glorieta Sandstone, 180 to 220 feet thick, crops out as a double cliff in the face of the Sierra Lucero (New Mexico Geological Society). Gypsum is interbedded with the sandstone. The Glorieta rests conformably on and intertongues with the Los Vallos Member of the Yeso Formation (Kelley and Wood).

No wells or springs are known to yield water from the Glorieta Sandstone in eastern Valencia County. On the uplifted block of the Ojuelos fault, ground water moves westward toward the fault, probably partly through the Glorieta. Here small to moderate yields of water might be obtained from wells drilled into this formation. Water also might be obtained from the Glorieta in the vicinity of Sierra Lucero. However, water in the Glorieta in this area probably would be highly mineralized because of the interbedded gypsum.

San Andres Limestone

The San Andres Limestone crops out locally on the east side of the Ojuelos fault and extensively in Sierra Lucero. Reiche stated (p. 1199-1200) that in the Los Ojuelos district, "The San Andres Limestone, 90-100 feet thick . . . includes an upper 20-35 feet of limestone which is relatively massive and weathers yellowish-brown; an unexposed 35-foot slope-forming member of reddish clay or soft shale; and a lower 35 feet of thin-bedded, gray, locally cherty limestone, which in its lower part carries a poorly preserved gastropod fauna. . . ."

In Sierra Lucero Kelley and Wood mapped an evaporite member and an upper limestone member of the San Andres. (The Glorieta Sandstone, which has subsequently been elevated to formation rank, they included as the lowermost unit of the San Andres.) According to Kelley and Wood, the evaporite member of the San Andres crops out in a series of steep slopes and ledges in Sierra Lucero. The sandstone and shale beds which are interbedded with the gypsum in the evaporite member, are generally white to buff. The lower part of the formation also is exposed beneath basalt caprock on Mesa Lucero along the south and east sides of the mesa. The upper limestone member caps much of Sierra Lucero and crops out on the gentle dip slope on the west side of the sierra. The evaporite member is 300 to 350 feet thick, and the upper limestone member is 100 to 120 feet thick (New Mexico Geological Society).

Two wells (7.4W.25.111 and 7.4W.35.443) obtain water from the San Andres in eastern Valencia County. The water probably is yielded to the wells from the lower part of the limestone member of the San Andres. Well 7.4W.35.443 was blowing air when visited, which suggests that the limestone member is cavernous above and presumably also below the water table. Wells that penetrate cavernous formations often blow or suck air in response to changes in barometric pressure. Two springs (7.2W.18.313 and 7.2W.30.132) yield water from the limestone member of the San Andres in the Rio Puerco fault zone. In the Rio San Jose valley two mound springs (7.4W.3.344 and 7.4W.11.431) yield water probably from the limestone member of the San Andres.

TRIASSIC SYSTEM

Reiche (p. 1200) mentioned that the Chinle Formation, which is incompletely exposed in the Los Ojuelos district, " . . . appears to be conformable on the Permian strata. Dark-red clays, siltstones and sandstones, minor buff to brown sandstones, and a few limestones are present." The Chinle Formation as described by Reiche is the topmost pre-Santa Fe unit exposed on the upthrown block of the Ojuelos fault.

In the Lucero area Kelley and Wood mapped the Shinarump separately from the Chinle. The Shinarump Member of the Chinle Formation crops out widely on the gentle west slope of Sierra Lucero where sandstones in the lower part of the formation cap the slope. The Shinarump here consists predominantly of red-brown shale and minor amounts of sandstone. The unit contains little or no conglomerate. In this report all Triassic red beds are included in one map unit. The Chinle probably underlies the basalt in much of the Mesa Lucero area. The red shale of the Chinle under the basalt cap of Mesa Lucefo accounts for the extensive landslide splinters and blocks on the west and north sides of the mesa. The Chinle crops out locally beneath extensive travertine deposits in the northern part of the Rio Puerco fault zone. The formation is more than 1000 feet thick (New Mexico Geological Society, p. 117).

Los Ojuelos, the three springs in sec. 20, T. 6 N., R. 4 E., on the Ojuelos fault, yield water from sandstones in the Chinle Formation. No ground water is known to be yielded by wells from rocks of Triassic age in eastern Valencia County; however, ground water probably could be obtained from wells finished in sandstone beds of the Chinle Formation where this unit occurs in the subsurface east of the Ojuelos fault. Immediately east of Los Ojuelos, of course, wells that yielded water from the Chinle Formation would tend to reduce the discharge of the springs. In the northern part of the Rio Puerco fault zone, several springs yield highly mineralized water from Triassic rocks. One spring on the north side of Mesa Lucero (8.3W.35.100) reportedly yields water low in dissolved solids from the Chinle.

JURASSIC SYSTEM

Rocks of Jurassic age occur only in the northern part of the Lucero area in eastern Valencia County. They thin abruptly south of the Rio San Jose, and the southernmost outcrop is in sec. 18, T. 7 N., R. 2 W. The Entrada, Todilto, and Morrison formations are all present in the outcrops. On the south side of Mesa Gigante, a few miles north of the northwest corner of the mapped area, the Entrada Sandstone is 160 to 220 feet thick; the Todilto Limestone is 90 to 110 feet thick; and the Morrison Formation may be as much as 600 feet thick.

No wells obtain water from rocks of Jurassic age in eastern Valencia County. However, three springs (8.2W.I9.421, 8.2W.30.340, and 8.3W. 12.342) yield water from sandstone in the Morrison Formation. The chemical quality of water from each of the springs differs from that of the other two. This difference suggests that the water being discharged from the Morrison Formation is migrating into it from other nearby rocks.

CRETACEOUS SYSTEM

The Dakota Sandstone and the Mancos Shale comprise the rocks of Cretaceous age cropping out in the area of this investigation. These rocks are best exposed in the sides of Mesa Redonda, the small mesa in secs. 14 and 23, T. 8 N., R. 3 W. They also crop out in the northern part of the Lucero fault zone west of the Santa Fe fault. Spring 7.2W.6. 210 reportedly discharges water from the Mancos. Spring 7.2W.6.434 discharges water from the Dakota Sandstone. These rocks are not known to yield water to wells in eastern Valencia County.

TERTIARY SYSTEM

Rocks of pre-Santa Fe Age

Outcrops of rocks of Tertiary age older than the Santa Fe Group of middle (?) Miocene to Pleistocene (?) age have not been found in eastern Valencia County. Immediately south of Valencia County, in T. 4 N., R. 3 W., Socorro County, Spiegel assigned rocks exposed in Red

Tanks Arroyo to the Popotosa Formation of late Miocene age. North of the outcrop these rocks are covered by surficial deposits. In Valencia County, typical buff siltstones of the Santa Fe Group crop out in an arroyo about one mile north of the county line. Here the Santa Fe is capped by a well-cemented conglomerate as much as five feet in thickness (fig. 6A).

Figure 6A

CONGLOMERATE CAPPING SILTSTONE OF THE SANTA FE GROUP IN THE NE1/4NE1/4 SEC. 10, T. 4 N., R. 3 NV., VALENCIA COUNTY, N. MEX.

In compiling the geologic map (p1. 1), it was assumed that the surficial gravel is underlain by the Santa Fe Group in Valencia County. The Popotosa Formation and early Tertiary terrestrial sediments may underlie the Santa Fe in part or all of the Rio Grande trough. Their distribution in the subsurface, however, has not been determined.

The volcanic rocks in El Cerro have been assigned a ". . . probable pre-Santa Fe age . . ." by Kirk Bryan *(in* Wright, p. 398). According to Bryan, the hill consists of rhyolitic tuff and lava.

Tertiary rocks of pre-Santa Fe age are not known to yield water to wells in eastern Valencia County.

TERTIARY AND QUATERNARY (?)

SYSTEMS Santa Fe Group

The Santa Fe Group is a thick accumulation of terrestrial sediments which were deposited in the Rio Grande graben during middle (?) Mio•

cene to Pleistocene (?) time. The group consists of interbedded sand, silt, clay, and conglomerate, mostly buff to reddish brown, with some white to gray. The material is thinly bedded and commonly is poorly indurated. The description of a 200-foot partial section of the Santa Fe exposed in the side of the Rio Grande valley west of Belen exemplifies the lithologic characteristics of the part of the group that usually crops out in Valencia County (fig. 6B and table 1). Near the base of this out-

Figure 6B

OUTCROP OF THE SANTA FE GROUP IN THE WEST WALL OF THE RIO GRANDE VALLEY IN THE NEIANWIA SEC. 23, T. 5 N., R. 1 E., NEAR BELEN, N. MEX. The stratigraphic section in Table 1 was measured along the road in the foreground.

crop, a driller's log of well 5.1.13.332 shows that for at least 500 feet beneath the outcrop the lithologic characteristics of the Santa Fe are similar to those in the outcrop (table 2).

Volcanic rock (usually called *malpais* or *lava* in drillers' logs) reportedly is interbedded with the clastic sediment in the subsurface in the north-central part of the area studied. Logs of water wells and oil-test holes indicate that these rocks may occur near the surface and to depths of several thousand feet. The rocks are presumed to be flows or, in some places, sills of basalt. Well 7.1W.2.324 reportedly yields water from malpais between 570 and 612 feet below land surface.

El Cerro de Los Lunas, a mass of volcanic rock at the margin of the Rio Grande valley, is equivalent in age to part of the Santa Fe Group.

TABLE 1. STRATIGRAPHIC SECTION OF PART OF THE SANTA FE GROUP EXPOSED ALONG THE ROAD IN THE NENANWIA SEC. 23, T. 5 N., R. 1 E., WEST OF BELEN, VALENCIA COUNTY, N. MEX.

DESCRIPTION	THICKNESS (feet)
Tertiary and Quaternary(?) Systems:	
Santa Fe Group:	
Lag gravel, maximum particle size 2 inches, particles partly coated white	
Sandstone, very silty, and little gravel, calcareous cement, white, friable, caliche	2
Clay and sand, brownish red to buff, partly compacted and cemented, clay breaks with hackly surface, a few layers up to 2 inches thick contain nodules of caliche	4
Gravel, very sandy, gray to reddish tan, maximum size 3 inches, slightly cemented with calcite, very friable, cross-bedded, contains small lenses of very silty sandstone	12
Sandstone, quartzose, buff, coarse to fine, partly cemented, very finely laminated, locally magnetite sand between laminae near top, poorly cross-bedded; few medium gravel lenses	16
Shale, partly slightly sandy, grayish to reddish tan, compact, hackly fracture, beds 1 to 2 feet thick; alternating with sandstone, silty, white, very fine to fine, slightly cemented, beds 1 to 2 feet thick except for 5-foot bed at base of unit	39
Gravel, very sandy, brownish gray, fine to medium, little coarse, mostly unconsolidated, caps spurs	6
Sandstone, slightly silty, yellowish brown, fine to medium, little coarse, mostly unconsolidated, few thin layers tightly cemented, lower 5 feet poorly laminated	8
Gravel, very sandy, gray, fine, unconsolidated	7
Sand, tan, fine to coarse, mostly unconsolidated	62
Gravel, very sandy, gray, fine, unconsolidated, caps spurs	6
Sandstone, white, fine to coarse, very slightly friable, thin-bedded	4
Sand, silty, very argillaceous at base, buff, unconsolidated except compact where argillaceous; little clay near base	32
Total thickness exposed	198.1

Wind Mesa and Parea Mesa, masses of volcanic rock a few miles north of Valencia County, also appear to be equivalent in age to part of the Santa Fe Group. Basalt flows to the west, interbedded with sediments of the Santa Fe Group, are exposed in two small hills near the northeast corner of T. 6 N., R. 2 W. Volcanic rocks within the Santa Fe Group also are reported near the east line of sec. 17, T. 5 N., R. 4 E. Here a small tabular igneous body has been reported as an early Tertiary intrusive by Read et al. and a small remnant of ". . . an olivine basalt flow . . ." by Stark (p. 30).

Locally, outcrops of the Santa Fe Group contain pumice. A 6-foot lens of white, sugary, friable, nearly pure pumice crops out near the center of sec. 26, T. 7 N., R. 1 E., northwest of El Cerro de Los Lunas. Elsewhere, pumice in the Santa Fe usually occurs as pebbles and discrete grains in the silt or sand of the normal sedimentary sequence. A stratum of pumiceous, sandy conglomerate five feet thick crops out in

TABLE 2. MODIFIED DRILLER'S LOG OF WELL 5.1.13.332, BELEN MUNICIPAL WELL 3

Description	Thickness (feet)	Depth (feet)
Quaternary System:		
Sand, brown, and pea gravel in streaks	25	25
Tertiary and Quaternary(?) Systems:		
Santa Fe Group:		
Sand, cemented, hard; fine gravel; gray conglomerate	4	29
Clay, brown, silty; interbedded sandstone layers	36	65
Sand and gravel, loose	4	69
Clay, brown; interbedded sandstone layers	8	77
Sand and gravel, gray, loose	5	82
Sandstone and brown clay, interbedded	10	92
Sand and gravel; streaks and interbeds of brown clay	16	108
Sandstone, hard; interbedded clay	19	127
Sand, fine, brown, gray; little clay; water	29	156
Sandstone, hard; interbedded brown clay	17	173
Sand, coarse, gray, partly cemented; gravel; water	11	184
Clay, light red; streaks fine gravel; brown sandstone	10	194
Sand, fine, coarse, brown, gray; little clay interbedded	25	219
Clay, brown; few sandstone and gravel interbeds, hard	64	283
Sand, coarse, gravelly; clay, brown; some water	23	306
Clay, brown, pink; fine gray sand	40	346
Sand, gray; small gravel; water	6	352
Clay, pink, brown	11	363
Sand, coarse, gray; little gravel	13	376
Clay, brown; gravel	13	389
Sand, gray, loose; water	2	391
Clay, sandy, yellow	7	398
Sandstone, brown, gray; interbedded clay, sandy, brown, red; little gravel	14	412
Sand, coarse; gravel; water	5	417
Clay, sandy, brown; sandstone	28	445
Sand, brown, gray, loose; interbedded loose clay and gravel	16	461
Sand, coarse; gravel; red clay; water	24	485
Clay, brown; sand	34	519

Hell Canyon Wash in the SDAND/$_4$ sec. 26, T. 8 N., R. 3 E. This stratum is cross-bedded, with the dip of the cross-beds to the west.

Beds of cemented conglomerate are present on the west side of the Rio Grande trough in eastern Valencia County. The beds range in thickness from two to ten feet. In the SW% sec. 5, T. 6 N., R. 2 W., a small mesa, several hundred feet high, is capped by a conglomerate bed ten feet thick. Cemented conglomerate also is exposed at the foot of the mesa on the south side, about 400 feet lower stratigraphically. This bed probably was about four feet thick before erosion.

The outcrops of the Santa Fe Group, as shown on the generalized geologic map (pl. 1), include some rock units that are related to, but technically not part of, the Santa Fe Group. These units include the so-called "pediment gravels" which are lag gravels on both Recent and older erosion surfaces; caliche beds at the top of the present Santa Fe outcrop; and fanglomerate material, particularly at the foot of the Manzano Mountains, which is continuously being added to the bajada. In this study no attempt was made to subdivide the Santa Fe Group. Wright has described 4100 feet of what *he* considered to be playa deposits exposed in the Gabaldon anticline. The base of the Santa Fe section was not exposed. He correlated the playa deposits with the lower and middle members of the Santa Fe described by Bryan and McCann (1937) in Sandoval County to the north. Playa deposits have not been described elsewhere in the Santa Fe. Wright stated that the playa deposits are overlain by at least 700 feet of alluvial-fan material, which he correlated with Bryan and McCann's upper member. The total Santa Fe section described is thus about 4800 feet thick.

Caliche caps much of the Santa Fe Group where it crops out on surfaces with gentle relief. Caliche is well exposed along the escarpments of the Llano de Albuquerque and along the east side of the Rio Grande north of El Cerro. In most places the caliche is poorly developed and ranges from a foot to a few feet in thickness.

The thickness of the Santa Fe Group and other rocks varies widely in different parts of the graben. The Grober No. I Fuqua oil-test hole in the NEIA NWIA NE ¼ sec. 19., T. 5 N., R. 3 E. penetrated 4550 feet of the Santa Fe Group, according to R. L. Bates *(in* Reiche, 1949). Drillers' logs from several oil-test holes within a radius of a few miles of Dalies suggest that the Santa Fe in that area also is several thousand feet thick. The electric and gamma ray neutron logs of the Humble No. 1 Santa Fe Pacific test hole at the center of the SE1ASEIA sec. 18, T. 6 N., R 1 W., on the flank of the Gabaldon anticline, suggest that the Santa Fe Group and earlier Tertiary rocks here extend to a depth of about 9700 feet; the proportionate thickness of Santa Fe to pre-Santa Fe Tertiary rocks is open to speculation. Sample cuttings from this hole are on file at the State Bureau of Mines and Mineral Resources Division of the New Mexico Institute of Mining and Technology, but they have not been described. As mentioned previously, Wright described 4800 feet of Santa Fe exposed on the Gabaldon anticline; the base of the deposit was not exposed. On the uplifted block of the Ojuelos fault, the Santa Fe Group and younger sedimentary rocks together probably have a maximum thickness of only a few hundred feet. The pre-Tertiary bedrock floor of the Rio Grande graben may have considerable relief and be highly faulted. The maximum thickness of the Santa Fe Group within the Rio Grande graben is probably more than 5000 feet.

Part of the Santa Fe Group has been removed by erosion. El Cerro de Los Lunas was covered by the Santa Fe and later exhumed. The beveled edges of the eroded strata are exposed west of the hill. El Cerro (near Tome) probably also was completely covered. Remnants of the Santa Fe crop out high on the sides of this hill.

Few quantitative data are available on the hydraulic characteristics of the Santa Fe Group in eastern Valencia County. Most of the wells that obtain water from the Santa Fe are stock wells equipped with windmills. Most of the stock wells end between 30 and 60 feet below the water table, although some penetrate considerably more than 100 feet. A few wells (5.1.13.332, 7.2.18.421, and possibly wells 4.2.32.141 and 4.2.32.243) near the Rio Grande valley, yield about 1000 gpm from the Santa Fe. These wells are on the outcrop of alluvium of Quaternary age, rather than on the Santa Fe. However, the water from each well is probably derived from the Santa Fe. The alluvium is mostly or entirely above the water table. The specific capacities of these wells are 25 gpm per foot of drawdown or slightly more.

At greater distances from the Rio Grande valley, maximum yields are in the range of 100 to 160 gpm. These yields have been obtained from only three wells (4.2.25.434, 4.2.36.221, and 6.1.5.412). On the basis of reported data, specific capacities are on the order of 2 to 3 gpm per foot of drawdown. Deeper penetration below the water table might result in larger yields and specific capacities, although well 6.1.5.412 was drilled nearly 630 feet below the water table. The small number of large-capacity wells or of wells having high specific capacities in the Santa Fe Group, particularly east of the river valley, may be due mainly to the lack of attempts to construct such wells. Discharges of at least 100 gpm probably can be obtained from properly constructed and developed wells wherever the Santa Fe is thick enough to allow deep penetration below the water table. Areas in which the potential is considerably higher than 100 gpm will be proved only by drilling. Where the Santa Fe is thin, as on the upfaulted block between the Ojuelos fault and the Manzano Mountain front, the potential yield from the aquifer may not be so great as it is farther west where the aquifer is thicker. However, the greater content of gravel in the Santa Fe near the mountains, locally, could cause high permeability in the sediments and possibly large yields of water could be obtained at places here.

QUATERNARY SYSTEM

The rocks of Quaternary age described in this section include stream alluvium in the graben, basalt flows on the Llano de Albuquerque and around the north toe of Mesa Lucero, and part of the travertine deposits along the Rio Puerco fault zone. The landslide and mudflow deposits are principally where basalt flows overlie shale of Triassic age on Mesa Lucero. The alluvium of the Rio Grande is divided into older alluvium and younger alluvium of Recent age, depending on the time of deposition. The alluvium in other stream valleys has not been subdivided.

Older Alluvium

The sediments identified in this report as older alluvium form the depositional terraces that are about 120 and 160 feet above the present river level. The deposits are now preserved along most of the east side of the river valley. On the west side of the valley they are preserved northwest of Los Lunas (pl. 1). The contacts are indistinct along the margins of the deposits, so the geologic map indicates only the general location of the contacts. The alluvium associated with the 160-foot terrace is at least a few tens of feet thick. The alluvium associated with the 120-foot terrace is 132 feet thick where it was penetrated by well 7.2.18.421. *(See* table 3.)

The alluvium was derived largely from sediments of the Santa Fe Group. It consists of interbedded and intermixed brown, buff, and gray sand, silt, clay, and gravel. The sand is commonly cross-bedded. The alluvium commonly is uncemented, but the clay beds are mostly compacted. The principal difference between the older alluvium and sediments of the Santa Fe is in the degree of cementation. The alluvium is more easily distinguished from sediments of the Santa Fe Group where the alluvium is directly associated with a terrace. The upper part of the alluvium associated with the 120-foot terrace is well exposed in a road cut in the NW/SE/SE/ sec. 20, T. 7 N., R. 2 E. (fig. 7A).

Beds of gravel are interspersed throughout the older alluvium; however, they appear to be best developed in the lower part of the deposit. The thick gravel beds along the east side of the Rio Grande may be a part of the alluvium associated with *the* 120-foot terrace. Part of the gravel sequence is well exposed in a gravel quarry in the SW I/ sec. 81, T. 7 N., R. 3 E.

A zone of caliche is locally poorly developed on the 160-foot terrace east of Belen. Caliche was not found on the 120-foot terrace. Climatic conditions that had sustained formation of caliche prior to the establishment of the 120-foot terrace were apparently modified, and no caliche has developed since.

The deposits of older alluvium are above the water table, except east of the river in the southernmost part of the county. Here the lower part of the older alluvium may be saturated. The deposits are of interest because they probably facilitate recharge to the Santa Fe. Recharge is discussed in a later section.

Alluvium of Recent Age

The alluvium of Recent age is limited to the flood plain of the Rio Grande and to the lower part of the principal tributaries in eastern Valencia County. It consists, generally, of unconsolidated sand, silt, gravel, and clay. The strata are usually tan to brown; some of the clayey beds are red. Below the water table much of the fine to medium sand is gray to bluish gray. "Blue black muck," at a depth of 34 feet, is recorded in the log of well 5.2.18.412, and a *"tree* stump" or log was found at a depth of 60 feet during the drilling of well 6.2.16.423. Gravel

TABLE 3. MODIFIED DRILLER'S LOG OF IRRIGATION WELL 7.2.18.421

Description	Thickness (feet)	Depth (feet)
Quaternary System:		
Soil, sandy	2	2
Older alluvium:		
Clay, stiff, brown, caliche	5	7
Clay, brown	11	18
Sand, fine, gray	2	20
Clay, sandy, brown	14	34
Sand, fine, brown	14	48
Clay, sandy, brown	27	75
Sand, fine, brown, and some clay	6	81
Sand, fine, brown, and pea gravel	1	82
Gravel	4	86
Sand, fine, brown	1	87
Gravel	8	95
Clay, brown	1	96
Sand and gravel, brown	9	105
Sand, fine, brown, and some gravel	6	111
Gravel	15	126
Sand, fine, brown	4	130
Clay and gravel, conglomerate	2	132
Tertiary and Quaternary(?) Systems:		
Santa Fe Group:		
Sand and gravel, gray, formation is tight	10	142
Clay, sandy, brown, compact and dense	3	145
Sand, gray, coarse, streaks of white clay, water. Porosity is poor as formation is tight	29	174
Clay, brown, with some gravel	1	175
Sand, coarse, brown, some packed pea gravel, water	3	178
Sand, coarse, brown, and cemented gravel	1	179
Clay, brown, and gravel	1	180
Sand, coarse, brown, and gravel	2	182
Clay, brown, and gravel	15	197
Clay, sandy, brown	8	205
Sand, coarse, gray, water	1	206
Sand, coarse, gray, and pea gravel, water	6	212
Clay, gray	1	213
Sand, coarse, gray, and pea gravel, water	2	215
Clay, gray	2	217
Sand, medium coarse, brown, and pea gravel and clay, water	4	221
Sand, coarse, brown, and gravel	4	225
Clay, gray	5	230
Clay, brown, and sand	2	232
Sand, fine, brown	3	235
Clay, brown	13	248
Sand, fine, brown	10	258
Clay, brown, and sand	2	260
Sand, coarse, brown, and gravel, water	5	265
Clay, brown, and cemented sand	3	268
Sand, coarse, brown, and gravel, water	10	278
Clay, brown, very dense	17	295
Sand, coarse, brown, and pea gravel, water	5	300

Clay, brown, and cemented sand	6	306
Sand, coarse, gray, and small gravel	3	309
Clay, brown, and conglomerate	5	314
Sand, hard, gray, cemented	1	315
Sand, coarse, gray, loose, taking water	9	324
Clay, sandy, brown	1	325
Sand, coarse, gray, water	14	339
Clay, brown, and cemented sand	3	342
Sand, fine, brown, and clay	23	365
Sand, coarse, brown, cemented	3	368
Clay, brown, and cemented sand	3	371
Sand, coarse, gray, water	12	383
Sand and gravel, cemented	2	385
Sand, coarse, gray, water	4	389
Clay, gray, sticky	5	394
Clay, sandy, brown	4	398
Clay, light-brown	3	401
Clay, reddish brown	4	405
Clay, sandy, brown	2	407

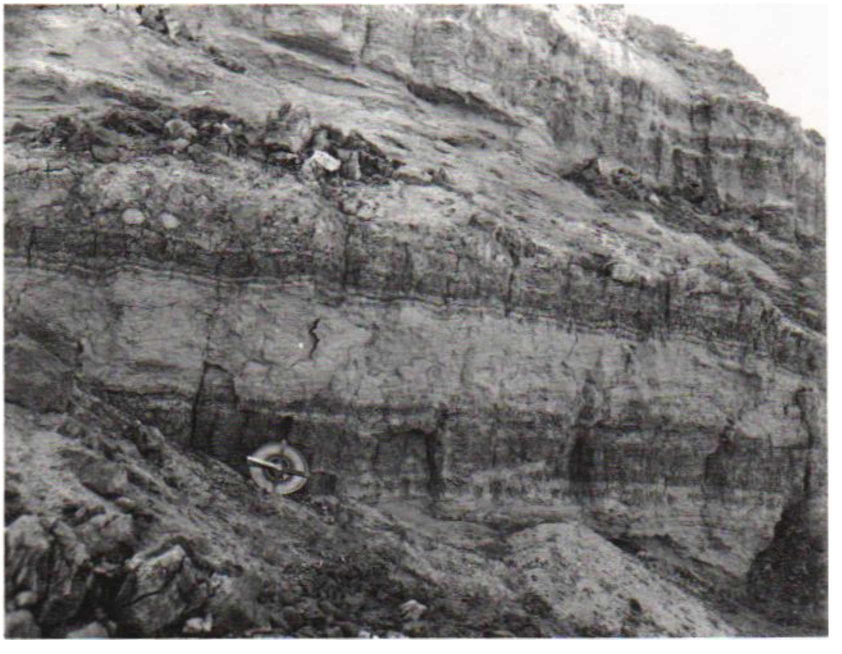


Figure 7A

OLDER ALLUVIUM ASSOCIATED WITH THE 120-FOOT TERRACE OF THE Rio GRANDE

Outcrop in the NWIASEIASEIA sec. 20, T. 7 N., R. 2 E., west of Los Lunas, N. Mex.

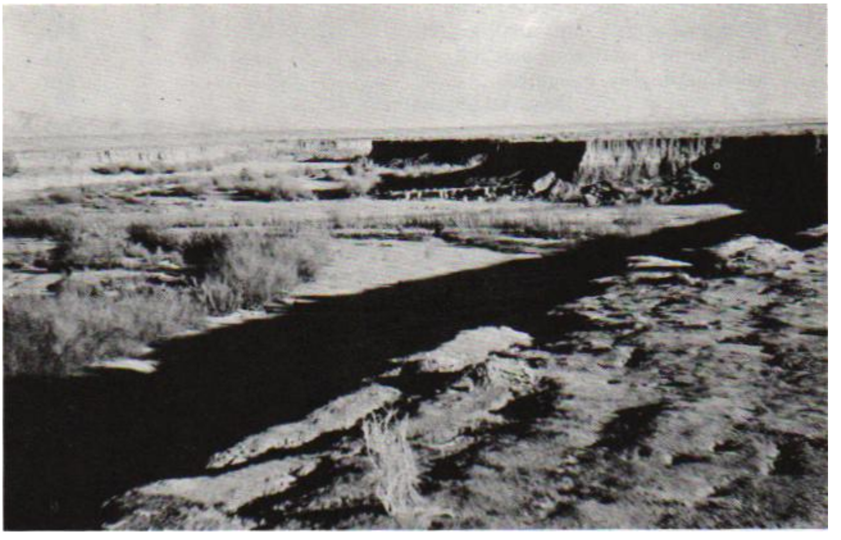


Figure 7B

THE RIO PUERCO CHANNEL IN SEC. 6, T. 6 N., R. 1 W., SOUTH OF STATE HIGHWAY 6

The channel has been incised 40 *feet into* alluvium of Recent Age in historic time.

is more common below a depth of 35 feet than above, according to drillers' logs.

The alluvium under the Rio Grande flood plain probably has a maximum thickness of little more than 120 feet. In the driller's log of well 5.2.18.412 (Belen Municipal well No. 2), the depth of the base of the alluvium was provisionally set at 119 feet (table 4). Large-capacity wells that obtain water from the alluvium average 80 to 100 feet deep. Some wells are 110 feet deep, only a very few being deeper than 110 feet. Most of the wells are bottomed near the base of a gravelly sequence of alluvium that probably represents the lower part of the river deposit.

Under most of the valley the alluvium is highly permeable and yields water readily to wells. Pumping rates of 1840 gpm have been measured, and pumping rates of 2500 gpm have been reported. The average specific capacity of 15 wells, in which the drawdown and discharge was measured by the Geological Survey, was 31 gpm per foot of drawdown. An additional 21 wells, in which the drawdown and discharge were reported, had an average specific capacity somewhat higher. Wells in the heavily pumped area on the east side of the river north of El Cerro have an average specific capacity 25 to 30 percent higher than the average for the entire valley in Valencia County. This is true for both measured data and reported data. Many extraneous factors,

TABLE 4. MODIFIED DRILLER'S LOG OF WELL 5.2.18.412, BELEN MUNICIPAL WELL 2

Description	Thickness (feet)	Depth (feet)
Quaternary System:		
Alluvium of recent age:		
Adobe	4	4
Sand, gray, water	29	33
Muck, blue-black	1	34
Sand, gray, water	4	38
Sand, gray, some gravel, water	18	56
Sand and gravel, concreted	23	79
Clay, dense, light-red	17	96
Sand, coarse, water	10	106
Sand, coarse, gravel	13	119
Tertiary and Quaternary(?) Systems:		
Santa Fe Group:		
Sand, brown, hard packed	18	137
Sandstone, soft	2	139
Clay, cream-colored	3	142
Sand, gray, water	10	152
Clay, cream-colored	3	155
Gravel, clean, water	5	160
Sand and gravel, concreted	9	169
Clay, sticky, cream-colored	6	175
Clay, red, hard-cemented sand	37	212
Sand, gray, and pea gravel, water	8	220
Clay, brown	4	224
Sand, coarse, gray, water	6	230
Clay, silt, pink	13	243
Sand, gray, coarse, water	2	245
Clay, sticky, red	13	258
Clay, sandy, red bed	13	271
Clay, red	5	276
Sandstone, soft, brown	1	277
Clay, red	6	283
Sand, packed, brown	2	285
Clay, red	2	287
Sand, packed, brown	2	289
Clay, red	1	290
Sand, packed, brown	2	292
Clay, red	4	296
Sand, fine, brown, water	8	304
Clay and gravel, hard	2	306
Clay and sand, brown	1	307
Clay, cream-colored	3	310
Sandstone, hard, gray	1	311
Clay, cream-colored	17	328
Sand, coarse, gray, water	9	337
Clay, red	2	339
Clay, sandy, brown	5	344
Clay and sand, brown	1	345
Clay, sandy, brown	6	351
Sand, coarse, gray, water	2	353

TABLE 4. MODIFIED DRILLER'S LOG OF WELL 5.2.18.412, BELEN MUNICIPAL WELL 2 (con't.)

Description	Thickness (feet)	Depth (feet)
Sand, gray, streaks of brown silt, tight formation, can be perforated, water	7	360
Clay, cream-colored	2	362
Sand, tight, gray, with streaks of brown silt	2	364
Sand, fine, gray, water	11	375
Clay, red	1	376
Sand, gray, coarse, water	1	377
Clay, red, sticky	35	412
Sand, very fine, brown, quicksand	7	419
Clay, red, dense and sticky	15	434
Sand, brown, and clay conglomerate	8	442
Sand, gray, water	3	445
Clay, brown, streaks of water sand	11	456
Clay, red conglomerate	4	460

such as well diameter, well completion and development procedures, and type and number of perforations in the casing, affect specific capacities; however, there is little question but that the higher specific capacities of wells in this part of the valley indicate higher aquifer transmissibility.

Theis and Taylor (1939) have calculated that the coefficient of transmissibility for the alluvial aquifer is 50,000 gpd (gallons per day) per foot. (The coefficient of transmissibility, commonly designated by T, is the amount of water in gallons that will pass in one day through a vertical strip of the aquifer one mile wide and extending through the entire thickness of the aquifer, under a gradient of one foot a mile. It is a measure of the overall permeability of the aquifer.) Theis and Taylor determined that the transmissibility is the same whether measured parallel or perpendicular to the alignment of the river. In addition, they arrived at a specific yield for the alluvium of 14 percent. (Specific yield is the volume of water that will drain by gravity from a unit volume of aquifer. It is expressed as a percent of the aquifer volume.)

Clay layers near the top of the aquifer, and presumably throughout the aquifer, restrict the vertical movement of ground water. Perched ground water, as is indicated by the anomalously high altitude of the water table in well 6.2.18.211, may be caused by beds of clay, which slow or prevent the movement of recharge water to the true water table. A short pumping test of well 6.2.5.311 suggests that beds of clay a short distance below the water table separate the aquifer into two distinct zones with different hydrologic properties. Above the clay layers the water is unconfined, whereas below the confining clay layers the ground water is under slight artesian pressure.

The Rio Puerco valley, like the Rio Grande valley, is underlain by a thick deposit of alluvium. The present channel of the Rio Puerco is incised as much as 40 feet into the alluvium (fig. 7B). Near the confluence of the Rio Puerco with the Rio Grande, a few miles south of Valencia County, the thickness of the Rio Puerco alluvium is probably about the same as that of the Rio Grande. The alluvium exposed in the near-vertical walls of the present channel consists of silt and sand beds and some clay. Round clay balls, many more than two feet across, are exposed in the outcrop. Because of the poor chemical quality, ground water in the Rio Puerco alluvium has not been utilized widely.

The Rio San Jose valley is underlain by alluvium that yields ground water to a few stock wells. The alluvium consists of sand, silt, and gravel. It reportedly contains interbeds of malpais which are probably basaltic lava flows similar to those covering the present surface in part of the area.

Occurrence of Ground Water

Ground water in eastern Valencia County occurs mostly under water-table conditions. The water table is the free upper surface of a body of ground water that is not confined under pressure. Below the water table all accessible pore spaces and other openings in the rock contain water. The rock is saturated.

Locally, ground water in eastern Valencia County occurs under artesian conditions. Artesian conditions are those in which ground water is confined under pressure between rocks of very low permeability. The artesian pressure is maintained by water in the recharge area standing above the general level of the aquifer. A well drilled into an artesian aquifer may be dry until the upper confining bed is penetrated. When the confining bed is penetrated, however, the water rises in the well to the height of the piezometric surface. The piezometric surface is a pressure surface connecting all potential static water levels for an aquifer. It indicates the altitude at which water will stand in a well that is drilled into an aquifer at any location. The water table in an unconfined aquifer is a special case of a piezometric surface.

A sloping piezometric surface indicates a pressure gradient. Because water tends to move in the direction of lowest pressure potential, a sloping surface implies that the movement of ground water is in the direction of downward slope. The movement of ground water in response to a pressure gradient is generally very slow, because of the small, tortuous channels through which the water must move. Relatively steep pressure gradients, that is, steeply sloping piezometric surfaces, therefore, are common in ground-water reservoirs. The rate of movement of ground water is usually measured in feet per year.

STRUCTURAL CONTROL OF GROUND WATER

The occurrence of ground water is inevitably controlled by the geology of an area. Structural adjustments that have folded, faulted, offset, or otherwise affected aquifers, also affect the occurrence and movement of the ground water that is contained within the aquifers. The borders of the Rio Grande graben are areas where this control is well displayed. Here the traces of major faults are also lines separating distinctive areas of ground-water occurrence.

THE FAULTED BORDER OF THE MANZANO MOUNTAINS

Bustamonte Spring (3.4.11.144) and a small unnamed spring a mile to the south (3.4.14.140) probably are structurally controlled. The springs are on each side of the mouth of a wide re-entrant in the west face of the south Manzano Mountains (pl. I). The trace of a major Laramide thrust fault crosses the mouth of the re-entrant, but it is here covered by alluvium. The two springs are on or very near the trace of the fault. The water that is discharged from Bustamonte Spring probably rises along the fault. The water that is discharged from spring 3.4.14.140 may rise along the fault, or it may be water from the alluvium that is forced to the surface by thinning of the alluvium where post-Laramide normal movement on the fault has elevated the bedrock under the re-entrant.

THE OJUELOS FAULT ZONE

Several springs along the trace of the Ojuelos fault discharge ground water from the eastern uplifted block. Among the largest are the three springs known collectively as Los Ojuelos, which are in sec. 20, T. 6 N., R. 4 E. Others are Carrizo Spring in sec. 8, T. 6 N., R. 4 E. and Ojo de la Cabra in sec. 29, T. 8 N., R. 4 E. Two former springs (6.4.5.232 and 7.4.6.434) were dry when visited in 1956-57. A large cottonwood tree commonly marks the site of each of the springs and seeps (fig. 8A). These are the only large trees on the east slope of the Rio Grande physiographic trough.

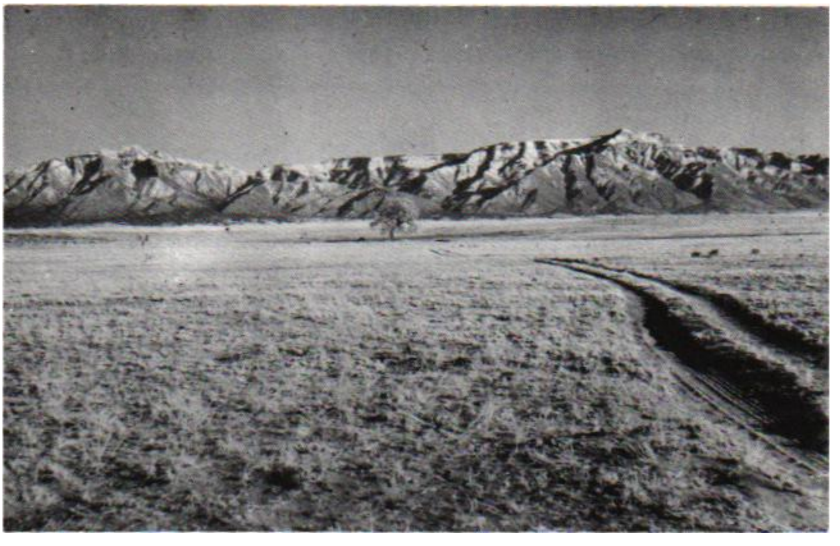


Figure 8A

SLOPING SURFACE BETWEEN THE MANZANO MOUNTAINS, IN THE BACKGROUND, AND THE RIO GRANDE

The cottonwood tree in the middle ground marks the location of spring 7.4.6.434 on a branch of the Ojuelos fault.

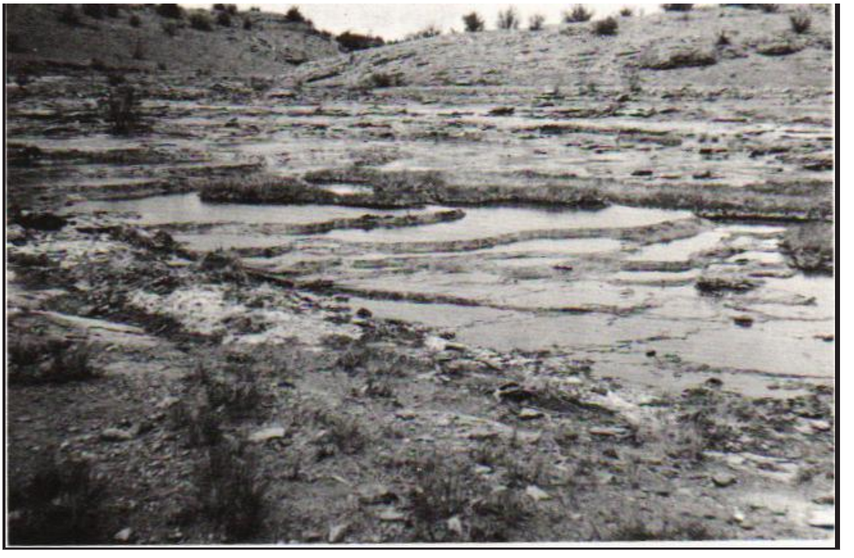


Figure 8B

TRAVERTINE DAMS THAT HAVE PRECIPITATED FROM GROUND WATER DISCHARGED FROM SPRING 6.3W.35.340, VALENCIA COUNTY, N. MEX.

The Madera Limestone crops out in the background.

Ground water moves westward from the Manzano Mountains toward the Rio Grande in the Cenozoic sediments which rest on rocks of Permian and Triassic age in the up thrown block of the Ojuelos fault. Ground water also is presumed to move westward toward the fault through permeable beds of the older underlying rocks. East of the Ojuelos fault the water table in much of the area is less than 100 feet below land surface; at the fault the several springs indicate that the water table is at the surface; west of the fault the water table is 400 to 500 feet below the surface (pl. 2). As water moves across the fault into the more permeable rocks of the Santa Fe, it cascades abruptly to the lower level within a short distance. The slope of the water table east of the fault is between 100 and 200 feet a mile (pl. 3). West of the fault, beyond the zone of cascading ground water, the water-table slope in most places is less than 10 feet a mile. Although the Ojuelos fault does not have a topographic expression that is recognizable in the southern part of Valencia County, the location of the ground-water cascade over the fault can be determined within four or five miles by the configuration of the water table. Unfortunately, the control points at which water-level altitudes could be obtained are not spaced closely enough for more precise location of the fault.

Ojo de la Cabra (8.4.29.424) is in a tributary to Hell Canyon Wash where that tributary crosses a prong of the Ojuelos fault. Water discharging from this spring flows down the tributary about a quarter of a mile, enters Hell Canyon Wash, and continues down the narrow valley to the point at which another fault crosses the canyon. Here the surface flow soaks into the ground. The fault splinter crossed by the surface flow is apparently saturated with ground water along the arroyo.

The average permeability of rocks of pre-Tertiary age in the uplifted block of the Ojuelos fault is surely less than the permeability of the overlying Cenozoic sediments. However, because of the thinness of the Cenozoic deposit, the coefficient of transmissibility of the pre-Tertiary rocks may be as high or higher than that of the Cenozoic rocks. If this is true, the pre-Tertiary rocks, which are a few thousand feet thick and are in fault contact with the Santa Fe Group along the Ojuelos fault, transmit more water than the overlying Cenozoic rocks.

THE GABALDON AREA AND THE WESTERN PART OF THE RIO GRANDE GRABEN

Certain inferences regarding the structure of the western part of the Rio Grande graben can be drawn from the configuration of the water table. The gradient of the water table is a function of the transmissibility of the aquifer. In general, where the slope is steep, the ability of the rocks to transmit water is low, and where the slope is gentle, the ability of rocks to transmit water is high. The slope of the water table in the central part of the graben ranges from-two to four feet a mile (pl. 3). The slope increases sharply along a sinuous line near the west side of the graben. In T. 5 N., R. 2 W., the slope is as much as 300 feet a mile. The exact location of the break in slope is difficult to determine because of the sparse data. Such a difference in transmissibility must be due to a difference in the thickness or the permeability of the sediments.

The easterly bulge of the steeply sloping water table in T. 6 N., R. 1 and 2 W. is apparently due to the structurally high position of the fine sediments in the Gabaldon anticline. In addition, the southwest-trending faults in sec. 19, T. 6 N., R. 1 W. and in sec. 35, T. 6 N., R. 2 W. (pl. 1) may have a retarding effect on the southeastward movement of ground water.

North of the Gabaldon anticline the steep slope of the water table combined with a topographic scarp on the east side of Cat Mesa suggest a north-south trending fault in the Santa Fe. The transmissibility of the rocks west of the fault is much lower than that of the rocks to the east. This could be due to fine-grained sedimentary rocks that have been uplifted to a structurally high position in the western block. The transmissibility of the Santa Fe would be reduced in proportion to the amount of uplift because the thickness of the Santa Fe on the uplifted block would be decreased by the amount of the uplift.

South of the Gabaldon anticline the steeply sloping part of the water table swings southwest around the end of the anticline and then back to the southeast, thus delineating a ground-water trough in the central part of T. 5 N., R. 2 W. The depth of the trough and the configuration of the water table south of the axis of the trough are based on widely scattered control points. The alignment of the contours in the Valencia County part of T. 4 N., R. 2 W. possibly should be southward instead of southeastward. The steep slope of the water table south and southeast of Gray Mesa is probably due, at least in part, to the thinning of the Santa Fe Group. Thus, it may indicate that one or more faults occur east of the fault mapped by Kelley and Wood, which is shown on the geologic map (pl. 1). A water well in Socorro County, a little more than a mile south of Valencia County, is located a short distance west of the mapped fault. Spiegel reported that the depth to water in the well (4N.3.24.131) was 241 feet and that it yielded water from rocks of Tertiary age. The presence of more than 241 feet of Tertiary rocks at this location suggests that some downfaulting of the graben occurred to the west of the well.

THE RIO PUERCO FAULT ZONE

The Rio Puerco fault zone, marking the boundary between the Lucero uplift and the Rio Grande graben in Valencia County, is a locus of many springs. The springs are closely spaced along the northern part of the fault zone in Valencia County (pl. 3). All of them are small, discharging only a few gallons a minute to less than a gallon a minute into small canyons in the side of the uplifted Lucero block. In addition to the springs shown on Plate 3, other seeps, moist spots, and signs of springs were observed but not mapped. The springs are larger but are more widely spaced along the Comanche thrust fault in the southern part of Valencia County. In that area they occur in water gaps which cross the hogback between Los Valles and the Rio Grande graben.

The Rio Puerco fault zone separates two quite different groundwater areas: an area of aquifers in Paleozoic and Mesozoic rocks on the west, and an area of aquifers in Tertiary rocks on the east. The fault, which acts as a dam, restricts the general eastward migration of ground water. Water discharged from the springs along the fault zone flows eastward only a short distance onto the outcropping Santa Fe before sinking back into the ground. It is assumed that some water also leaks across the fault zone underground. The amount of leakage across the fault is probably greater in the area of normal faults in the north than in the area of the Comanche thrust fault.

Travertine and salt are now being deposited by springs in both the northern and southern parts of the fault zone in Valencia County. A particularly interesting type of deposition, although not typical, is the series of many small travertine dams in the canyon below spring

6.3W.35.340 (fig. 8B). In T. 4 and 5 N., as much as 100 feet of older travertine on and east of the Comanche thrust fault is exposed where canyons are cut through the hogback of the thrust block. As the base of the travertine is not exposed in the canyons, the total thickness of the deposit is not known. The observed thickness of these deposits, however, suggests long-continued spring activity.

GROUND WATER IN THE LUCERO UPLIFT

In this report the Lucero uplift in eastern Valencia County is divided into two hydrologic districts: the Los Valles—Sierra Lucero district in T. 5 through 7 N., R. 3 W. and T. 4 through 6 N., R. 4 W., and the broad valley of the Rio San Jose, mostly in T. 8 N., R. 3 and 4 W. The slope of the water table in these two districts indicates that in Los Valles the unconfined ground water is moving south-southeast toward the Rio Puerco fault zone and that in the part of the Rio San Jose valley included in this report ground water is moving generally north to northeast. The two valleys are separated by Sierra Lucero in which beds of sandstone, limestone, evaporite rocks, and shale, totaling nearly 2000 feet thick, are exposed. Some of the rocks are aquifers; some are not. The hydrologic continuity, if any, through the Sierra Lucero has not been determined.

THE LOS VALLES-SIERRA LUCERO DISTRICT

Ground water in the Los Valles—Sierra Lucero district occurs in two separate aquifers. This is evident from the difference in the chemistry of water from the two aquifers. The upper aquifer consists of sandstone in the upper part of the Abo Formation and the lower part of the Yeso Formation. The lower aquifer is the Madera Limestone. The two aquifers are separated hydraulically by shale and siltstone in the lower part of the Abo Formation. The sandstone in the Abo and Yeso crops out in the cuesta that separates east and west Los Valles. All the wells in the central and western parts of Los Valles yield water from the upper aquifer. The depth to water in these wells ranges from 45 to 100 feet (pl. 2).

The source of recharge for water in the upper aquifer is probably partly from precipitation on the outcrop in the cuesta and on the alluvium of Quaternary age where it overlies the sandstone. Recharge also is derived from downward leakage from younger strata in the Sierra Lucero. The configuration of the water table in Los Valles (pl. 3) indicates that ground water in the upper aquifer moves generally to the east-southeast. Water discharging as flow from the aquifer, therefore, must cross the shale and siltstone in the lower part of the Abo Formation, which crops out in the floor of east Los Valles. The amount of ground water that can move across this outcrop is small, and the water is probably restricted to the alluvium underlying dry arroyos and resting on the Abo.

The lower aquifer in the Los Valles area is the Madera Limestone and possibly the underlying Sandia Formation. Ground water in the lower aquifer occurs in fractures and in solution channels in the limestone. Where the Madera is overlain by the Abo Formation, the ground water is under artesian pressure. In the extreme eastern part of Los Valles, where the Madera crops out in the hogback, the ground water in this aquifer is unconfined. Most of the wells in eastern Los Valles yield water from the Madera Limestone, and the springs in the water gaps in the hogback rise from the Madera.

The chemical character of the ground water that is discharged from springs on outcrops of the Madera Limestone in the hogback is distinctly different from that of ground water produced from the upper aquifer in western Los Valles (p1. 4). However, the chemical character of water from all springs along the fault zone on the margin of the Lucero uplift is similar, whether the water comes from the Madera in the southern part of the area or younger rocks to the north. The chemical similarity of water from all the springs suggests that the water has a common source. The source must be the Madera Limestone, because the Madera is the only formation that crops out against the fault zone in the southern part of the area and because the overlying Abo and Yeso formations in Los Valles yield water having distinctly different chemical characteristics.

If it is assumed that the water discharging from the springs is not of magmatic origin (that is, not derived from magma or molten material at great depth), an assumption that is reasonable in view of the chemical data discussed in a later section, then the immediate source of the water is to the west, and the Rio Puerco fault zone acts as a dam to the general eastward movement of ground water.

To the west, beyond the area of interest of this report, the Madera occupies a structural low, the Acoma embayment. The movement of ground water in the Madera, therefore, is updip, eastward, out of the Acoma embayment into the Los Valles area. In the southern part of the area the water generally discharges from the lowest outcrops of Madera on the hogback. Thus, the level of the water gaps through the hogback limits further eastward movement through the Madera. Locally, however, the water level in the Madera in Gray Mesa appears to be considerably higher than the altitudes of the floors of the water gaps. The water level in well 5.3W.28.143 near the south end of the hogback is about 80 feet higher than the water level at spring 5.3W.29.441, a little more than half a mile away. The high water table could be maintained by updip pressure in the formation if the permeability normal to the bedding is low. On the other hand, the water table at this well may be perched. In either event the water standing higher in the hogback than in the floors of the water gaps is probably in part locally recharged, and therefore probably contains smaller amounts of dissolved solids than the water discharging at the springs.

The ground water from the upper aquifer must also discharge through the water gaps where the springs in the Madera are located. The amount of water that is discharged from the upper aquifer is so small that it apparently does not strongly affect the composition of the water from the Madera.

In the northern part of the Rio Puerco fault zone in Valencia County, the Madera Limestone is at least several hundred feet, and possibly more than a thousand feet, below the surface. Springs here are associated with rocks as young as the Mancos Shale of Late Cretaceous age. In this area, where the Rio Puerco fault zone consists of a complex system of normal faults, ground water evidently rises from the Madera to the surface along the planes of the faults and the associated fractures. Ground water discharging from these springs commonly has a slightly higher ratio of sulfate to chloride than does water from the springs to the south. This suggests that somewhat more water is contributed to these springs from aquifers in the Abo and Yeso formations than these formations contribute to springs in the southern part of the fault zone. Like the Madera, the Abo and Yeso formations here are mostly in the subsurface.

THE RIO SAN JOSE VALLEY

In the part of the Rio San Jose valley included in this investigation the water table slopes generally to the north, from the uplands of the Sierra Lucero toward the Rio San Jose, at about 75 feet a mile (pl. 3). The depth to water in wells ranges from 6 feet in well 7.4W.10.124 to a reported depth of 144 feet in well 8.4W.15.123. Part of the ground water is discharged into the Rio San Jose at Suwanee Spring (8.3W.10.224) and Dipping Vat Spring (8.3W.12.342). The flows from these two springs were estimated to be 30 and 400 gpm, respectively, when they were visited.

The principal aquifer in the Rio San Jose valley is alluvium of Quaternary age. With the exception of wells 7.4W.25.111 and 7.4W.35. 443, all the wells in the area apparently obtain water from the alluvium. The wells which produce from the alluvium yield as much as 3 gpm. Wells 7.4W.25.111 and 7.4W.35.443 are on the westward-sloping surface of Sierra Lucero, and they probably obtain water from cavernous limestone beds in the San Andres Limestone.

Mounds as high as ten feet above the general land surface have formed around the orifices of springs 7.4W.3.344 and 7.4W.11.431. The surfaces of the mounds slope gently away from the springs in all directions. The mounds were formed by precipitation of calcium carbonate from the spring water as it discharged onto the surface. Sand blown onto the mounds during cementation is included in the deposit. Each spring is in the center of the mound at the highest point and consists of a natural vertical pipe six to eight feet in diameter; the depths were not measured.

The water level in spring 7.4W.3.344 is approximately 20 feet above the elevation of the water table, as interpolated from wells surrounding the spring. The water level in spring 7.4W.11.431 may be as much as 40 feet higher than the water table. Thus, both springs are artesian. At the time they were visited, the flow from spring 7.4W.8.844 was estimated to be 1 gpm and the flow from spring 7.4W.11.431, 5 gpm.

The chemical quality of the water discharging from the mound springs (discussed later) suggests that the upper limestone member of the San Andres Limestone is the source of the ground water. The San Andres Limestone may be separated from the overlying alluvium by the Shinarump Member, and possibly higher parts, of the Chinle Formation at the springs. If so, the water must move from the San Andres Limestone up through the Triassic rocks, thence through the alluvium to discharge at the surface. Lucero Spring (7.4W.11.431) reportedly is dry at times. The flow from the spring increases after large rains. These reactions suggest that the recharge area for the spring is nearby. The limestone member of the San Andres crops out within one and a half miles of Lucero Spring.

GROUND WATER IN THE RIO GRANDE GRABEN

The thickest and most extensive aquifer in eastern Valencia County consists of sediments of the Santa Fe Group which fill the Rio Grande graben to a depth of several thousand feet. The configuration of the water table within the Santa Fe indicates that the main body of ground water is moving generally southward across eastern Valencia County. *(See* pl. 3.) The slope of the water table from north to south averages four and one-half feet a mile, the same as the gradient of the river. Along the margins of the graben the water table slopes sharply downward from the Rio Puerco fault zone on the west and from the Manzano Mountains on the east. The depth to water in the Rio Grande graben in eastern Valencia County ranges from 0 at the springs to nearly 700 feet under Cat Mesa in the north-central part of T. 7 *N., R. 1* W. (pl. 3). The depth is less than 15 feet below the surface under most of the flood plain in the Rio Grande valley.

The water-table contour map (pl. 3) shows that, in the Rio Grande graben in Valencia County, ground water, which moves downgradient, ultimately moves toward the river. The Rio Grande surface-water system is a southward-flowing drain for ground water in the graben. The hydrology of the alluvium in the Rio Grande valley and of the river proper are of special interest and will be described separately from the hydrology of the Rio Grande graben.

An unusual water-table feature in the graben is the ground-water trough that extends northward from the vicinity of Dalies in sec. 5, T. 6 N., R. 1 E. This is the southern termination of a trough that reaches northward across Bernalillo County and extends an unknown distance into Sandoval County (Bjorklund and Maxwell, 1961). The trough is asymmetric in cross section throughout its length. Along the north boundary of Valencia County the slope of the water table on the east side of the trough is a little more than two feet a mile for seven miles. The slope of the water table on the west side of the trough is 30 feet a mile. In central Bernalillo County the relief on the east side of the trough is approximately 30 feet; in the southern part of Sandoval County the relief is approximately 50 feet. The ground-water trough broadens and swings toward the Rio Grande in the vicinity of Dalies. A short distance south of Dalies it loses its identity in a trough imposed on the water table by the Rio Grande.

A water-table trough that is not attributable to conditions of recharge or discharge can be maintained only if the transmissibility of the aquifer along the central part of the trough is greater than on the sides. Ground water normally moves down a water-table slope or gradient in a direction approximately at right angles to the contours. Thus, water moves toward the center of a trough from both sides. The total volume of water that moves to the central part of the trough from the sides under relatively steep hydraulic gradients must then move down the center of the trough under a gradient that is much less than that on either side. High transmissibility in the project area and to the north could be caused either by an anomalously thick strip of the Santa Fe Group or by an unusually permeable zone in the Santa Fe.

Joesting, Case, and Cordell (1961) have mapped a low-gravity anomaly in T. 7 N., R. 1 W. in Valencia County that extends northward into Bernalillo County. They stated that this gravity low, and other gravity lows to the north in Bernalillo and Sandoval counties, ". . . may coincide with comparatively great thicknesses of low-density valley fill" (p. 148). The gravity lows are approximately coextensive with the ground-water trough in Valencia County and its extension northward into Bernalillo and Sandoval counties (Titus, 1961). Thus, the two lines of evidence, low-gravity anomalies and high ground-water transmissibilities, reinforce the hypothesis that the Santa Fe Group is unusually thick between the Rio Grande valley and the Rio Puerco valley. The groundwater data further suggest that the thick Santa Fe section occurs in a strip only a few miles wide.

Anomalously high permeability also may be a factor in maintaining the ground-water trough. Numerous small volcanic centers, the southernmost of which are in Valencia County in the vicinity of sec. 6, T. 7 N., R. 1 E., lie in a discontinuous line extending northward along the axis of the water-table trough (Titus). These volcanic centers are likely to have related fractures in the Santa Fe Group. Fractures could increase the gross permeability of the aquifer without affecting the local permeability of sand and gravel beds. The few wells in the trough in Valencia and Bernalillo counties do not indicate that the sediments are unusually permeable in the upper part of the saturated zone of the Santa Fe. Fracture permeability may not be reflected in production performance of wells unless the fractures are near the wells.

Evidence cited above suggests that both an unusually thick section of aquifer and a north-south-aligned fracture system are contributing factors in the existence of the ground-water trough. The trough may coincide with the axis of a down-faulted block within the graben. A few faults in the Santa Fe Group have been mapped along the valley of the Rio Puerco and in the vicinity of the volcanoes near the Valencia County line in Bernalillo County (Kelley, 1954) that could be part of a set of faults bounding a down-faulted block. Exposures of the Santa Fe are generally poor on the Llano de Albuquerque, and the group has never been mapped in detail in this part of the Rio Grande graben. More detailed mapping might allow delineation of the block.

GROUND WATER IN THE RIO GRANDE VALLEY

Hydrologically, the ground water in the alluvium of the Rio Grande valley and the Rio Grande surface-water system must be considered together. The Rio Grande surface-water system consists of water in the channel of the river, water diverted from the river into the many irrigation-supply ditches and, thence, onto the fields, and water in artificial drainage ditches. The surface-water part of the hydrologic unit within the Rio Grande valley is intimately connected to the ground-water body. The alluvium is recharged by water from the river, from the irrigation ditches, and from the irrigated fields. The aquifer discharges water into the drains. The alluvium is underlain and is bounded on both sides by the Santa Fe Group, and the two aquifers are apparently in complete hydraulic connection.

A complex system of surface-water distribution ditches has been in use in the valley of the Rio Grande for many years. Bloodgood (1930), in his description of the hydrology of the middle Rio Grande valley, mentioned highline ditches that were shown on a soils map published in 1914. The highline ditches, which are on the slopes above the floor of the valley, supply water to the secondary irrigation ditches that crisscross the flood plain and serve the farms. The ditches were originally built and maintained by individual farmers or groups of farmers. The ditch system was subsequently consolidated, and it is now (1962) maintained by a conservancy district.

The drainage ditches (pl. 3), which were constructed during the years 1928 to 1931, consist of two types: riverside drains and interior drains. Each has a particular location and performs a special function. The riverside drains are located immediately outside the levees on both sides of the river. They parallel the river throughout most of its reach in Valencia County. The bottoms of the riverside drains are several feet lower than the bed of the river. These drains intercept leakage from the river, which otherwise would move underground from the river channel to the flood plain and raise the water table. The intercepted water moves down the valley in the drain; downstream the drain level approaches river level, returning the water to the river by gravity flow. The interior drains generally are near the center of the flood plain on each side of the river. Where possible, they occupy the lowest part of the flood plain. The interior drains prevent the water table from rising in the alluvium because of recharge from irrigation, leakage from the ditches, and recharge across the geologic contact from the Santa Fe Group. The combined effect of the two types of drains is to maintain the water table under the flood plain at a depth that is not injurious to crops grown on the land.

A sharp ground-water ridge lies beneath the channel of the Rio Grande (pl. 3). Here the water table is at or very near the surface because of leakage from the river. The shape and height of the ridge adjust continually to changes in the amount of leakage. In drawing the contours on the water-table map (pl. 3), it was assumed that the crest of the ground-water ridge was at the altitude of the bed of the river and that the foot of the ridge was at the altitude of the water in the riverside drains. From the riverside drains the water table slopes away from the river toward the interior drains. In general, the interior drains east of the river seem to have a greater depressing effect on the water table than those to the west. Part of this effect is probably due to greater topographic relief on the flood plain east of the river. The depth to water under most of the flood plain in Valencia County is between seven and nine feet (fig. 9).

A detailed water-table contour map was drawn by Theis (1938) from water-level measurements made in October 1936. The similarities between the configuration of the water table in 1936 and the configuration of the water table as shown on Plate 3 of this report are notable. Differences larger than a foot or two in the altitude of the water table are unusual. However, two areas of significant difference stand out. The water table is two to five feet lower in the vicinity of the southeast corner of T. 7 N., R. 2 E., where the concentration of irrigation wells is greatest. In the vicinity of Belen the water table has been lowered almost five feet. Variations of about a foot are numerous. Some of these variations are probably imaginary and are caused by the necessity for interpolation of the contour location between wells.

Theis and Taylor estimated that the southward underflow in the alluvium under the flood plain of the Rio Grande in the Albuquerque and Belen divisions was about 750 acre-feet a year. This computation

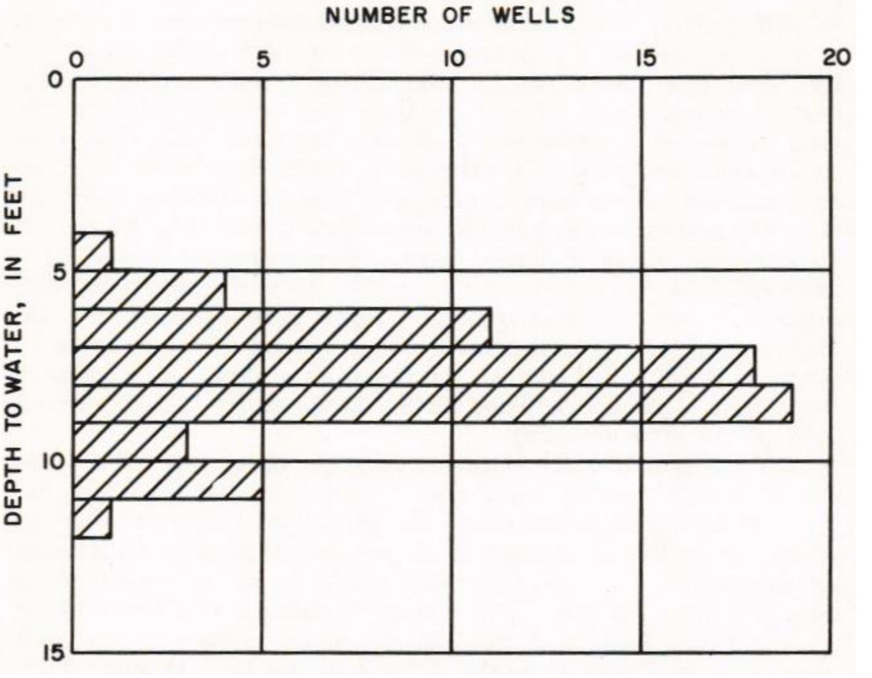


Figure 9

DEPTH TO WATER IN DEEP WELLS ON THE FLOOD PLAIN OF THE Rio GRANDE IN VALENCIA COUNTY, N. MEX.

was based on a coefficient of transmissibility of 50,000 gpd per foot, a water-table gradient of five feet a mile, and an average width of the flood plain of two and one-half miles. The hydraulic characteristics of the alluvium in the Rio Grande valley have been described in detail by Theis and by Theis and 'Taylor.

Quality of Water

The chemical quality of ground water in eastern Valencia County is indicated by more than 75 chemical analyses made by the U.S. Geological Survey. Parts of selected analyses are given in Tables 5, 6, and 7 to show the general character of water in the several parts of the area. Additional data are summarized in the diagrams accompanying this discussion. The complete analyses are included in an appendix to the report.

The analyses show only the chemical characteristics of the water. Because the analyses do not include any determination of the biological material contained in the water, they do not indicate the sanitary condition of the water.

Water may contain dissolved mineral material that imparts an objectionable odor or taste and yet be free of harmful bacteria. On the other hand, water may have no noticeable taste or odor and yet contain disease-producing bacteria. As a general rule, wells that are designed to yield water for domestic consumption should not be constructed near a source of contamination, should be cased from the surface to a point below the water table, and should be constructed so as to prevent surface water from entering the well. The water from a *new* well should be tested for bacteria before the well is put into production or at any time that contamination is suspected.

The amounts of the mineral constituents dissolved in the water are reported in parts per million (ppm). One part per million is equivalent to a unit weight of the constituent dissolved in a million unit weights of solution. Plates 4 and 5 and Figure 10 were prepared using amounts of the constituents as reported in equivalents per million (epm). Equivalents per million takes into account not only the weight concentrations of the ions but also the concept of chemical equivalence; it is calculated by dividing the concentration in parts per million by the chemical combining weights of the constituents. For a more complete discussion of the units used in reporting chemical analyses, the reader is referred to Hem (1959).

GENERAL CONSIDERATIONS OF QUALITY RELATIVE TO USE

The following discussion of the chemical constituents in ground water has been adapted in part from reports by the California State Water Pollution Control Board (1957), Hem (1959), and McLaughlin (1954). For detailed information regarding the effects of the many substances that may be dissolved in water, the reader is referred to the first two reports.

DISSOLVED SOLIDS

The concentration of dissolved solids in water is determined from the weight of dry residue remaining after evaporation of a sample of the water or from the sum of determined constituents. The residue also may include some organic material and some water of crystallization. On the other hand, some of the salts may be volatilized during the drying, and dissolved gases may be driven off; thus, the figure reported as dissolved solids is an approximation of the sum of the constituents in the water.

The U.S. Public Health Service (1962) recommends that, in water to be used for drinking and culinary supply under conditions subject to the Federal quarantine regulations, total solids should not exceed 500 ppm for water of good chemical quality. However, if such water is not available, a total solids content of 1000 ppm may be permitted. According to the California State Water Pollution Control Board (p. 245), "Many communities in the United States and other countries use water containing from 2,000 to 4,000 ppm of dissolved salts, when no better water is available. Such waters are not palatable, do not quench thirst, and may have laxative effects upon new users. However, no harmful physiological effects of a permanent nature have been called to the attention of health authorities. . . ."

The use of highly saline water can cause, among animals as well as among men, physiological disturbances of varying degrees of severity. It is generally assumed that water which is safe for human consumption may be used safely by stock. On the other hand, it appears that animals can tolerate water of higher salinities than can man, and it is conceivable that they differ in their tolerance of specific substances. Within limits, animals can adjust gradually to the consumption of water which would be impossible for them to consume without a period of adjustment. The tolerance of stock for water containing high concentrations of dissolved solids depends on many factors, including species, age, amount of liquid consumed, and the salt content of the diet. The standards in use in western Australia, an area with certain similarities to our arid southwest, indicate a safe upper limit for continuous use of about 10,000 ppm for cattle and about 12,900 ppm for adult, dry sheep; for other species, the standards range downward to that of poultry, which has a safe upper limit of about 2860 ppm (California State Water Pollution Control Board).

The dissolved solids in samples of ground water from eastern Valencia County ranged from 168 ppm in water from well 4.3.26.144 to 33,900 ppm in water from spring 7.2W.18.313.

SPECIFIC CONDUCTANCE

Electrical conductance is a measure of the ability to conduct an electrical current. The specific conductance is the electrical conductance measured through two opposing and parallel electrodes of 1 sq cm in area and separated from each other by 1 cm. Because conductance is the reciprocal of resistance, the units in which specific conductance is reported are reciprocal ohms or mhos. The units in which the U.S. Geological Survey reports specific conductance are micromhos, mhos x 10^{-6}. The ability of water to conduct an electrical current is dependent on the concentration and type of dissolved solids. Various ions affect conductance in different degrees. However, Hem has stated that unless the water has an unusual composition, a very rough approximation of the dissolved solids may be obtained by multiplying the specific conductance by a factor of 0.55 to 0.75. The specific conductance of water can be quickly and easily determined, which makes it a useful measurement in the study of water quality.

HARDNESS

The term *hardness* is associated with the chemical reactivity of certain dissolved solids with soap. Soap will not lather in water until all the ions that cause hardness have been precipitated as insoluble salts. Salts of calcium and magnesium cause virtually all the hardness in water.

Hardness is classified as carbonate or noncarbonate on the basis of the anion with which the calcium and magnesium may combine. Carbonate hardness includes that part of the hardness that is equivalent to the carbonate and bicarbonate anions present in the water. Any hardness in excess of this amount is called noncarbonate hardness.

Hardness of water for household use is not particularly noticeable unless it exceeds 100 ppm. As hardness increases above 100 ppm, it becomes noticeable, necessitating use of more soap and contributing to increasing incrustation of pipes and utensils. Excessive hardness is undesirable in water to be used for boiler feed, for laundries, for food processing, and for several other industrial processes.

Ground water in eastern Valencia County contains calcium and magnesium hardness ranging from 19 ppm in well 3.5.32.210 to 3940 ppm in spring 6.3W.35.340.

FLUORIDE

Natural waters ordinarily do not contain large concentrations of fluoride. The fluoride content is of interest, however, because of its effect on teeth. The U.S. Public Health Service has set limits as follows on the fluoride content of water to be used on public carriers in interstate commerce and for other water supplies under its jurisdiction:

> (3) (i) When fluoride is naturally present in drinking water, the concentration should not average more than the appropriate upper limit in Table I. Presence of fluoride in average concentrations greater than two times the

optimum values in Table I shall constitute grounds for rejection of the supply.

(ii) fluoridation (supplementation of fluoride in drinking water) is practiced, the average fluoride concentration shall be kept within the upper and lower control limits in Table I.)

Table I

Annual average of maximum daily air temperatures [a] (°F)	Recommended Control Limits (Fluoride concentrations in mg/l [=ppm])		
	Lower	Optimum	Upper
50.0-53.7	0.9	1.2	1.7
53.8-58.3	.8	1.1	1.5
58.4-63.8	.8	1.0	1.3
63.9-70.6	.7	0.9	1.2
70.7-79.2	.7	0.8	1.0
79.3-90.5	.6	0.7	0.8

a. Based on temperature data obtained for a minimum of five years. (U.S. Public Health Service, 1962, p. 2154).

Numerous articles have been published that lead to the generalization that water containing less than about 1 ppm of fluoride will seldom cause mottled enamel on the teeth of children and that maintenance of 0.8 to 1.5 ppm of fluoride in drinking water will aid in the prevention of dental decay, especially among children.

The amount of fluoride in water in eastern Valencia County ranges from 0.2 ppm in well 5.1.28.114 and in spring 8.3W.35.100 to 5.8 ppm in spring 7.2W.7.124. All but two of the samples that contain more than 1.5 ppm fluoride were obtained from the Rio Puerco fault zone and the Santa Fe Group between the Rio Puerco and the Rio Puerco fault zone. Well 3.5.32.210, in the southeastern part of the county, contains 1.8 ppm; well 7.2.28.243, one of the two wells supplying Los Lunas, also contains 1.8 ppm. Well 7.2.28.234, the other Los Lunas well, contains 0.8 ppm. Water from Belen municipal well 5.1.13.332 contains 1.0 ppm of fluoride.

NITRATE

Nitrate is the end product of oxidation of nitrogen from all sources, and this is the form in which nitrogen predominates in water. Small amounts of nitrate are derived from weathering of rock material and from nitrogen dissolved in rain water. However, the bulk of the nitrate that occurs in surface water and in ground water results from biological activity. Certain plants, the legumes, are able to take nitrogen from the air and fix it in soil as nitrate. Decay of plant debris and animal excrement and application of inorganic nitrogenous fertilizers add nitrate to the soil.

Infant methemoglobinemia, a disease characterized by certain blood changes and cyanosis (blue babies), may be caused by high nitrate concentrations in water used for preparing feeding formulas. It has been widely recommended that water containing more than 45 ppm nitrate should not be used for infants. In much higher concentrations nitrate in water is toxic to adults. *(See* California State Water Pollution Control Board, 1952, p. 300-801.) High concentrations of nitrate in water, aside from being poisonous, may indicate biological contamination.

Of 48 samples of water from eastern Valencia County that were analyzed for nitrate, only one had a concentration of more than 20 ppm and only three had concentrations of more than 10 ppm. The concentrations ranged from none in wells 7.2.21.332 and 7.4.23.123 to 358 ppm (approximate) in well 8.3.32.412.

SODIUM-ADSORPTION RATIO

The sodium-adsorption ratio (SAR) was developed by the U.S. Salinity Laboratory, Department of Agriculture (1954), for use in classifying soils and water used in the production of crops. The SAR is defined by the equation: $SAR = Na+ / (\sqrt{Ca++ + Mg++)} \quad /2$

in which the concentrations are in epm. This equation was determined empirically on the basis of the rate with which exchangeable cations are adsorbed by the soil.

Sodium is required in very small amounts, if at all, for plant growth, and in high concentrations it is toxic to plants and deleterious to soil texture. A high ratio of sodium to calcium and magnesium in irrigation waters causes clay particles to swell, closing the pore spaces of the soil and restricting the circulation of water and air. Sodium-saturated soils are greasy to the touch, and, as the concentration of sodium increases, the soil may darken.

The sodium, or alkali, hazard of irrigation water is measured numerically by the SAR. The relationship between SAR and the specific conductance for water in eastern Valencia County is illustrated in Figure 10.

QUALITY OF WATER BY AREAS

Los VALLES AND THE RIO PUERCO FAULT ZONE

Water from wells and springs in the vicinity of Los Valles and the Rio Puerco fault zone contains moderate to large amounts of dissolved solids. (Chemical analyses of water from selected wells and springs in the area are shown in Table 5; additional analyses are included in Appendix D. Water from the wells which are in the western part of Los Valles contains from 3790 to 4780 ppm of dissolved solids. Water from the springs which are on or near the trace of the Rio Puerco fault zone contains from 13,540 to 33,900 ppm of dissolved solids.

TABLE 5. CHEMICAL QUALITY OF WATER FROM SELECTED WELLS AND SPRINGS WEST OF THE RIO PUERCO FAULT ZONE IN EASTERN VALENCIA COUNTY, N. MEX.

Analyses by U.S. Geological Survey. Chemical constituents in parts per million.

Well No.	SiO_2	Ca	Mg	Na + K as Na	HCO_3	CO_3	SO_4	Cl	F	NO_3	Dissolved solids	Hardness as $CaCO_3$ Ca,Mg	Hardness as $CaCO_3$ Non-carbonate	Specific conductance	pH
Los Valles—Wells															
5.3W.19.111	20	405	233	336	177	0	2,300	100	0.7	19	3,790	1,970	1,820	3,960	7.7
6.3W.10.233	—	—	—	461	274	0	2,570	300	—	—	—	2,320	2,100	4,730	7.2
6.3W.28.333	22	556	273	469	315	0	2,610	385	0.7	12	4,780	2,510	2,250	5,210	7.2
Rio Puerco Fault Zone—Springs															
4.3W.6.444	25	681	314	7,450	2,440	0	3,490	9,610	2.0	—	22,700	2,990	990	31,000	7.0
6.2W.6.433	21	534	448	3,690	1,390	0	2,640	5,160	1.0	—	13,540	3,170	2,030	—	—
7.2W.18.313	34	918	220	11,200	2,840	—	8,910	11,100	3.4	—	33,900	3,200	868	—	—
San Jose Valley—Wells															
7.4W.15.222	11	611	147	146	385	0	1,860	136	1.2	0.2	3,350	2,130	1,810	3,420	7.0
8.3W.20.211	33	453	252	376	161	0	2,240	364	—	8.3	3,810	2,170	2,030	4,500	7.4
San Jose Valley—Springs															
7.4W.3.344	—	606	150	—	408	—	1,970	146	—	—	3,440	2,130	1,790	—	—
7.4W.11.431	25	647	183	273	603	0	1,940	315	1.4	0.8	3,930	2,370	1,870	4,260	6.7
8.3W.10.224	29	258	99	558	224	0	1,530	344	—	3.6	3,020	1,050	867	3,790	7.7

In water from the wells in Los Valles, calcium is slightly more common than either magnesium or sodium plus potassium among the cations, and sulfate predominates among the anions. This is illustrated in Plate 4 which shows the proportions of the cations, calcium, magnesium, and sodium plus potassium, on one triangular diagram and the proportions of the anions, chloride, sulfate, and carbonate plus bicarbonate on the other triangular diagram. *(See* Piper, 1944.) Thus, sulfate comprises roughly 85 percent of the total of the four anions, and calcium comprises roughly 40 percent of the total of the four cations in water from wells. The concentration of sulfate, the predominant anion, is as great as 2610 ppm, and the concentration of calcium, the predominant cation, is as great as 556 ppm.

Water from the springs contains from 5160 to 11,100 ppm of chloride and from 2640 to 8910 ppm of sulfate among the anions. Although the absolute amounts of these constituents in the water varies considerably, Plate 4 indicates that the proportions of the ions is only slightly variable. Among all samples from the springs, chloride comprises from 50 to 70 percent and sulfate from 20 to 40 percent of the anions. Sodium and potassium together comprise from 70 to nearly 100 percent of the cations; the amount of potassium is probably minor. Water from the springs is predominantly a sodium chloride water.

The chemical characteristics of any body of ground water are the result of the geologic environment through which the water has passed. In view of the great differences in both the proportions of the various chemical constituents and the total amount of material in solution in the water, water from the springs and the wells probably was derived from different sources. Furthermore, the data do not suggest mixing between the two waters.

The wells in the western part of Los Valles tap aquifers in the lower part of the Yeso Formation and the upper part of the Abo Formation. The springs in the southern part of the Rio Puerco fault zone discharge water from the Madera Limestone which directly underlies the Abo Formation. Shales and siltstones in the lower part of the Abo Formation apparently form an aquiclude that prevents transfer of water between the two ground-water bodies.

The large amount of sulfate in the water from the wells tapping the Abo and Yeso formations suggests that the water recharging these aquifers is in contact with gypsum (a calcium sulfate mineral). Gypsum is abundant in the Yeso Formation and the overlying Glorieta Sandstone and San Andres Limestone. These formations all crop out in the face of Sierra Lucero, which forms the west wall of Los Valles. Recharge to the aquifers is probably from local precipitation.

The chemical similarity between all samples analyzed from the springs along the fault zone strongly suggests a single source for the water. However, the springs are associated with rocks of all geologic ages from Pennsylvanian to Cretaceous. Geologic and hydrologic conditions indicate that the water must either move into the area from the west or originate at depth and rise along the fault plane.

If water were rising along the fault plane from great depth, the water probably would be partly of magmatic origin. White (1957) has proposed criteria for differentiating sodium chloride water of connate origin (fossil sea water) from similar water of "volcanic" origin. For recognizing water of "volcanic" origin, the criteria include silica concentrations of between 100 and 700 ppm, calcium concentrations of less than 100 ppm, and magnesium concentrations of less than 10 ppm. All water collected from the springs along the Rio Puerco fault zone has significantly less silica and more calcium and magnesium than stipulated by White for "volcanic" water. Other criteria used by White include limiting values for the ratios

$$\frac{CO_3 + HCO_3}{Cl}, \quad \frac{SO_4}{Cl}, \quad \frac{Ca + Mg}{Na + K}$$

Some of the samples from the Rio Puerco fault zone fall within the values for connate water and outside those for "volcanic" water; all the remainder are in an overlapping range that includes water from both sources. This, however, still strongly suggests connate origin, as it has been shown that all the water probably comes from the same source. The criteria proposed by White suggest that the water from the springs is not of volcanic or magmatic origin.

The geologic evidence described earlier suggests that ground water moving toward the Rio Puerco fault zone from the west must move through the Madera Limestone and the Sandia Formation.

THE RIO SAN JOSE VALLEY

The chemical quality of the ground water in the valley of the Rio San Jose is indicated by several analyses in Table 5. The chemical characteristics of water from the mound springs (7.4W.3.344 and 7.4W. 11.431) and from well 7.4W.15.222 are very similar. The dissolved solids in water from these three sources range from 3350 to 3930 ppm, and the water is extremely hard. Sulfate is the principal anion and calcium is the principal cation. Thus, like the shallow ground water in the Los Valles area, the water in the Rio San Jose valley is gypseous.

Comparison of the water-analysis diagram for the Rio San Jose valley (pl. 5) with that for the Los Valles area (pl. 4) shows that ground water from west and northwest of Mesa Lucero in the Rio San Jose valley occupies a position on the chart similar to that of water from the shallow aquifer in Los Valles. The alluvium of the Rio San Jose valley is underlain largely by rocks of the Shinarump Member and other units of the Chinle Formation, none of which contains much gypsum, if any. Thus, recharge to the alluvium in the Rio San Jose valley is inferred to be primarily from the San Andres Limestone, which contains gypsum in abundance.

Suwanee Spring (8.3W.10.224) and Dipping Vat Spring (8.3W.12.342) discharge part of the ground water in the alluvial aquifer into the Rio San Jose. The slope of the water table indicates movement from the vicinity of the mound springs, which are west of Mesa Lucero, toward Suwanee and Dipping Vat Springs. The water-analysis diagram (pl. 5), however, shows that the quality of water discharging into the Rio San Jose differs from the quality of the ground water west of Mesa Lucero, insofar as the proportion of the cations is concerned. The water discharging into the Rio San Jose from Suwanee and Dipping Vat springs contains a larger proportion of sodium and a smaller proportion of calcium than the ground water from the source area. The proportion of magnesium remains about the same.

Cation-exchange reactions within the aquifer are suggested by this relationship. Clay particles in soils and rocks are capable of adsorbing (that is, attracting and holding) charged particles (ions) on the surface and within the crystalline structure of the particles. Cations (ions with positive charges) are much more commonly involved in adsorption than are anions (ions with negative charges). The adsorbed cations are bound more or less loosely to the crystal lattice of the clay. The type of cation that is adsorbed on a clay particle, that is, calcium, magnesium, sodium, or other, depends in part on the abundance of the ion within the soil solution. Thus, when water surrounding the clay particle contains a predominance of one type of cation and the cations adsorbed on the clay particle are predominantly of a second type, the tendency is for exchange to occur until the ions adsorbed on the particle are in equilibrium with those in the water.

The ground water entering the alluvial aquifer from the Sierra Lucero and the uplands to the west of the Sierra Lucero has been shown to contain relatively large concentrations of calcium and sulfate. Ground water with a high calcium concentration moving through the silty and clayey alluvial material is apparently exchanging calcium ions for sodium ions adsorbed on the clay. Potassium, which is reported with sodium, is probably a minor constituent in the ground water. The chemical characteristics of water from well 8.3W.20.211 tend somewhat to strengthen the argument for ion exchange. This well is approximately halfway *between* the mound springs and the springs discharging into the Rio San Jose. Water from this well has a lower proportion of calcium and a slightly higher proportion of sodium than the water from the mound springs. The support is not clear cut, however, because the magnesium proportion is higher than in samples from either the recharge area to the southwest and the discharge area to the northeast. The explanation for the high magnesium content also may lie in ion exchange, although the answer is not obvious.

THE RIO GRANDE GRABEN

The concentration of dissolved solids in the ground water from the Santa Fe Group in eastern Valencia County ranges between wide limits. The areal distribution of concentrations, however, follows a regular pattern within the graben. The specific conductance of samples of ground water from the Santa Fe Group is shown in Plate 6. The specific conductance of water from the Santa Fe Group east of the Rio Grande valley, with one exception, ranges from 257 to 449 micromhos. The range of dissolved solids in the water is estimated to be between 150 and 300 ppm on the basis of chemical analyses and extrapolation of the maximum and minimum values using specific-conductance values. The exception is the water from well 8.3.32.412, which has a specific conductance of 1020 micromhos. The chemical analysis shows that the nitrate concentration in water from this well is approximately 358 ppm. The high nitrate concentration and high specific conductance suggest that the water in the well is contaminated.

The data from several representative chemical analyses of water from the Santa Fe Group are given in Table 6. In general, sodium and calcium predominate over magnesium among the cations, and bicarbonate and sulfate predominate over chloride among the anions.

Ground water near the Socorro County line in T. 3 N., R. 3 E. contains larger concentrations of dissolved solids than have been found elsewhere in the Santa Fe Group east of the Rio Grande in Valencia County (pl. 6). A chemical analysis of water from well 3.3.10.324, made in 1906, shows 834 ppm dissolved solids. An earlier analysis, in 1903, of water from nearby well 3.3.10.324a shows 945 ppm of dissolved solids. The principal anion in the water is sulfate (Spiegel). Spiegel reported that water from well 3.3.5.331 (his well V3N.3E.5.320) had a salty and bitter taste. He thought the poorer quality of ground water in this area was caused by recharge to the Santa Fe Group from gypseous water flowing intermittently in Abo Arroyo in Socorro County a short distance south of Valencia County. This is the northern boundary of a large area in Socorro County in which the Santa Fe Group contains ground water that is high in sulfate.

The specific conductance of water from the Santa Fe Group in T. 7 N., R. 2 E., where it underlies the alluvium of the Rio Grande valley and the older alluvium west of the valley, ranges from 457 to 539 micromhos. Water from well 7.2.28.243, which had a specific conductance of 470 micromhos, contained 336 ppm of dissolved solids. This is one of two wells that supply water for the village of Los Lunas. The high specific conductance of water in the Santa Fe,under the Rio Grande valley and west of the valley, compared to that east of the valley, signifies some recharge from the alluvium since ground water from the alluvium

TABLE 6. CHEMICAL QUALITY OF WATER FROM WELLS IN THE SANTA FE GROUP IN VALENCIA COUNTY, N. MEX.

Analyses by U.S. Geological Survey. Chemical constituents in parts per million.

Well No.	SiO_2	Ca	Mg	Na + K	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness as $CaCO_3$		SAR	Specific conductance	pH
													Ca,Mg	Non-carbonate			
East of the Rio Grande valley																	
4.2.35.214	32	24	6.3	34	115	0	49	9	0.8	1.6	—	214	86	0	1.1	310	—
5.3.8.222	54	33	6.2	17	132	0	23	9	—	1.1	—	208	108	0	0.7	277	7.8
7.3.13.434	26	—	—	14	152	0	20	3.5	0.8	1.3	—	—	123	0	0.6	286	7.6
In and near the Rio Grande valley																	
5.1.13.332	31	37	15.	99	178	0	176	24	1.0	4.7	—	476	154	8	3.5	720	7.9
7.2.18.421	—	—	—	—	182	0	86	24	—	—	0.12	—	64	0	—	539	8.3
7.2.21.332	48	12	3.1	100	186	0	76	18	1.0	5.0	—	350	42	0	6.7	506	—
7.2.28.243	50	10	3.1	96	187	0	73	9.0	1.8	0.1	—	336	38	0	6.8	470	8.1
West of the Rio Grande valley																	
5.1.28.114	24	322	119.	221	166	0	1,230	252	0.2	1.3	—	2,420	1,290	1,160	2.7	2,960	7.2
6.1.5.421	39	17	8.4	114	160	0	155	18	0.9	6.1	—	437	77	0	5.7	660	—
6.2W.13.234	22	9.1	9.8	1,410	866	8	1,190	820	5.0	0.8	—	3,880	63	0	77.0	5,800	8.3

usually contains larger amounts of dissolved solids than that from the Santa Fe.

The specific conductance of water from the Santa Fe Group west of the axis of the ground-water trough ranges from 2480 to 8540 micromhos. In general, the water near the Rio Puerco fault zone has the highest specific conductance, and the specific conductance decreases toward the axis of the trough. The decrease undoubtedly is due to dilution of the ground water by recharge from precipitation and from the Rio Puerco and its tributaries. The Rio Puerco is intermittent, flowing only during periods of storm runoff, and the quality of the water is variable. The type as well as the total amount of dissolved solids in the floodwater changes between flows because the floods originate in different parts of the drainage basin. The few chemical analyses of water from the Rio Puerco range in specific conductance from 594 to 3450 micro-mhos. The quality of most flows of the Rio Puerco probably fall within these limits. The maximum specific conductance of the river water recorded here is somewhat less than the conductance of ground water at and west of the Rio Puerco in the Santa Fe Group.

The floor of the ground-water trough in the Santa Fe Group is broad and nearly flat in Valencia County. Ground water from the east and west sides of the trough apparently is mixed in the broad axial belt. Water from well 5.1.13.332, the municipal supply well for Belen, is representative of ground water from near the axis of the trough. This water has a specific conductance of 720 micromhos and contains 476 ppm of dissolved solids. The specific conductance of water in the belt of mixing ranges from 500 to 1000 micromhos. This range is much nearer the average specific conductance for water from the eastern source than for water from the western source. It may be inferred, solely on the basis of the quality of ground water, that in the upper part of the aquifer from where ground water is pumped, the volume of water entering the trough from the east is much greater than the volume entering from the west. In view of the known and inferred geology of the aquifer it seems likely that the lower and upper parts of the aquifer behave similarly.

The Santa Fe Group is several thousand feet thick. Samples of ground water have been collected only from near the top. Vertical variations in water quality within the aquifer probably are common. The chemical effect of recharge from surface water, for instance, is probably restricted to the upper part of the aquifer, especially where the recharging water contains lower amounts of dissolved solids than the water already in the aquifer. Under these conditions the recharging water, which is less dense, tends to float on the denser water in the aquifer. Even where recharge from surface sources is more saline than water in the aquifer, vertical mixing is probably slow. As a general rule, however, the salinity of ground water tends to increase with depth, although there are many exceptions to the rule.

THE RIO GRANDE VALLEY

The specific conductance of water in the alluvium of the Rio Grande valley generally ranges from 600 to 900 micromhos (table 7), representing a content of dissolved solids greater than 400 ppm. The water is hard, with a calcium-magnesium hardness of 220 to 370 ppm. Most of the irrigation wells in the Rio Grande valley are gravel-packed, including all the wells for which water analyses are shown, except well 4.2.8.243. Water samples from these wells probably consist of mixtures of water from all parts of the aquifer penetrated by the wells.

A thin zone of ground water that is high in dissolved solids relative to most of the water in the aquifer occurs in the upper part of the zone of saturation in the alluvium. The thickness of the zone probably varies both areally and in time. The maximum thickness is not known but probably is about ten feet. The zone may consist of a continuous gradation from poorest quality of water at or within a few feet of the water table to better quality of water below. The quality of the ground water in the upper zone has been determined by analyses of water from the drainage ditches on the flood plain and ground water from holes less than ten feet deep drilled by the U.S. Bureau of Reclamation (table 7). The specific conductance of samples from the drains ranges from 790 to 1150 micromhos. The specific conductance of samples from the shallow test holes ranges from 907 to 4080 micromhos.

The high concentration of dissolved solids in water from the upper part of the aquifer is probably due to evapotranspiration, the effect of which is to remove water from the soil or the ground-water body, leaving behind most of the dissolved solids. The concentration of solids in solution in the remaining water is thus increased.

In irrigated parts of the flood plain of the Rio Grande, large areas are overgrown by uncultivated plants that have phreatophytic growth habits. The term *phreatophyte* is applied to plants growing with parts of their root systems below the water table or in the capillary zone immediately above the water table. These plants take water directly from the ground-water reservoir, whereas most plants grow with their roots in the zone of aeration and must depend on periodic wetting of the soil from precipitation or some other source. As the phreatophytes remove water from the upper part of the ground-water reservoir, more water moves in to replace that which has been transpired. The replacement water brings with it a normal complement of dissolved solids. This process in the Rio Grande valley evidently has resulted in high concentrations in the upper layers of water. Cultivated plants also contribute to the phenomenon. Alfalfa, among other crop plants, can grow as a phreatophyte. In addition, plants with root zones above the water table may cause precipitation of salts around their roots; subsequent application of water in excess of the moisture-retaining capacity of the soil

TABLE 7. CHEMICAL QUALITY OF WATER FROM WELLS IN THE ALLUVIUM IN THE RIO GRANDE VALLEY IN VALENCIA COUNTY, N. MEX.

Analyses by U.S. Geological Survey. Chemical constituents in parts per million.

Well No.	Ca	Mg	Na	HCO_3	CO_3	SO_4	Cl	F	NO_3	B	Dissolved solids	Hardness as $CaCO_3$		Per-cent Na	SAR	Specific conduct-ance	pH
												Ca,Mg	Non-carbon-ate				
Irrigation wells (total depth more than 35 feet)																	
4.2.8.243	—	—	43	203	0	115	24	—	1.4	—	—	228	62	29	1.2	631	7.4
5.2.32.143a	—	—	—	273	0	198	45	—	—	0.09	—	364	140	—	—	900	7.5
6.2.3.344	102	18	67	282	0	180	39	—	2.1	—	—	328	98	31	1.6	879	7.6
7.2.26.112	71	13	33	222	0	108	4	0.4	0.6	—	409	230	48	24	0.9	609	7.6
Shallow observation wells (total depth less than 10 feet)																	
4.2.7.141	286	84	579	578	0	965	595	—	1.9	—	3,000	1,060	586	54	7.7	4,080	—
4.2.7.423	112	19	69	420	0	86	50	—	3.7	—	540	358	14	29	1.0	948	—
6.2.29.113	94	26	172	524	0	216	42	—	1.7	—	838	342	0	52	4.0	1,290	—
7.2.26.433	128	35	374	544	0	570	168	—	0.6	—	1,530	464	18	64	8.0	2,260	—

(field capacity) leaches the accumulated material out of the root zone, carrying it down to the water table.

Under uncontrolled conditions on a river flood plain, the concentration of dissolved solids in the upper part of the ground-water reservoir should reach an equilibrium, which is dependent on transpiration per unit area and salt tolerance of the plants, on one hand, and dilution of ground water by precipitation and overbank flood flows of the river, on the other hand. In the Rio Grande valley, under the present water regimen, the concentration of dissolved solids is influenced in addition by application of irrigation water from the river and from the lower part of the aquifer and by the effect of the drains in removing water from the upper part of the aquifer.

In the Middle Rio Grande Irrigation Project area, each parcel of water is likely to be used several times in its passage through the area. Part of the water that is spread on the land infiltrates into the ground and returns by subsurface flow to the drains, from which the water is diverted into another set of supply ditches downstream. Each time the water is applied to the land, the part that percolates below the root zone is enriched in dissolved solids. The effect is a net increase in dissolved solids downstream. In some places this effect may be partly nullified by the addition of water that is low in dissolved solids from surface or subsurface sources.

The diagrammatic classification in Figure 10 of irrigation water from several sources in the Rio Grande valley shows that as the specific conductance of surface water and ground water in the alluvium increases, so does SAR. This diagram is designed to show the hazard to crops or soil conditions inherent in irrigating with waters of different specific conductance and SAR. A detailed description of the levels of hazard indicated on the diagram may be found in Wilcox (1955).

Analyses of water from the Santa Fe Group west of Los Lunas fall outside the major linear group on the diagram. The analyses of water from a single source in the river valley, such as those for drains, tend to fall close together in the linear group. Note that the samples of water from the Rio Grande and from ditches into which water is diverted from the Rio Grande have the lowest specific conductance and SAR. (The average range of specific conductance of water from the Rio Grande at Albuquerque, based on many samples, is 200 to 600 micromhos.) The specific conductance of water from wells that are more than 35 feet deep in the alluvium is a little higher than that of water from the Rio Grande; the specific conductance of water from the drains is higher than that of water from the deep wells; and the specific conductance of water from the shallow wells in the alluvium is higher than that of water from the drains. The highest specific conductance of water that was measured in the valley was 4080 micromhos.

The depth of the shallow wells is roughly the same as that of the drainage ditches. Inasmuch as the wells do not remove significant quan-

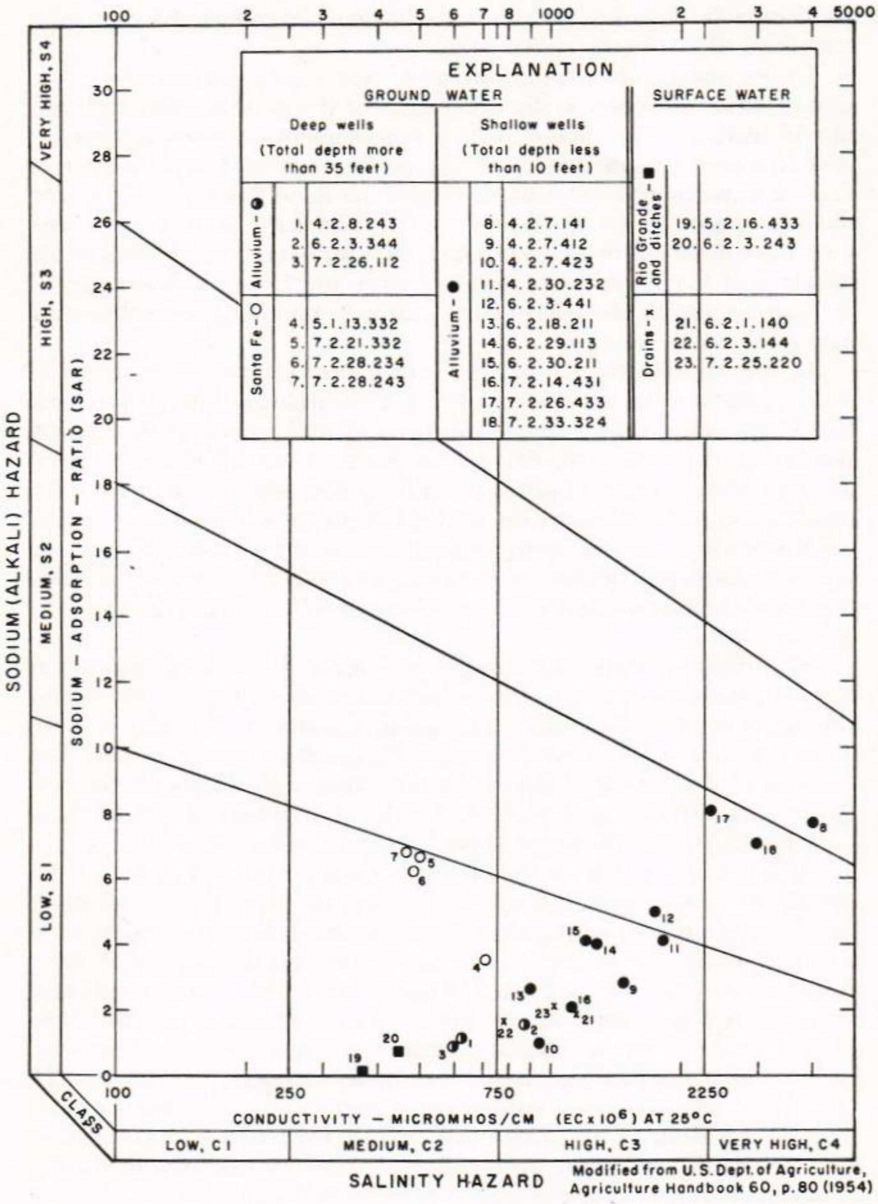


Figure 10

CLASSIFICATION OF IRRIGATION WATER FROM SEVERAL SOURCES IN THE RIO GRANDE VALLEY, VALENCIA COUNTY, N. MEX.

tities of water from the aquifer, the quality of the water from the wells probably closely reflects the quality of the water in the part of the aquifer penetrated by the wells. On the other hand, the drains, when they are effective, continually remove water from the aquifer. The fact that the specific conductance of water from the drains is lower than that of water from the shallow wells suggests that water enters the drains from beneath as well as from the sides. This is consistent with the general concept of the effect of a drain on a water-table aquifer. The samples collected from the drains in Valencia County represent a mixture of the water from the thin upper zone with the water that contains less dissolved solids from deeper in the aquifer. Owing to stratification of the alluvium, the drains may tend to remove proportionally more water from the upper part of the aquifer than from the lower part. This could be an important, but as yet unmeasured, factor in the control of water containing an excess of dissolved solids at the top of the aquifer.

Water from the river and from most of the deeper wells in the alluvium and the Santa Fe Group near the Rio Grande valley has a medium salinity hazard and low sodium hazard (fig. 10). Water from the drains has a high salinity hazard and a low sodium hazard. Water from the shallow wells ranges from high salinity hazard and low sodium hazard to very high salinity hazard and high sodium hazard.

Odors of sulfide gases were detected in water being pumped from many wells. Most of the wells from which sulfide gases were being released are in T. 7 N., R. 2 E., in the area of heaviest irrigation pumping. The odor of sulfide gas also was noticed in water from irrigation wells a few miles south of Belen. Hydrogen sulfide gas often results from the decay of organic material and the activity of sulfate-reducing bacteria under reducing conditions. It is known that plant material was buried with the alluvium at the time of deposition, and it is inferred that this is the source of the sulfide gases in water yielded from the wells.

Natural Recharge and Discharge

RECHARGE

The principal sources of recharge to the aquifers in eastern Valencia County are (1) movement of water into the aquifers by subsurface flow across geologic boundaries, (2) precipitation on the outcrops, and (3) surface-water flow across the outcrops. The ultimate source of recharge water is precipitation.

MOVEMENT OF WATER ACROSS GEOLOGIC BOUNDARIES

The Santa Fe Group probably receives subsurface recharge across both the eastern and western structural boundaries of the Rio Grande graben in Valencia County. The water moves in the direction of the hydraulic gradient (p1. 3) toward the central part of the graben. However, the volume of water that moves across the geologic boundaries cannot be calculated from the data that are now available. Furthermore, the water that crosses the geologic boundaries is mixed with recharge water from streams that flow onto the outcrop of the Santa Fe Group from the bordering uplands.

The subsurface recharge from the Manzano Mountains must move through the uplifted structural block that lies between the Ojuelos fault and the mountains. The transmissibility of this block is probably low. Thus, though the gradient of the water table is steep, the groundwater probably moves slowly.

Subsurface movement across the Rio Puerco fault zone contributes recharge to the Santa Fe Group along the west side of the graben. The amount of water that passes through the fault zone is probably small. The amount of leakage is possibly greater to the north in the area of normal faulting than to the south in the area of thrust faulting. The water table in the Santa Fe within three to ten miles of the Rio Puerco fault zone slopes steeply toward the ground-water trough (p1. 3). The steep slope of the water table indicates that the transmissibility of the aquifer is low.

PRECIPITATION

The average annual precipitation at Los Lunas is a little more than eight inches (New Mexico State Engineer, 1956). Figure 11 shows the average monthly distribution of the precipitation. The precipitation is greatest during July, August, and September. Since the records were started in 1889, the maximum precipitation recorded for one year at Los Lunas was 16.37 inches in 1891, and the minimum precipitation for one year was 2.15 inches in 1917.

These data do not show the variations in precipitation at different places in eastern Valencia County. However, the data for Los Lunas are probably fairly representative of the precipitation pattern in the Rio Grande trough. Precipitation on the uplands of Sierra Lucero is greater than in the trough and may be as much as 14 inches a year. In the Manzano Mountains the average annual precipitation at places may be as much as 30 inches a year (New Mexico State Engineer). All the ground water within the upland area of both the Sierra Lucero and the Manzano Mountains is derived from precipitation directly on the mountains.

Water that reaches the outcrop of an aquifer, either by precipitation or by surface flow, must meet several prior demands before any becomes available for recharge to the aquifer. Part of the precipitation soaks into the soil and part runs off the surface. Of the water that soaks into the soil, still only a part is available for recharge to the ground-water reservoir. Soils have the capacity to retain a certain amount of water

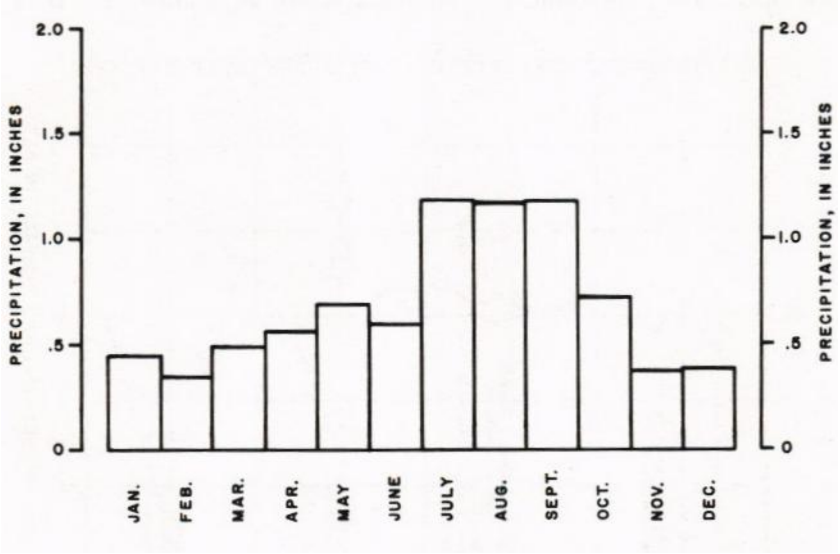


Figure 11

AVERAGE MONTHLY PRECIPITATION AT LOS LUNAS, N. MEX.
(From US. Weather Bureau, 1956-61)

in capillary openings and on the surfaces of individual grains. The ratio of the volume of water held against the force of gravity to the total volume of the porous material is the specific retention of the material. The specific retention of soil and rock above the water table must be satisfied before any water can move downward to the water table. The water held by specific retention within the upper few feet of the soil zone or within the root zone of plants is available for evaporation and for transpiration. In arid regions such as New Mexico, where potential evaporation is much greater than precipitation, the percentage of total precipitation that reaches the water table as recharge is small indeed.

The terrace remnants of the ancestral Rio Grande probably facilitate recharge to the Santa Fe from precipitation and surface runoff. All the terraces are marked in part by shallow depressions which tend to collect and hold surface water, giving it more time to infiltrate. The 120-foot and 160-foot terraces are underlain by river alluvium, which may be more permeable than the Santa Fe Group. The older alluvium underlying the 120-foot terrace is not capped by caliche that would tend to prevent infiltration.

A hydrograph of well 7.2.18.242, on the 120-foot terrace about half a mile southwest of an intermittent lake, shows how quickly leakage (recharge) from the lake affects the water table. The well taps water in the Santa Fe Group; the water level in the well is below the base of the older alluvium. The hydrograph (fig. 12) shows small rises

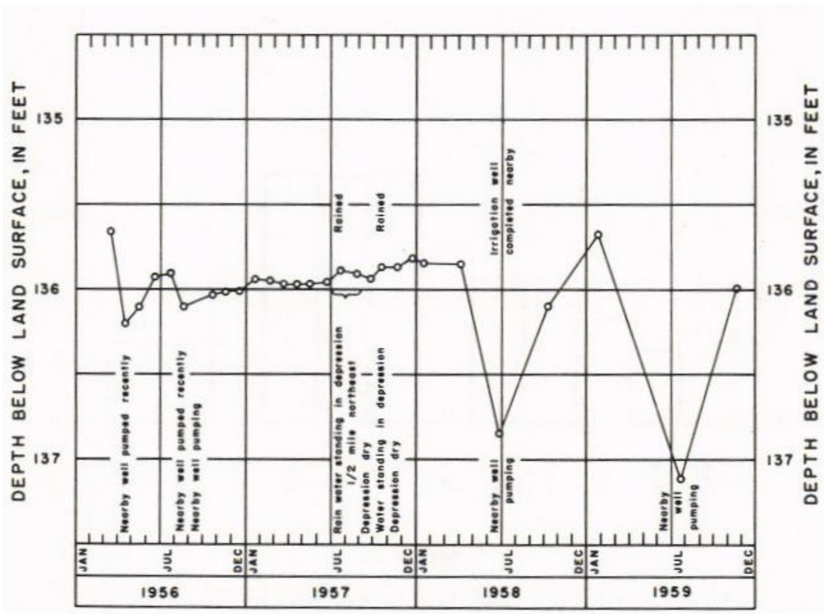


Figure 12

HYDROGRAPH OF IRRIGATION WELL 7.2.18.242, FINISHED IN THE SANTA FE GROUP

of water level in the well in July and October 1957 which can be correlated with the presence of water in the intermittent lake. The water level in the well declined in September and November, when the depression was dry.

Precipitation in the valley of the Rio Grande is a source of recharge to the alluvium. Here, where the depth to the water table is less than 15 feet, the recharge water should reach the water table within a few days after a storm. However, Figure 13 shows that two additional factors, recharge from irrigation and discharge by plants, must be considered to relate precipitation data to water-level fluctuations. The rising of the water table between the March and May measurements probably was due to recharge from ditch loss and irrigation at the beginning of the growing season. The declining of the water table between the May and November measurements probably was due to high evaporation and transpiration loss during the growing season and, after September, to a decrease in surface water in the ditches. Thus, though the months of greatest precipitation are July, August, and September (fig. 11), the recharge from precipitation during these months is more than offset by transpiration.

SURFACE WATER

The Rio Grande and the Rio Puerco are the largest single sources of recharge from surface runoff in eastern Valencia County. However, numerous arroyos cross the upland outcrops of the Santa Fe Group in the area, especially near the foot of the Manzano Mountains and the uplifted block of the Lucero. These arroyos are usually dry, but they occasionally carry storm runoff immediately after rainfall within their respective drainage areas. Peridds of flow are short and may be widely spaced in time because precipitation is sparse.

The channels of all the intermittent streams, except the Rio San Jose, are above the water table. Thus, the intermittent runoff in the arroyos is subject to both infiltration into dry sediments above the water table and to evaporation as it flows across the Santa Fe Group. Most of the immediate depletion of the arroyo flows presumably is due to infiltration and only a small part is due to evaporation. Ultimately, however, much of the water retained as soil moisture in the sediments above the water table also evaporates. The actual recharge from a given period of runoff is larger, if the soil moisture from preceding storms has not yet evaporated. Therefore, several closely spaced periods of runoff produce more recharge than the same number of periods widely spaced in time.

Hell Canyon Wash is the only arroyo that extends from the Manzano Mountains to the Rio Grande. Other arroyos east of the Rio Grande become smaller and disappear on the nearly featureless slope west of the Ojuelos fault. Only occasionally does storm runoff in these arroyos reach from the mountains to the Ojuelos fault. No runoff continues for more than a few miles west of the fault.

Water that discharges from the springs along the Ojuelos fault zone and the Rio Puerco fault zone runs on the surface for only a short dis-

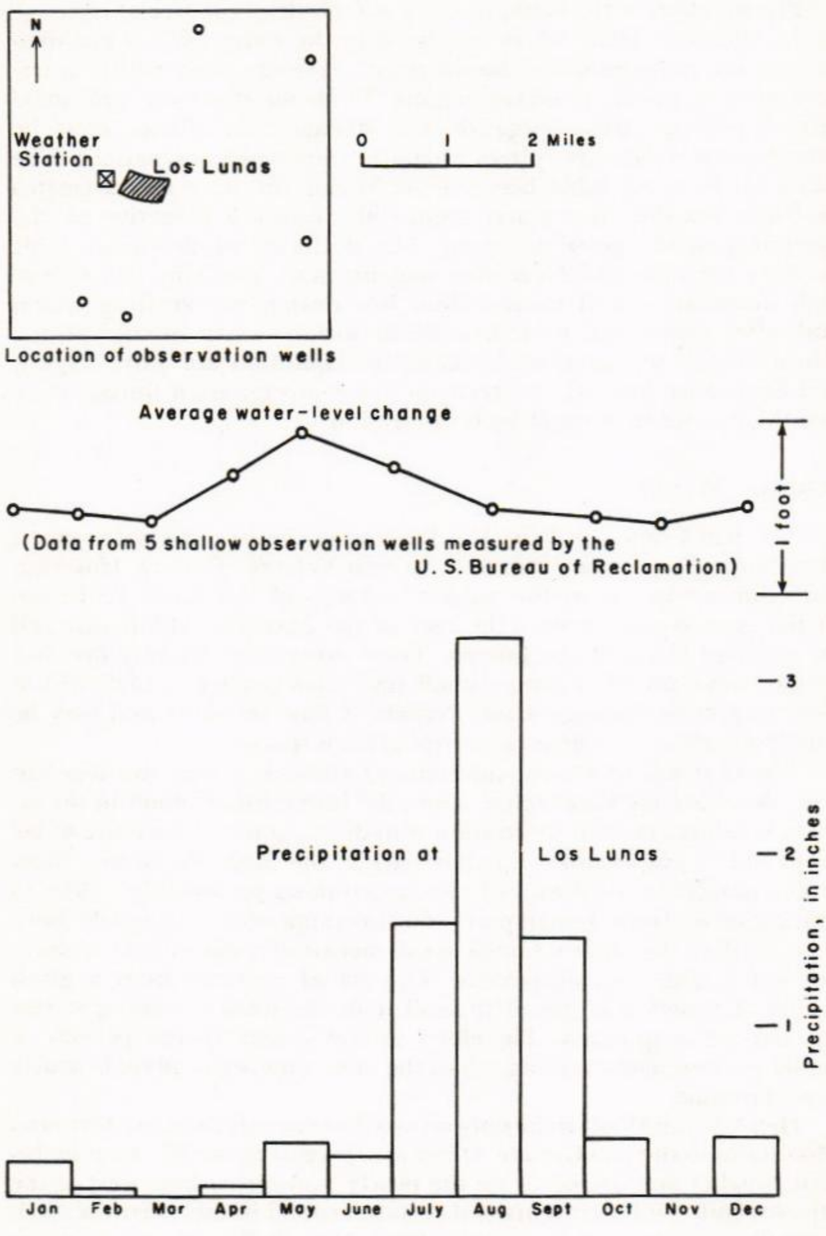


Figure 13

COMPARISON OF WATER-TABLE FLUCTUATION AND PRECIPITATION NEAR Los LUNAS, N. MEX.

tance before sinking back into the ground. The discharge of all springs along the 25 miles of the Rio Puerco fault zone in Valencia County was estimated to be less than 600 gpm at the time they were visited. More than 400 of the 600 gpm discharges into the Rio San Jose. Less than 200 gpm of spring discharge crosses the fault zone in the 22 miles between the Rio San Jose and the Socorro County line.

A large part of the recharge to the Santa Fe Group along the Rio Puerco fault zone is probably from storm runoff from the Lucero uplift. Water from the springs along the fault zone is high in dissolved solids (table 5), and water that leaks across the fault zone in the subsurface must be at least as high in dissolved solids. Yet water from the wells that tap the Santa Fe Group only a few miles east of the fault zone is much lower in dissolved solids than the water from the springs (table 6 and pl. 6). Hence, recharge must occur between the fault zone and the wells.

The U.S. Geological Survey maintains gauging stations on the Rio Puerco at the highway bridge in sec. 31, T. 7 N., R. 1 W. in Valencia County and about 30 miles downstream near its junction with the Rio Grande in Socorro County. These stations are designated, respectively, the Rio Puerco and the Bernardo. The Rio Puerco had a net loss of water within this 30-mile reach in six of the seven years from 1950 to 1956 (U.S. Geological Survey, 1950-1956). The highest loss was 3760 acre-feet in 1952. The Rio Puerco must lose water by infiltration within this reach every year. In 1955, when the river gained 4810 acre-feet in this reach, the ungauged tributaries to the Rio Puerco obviously contributed an amount of water equal to the infiltration loss between the two stations plus the recorded gain. It is significant that in each of the seven years considered, there was at least one month when a gain between the two stations was recorded. Therefore, though the Rio Puerco loses water to the ground-water body within this reach, the recharge that can be calculated from the gauge records is a minimum figure only.

The course of the Rio Puerco north of the Rio Puerco station is aligned with a change in the gradient of the water table; the gradient is gentle west of the river and steep east of the river. The gentle slope of the water table west of the Rio Puerco probably is maintained by water that is lost from the river.

The Rio Grande and the associated irrigation ditches constitute the largest source of ground-water recharge in eastern Valencia County. The Geological Survey maintains gauging stations on the Rio Grande and on irrigation ditches and drains at several points in and near eastern Valencia County. However, the gauging stations in Valencia County at the time of this study were not located so that the total surface flow within the Rio Grande valley could be determined at any line across the valley.

In the period from 1950 to 1956, the maximum discharge of the Rio Grande at Albuquerque during one year was 1,269,000 acre-feet in the 1952 water year (October 1951 through September 1952). The minimum discharge was 241,400 acre-feet in the 1951 water year. In four of the seven years the discharge was less than 300,000 acre-feet. Records for a few years are available (in the office of the Geological Survey, Branch of Surface Water, in Albuquerque) that show the diversion into irrigation ditches at the Isleta dam. The total diversion during the 1955 water year was about 130,000 acre-feet. A little more than 119,000 acre-feet of water was diverted in the 1956 water year. Approximately 65 percent of the diversion was into several ditches on the east side of the river, and 35 percent was into the Belen highline west of the river. Diversion was negligible during December, January, and February.

Most of the water diverted into the ditches is used for irrigation, or it leaks out of the ditches, but part spills from the ends of the ditches into the drains and returns to the river. The ratio of water used for irrigation to that returned to the river without being used varies according to the supply of water and to the changes in seasonal and daily demands for irrigation water.

The largest part of the water that is spread on the land for irrigation does not recharge the ground-water reservoir. Efficient irrigation depends on distributing the water so that most of it is used by the plants. Even in very efficient operations, however, it usually is necessary to allow some of the water to move down to the water table in order to leach undesirable concentrations of salts out of the root zone.

Water is diverted into the irrigation ditches at Isleta each year in March (fig. 14), and the flow in these ditches is maintained until sometime in November, if the supply in the Rio Grande is adequate. A sharp rise in the water table, indicated by changes in the water levels in shallow observation wells, begins in March and continues until May or June. This rise can be correlated directly with the diversion of water into the irrigation ditches. The water levels in wells reach a peak by about the end of June and then decline. The decline generally can be correlated with a decrease of water in the irrigation ditches because of a sharp decrease in the supply of water in the Rio Grande. A second rise in water levels may occur in the fall owing to (1) an increase of flow in the irrigation ditches if water becomes available, (2) a reduction in the amount of transpiration if a cold snap occurs while the ditches are full, or (3) a combination of the two factors. The water level declines sharply from November to March, the non-growing season for most crops. This decline is correlated with cessation of diversion into the irrigation ditches. The water table reaches a minimum elevation about the first of March just prior to the beginning of diversion again at Isleta.

The annual fluctuation of water levels in deep irrigation wells in the alluvium is similar to that in the shallow auger holes (fig. 15). However, the fluctuation of the water level in the irrigation wells is often complicated by pumping. Furthermore, the water levels in these wells are affected by several factors that may not affect the shallow holes. The irrigation wells, with few exceptions, are located next to a surface-water supply ditch, and water levels in the wells are affected by leakage from the ditch. Irrigation wells always are near, or surrounded by, irrigated land, so the water level in them may be influenced by irrigation water that is applied on the land.

Theis described a place in Socorro County where data indicate that ground water passes under the riverside drain and rises on the opposite side to a level higher than the water level in the drain. This situation could exist only if the subsurface movement were to take place under artesian conditions. Leaky artesian conditions exist, and are probably common, in the alluvium because of interbedded sand, silt, and clay. Where artesian conditions exist beneath the riverside drains, the effects of the drains would be partly or wholly restricted to the uppermost part of the aquifer. Thus, ground water may move from *the* river channel to the interior drains in the uppermost part of the zone of saturation by moving through the riverside drain itself, or it may bypass the riverside drain at depth.

The effect of recharge from the Rio Grande on ground-water levels is much less than the effect of recharge from irrigation and ditch loss. Correlation between the flow of the Rio Grande at Belen and the fluctuation of ground-water levels seems to be small, as indicated by water levels in 16 shallow observation wells between Isleta and Belen (fig. 14). The Rio Grande discharged about 30,000 acre-feet a month, during January and February of each of the three years of record, but the irrigation ditches were dry. The water levels under the flood plain continued to decline during these months.

Theis calculated that the alluvium in the Rio Grande valley between Isleta and Belen receives recharge from the sides of the valley at a rate of about 780 acre-feet a year per mile of valley. This recharge he termed the "mesa increment." He stated that perhaps a large part of the mesa increment is furnished by seepage from the highline canals. Theis and Taylor later modified the figures to about 820 acre-feet a year per mile of valley. The calculations were made from measurements of the average decline of water level in the alluvial aquifer during the winter and from corresponding measurements of flow in the interior drains. It was assumed that during the winter precipitation, evaporation, and transpiration were all low and approximately balanced each other. It was further assumed that all water that infiltrated into the aquifer from the Rio Grande during the winter was picked up by the riverside drains.

The water-table contour map (pl. 3) shows that the water table has a sharp break in slope under the highline ditch in the Rio Grande valley and slopes steeply from the ditch to the nearest interior drain. The steep slope implies movement of water into the alluvium from both sides of the valley. The water table in the Santa Fe Group on either side of the Rio Grande valley in the northern part of the county slopes

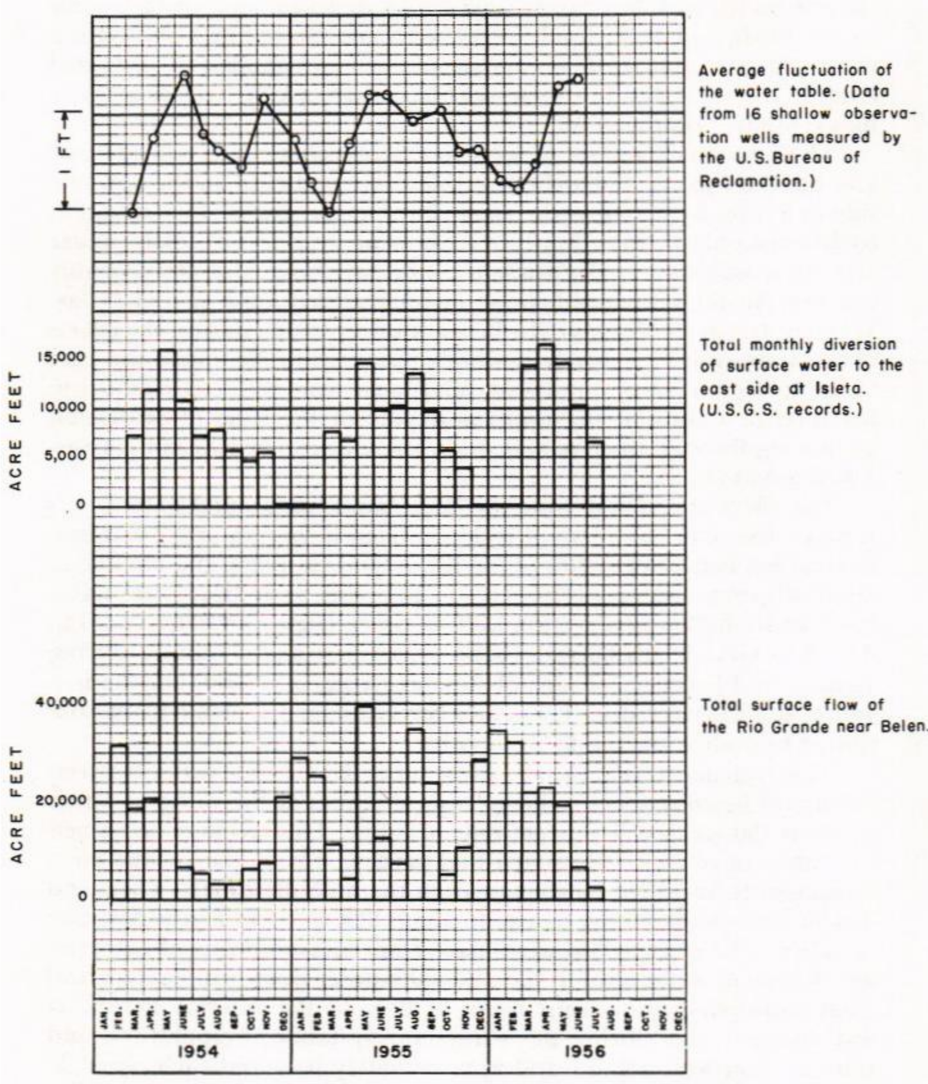


Figure 14

Comparison of water-table fluctuation, diversion of surface water for irrigation on the east side of the Rio Grande valley between Isleta and Belen, and flow of the Rio Grande near Belen, N. Mex.

generally downstream and near the valley has no significant component of slope toward the valley. This water-table configuration implies that in the northern half of the county little or no lateral movement of water from the Santa Fe Group into the alluvium occurs and that the relatively sharp slope of the water table from the highline ditch toward the center of the valley is maintained by water lost from the highline.

Eight hundred and twenty acre-feet of recharge a year per mile of valley in the 17-mile reach between Isleta and Belen is nearly 14,000 acre-feet a year. A little more than 115,000 acre-feet of water was diverted into the high lines at Isleta during the 1937 calendar year (U.S. Geological Survey, 1940). During the 1955 calendar year 61,970 acre-feet of water was diverted into the highlines.* Assuming that all the water is diverted into the highline canals in eight months, the total mesa increment that was calculated by Theis and Taylor would be supplied by a ditch loss of less than 1 cfs (cubic foot per second) per mile of ditch from each of the high lines. Thus, the total mesa increment could reasonably be accounted for by water loss only from the highline ditches.

Ground water probably moves vertically as well as horizontally from the Santa Fe Group into the alluvium. In the northern half of the county water from the Santa Fe Group may move into the alluvium where the local water table is low, such as under the drains. This recharge to the alluvium would tend to be balanced by discharge of water from the alluvium into the Santa Fe Group where the water table is high, such as along the river channel.

Adjacent to the Rio Grande valley in the southern part of the county the water table in the Santa Fe Group has a relatively large component of slope toward the valley. It is inferred that the alluvium receives recharge from the Santa Fe in this part of the valley. The alignment of the ground-water trough in the Santa Fe Group west of the river joins the alignment of the Rio Grande valley near Belen, and from Belen southward the alluvium may carry part of the water which moves down the trough from the north.

EFFECT OF VARIATIONS IN RECHARGE

In the northern part of eastern Valencia County and in southern Bernalillo County several wells were drilled in 1934 on Isleta Pueblo land. The water levels reported by the drillers at the time the wells were drilled were several feet higher than the levels in 1956. If the reported water levels are accurate, levels have declined as much as ten feet since the wells were drilled. Several springs along the Ojuelos fault have ceased to flow, reflecting a decline of the water table in that area. Two closely spaced wells belonging to the Santa Fe Railroad near the Socorro County line (3.3.10.324 and 3.3.10.324a) show a 2-foot rise of the water table between 1905 and 1949.

Water levels in many parts of eastern Valencia County have been a foot to several feet higher than they are at present. The levels probably have declined at different times in different parts of the area, and possi-

* US. Geological Survey, unpublished records.

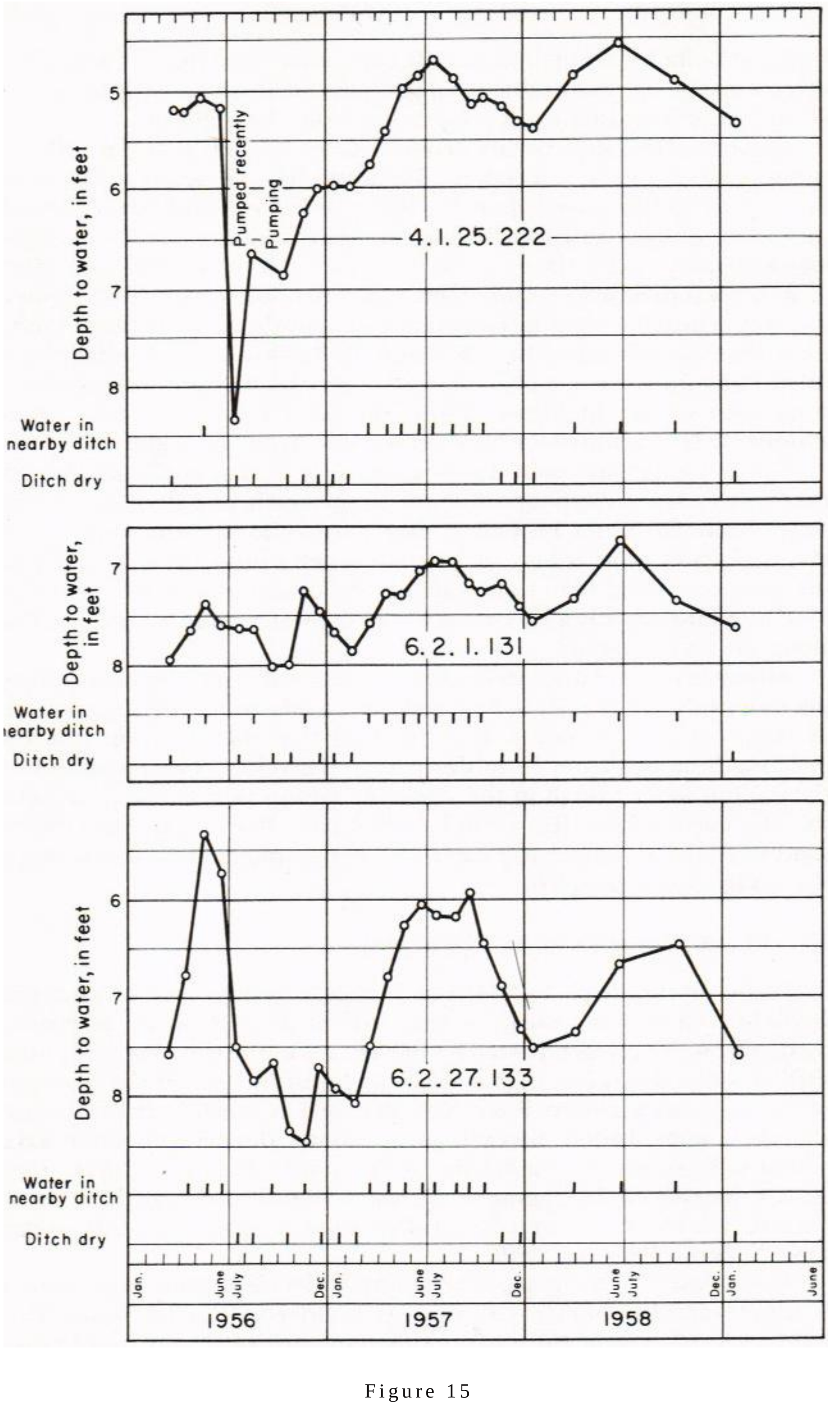


Figure 15

HYDROGRAP11S OF SELECTED IRRIGATION WELLS NEAR IRRIGATION DITCHES IN THE Rio GRANDE VALLEY, VALENCIA COUNTY, N. MEX.

bly water levels have been higher more than once. The most likely cause for the fluctuation in water levels outside the Rio Grande valley is variation in recharge resulting from changes in precipitation.

The availability and the chemical quality of water from the shallow aquifer in the Los Valles area changed within historic time. In 1956 Los Valles had no permanent residents, probably because the nearest supplies of potable water were more than 20 miles away (table 5). However, rock buildings that have been occupied within recent years stand at several ranch headquarters Mr. Juan Iriart, who was living at his ranch headquarters in sec. 26, T. 5 N., R. 4 W., in the early 1940's obtained drinking water from spring 4.3W.6.444. The quality of water from this spring deteriorated in the middle 1940's, and by 1945 it was no longer drinkable—so water was then obtained from well 5.3W.28.143. The quality of water from this well also deteriorated in a few years and became undrinkable (Arthur Bibo, oral communication, 1958). A still earlier period of availability of potable water in Los Valles is indicated by several old rock houses, now in ruins, which are in Los Valles and in the water gaps through the east rim of Los Valles.

The chemical quality of ground water that discharges into the Rio San Jose from Ojo Escondido (8.2W.19.421) seems to have changed in recent years in response to decreased recharge. A sample of water collected from this spring in 1941 contained 239 ppm of dissolved solids; the hardness was 164 ppm (Wright). When this spring was visited in 1956 the water had a bitter taste, which suggests that it contained more dissolved solids than were shown in the 1941 analysis. During the 15 years preceding 1941 the precipitation at Albuquerque was above normal (fig. 16), and precipitation in 1941 was the highest of record. Recharge caused by the above-normal precipitation probably resulted in the water being relatively low in dissolved solids in 1941. During 11 of the 15 years 1942 through 1956, the annual precipitation was below normal. Reduced recharge during this period probably resulted in the poorer quality of the water discharging from the spring in 1956.

Dendroclimatic investigations suggest that the regional climate of the Southwest has not changed radically during the past 1000 to 1500 years. The evidence is fragmentary and admittedly not conclusive (Schulman, 1956). However, tree-ring data indicate significant climatic fluctuations within the last few centuries. Unfortunately, long-term data are not available for the Rio Grande valley. Schulman discussed the dendroclimatology of the Colorado River basin above Lake Mead. He described the following climatic sequence: For several years prior to 1870 the area had phenomenally heavy rainfall and runoff. From 1870 to 1905 rain was scant, and drought was especially severe from 1893 to 1904. A 26-year wet interval followed, beginning in 1905 and ending in 1931. From 1931 to the end of the dendroclimatic record in 1950, the area was subject to drought.

As recently as 1907, the Rio Puerco in Valencia County was perennial and was referred to as a " . . . sluggish, muddy stream practically impassable on account of quicksand, except at times of low water . . . " (Lee, p. 14). Prior to about 1887, water from the Rio Puerco was used to irrigate land in *secs.* 5, 6, and 8, T. 6 N., R. 1 W. The land was farmed by residents of the former village of Los Cerros, which had a population of 50 to 60 (Bryan, 1928). The village was on the west side of the Rio Puerco south of the point at which State Highway 6 crosses the river. Since 1887 the Rio Puerco has become incised about 40 feet, and flow has become intermittent. Recharge to the Santa Fe from the Rio Puerco must have been greater prior to the decrease in the flow of the river.

DISCHARGE

Ground water is discharged naturally from an aquifer by subsurface movement across geologic boundaries into another aquifer, by evaporation or transpiration, and by discharge onto the land surface from springs and seeps. Only the last two of the three routes result in removal of ground water from storage. Subsurface flow of ground water across geologic boundaries, such as faults and contacts between rock units, has been described in the preceding section.

EVAPO TRANSPIRATION

Evaporation, the direct vaporization and transfer of water to the air, and transpiration, the vaporization of water from the pores of plants, result in removal of water from an aquifer system. The two vaporization processes together are termed evapotranspiration. Evapotranspiration may remove water either from the zone of aeration above the water table or the zone of saturation below it. Removal from the zone of aeration of either soil moisture or water in the process of percolating toward the water table may reduce the amount of recharge. Removal of ground waters. Salt cedars can develop extremely deep root systems. Their roots *have* been identified at depths of nearly 100 feet below land surface in the Mediterranean area. Salt cedars, as the name implies, are also tolerant to salt. Owing to this combination of growth characteristics, the tree is peculiarly adapted to the difficult conditions in the Rio Puerco valley. Throughout most of the valley in eastern Valencia County, the depth to water is between 10 and 100 feet pl. 2.

Salt cedars probably can drive where the depth to water is only a few tens of feet. Where the depth to water is great, the plants probably can sustain growth only when there is soil moisture in the zone above the water table. When the plant must lift water from great depths, it can only subsist.

Investigations in the Rio Grande valley by the U.S. Bureau of Agricultural Engineering for the Rio Grande Joint Investigation (Blaney

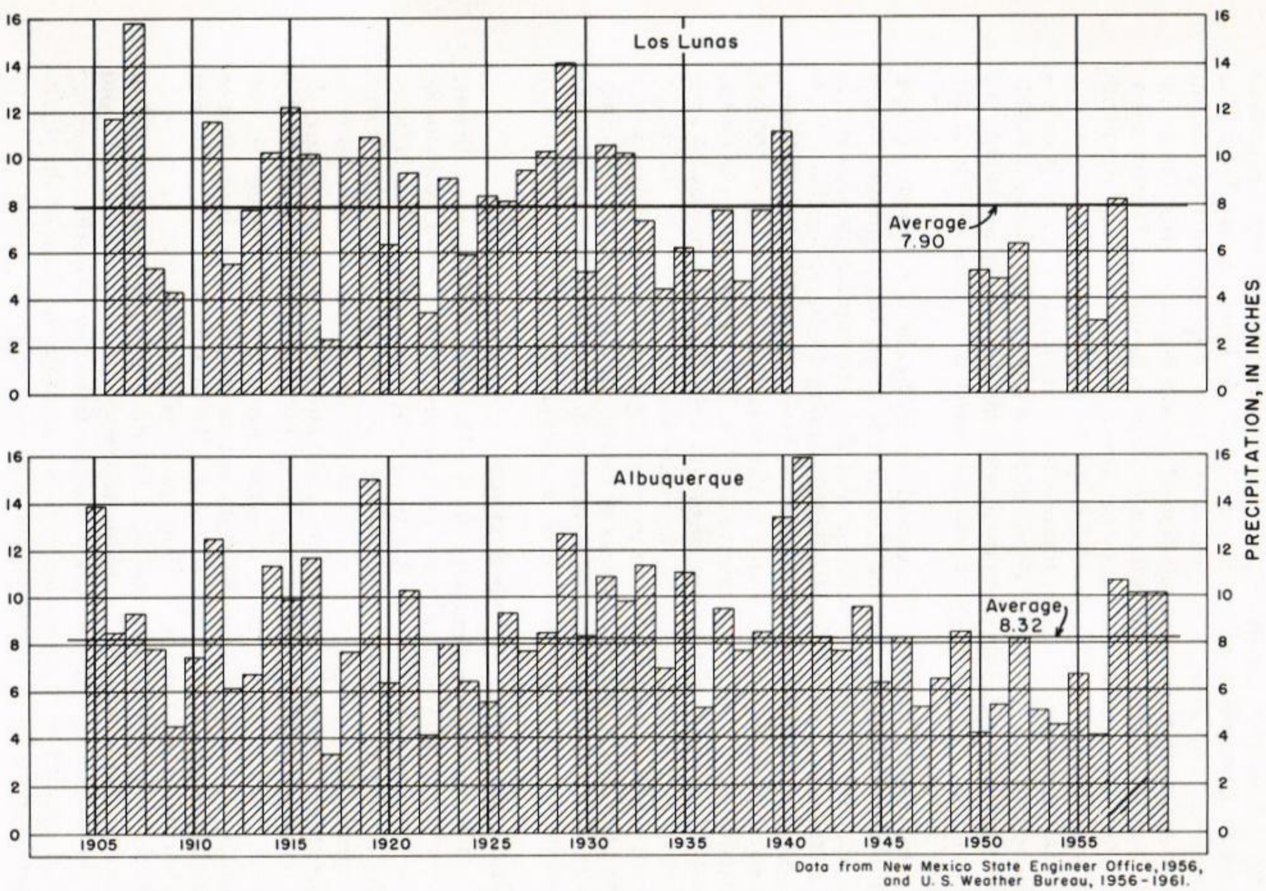


Figure 16

ANNUAL PRECIPITATION AT LOS LUNAS AND ALBUQUERQUE, N. MEX.

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Salt cedars probably can thrive where the depth to water is only a few tens of feet. Where the depth to water is great, the plants probably can sustain growth only when there is soil moisture in the zone above the water table. When the plant must lift water from great depths, it can only subsist.

Investigations in the Rio Grande valley by the U.S. Bureau of Agricultural Engineering for the Rio Grande Joint Investigation (Blaney et al., 1938, p. 367-368) indicate that the consumptive use of water in the Belen Division of the Middle Rio Grande Conservancy District (between Isleta on the north and Bernardo on the south, thus including nine miles of river valley south of Valencia County) was about 225,000 acre-feet or 2.92 acre-feet an acre in 1936. The consumptive use on the east side of the river between Isleta and Belen for the year was 2.7 acre-feet an acre. North of Belen, the entire loss may be derived ultimately from the Rio Grande and the irrigation system. South of Belen, where the alluvium is recharged by water moving out of the Santa Fe Group, part of the loss is replaced by recharge from the Santa Fe, and thus the net surface-water loss per mile of river should be less than to the north.

DISCHARGE TO THE LAND SURFACE

The drainage ditches on the flood plain of the Rio Grande valley are lines of ground-water discharge. They remove ground water from storage and channel it back to the Rio Grande. A direct relationship between the amplitude of water-level change and the distance to the nearest drainage ditch is suggested by the annual fluctuation of water levels in the three deep wells for which hydrographs are shown in Figure 15. The seasonal water-level change in well 6.2.1.131, which is about 200 feet from the nearest drain, is less than one foot. The change in well 4.1.25.222, which is about 500 feet from the nearest drain, is one foot or slightly more. The change in well 6.2.27.133, which is about 1700 feet from the nearest drain, is about two feet. The general rise of water levels in wells 4.1.25.222 and 6.2.1.131 during the three-year period of measurements may be due to above-average precipitation in 1957 and 1958 and to a greater supply of surface water for irrigation. Clogging of the drains by water plants or siltation on the bottoms of the drains also would tend to raise the water table.

Discharge from Large-Capacity Wells

IRRIGATION WELLS

Widespread use of ground water for irrigation is relatively new in the Rio Grande valley. All but one of the 81 irrigation wells that were used in eastern Valencia County in 1956 have been drilled since 1945. Seventy-four of the wells are within the area that is served by the ditches of the Middle Rio Grande Conservancy District. Water from most of these wells is used to supplement surface water from the ditches. A few farmers use ground water exclusively for irrigation, because ground water is less likely to introduce weed seeds into the fields. Wells provide part or all of the irrigation water for about 5000 acres of land within the Rio Grande Conservancy District in Valencia County.

Seven wells provide ground water to irrigate land outside of that served by the Conservancy District in eastern Valencia County. These wells irrigate about 680 acres on five farms. Two of the farms, which are served by three of the wells, are outside the river valley. The other four wells are on the sloping sides of the Rio Grande valley or in the valley of Abo Wash, a tributary to the Rio Grande.

The greatest concentration of irrigation wells in the Rio Grande valley is east of the river and north of El Cerro. In this area the concentration is as high as six wells a square mile. In the rest of the valley, the concentration rarely exceeds two irrigation wells a square mile and averages less than one well a square mile. Data on the amount of water that is pumped annually from irrigation wells are not available but the amount pumped varies from year to year as the availability of surface water changes.

A large volume of water in the Rio Grande valley may be removed from the alluvium in a short time by a single well or by a group of closely spaced wells. However, the cones of depression in the water table around pumped wells can expand only a relatively short distance before they intersect a source of recharge and probably also a place of discharge. The river and the irrigation ditches are sources of recharge, and the drains are places of discharge. Therefore, the immediate effects of pumping are that (1) the water that would have discharged from the alluvium into the drains is intercepted in the aquifer, and (2) where irrigated land is near the well, excess irrigation water tends to refill the cone of depression. The drains, which normally discharge water from the alluvium, locally may be sources of recharge to the aquifer when they are within a cone of depression. The water in the drains may return to the aquifer where the water table has been drawn down below the level of the water in the drain. The end result of removing ground water from the alluvium for consumptive use by pumping from a well is the same as removing water from the surface-water supply for that purpose; the difference is in the point of diversion from the hydrologic system. The pumping effects of the large-capacity wells in the alluvium probably extend below the alluvium into the Santa Fe Group. Where many large-capacity wells are closely spaced, the amount of water that is induced to move from the Santa Fe Group into the alluvium may be large.

One example of interference between wells was reported during this study. The owner of a domestic well reported that continuous pumping during the summer from an irrigation well about 1000 feet from the domestic well lowered the water level below the bottom of the domestic well. Mild and intermittent interferences between wells is probably common but unnoticed at many places in the valley.

MUNICIPAL WELLS

Belen and Los Lunas, the two incorporated communities in the area, each have a water-supply system that obtains water from municipally owned wells. The municipal wells, which are deeper than the irrigation wells in the valley, generally yield smaller quantities of water than the irrigation wells but the quality of the water is better.

Chemical analyses of water from the municipal wells are reported in Table 6. The significance of various chemical constituents in drinking water is discussed in the section on chemical quality of water.

The town of Belen has three wells capable of supplying water directly to the municipal distribution system. Wells No. 1 (5.2.18.414) and No. 2 (5.2.18.412) are on the flood plain of the river. They were drilled in 1927 and 1945, respectively. Both are bottomed in the Santa Fe Group below the base of the alluvium (table 4). These two wells presumably yield water from both the Santa Fe Group and the alluvium. Each well is capable of producing a few hundred gallons a minute. They are used to supplement the main supply during periods of peak demand in the summer and for emergency supply, as during operation of fire-fighting equipment.

Well No. 3 (5.1.13.332) is the main source of supply for the Belen water system. It is on a slope about a mile west of the center of town and was drilled in 1953. The well is 519 feet deep and, except for loose, surficial material, is wholly in the Santa Fe Group. The yield of the well was about 900 gpm in 1956. The static water level was not measured, but the water-table contour map (pl. 3) indicates that the depth to water is about 110 feet. The well is gravel-packed, and the casing is slotted opposite water-yielding strata below 203 feet.

The town of Belen supplied 158,835,996 gallons of water to customers during the 1955 fiscal year (July 1, 1954 to June 30, 1955) and 251,388,088 gallons during the 1956 fiscal year. These figures are based on water-meter readings taken by town officials. Data on the amount of water that was returned to the aquifer and the river by sewage disposal were not available.

The village of Los Lunas has two wells (7.2.28.234 and 7.2.28.243), both of which regularly pump into the community distribution system. The wells penetrate the alluvium and are bottomed a few hundred feet into the Santa Fe Group. Both are gravel-packed; presumably they derive water from the alluvium and the Santa Fe. The yields are reported to be 150 and 350 gpm, respectively.

The Los Lunas water system supplied 19,260,400 gallons of water to its customers in the 1955 fiscal year and 26,147,700 gallons in the 1956 fiscal year. The period of greatest demand is from July 1 to September 30. The annual flow of water through the Los Lunas sewage disposal plant is about 11 million gallons according to the U.S. Public Health Service (1958).

INDUSTRIAL AND RAILROAD WELLS

Only a few industrial and railroad wells are in use in eastern Valencia County. In the vicinity of Belen, ground water is used for the manufacture of ice, in numerous small business enterprises, and by the Santa Fe railroad for drinking water on trains and for miscellaneous uses in the shops. The railroad no longer requires a supply of water for steam engines, but wells are maintained at section locations in sec. 10, T. 3 N., R. 3 E. and at Dalies in sec. 5, T. 6 N., R. 1 E. to supply water for miscellaneous uses by railroad personnel. The El Paso Natural Gas Company uses ground water for cooling in its compressor station near the southeast corner sec. 25, T. 4 N., R. 2 E.

Summary

The principal hydrologic unit in eastern Valencia County includes several thousand feet of poorly consolidated sediments of the Santa Fe Group of middle(?) Miocene to Pleistocene(?) age in the Rio Grande graben and alluvium of Recent age along the valleys of the major streams.

Ground water is available in variable amounts throughout the Rio Grande graben. The alluvium of Recent age reportedly yields as much as 2500 gpm to irrigation wells in the Rio Grande valley, which is entrenched into rocks of the Santa Fe Group in the central part of the graben. The Santa Fe yields about 1000 gpm to a few irrigation wells short distances outside of the Rio Grande valley. Most wells tapping the Santa Fe Group are stock wells equipped with windmills. These wells are designed to pump only a few gallons a minute, so they are not indicative of potential yields from the aquifer. Small yields are available from the Santa Fe everywhere in the trough; larger yields (100 gpm and more) are probably possible at many places.

The maximum depth of the water table is more than 600 feet in an area east of the Rio Puerco valley at the Bernalillo County line, where a water-table low, or trough, enters Valencia County from the north. The water-table trough widens and joins the alignment of the Rio Grande valley at about the latitude of Belen. East of the Rio Grande valley the maximum depth of the water table is about 500 feet on the west side of the Ojuelos fault. The water table is at or near the surface along the Ojuelos fault.

The water table in the alluvium of the Rio Grande valley at most places is seven to nine feet below the surface. Drainage ditches 10 to 12 feet deep prevent the water table from rising to waterlog the land. Ground water in the zone several feet below the water table in the valley contains several times as much dissolved solids as is normally expected of water in the alluvium. Water from irrigation wells tapping the alluvium of the Rio Grande valley has a dissolved-solids content of 600 to 900 ppm. The dissolved-solids content of ground water in the Rio Grande graben ranges from about 200 ppm in the eastern part of the trough to about 4000 ppm in the western part.

Ground water is contributed to the Rio Grande graben from the structurally uplifted blocks that bound the graben on both sides. Igneous and metamorphic rocks of Precambrian age form the core of the Manzano and Manzanita mountains to the east of the graben; rocks of Late Paleozoic and Mesozoic ages crop out on the Lucero uplift to the west. No wells are known to produce water from rocks of Precambrian age in the Manzano and Manzanita mountains. However, the graben may be recharged to some extent by water moving through fractures in the rocks. This water contains only a few hundred parts per million of dissolved solids.

In the Lucero uplift, ground water occurs in an artesian and a water-table aquifer. The artesian aquifer is mostly in the Madera Limestone. Water from the artesian aquifer is high in sodium and chloride and discharges at numerous small springs along the Rio Puerco fault zone. The water-table aquifer includes permeable rocks of several formations above the Madera Limestone, where these rocks are at or near the surface. Wells tap the Abo and Yeso formations, the San Andres Limestone, and the alluvium. Water from this aquifer generally is high in sulfate. The natural discharge from both these aquifers is into the west side of the Rio Grande graben, thus accounting for the poor quality of the ground water in the western part of the graben.

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APPENDIX A.–RECORDS OF IRRIGATION, PUBLIC-SUPPLY, INDUSTRIAL, AND RAILROAD WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO

Location Number: number designates well and location (see well-numbering system, p. 7); * indicates chemical analysis of water, Appendix D.

Altitude: estimated from USGS topographic quadrangle maps.

Depth of well: measured depths to nearest 0.1 foot below land surface; reported depths to nearest foot.

Geologic source: Qal--alluvium; QTs--Santa Fe Group.

Depth to water: measured depths to nearest 0.1 foot; reported depths to nearest foot.

Yield: R--reported; M--measured by Geological Survey personnel.

Drawdown and length of test: measured to nearest 0.1 foot; reported to nearest foot; S--test indefinite length, usually several hours.

Use: I--irrigation, sole source of supply; Is--irrigation, supplements surface-water supply; Ps--public supply; Ind--industrial; RR--railroad; O--water-level observation; S--stock; N--not used.

Note: Unless otherwise specified, all wells are drilled and cased to total depth; method of lift is turbine pump. (Sp. cap. = specific capacity.)

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield: Rate (gpm)	Yield: Date	Drawdown: Amount (feet)	Drawdown: Length of test (hrs.)	Use	Remarks
3.3.10.324*	Santa Fe Railway Co.	1905	5179	470	13	QTs	365.7	8-26-49	---	--	--	--	RR	-
10.324a*	do.	1903(?)	5179	420	13	QTs	364	1905	50R	--	36	--	RR	150 feet west of well 3.3.10.324
4.1.24.122	J. W. Conant	1952	4787	80	16	Qal	21.9	3-28-56	800R	--	--	--	Is	-
25.222	Frank Metzler	1955	4769	123	16	Qal	5.2	3-29-56	1692M	9-19-56	46.7	S	Is, O	Monthly observation well; sp. cap. 36
4.2.6.124	Mr. Grumson	1955	4785	102	16	Qal	6.6	4-11-56	1400R	--	48	--	Is, O	-
6.144	do.	1952	4783	71	8	Qal	7.8	1-31-57	400R	--	--	--	Is	Centrifugal pump
8.243*	Mr. Pattison	1948	4783	38	12	Qal	5.8	4-12-56	---	--	--	--	Is	Centrifugal pump. Temperature 56°F
16.314	Mr. Cannon	1952(?)	4870	168	16	QTs	98.1	4-11-56	1600R	--	22	S	I	-
25.434	El Paso Natural Gas Co.	1956	5025	381.0	8	QTs	242.1	12- 3-56	160R	10-56	--	--	Ind	Used in natural gas pumping station
32.141	A. L. Wheeler	1952	4784	93.0	16	QTs(?)	24.0	4-12-56	900R	--	35.5	S	I, O	Temperature 69°F
32.243	do.	1950	4812	110	16	QTs(?)	46.4	4-12-56	1200R	--	37	S	I	Discharges into adjacent pond
36.221	El Paso Natural Gas Co.	1956	5045	412.5	8	QTs	262.0	11-26-56	110R	12-56	49	--	Ind	Used in natural gas pumping station; temperature 75°F; sp. cap. 2
5.1.12.434	W. D. Radcliffe	1952	4830	97	16	Qal	29.8	3-28-56	437M	9-20-56	39.6	S	Is	Temperature 64°F; sp. cap. 11
13.332	Town of Belen No. 3	1953	4914	519	36	QTs	--	11-28-56	893M	11-28-56	--	--	Ps	Principal water supply; temp. 69°F
24.234	Tibo Chavez	1954	4831	160	12	Qal	36.4	4-18-56	700R	--	--	--	Is	-
5.2.4.211	C. R. Nuckols	1951	4814	80	16	Qal	6.4	3-15-56	1000R	--	--	--	Is, O	-
5.321	J. D. Stevenson	1956	4810	40	10	Qal	7.6	3-29-56	---	--	--	--	Is	Driven well; partly completed when visited; plan 60 ft deep;centrif. pump
9.411	J. A. Graham	1911(?)	4832	51	72x72	Qal	25.5	3-15-56	---	--	2-3	--	I	Dug well; centrifugal pump

APPENDIX A.—RECORDS OF IRRIGATION, PUBLIC-SUPPLY, INDUSTRIAL, AND RAILROAD WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield: Rate (gpm)	Yield: Date	Drawdown: Amount (feet)	Drawdown: Length of test (hrs.)	Use	Remarks
5.2.18.412	Town of Belen No. 2	1945	4802	460	14	QTs(?)	--	1- 7-57	450R	--	--	--	Ps	Emergency supply, seldom used
18.414	Town of Belen No. 1	1927	4802	339	12	QTs(?)	--	1- 7-57	300R	--	--	--	Ps	Used few hours daily in summer
18.421	Santa Fe Railway Co.	--	4806	-	5(?)	Qal	--	1-10-57	---	--	--	--	N	Jet pump; formerly used for railroad
18.423	do.	--	4805	-	5	Qal	13.4	1-10-57	---	--	--	--	N	do.
18.423a	do.	--	4805	-	5(?)	Qal	--	1-10-57	---	--	--	--	N	do.
18.423b	do.	1945	4804	-	12	Qal	--	1-10-57	---	--	--	--	RR	-
19.232	Railways Ice Co. No. 1	1944(?)	4805	110	10	Qal	--	1-10-57	360R	--	--	--	Ind	Water used for cooling only
19.232a	Railways Ice Co. No. 3	1944	4805	110	10	Qal	--	1-10-57	501R	--	--	--	Ind	do.
19.232b	Railways Ice Co. No. 4	1952	4805	120	12	Qal	--	1-10-57	376R	--	--	--	Ind	do.
28.124	Mr. Campbell	1953	4800	86	16	Qal	7.1	4-12-56	1600R	--	38	S	I	-
32.143	James Matsu	1950	4790	48	12	Qal	6.4	4-12-56	500R	--	--	--	N	About 20 feet from well 5.2.32.143a
32.143a*	do.	1957	4790	100	18	Qal	--	6-26-58	1500R	6-26-58	29.2(?)	7	Is	Replaces well 5.2.32.143
6.1.5.412	Santa Fe Railway Co.	1926	5310	1107	15	QTs	477.7	4-25-56	117R	1926	70	--	O	Formerly used for railroad
5.412a	do.	1937	5310	1176	15	QTs	--	4-25-56	---	--	--	--	N	do.
5.421*	do.	1944	5310	1178	16	QTs	485.	1946	22M	5-24-56	--	--	RR	-
6.2.1.131	L. N. McCullough	--	4836	75	15	Qal	8.0	3-13-56	---	--	--	--	Is, O	Monthly observation well
1.223	L. D. Harris	1951	4850	127	16	Qal	16.7	3- 9-56	1600R	--	--	--	Is	-
2.124	J. D. Evans	1955	4840	100+	18	Qal	7.6	3- 9-56	1835M	9-14-56	38.0	4	Is	Used with 6.2.2.411 when visited;sp.cap.48
2.141	Maurice Richeson	1951	4840	72	12	Qal	8.3	4-27-56	1400R	--	--	--	Is	Well not pumped in 1955 or 1956
2.343	E. J. House	1955	4834	96	12	Qal	7.3	3-13-56	---	--	--	--	Is	May not have been used in 1956
2.411	Allene Woodmansee	1950	4836	61	16	Qal	8.7	3-13-56	825M	9-14-56	23.9	5	Is	Used w/6.2.2.124 when visited;sp.cap.34
2.431	L. N. McCullough	1953	4835	120	20(?)	Qal	9.5	11-26-56	1500R	--	--	--	Is	
2.444	L. D. Harris	1953	4836	90(?)	18	Qal	7.0	3- 9-56	1800R	--	--	--	Is	-
3.344*	Albert Jaramillo	1951	4838	103	16	Qal	8.8	4-12-56	1300R	--	38	24	Is	-
4.411	Paul L. LeClaire	1954	4837	83	12	Qal	5.2	3-27-56	1000R	--	--	--	Is	-
5.212	N. Mex. Penitentiary Farm No. 4	--	4840	200	--	Qal	8.3	3-26-56	735M	9-20-56	22.6	S	Is	Specific capacity 32
5.244	N. Mex. Penitentiary Farm No. 5	--	4838	120	16	Qal	7.9	3-26-56	1282M	10- 1-56	65.4	S	Is, O	Specific capacity 20; temperature 60°F
5.331	N. Mex. Penitentiary Farm No. 2	--	4837	120	--	Qal	11.4	3-27-56	895M	9-19-56	30.5	S	Is	Specific capacity 13
6.442	N. Mex. Penitentiary Farm No. 1	--	4840	150	12(?)	Qal	14.2	3-27-56	459M	9-19-56	34.6	27	Is	Specific capacity 13

APPENDIX A.–RECORDS OF IRRIGATION, PUBLIC-SUPPLY, INDUSTRIAL, AND RAILROAD WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location Number	Owner or name	Year Drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield: Rate (gpm)	Yield: Date	Drawdown: Amount (feet)	Drawdown: Length of test (hrs.)	Use	Remarks
6.2.6.444	State Agricultural Experiment Farm	1957	4840	-	18	Qal	12.9	7-12-57	---	--	--	--	Is	New well, no pump when visited
7.421	R. D. Braught	1954	4840	96	18	Qal	13.2	3-27-56	1250R	--	10(?)	1	Is	Driller's log
10.142	Bartlett Smith	1953	4834	83	12	Qal	8.5	4-24-56	1000R	--	--	--	Is, O	-
11.112	E. J. House	--	4834	65	12	Qal	8.8	3-13-56	---	--	--	--	Is	Unused when visited; may get pump later
16.423	Tome Church(?)	1951	4828	90	16	Qal	7.9	3-14-56	600R	--	--	--	Is, O	Yield inadequate
19.413	Medarto Sanchez(?)	--	4825	-	16	Qal	9.8	3-27-56	---	--	--	--	Is, O	Has been used to irrigate several small fields (each about 10 acres)
21.443	F. B. Marquez	1955	4822	63	5	Qal	--	--	200R	--	--	--	Is	Two wells here, 3 ft apart, joined by manifold; no pump attached when visited
27.133	C. M. Campbell	1952	4819	105	16	Qal	7.6	3-15-56	1200R	--	--	--	Is, O	Monthly observation well
28.323	Adelino Sanchez	1949	4821	83	14	Qal	8.2	3-15-56	---	--	--	--	Is	-
30.312	A. R. Stradling	1952	4833	120	18	Qal	--	--	---	--	--	--	N	Caved
30.313	do.	1952	4833	160	18	Qal	20.1	3-27-56	1000R	1953	70	6	Is, O	-
31.421	A. A. Archuleta	1952	4813	87	12	Qal	5.0	4-13-56	---	--	--	--	Is	Yield barely adequate
32.121	Bob Pearce	1954	4817	100	16	Qal	8.7	3-28-56	2000R	5-20-54	26	12	Is	-
34.212	Ray Hobbs	1946(?)	4829	-	--	Qal	17.2	3-15-56	---	--	--	--	Is	-
7.2.1.114	Golden "C" Ranch	1956	4868	-	15	Qal	6.3	9-27-57	---	--	--	--	Is	-
2.112	---	--	4870	-	--	Qal	8.4	3- 7-56	---	--	--	--	Is	-
2.131	B. C. Ringer	1952(?)	4867	-	15	Qal	6.9	3- 7-56	1014M	9-12-56	35.0	4	Is	Specific capacity 29
2.141	Ray Birch	1950(?)	4867	125	18	Qal	8.2	3- 8-56	1000R	--	--	--	Is	-
2.311	D. L. Braught	1949	4866	76	12	Qal	--	--	750R	--	12	8	Is	Centrifugal pump
2.313	W. L. Stroope	1951	4865	91	18	Qal	6.5	3- 7-56	1700R	--	10(?)	--	Is	-
2.322	Bryan Beets	1951	4866	83	16	Qal	8.0	5-25-56	1500R	--	--	--	Is	-
2.422	B. C. Ringer	--	4868	55.9	18	Qal	10.0	3- 8-56	861M	9-12-56	12.0	4	Is	Specific capacity 71
3.234	D. L. Braught	1956	4867	80	18	Qal	--	--	1386M	9-13-56	47	8	Is	Specific capacity 30
11.121	Chester Carpenter	1951	4864	80	20	Qal	7.6	3- 8-56	1200R	--	--	--	Is	-
11.212	Edgar Murray	1950	4864	64	16	Qal	8.4	3- 8-56	1150R	--	28	72	Is	-
11.343	C. C. Bristow	1951	4859	98	16	Qal	6.0	4-13-56	1350R	--	38	2	Is, O	-
11.424	R. M. Wasmer	1951(?)	4816	74	18	Qal	8.1	4-13-56	1800R	--	29	8	Is	-
13.143	C. L. Heiman	1950	4857	61	16	Qal	11.6	3-12-56	777M	11-26-56	18.0	1-1/2	Is	Specific capacity 43
17.131*	Los Lunas Hospital	1948	4985	530	20	QTs	135.2	4-18-56	924M	8-21-56	30.6	1-1/3	I	Emergency supplement for 7.2.18.421; specific capacity 23

APPENDIX A.–RECORDS OF IRRIGATION, PUBLIC-SUPPLY, INDUSTRIAL, AND RAILROAD WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield: Rate (gpm)	Yield: Date	Drawdown: Amount (feet)	Drawdown: Length of test (hrs.)	Use	Remarks
7.2.18.242	Los Lunas Hospital	1947(?)	4986	388.3	20	QTs	135.7	3-14-56	---	--	--	--	O	Monthly obs.well; 114 ft to 7.2.17.131
18.421*	do.	1958	4985	407	16	QTs	134.5	6-16-58	1284M	6-20-58	51.0±	3+	I	Replaces 7.2.17.131; sp. cap. 25
21.314	do.	1946	4882	243	10	QTs	40.7	5-25-56	108R	1955	--	--	Is	Sucks air; 108 gpm inc. surge;irrigates small orchard, trees in parkway
21.332*	do.	1952	4878	607	20	QTs	32.5	3-26-56	760M	3-26-56	--	--	Is, Ps	Reported drawdown 57 ft @ 1500gpm when tested by driller; temperature 67°F
24.134	Mr. McGarrah	--	4851	100(?)	12	Qal	7.1	5-16-56	1500R	--	--	--	Is, O	-
24.342	N. S. Hill	1952(?)	4849	-	--	Qal	8.4	3-12-56	---	--	--	--	Is	-
25.314	Jack Freeman	1954(?)	4846	90(?)	16	Qal	10.2	3-12-56	---	--	--	--	Is	-
25.344	B. P. Washburn	--	4843	79	--	Qal	--	--	1100R	--	--	--	Is	-
25.344a	do.	1951(?)	4843	46.7	16	Qal	7.4	3-14-56	---	--	--	--	N	Open hole 7 feet from 7.2.25.344
26.112*	Roy and Truman Stovall	1953	4851	74	18	Qal	4.8	4-13-56	1500R	1953	35	20	Is	Temperature 59°F
26.234	Mr. Turner	1950	4848	71	10	Qal	7.1	5- 8-56	---	--	--	--	Is	-
26.242	B.P. Washburn	--	4848	80	--	Qal	9.4	3-14-56	1000R	--	--	--	Is	Owner reports yield not quite adequate for acreage irrigated (approx. 60)
27.424	L. D. Harris	1953	4850	97	16	Qal	6.8	3- 9-56	1200R	--	--	--	Is	-
28.114	Ernest Sichler	1952	4863	108	16	Qal	19.8	4-13-56	1557R	3-12-53	25	S	Is	Cased to 100 ft; temperature 62°F
28.234*	Village of Los Lunas	1939	4851	365	6	QTs	10.	11-28-56	150R	--	--	--	Ps	Temperature 65°F
28.243*	do.	1950	4851	400	8	QTs	10.	11-28-56	350R	--	--	--	Ps	Temperature 64°F
29.442	Jack Wood	1951	4847	87	13	Qal	7.7	3-26-56	---	--	--	--	N	Caved
32.321	N. Mex. Penitentiary Farm No. 3	--	4840	150	--	Qal	7.1	3-27-56	450R	--	--	--	Is	-
33.232	N. C. Ribble	1951	4844	90	16	Qal	7.1	3-27-56	---	--	--	--	Is, S	Helical pump
34.221	Rio Grande Produce Co. No. 2	1951	4846	120	18	Qal	7.7	3- 9-56	2500R	--	44	24	Is	-
34.222	Rio Grande Produce Co.	--	4844	-	--	Qal	--	--	---	--	--	--	N	Centrifugal pump
35.243	Ernest Greene	1950	4842	46+	12	Qal	8.9	3-13-56	---	--	--	--	Is	-
35.314	Rio Grande Produce Co. No. 1	1949	4841	100	--	Qal	--	--	1515M	9-14-56	30	12	Is	-
35.334	Ward Hobbs	1956	4842	100	16	Qal	8.3	3-13-56	---	--	--	--	Is	New well, to irrigate 70 acres; cased to 90 feet
35.343	Ed Tixier	1951	4842	68	14	Qal	8.8	4-27-56	782M	9-20-56	21.5	S	Is	Specific capacity 36
35.411	Ernest Greene	1954	4842	75	15	Qal	7.6	3-13-56	1100R	--	--	--	Is	-
35.422	K. H. Mims (lessee)	--	4843	-	12	Qal	--	--	---	--	--	--	N	Formerly used for irrigation

APPENDIX A.–RECORDS OF IRRIGATION, PUBLIC-SUPPLY, INDUSTRIAL, AND RAILROAD WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield: Rate (gpm)	Yield: Date	Drawdown: Amount (feet)	Drawdown: Length of test (hrs.)	Use	Remarks
7.2.36.111	Scotte Turnbull	--	4845	-	14	Qal	9.3	4-27-56	1500R	--	--	--	Is	-
36.141	K. H. Mims	1950	4842	57.0	8	Qal	6.7	4-19-56	---	--	--	--	N	-
36.311	do.	1950	4841	62	14	Qal	8.5	4-27-56	800R	--	--	--	Is	-
7.3.19.334	Leroy Evans	1946(?)	4870	84.0	16	Qal	23.9	3-12-56	700R	--	--	--	N	-
8.2.35.334	H. Whitley	1955	4869	80-100	16	Qal	6.9	3- 7-56	1700R	--	--	--	Is, O	-
35.434	Albert Davis	1951	4869	78	18	Qal	6.2	4-13-56	1900R	--	45	S	Is	-
8.3W.5.212	Dan's Cafe	1935(?)	5503	114(?)	--	Qal	100(?)	--	---	--	--	--	Ps	500 to 1000 gpd reported use
6.224	---	1930(?)	5510	120	--	Qal	116(?)	1957(?)	---	--	--	--	Ps	-

APPENDIX B.—RECORDS OF STOCK, DOMESTIC, AND OBSERVATION WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO

Location number: number designates well and location (see well-numbering system, p. 7); * refers to chemical analysis of water, Appendix D.

Altitude: estimated from USGS topographic quadrangle maps.

Depth of well: measured depths to nearest 0.1 foot below land surface; reported depths to nearest foot.

Geologic source: Qal--alluvium; QTs--Santa Fe Group; Ps--San Andres Limestone; Py--Yeso Formation; Pa--Abo Formation; Pb--Bursum Formation; Pm--Madera Limestone.

Depth to water: measured depths to nearest 0.1 foot; reported depths to nearest foot; P--pumped recently.

Yield: estimated by Geological Survey personnel unless noted; R--reported; M--measured by Survey personnel.

Method of lift: F--force pump; L--lift pump; J--jet pump; T--turbine pump; W--windmill power; G--internal combustion power; E--electric power; N--none.

Use: S--stock; D--domestic; O--water-level observation by Geological Survey; Or--water-level observation by Bureau of Reclamation; N--not used.

Note: Unless specified, all wells are drilled and cased to total depth.

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield (gpm)	Method of lift	Use	Remarks
3.3.5.331	West and Pyle Cattle Co.	--	5098	350	6	QTs	304.0	5-23-56	-	L, W	S	-
3.5.9.424	Mr. Padilla	--	--	82 +	-	Pb	82.0+	3-27-50	-	--	S,D	Data from Spiegel (1955)
28.444*	C. Pohl	1906	5835	21	-	Pa	10.9	8-29-49	-	L, W	D	Dug well; data from Spiegel (1955)
32.210*	M. A. Pohl	1945(?)	5800	24	24	Pb	19.7	8-29-49	1/8R	L, W	S	do.
4.1.9.324*	B. C. Ringer	--	5178	400. +	6	QTs	380.4	5-11-56	3	F, G	S	Will pump dry; temperature 73°F
4.2.2.222	do.	--	4959	--	6	QTs	162.0	5-15-56	7R	L, W	S	-
2.334	do.	--	4958	180 +	5	QTs	171.2	5-15-56	-	L, W	S	-
7.141*	---	1951	4778	6.9+	-	Qal	4.1	6-18-56	-	N	Or	Bur. Reclamation data, well BW 9-3
7.412*	---	1951	4781	8.6+	-	Qal	6.0	6-18-56	-	N	Or	Bur. Reclamation data, well BW 9-2
7.423*	---	1951	4778	6.0+	-	Qal	3.8	6-18-56	-	N	Or	Bur. Reclamation data, well BW 9-1
9.234	B. C. Ringer	--	4857	94.0(?)	5	QTs	75.0	5-15-56	5R	L, W	S	-
21.343	L. Miranda	--	4845	--	-	QTs	--	4-12-56	-	L, W	S	-
22.121*	Mr. Cannon	--	4901	135.0	4	QTs	122.2	4-11-56	2	L, W	S	Temperature 68°F
30.232*	---	1951	4768	6.6+	-	Qal	5.0	6-18-56	-	N	Or	Bur. Reclamation data, well BW 11-2
35.214*	Mr. Cannon	--	4947	187	-	QTs	170.1	5-16-50	2	L, G	S	Will pump dry; temperature 61°F
4.3.7.242	B. C. Ringer	--	5062	300	6	QTs	P261.8	5-15-56	6	L, W	S	Water level rising when measured
10.414	do.	--	5110	320	5	QTs	290.2	5-15-56	6	L, W	S	-
20.134	West and Pyle Cattle Co.	Before 1931	5032	360	6	QTs	236.8	5-23-56	-	L, W	S	-
26.144*	do.	Before 1931	5132	400	6	QTs	317.1	5-23-56	-	L, W	S	Temperature 71°F
4.4.28.144	do.	1918(?)	5515	36.8	6	Qal	--	5-23-56	-	N	N	Dry
28.222	do.	Before 1931	5637	400 +	6	Qal(?)	124.7	5-23-56	1	L, W	S	-

APPENDIX B.—RECORDS OF STOCK, DOMESTIC, AND OBSERVATION WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield (gpm)	Method of lift	Use	Remarks
4.1W.12.341	F. Padilla	--	4874	60 +	6	QTs	57.6	5- 9-56	5	L, W	S	Salty and gypseous taste; temp. 63°F
4.2W.2.433*	F. D. Huning	1947	5243	439	5	QTs	--	4-30-56	2	L, W	S	Temperature 74°F
2.433a	do.	--	5243	381.3	-	QTs	380.5	2- 4-57	-	N	N	20 yards from 4.2W.2.433
4.3W.7.212	Ward and Dysart(?)	--	5849	2.0	6	Qal	1.4	4-30-57	-	L, W	S	Windmill disconnected
5.1.1.213	W. M. Crowder	--	4865	--	8	QTs	53.8	4-25-56	2	L, W	D,S	Temperature 64°F
13.344	Raphael Sanchez	--	4867	80	5	QTs	65.9	3-29-56	2	L, W	S,D	Temperature 63°F
24.344*	Justo Gabaldon	1954	4875	96	4	QTs	74.9	3-29-56	9R	L, W	S	Reported sp. cap. 1.5 gpm/ft drawdown; temperature 66°F
28.114*	B. C. Ringer	--	5198	--	6	QTs	393.1(?)	5-18-56	4	F, G	S	Temperature 72°F
5.2.21.223	do.	--	4850	60 +	6	QTs	52.2	5-15-56	4	L, G	S	-
5.3.8.222*	do.	--	5060	--	6	QTs	238.8	5-15-56	5R	L, W	S	-
11.331*	do.	--	5134	--	8	QTs	296.9	5-15-56	-	L, W	S	-
19.212	do.	--	5019	260 +	8	QTs	209.2	1-30-57	6R	L, G	S,O	-
26.313	do.	--	5127	320 +	6	QTs	F307.2	1-30-57	6R	L, W	S	Water level rising when measured
32.424	do.	--	5062	280 +	6	QTs	240.7	1-30-57	-	L, W	S	-
5.4.3.114	Mrs. R. V. de Baca	1946	5620	42	6	QTs	13.0	1- 9-57	5	L, W	S	Temperature 60°F
16.323	R. G. Sanchez	1950	5513	72	6	Qal,Ps(?)	13.9	1- 9-57	low	L, W	N	-
5.1W.14.231*	F. D. Huning	--	4920	--	6	QTs	90.7	5-24-56	5	L, W	S	Temperature 63°F
18.433	do.	--	5390	600	8	QTs	555.8	5-18-56	-	N	N	Formerly used for stock
20.222	do.	--	5195	410	8	QTs	--	4-30-56	-	L, W	S	-
32.423	do.	--	5188	412	8	QTs	370.6	4-18-56	5	L, W	S	-
5.2W.21.422	do.	1953	5401	620	8	QTs	545.5	5-24-56	-	L, W	S	-
5.3W.19.111*	C. E. Darnell	--	6027	55.0(?)	6	Pa	47.6	5- 1-57	3	L, W	S	Temperature 64°F
20.232	do.	--	5903	--	8	Pm	--	2- 5-57	-	L, W	S	-
20.333	do.	--	5882	91.4	6	Pm	67.0	2- 5-57	-	L, W	S	Windmill disconnected
28.143	do.	--	5910	25.0	48	Pm	18.8	2- 5-57	-	L, W	S	Dug well. Windmill disconnected
5.4W.26.411	Juan Iriart	--	6063	150	6	Pa	66.6	2- 5-57	-	L, W	S	-
6.1.5.431	Bailes and von Glahn	1949	5310	6169	18	QTs(?)	126.8	4-25-56	-	N	N	Abandoned oil test; bottomed in Dakota Sandstone(?); water under artesian pressure(?)
33.433	do.	--	5231	556	8	QTs(?)	417.5	5-24-56	-	F, W	S	-
6.2.3.441*	---	1951	4834	4.9+	-	Qal	2.0	6-15-56	-	N	Or	Bur. Reclamation data, well BE 4-4

APPENDIX B.—RECORDS OF STOCK, DOMESTIC, AND OBSERVATION WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield (gpm)	Method of lift	Use	Remarks
6.2.18.211*	---	1951	4839	7.8+	-	Qal	2.8	6-15-56	-	N	Or	Bur. Reclamation data, well BW 4-4; perched water table?
29.113*	---	1951	4819	7.1+	-	Qal	4.2	6-15-56	-	N	Or	Bur. Reclamation data, well BW 5-4
30.211*	---	1951	4821	9.5	-	Qal	5.7	6-15-56	-	N	Or	Bur. Reclamation data, well BW 5-5
6.3.4.243	Ward Hobbs	--	5077	--	5	QTs	239.7	7-11-57	-	L, W	S	Not in use when visited
9.134	do.	--	5041	--	6	QTs	204.9	7-12-57	-	L, W	S	-
21.312	Tome Land and Development Co.	1924(?)	5036	300 +	6	QTs	208.1	1-18-57	7	L, W	S	-
6.1W.14.112	F. D. Huning	1950(?)	5021	226	8	QTs(?)	184.2	2-10-56	-	L, W	S	-
15.313	do.	1944	5002	216	8	QTs(?)	R174.4	2-13-56	-	L, W	S	Water level rising when measured
6.2W.1.322	E. B. Lovelace	--	5075	77.5	6	QTs	73.2	4-26-56	-	N	N	Formerly used to water stock
8.213	do.	--	5322	--	7	QTs	41.8	2- 6-57	-	L, W	S	-
13.234*	do.	--	5118	132.2	4	QTs	74.5	4-26-56	3	L, W	S	Temperature 62°F
22.111	do.	1953	5380	279.6(?)	6	QTs	225.5	5- 1-57	-	L, W	S	Windmill disconnected
31.412	do.	1957	5620	200 +	6	QTs	62.9	5-29-57	-	N	S	Drilled for domestic use; not potable
31.431*	do.	--	5590	--	60	Qal	9.8	2- 6-57	-	L, W	S	Dug well
6.3W.10.233*	D. D. Romero	--	6032	--	6	Py	P 97.3	10-22-57	2	L, W	S	Water level rising when measured; temperature 58°F
28.333*	do.	--	6005	--	4	Pa(?)	--	2- 6-57	5	L, W	S	Temperature 59°F
7.1.10.323	Isleta Pueblo	1934	5263	437	5	QTs	407	12- 7-34	10R	L, W	S	-
7.2.5.412	do.	1934	4985	184	6	QTs	R132.2	1-15-57	15R	L, W	S	Water level rising slowly when measured
14.431*	---	1951	4853	4.2+	-	Qal	3.0	6-14-56	-	N	Or	Bur. Reclamation data, well BE 2-4
18.422	Los Lunas Hospital	1958	4985	190 +	5	QTs	--	--	15	T, E	D	Not equipped with pump when visited
22.314	Shepherd Casey	--	4853	41	-	Qal	8.6	3-14-56	-	L, W	N	Formerly used for domestic supply
26.433*	---	1951	4843	9.5+	-	Qal	5.9	6-14-56	-	N	Or	Bur. Reclamation data, well BE 3-3
33.324*	---	1951	4841	6.5+	-	Qal	5.8	6-15-56	-	N	Or	Bur. Reclamation data, well BW 3-2
7.3.2.214	Isleta Pueblo	--	5262	633.0(?)	8	QTs	P607.4	2-14-56	-	L, W	S	Water level rising when measured
6.122	do.	1939	4900	66	6	Qal	36.8	1- 8-57	10R	L, W	N	Windmill broken
13.434*	do.	--	5295	--	5	QTs	300 +	5-31-57	5	F, W	S,D	Used by cowboy in range cabin; 66°F
26.212	R. G. Sanchez	--	5215	--	6	QTs	370.1	7-11-57	-	F, G	S,D	Used by cowboy in range cabin; water level rising when measured
28.221	Raphael Maes	--	5109	--	6	QTs	265.1	7-11-57	3	L, W	S,D	Used sometimes by cowboy in r. cabin
35.313*	Andres Cordova	1939	5165	345	6	QTs	P321.8	7-11-57	3	L, W	S	Water level rising slowly when measured; temperature 75°F

APPENDIX B.—RECORDS OF STOCK, DOMESTIC, AND OBSERVATION WELLS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Year drilled	Altitude (ft)	Depth of well (feet)	Diameter of casing (in.)	Geologic source	Water level: Depth to water (ft)	Water level: Date measured	Yield (gpm)	Method of lift	Use	Remarks
7.4.11.144	Isleta Pueblo	1934	5715	239	6	QTs	193	11-26-34	12R	L, W	S	Temperature 63°F
23.123*	do.	--	5745	--	5	QTs	P247.0	5-31-57	4	L, W	S	Water level rising when measured; 66°F
35.333	Andres Cordova	1954	5699	180	6	QTs	160.5	7-11-57	-	L, W	S	-
7.1W.2.324	Isleta Pueblo	1934	5423	612	6	QTs	569	11-28-34	12R	L, W	S	-
19.124	F. D. Huning	--	5123	175	8	QTs	144.5	1-17-57	-	L, W	S	-
23.334	do.	1945	5350	576	7	QTs	508.8	4-26-56	3	F, W	S	Temperature 73°F
31.124*	do.	--	5048	96.9	6	QTs	74.1	2-10-56	2	L, W	S	Temperature 64°F
7.2W.10.444	Laguna Pueblo	--	5211	320	6	QTs	212.4	1-17-57	7R	L, W	S	-
29.214	do.	1939(?)	5220	220	6	QTs	148.7	1-17-57	15R	L, W	S	-
34.341	New Mexico & Arizona Land Co.	--	5173	137 (?)	6	QTs	122.6	2-10-56	-	L, W	S	-
7.3W.9.431	Albert Barrington	--	6460	--	6	---	--	--	-	L, W	S	Not in use when visited
7.4W.2.343	do.	--	5785	48.2	6	Qal	36.0	2- 8-57	-	L, W	S	-
10.124	do.	--	5830	--	48	Qal	6.0	2- 8-57	-	L, W	S	Dug well, not in use when visited
13.114	do.	1953	5855	--	5	Qal	83.8	6- 4-57	3	L, W	S	Temperature 60°F
15.222*	do.	--	5834	--	6	Qal	26.1	6- 4-57	2	L, W	S	Water level rising slowly when measured; temperature 62°F
25.111	do.	--	5980	140.6(?)	6	Ps	123.4	6- 7-57	-	L, W	S	-
35.443	do.	--	6219	--	5	Ps	--	6- 7-57	-	L, W	S	Blowing air when visited
8.3.32.412*	Isleta Pueblo	1934	4977	123	6	QTs	105 P113.5	11- 1-34 1- 8-57	3	L, W	S	Water level rising slowly when measured; temperature 66°F
8.3W.8.222	Albert Barrington	--	5495	--	6	Qal	99.0	2- 8-57	3	L, W	S	Temperature 62°F
10.313	do.	1953	5470	--	6	Qal	80.0	6- 4-57	-	L, W	S	-
18.444	do.	--	5550	--	5	Qal	--	2- 8-57	-	L, W	S	-
19.343	do.	--	5593	--	6	Qal	43.2	6- 4-57	1	L, W	S	Gypseous taste; temperature 60°F
20.211*	do.	--	5534	--	6	Qal	--	2- 8-57	3	L, W	S	Temperature 59°F
8.4W.15.123	Laguna Pueblo	1935	5616	186	5	Qal	144	1-22-35	1	L, W	S	
22.342	do.	1935	5650	123	6	Qal	91.2	7-24-58	3	L, W	S	

APPENDIX C.–RECORDS OF SPRINGS IN EASTERN VALENCIA COUNTY, NEW MEXICO

Location number: number designates spring and location (see well-numbering system, p. 7); * indicates chemical analysis of water in Appendix D

Altitude: Estimated from USGS topographic quadrangle maps

Geologic source: Qal--alluvium; QTs--Santa Fe Group; Km--Mancos Shale; Kd--Dakota Sandstone; Jm--Morrison Formation; Trc--Chinle Formation; Trs--Shinarump Member; Ps--San Andres Limestone; Py--Yeso Formation; Pa--Abo Formation; Pm--Madera Limestone; p€ --Precambrian rocks

Yield: estimated by Geological Survey personnel unless specified; R--reported, M--measured by Geological Survey personnel

Use: S--stock water; N--not used

Location number	Owner or occupant	Name	Altitude (feet)	Character of material	Geologic source	Occurrence	Yield: Rate (gpm)	Yield: Date	Yield: Use	Temperature (°F)	Remarks
3.4.11.144	West and Pyle Cattle Co.	Bustamonte Spring	5920(?)	Granite and quartzite	p€	On contact between alluvium and p€ rock	3	5-23-56	S	-	Water probably comes from fractures in granite or quartzite
14.140	West and Pyle Cattle Co.	---	5897	Alluvium	Qal	---	2.5M 0.1M	9- 2-49 3-27-50	-	-	Data from Spiegel (1955)
3.5.30.100	---	---	--	Limestone	Pm	---	1/4-1/2	12- 2-49	-	-	Data from Spiegel (1955); slight sulfate taste
4.3W.6.444*	Ward and Dysart(?)	---	5840	Limestone	Pm	Gap in hogback upstream from fault	---	--	S(?)	68	Precipitate covers arroyo floor
5.4.2.333	Mrs. R. V. DeBaca	Trigo Spring	5680	Alluvium	Qal	Channel across uplifted fault block	5	1- 9-57	S	51	Reported little fluctuation in discharge
9.413	Manuel DeBaca	Ojo Jedeondilla	5520	Alluvium	Qal	do.	2	1- 9-57	S	58	Reported never dry
5.3W.29.441*	C. E. Darnell(?)	Coyote Spring	5810	Limestone	Pm	Wide gap in hogback upstream from fault	3 R	1941	S(?)	64	Precipitate covers estimated 30 acres of flat arroyo floor
6.4.5.232	Andres Cordova	Maes Spring	5445	Sand and gravel	QTs	Channel across uplifted fault block	dry	1-11-57	N	-	---
8.321	Andres Cordova	Carrizo Spring	5370	Sand and gravel	QTs	On fault scarp	10	1-18-57	S	58	Reported little fluctuation in discharge
20.144	Tome Land and Development Co.	Ojo Alamo	5354	Sandstone	Trc	Channel across uplifted fault block	25	1- 8-57	S	58	Reported little fluctuation in discharge
20.321	Tome Land and Development Co.	Ojo Huelos } Los Ojuelos	5388	Sandstone	Trc	On fault scarp	15	1- 8-57	S	58	Reported little fluctuation in discharge
20.342	Tome Land and Development Co.	Ojo Lemita	5401	Sandstone	Trc	Channel across uplifted fault block	7	1- 8-57	S	-	Reported little fluctuation in discharge
6.2W.6.433*	E. B. Lovelace	---	5400	Sandstone	Py	Fault zone	50	2- 6-57	S	-	Precipitate covers arroyo floor
6.3W.35.340*	D. D. Romero(?)	---	5790	Limestone	Pm	Gap in hogback upstream from fault	30	2- 6-57	S	58	Water cascades through numerous pools impounded by small dams built by precipitates from water
7.4.6.434	Isleta Pueblo	---	5371	Sand and silt	QTs	Fault scarp	dry	2-14-56	N	-	Dug pit approx. 5 feet deep; dry
7.2W.6.210*	Laguna Pueblo	---	5480(?)	---	Km	---	0.3R	1941	-	-	Data partly from Wright (1946)
6.434*	Laguna Pueblo	---	5350	Sandstone	Kd(?)	Fault zone	3	2-20-56	N	58	Large travertine deposits
7.124*	Laguna Pueblo	---	5450	Shale and sandstone	Trc	Fault zone	3 R	8-25-41	-	76(?)	Data partly from Wright (1946)
7.320*	Laguna Pueblo	---	5480(?)	Shale and sandstone	Trc	Fault zone	0.1R	1941	-	-	Data partly from Wright (1946)
18.140*	Laguna Pueblo	---	5500(?)	Shale and sandstone	Trc	Fault zone	0.2R	1941	-	-	Data partly from Wright (1946)

APPENDIX C.–RECORDS OF SPRINGS IN EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or occupant	Name	Altitude (feet)	Character of material	Geologic source	Occurrence	Yield: Rate (gpm)	Yield: Date	Use	Tem-pera-ture (°F)	Remarks
7.2W.18.312*	Laguna Pueblo	---		Shale and sandstone	Trc	Fault zone	0.05R	1941	-	-	Data partly from Wright (1946)
18.313*	Laguna Pueblo	---		Limestone	Ps	Fault zone	0.02R	1941	-	82(?)	Data partly from Wright (1946)
30.132*	Laguna Pueblo	---	5645	Limestone	Ps	Fault zone	0.35R	1941	-	75(?)	Data partly from Wright (1946)
30.320*	Laguna Pueblo	---	5600(?)	Sandstone and gypsum	Py	Fault zone	0.05R	1941	-	86(?)	Data partly from Wright (1946)
31.140*	Laguna Pueblo	---	5560(?)	Sandstone	Pa	Fault zone	0.05R	1941	-	80(?)	Data partly from Wright (1946)
7.4W.2.144	Albert Barrington	Lower Water Spring	5720	Alluvium	Qal	Fault zone	---	--	-	-	---
3.344*	Albert Barrington	---	5812	Conglomerate(?)	Trs(?)	Vertical vent in floor of valley	1	2- 8-57	S	48	Water flows from center of travertine mound about 10 ft above surrounding topography
11.431*	Albert Barrington	Lucero Spring	5825	Conglomerate(?)	Trs(?)	Vertical vent in floor of valley	5	6- 4-57	S	60	Water flows from center of travertine mound about 10 ft above surrounding topography; flow reportedly increases soon after rain; occasionally dry
8.4.29.424*	Isleta Pueblo	Ojo de la Cabra	5445	Sand and silt	QTs	Fault zone	10	2-15-56	S	60	---
8.2W.19.421*	Laguna Pueblo	Ojo Escondido	5203	Sandstone	Jm	Fault zone	20	2-20-56	S	62	Bitter taste; little precipitate near seeps
30.340*	Laguna Pueblo	---	5320(?)	Shale and sandstone	Jm(?),Kd(?)	---	5 R	1941	-	72(?)	Data from Wright (1946), Kelley and Wood (1946)
8.3W.10.224*	Laguna Pueblo	Suwanee Spring	5360	Alluvium	Qal	Lava filled shallow valley	30	4- 2-58	S	-	---
12.342*	Laguna Pueblo	Dipping Vat Spring	5320	Sandstone(?)	Jm (Qal?)	Canyon in sandstone	400	4- 2-58	S	60	---
35.100*	Laguna Pueblo	---	5800(?)	Shale and sandstone	Trc	Basalt slump blocks; water probably perched on or in Chinle	1	9- 3-41	-	65	Data partly from Wright (1946)

APPENDIX D.—CHEMICAL ANALYSES OF GROUND WATER FROM EASTERN VALENCIA COUNTY, NEW MEXICO

Location number: number designates well or spring from which sample was obtained and location (see well-numbering system, p. 7); (S) preceding number denotes spring in this appendix only

Geologic source: Qal--alluvium, Quaternary age; QTs--Santa Fe Group, Tertiary and Quaternary (?) age; Km--Mancos Shale, Late Cretaceous age; Kd--Dakota Sandstone, Early and Late Cretaceous age; Jm--Morrison Formation, Late Jurassic age; Trc--Chinle Formation, Late Triassic age; Ps--San Andres Formation, Permian age; Py--Yeso Formation, Permian age; Pa--Abo Formation, Permian age; Pb--Bursum Formation, Permian age; Pm--Madera Formation, Pennsylvanian age

(Analyzed by U.S. Geological Survey. Chemical constituents in parts per million)

Location number	Owner or name	Date collected	Geologic source	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium plus Potassium (as Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
3.3.10.324	Santa Fe Railway Co.	10- 3-06	QTs	--	--	-	132	38	85	--	--	455	33	-	--	--	834	--	--	28	1.8	--	-
10.324a	Santa Fe Railway Co.	8-12-03	QTs	--	--	-	88	42	68	68	--	449	37	-	--	--	945	392	336	27	1.5	--	-
3.5.28.444	C. Pohl	8-29-49	Pa	--	16	-	32	25	66	272	0	55	27	1.0	7.6	--	364	183	--	44	2.1	611	-
32.210	M. A. Pohl	8-29-49	Pb	--	13	-	4	2.2	264	336	42	70	120	1.8	0.1	--	682	19	0	97	26	1,140	-
4.1.9.324	B. C. Ringer	4-24-56	QTs	73	--	-	--	--	192	98	0	869	292	-	0.5	--	--	980	900	30	2.7	2,480	7.2
4.2.7.141	---	10-31-51	Qal	--	--	-	286	84	579	578	0	965	595	-	1.9	--	3,000	1060	586	54	7.7	4,080	-
7.412	---	10-31-51	Qal	--	--	-	164	25	147	502	0	317	62	-	1.8	--	1,010	512	100	38	2.8	1,480	-
7.423	---	10-31-51	Qal	--	--	-	112	19	69	420	0	86	50	-	3.7	--	540	358	14	29	1.0	948	-
8.243	Mr. Pattison	4-11-56	Qal	56	--	-	--	--	43	203	0	115	24	-	1.4	--	--	228	62	29	1.2	631	7.4
1/ 22.121	Mr. Cannon	3-27-50	QTs	--	49	-	40	9.7	21	143	--	40	17	0.4	2.4	--	250	140	23	25	0.8	357	-
30.232	---	10-30-51	Qal	--	--	-	94	62	210	848	0	1.2	176	-	1.1	--	966	490	0	48	4.1	1,820	-
35.214	Mr. Cannon	2-24-50	QTs	--	32	-	24	6.3	34	115	0	49	9	0.8	1.6	--	214	86	0	47	1.1	310	-
35.214	Mr. Cannon	4-11-56	QTs	71	32	-	23	5.9	34	108	0	51	8	0.8	1.1	--	210	82	0	47	1.6	317	7.4
4.3.26.144	West & Pyle Cattle Co.	3-29-50	QTs	--	17	-	20	6.0	28	98	--	40	7	0.6	1.6	--	168	74	0	45	1.4	263	-
4.2W.2.433	F. D. Huning	5-24-56	QTs	74	53	-	41	18	823	644	0	640	538	3.1	5.3	--	2,360	176	0	91	27	3,820	7.8
(S)4.3W.6.444	Ward and Dysart (?)	4-30-57	Km	68	25	-	681	314	7,450	2440	0	3490	9,610	2.0	-	--	22,700	2990	990	84	59	31,000	7.0
5.1.13.332	Town of Belen	11-28-56	QTs	69	31	-	37	15	99	178	0	176	24	1.0	4.7	--	476	154	8	58	3.5	720	7.9
24.344	Justo Gabaldon(?)	4-13-56	QTs(?)	66	--	-	--	--	125	202	0	213	44	-	1.0	--	--	178	12	60	4.1	890	7.5
28.114	B. C. Ringer	4-24-56	QTs	72.2	24	-	322	119	221	166	0	1230	252	0.2	1.3	--	2,420	1290	1160	27	2.7	2,960	7.2
5.2.32.143a	James Matsu	6-26-58	Qal	59	--	-	--	--	--	273	0	198	45	-	-	0.09	--	364	140	--	--	900	7.5
5.3.8.222	B. C. Ringer	6-17-58	QTs	70	54	-	33	6.2	17	132	0	23	9	-	1.1	--	208	108	0	26	0.7	277	7.8
11.331	B. C. Ringer	6-17-58	QTs	62	--	-	--	--	--	139	0	64	11	-	-	--	--	123	9	--	--	391	7.2
5.1W.14.231	F. D. Huning	5-24-56	QTs	63	--	-	--	--	--	416	0	1780	228	-	-	--	--	1580	1240	--	--	3,970	7.2
5.3W.19.111	C. E. Darnell	5- 1-57	Pa	64	20	-	405	233	336	177	0	2300	100	0.7	19.0	--	3,790	1970	1820	27	3.3	3,960	7.7

1/ Sample obtained from stock tank.

APPENDIX D.–CHEMICAL ANALYSES OF GROUND WATER FROM EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Date collected	Geologic source	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium plus Potassium (as Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
(s)5.3W.29.441	C. E. Darnell(?)	1941	Pm	64	5.9	0.80	284	245	10,600	2700	--	4510	12,500	1.6	-	--	29,500	1720	0	93	108	--	-
6.1.5.421	Santa Fe Railway Co.	12-18-51	QTs	--	39	-	17	8.4	114	160	0	155	18	0.9	6.1	--	437	77	0	76	5.7	660	-
.5.421	Santa Fe Railway Co.	4-26-56	QTs	--	--	-	--	--	118	152	0	162	18	-	5.1	--	--	67	0	79	6.2	668	7.8
6.2.3.344	Albert Jaramillo	9-18-51	Qal	--	--	-	102	18	67	282	0	180	39	-	2.1	--	--	328	98	31	1.6	879	7.6
3.441	---	10-30-51	Qal	--	--	-	128	28	235	272	10	504	127	-	3.1	--	1,200	434	195	54	4.9	1,760	-
18.211	---	11- 1-51	Qal	--	--	-	76	16	95	172	0	220	60	-	8.4	--	564	256	114	45	2.6	907	-
29.113	---	11- 1-51	Qal	--	--	-	94	26	172	524	0	216	42	-	1.7	--	838	342	0	52	4.0	1,290	-
30.211	---	11- 1-51	Qal	--	--	-	82	24	166	470	0	187	59	-	0.8	--	786	303	0	54	4.1	1,210	-
(s)6.2W.6.433	E. B. Lovelace	8- 7-41	Py	78	21	0.02	534	448	3,690	1390	0	2640	5,160	1.0	-	--	13,540	3170	2030	72	28	--	-
13.234	E. B. Lovelace	5-29-57	QTs	62	22	-	9.1	9.8	1,410	866	8	1190	820	5.0	0.8	--	3,880	63	0	98	77	5,800	8.3
31.431	E. B. Lovelace	9-13-50	Qal	--	25	-	278	118	1,080	275	0	1090	1,540	-	3.8	--	4,270	1180	953	67	14	6,520	7.7
6.3W.10.233	D. D. Romero	10-22-57	Py	--	--	-	--	--	461	274	0	2570	300	-	-	--	--	2320	2100	30	4.2	4,730	7.2
28.333	D. D. Romero	5- 1-57	Pa	59	22	-	556	273	469	315	0	2610	385	0.7	12	--	4,780	2510	2250	29	4.1	5,210	7.2
(s)6.3W.35.340	D. D. Romero(?)	1941	Pm	71	15	0.57	704	356	4,650	2050	--	2660	6,240	-	-	--	15,630	3220	1540	76	36	--	-
(s)6.3W.35.340	D. D. Romero(?)	5- 1-57	Pm	58	16	-	823	460	5,830	2550	0	3250	7,900	1.6	-	--	19,700	3940	1860	76	40	26,700	6.5
7.2.14.431	---	10-30-51	Qal	--	--	-	125	26	95	364	0	257	41	-	1.1	--	749	419	120	33	2.0	1,120	-
17.131	Los Lunas Hospital	6-19-47	QTs	--	--	-	--	--	88	187	0	67	14	-	-	--	--	51	0	--	--	457	7.2
18.421	Los Lunas Hospital	6-26-58	QTs	66	--	-	--	--	--	182	0	86	24	-	-	0.12	--	64	0	--	--	539	8.3
21.332	Los Lunas Hospital	8- 6-52	QTs	--	48	0.04	12	3.1	100	186	0	76	18	1.0	0.5	--	350	42	0	84	6.7	506	-
21.332	Los Lunas Hospital	3-26-56	QTs	67	--	-	--	--	94	184	0	70	16	-	0.0	--	--	43	0	83	6.2	492	7.9
26.112	Roy & Truman Stovall	3- 9-56	Qal	59	35	-	71	13	33	222	0	108	4	0.4	0.6	--	409	230	48	24	0.9	609	7.6
26.433	---	10-30-51	Qal	--	--	-	128	35	374	544	0	570	168	-	0.6	--	1,530	464	18	64	8.0	2,260	-
28.234	Village of Los Lunas	11-28-56	QTs	65	51	-	10	4.3	94	180	0	68	18	0.8	0.1	--	344	42	0	83	6.2	488	8.0
28.243	Village of Los Lunas	10-16-57	QTs	--	50	-	10	3.1	96	187	0	73	9.0	1.8	0.1	--	336	38	0	85	6.8	470	8.1
33.324	---	10-31-51	Qal	--	--	-	240	42	447	416	0	1170	130	-	1.2	--	2,300	772	430	56	7.0	3,000	-
7.3.13.434	Isleta Pueblo	5-31-57	QTs	--	26	-	--	--	14	152	0	20	3.5	0.8	1.3	--	--	123	0	20	0.6	286	7.6
35.313	Andres Cordova	7-11-57	QTs	--	--	-	--	--	--	--	--	--	6.0	-	-	--	--	--	--	--	--	257	-
7.4.23.123	Isleta Pueblo	3-22-56	QTs	66	--	-	--	--	83	204	0	38	14	-	0.0	--	--	45	0	80	5.4	449	7.7
7.1W.31.124	F. D. Huning	4-26-56	QTs(?)	64	27	-	110	55	1,940	910	0	2440	1,010	0.4	2.3	--	6,170	500	0	38	89	8,540	7.7
(s)7.2W.6.210	Laguna Pueblo	1941	Km	--	--	-	227	185	11,400	2050	--	7800	11,600	-	-	--	32,400	1330	0	95	136	--	-
(s)7.2W.6.434	Laguna Pueblo	1941	Kd(?)	80	--	-	312	133	9,460	2100	--	6380	9,600	-	-	--	27,100	1330	0	94	113	--	-
(s)7.2W.6.434	Laguna Pueblo	2-20-56	Kd(?)	58	--	-	92	126	9,670	2440	0	6300	9,400	-	-	--	--	748	0	97	154	35,200	7.7

APPENDIX D.—CHEMICAL ANALYSES OF GROUND WATER FROM EASTERN VALENCIA COUNTY, NEW MEXICO *(continued)*

Location number	Owner or name	Date collected	Geologic source	Temperature (°F)	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium plus Potassium (as Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
(S)7.2W.7.124	Laguna Pueblo	8-25-41	Trc	76	37	0.08	108	138	10,000	1710	0	6710	9,940	5.8	-	--	27,900	837	0	96	151	--	-
(S)7.2W.7.320	Laguna Pueblo	1941	Trc	--	--	-	324	152	9,250	2210	--	6670	9,070	-	-	--	26,700	1430	0	93	106	--	-
(S)7.2W.18.140	Laguna Pueblo	1941	Trc	--	--	-	418	187	10,200	1610	--	8040	10,200	-	-	--	30,000	1810	492	92	105	--	-
(S)7.2W.18.312	Laguna Pueblo	1941	Trc	--	--	-	566	188	--	2030	--	7390	9,210	-	-	--	27,800	2180	521	90	86	--	-
(S)7.2W.18.313	Laguna Pueblo	1941	Ps	82	34	1.8	918	220	11,200	2840	--	8910	11,100	3.4	-	--	33,900	3200	868	88	89	--	-
(S)7.2W.30.132	Laguna Pueblo	1941	Ps	75	32	15.	702	214	6,640	2170	--	5640	6,560	2.8	-	--	20,920	2630	853	85	56	--	-
(S)7.2W.30.320	Laguna Pueblo	1941	Py	86	--	-	297	224	--	1370	--	6710	8,880	-	-	--	25,700	1660	540	--	--	--	-
(S)7.2W.31.140	Laguna Pueblo	1941	Pa	80	20	0.18	603	271	5,350	1620	--	5380	5,120	1.2	-	--	17,500	2620	1290	82	46	--	-
(S)7.4W.3.344	Albert Harrington	1941	Qal(?)	65	--	-	606	150	--	408	--	1970	146	-	-	--	3,440	2130	1790	--	--	--	-
(S)7.4W.11.431	Albert Harrington	1941	Qal(?)	62	20	1.4	640	177	327	625	--	1960	326	1.0	-	--	4,010	2320	1810	23	3.0	--	-
(S)7.4W.11.431	Albert Harrington	6- 4-57	Qal(?)	40	25	-	647	183	273	603	0	1940	315	1.4	0.8	--	3,930	2370	1870	20	2.4	4,260	6.7
15.222	Albert Harrington	6- 4-57	Qal	62	11	-	611	147	146	385	0	1860	136	1.2	0.2	--	3,350	2130	1810	13	1.4	3,420	7.0
8.3.32.412	Isleta Pueblo	2-14-56	QTs	66	--	-	--	--	43	122	0	72	22	-	approx. 358	--	--	400	300	19	0.9	1,020	7.2
(S)8.4.29.424	Isleta Pueblo	2-15-56	QTs	60	--	-	--	--	12	186	0	29	9.0	-	1.2	--	--	169	16	16	0.4	403	7.3
(S)8.2W.19.421	Laguna Pueblo	9- 8-41	Jm	73	12	0.02	33	20	29	220	0	32	5.6	0.7	0.1	--	239	164	0	28	1.0	--	-
(S)8.2W.30.340	Laguna Pueblo	1941	Jm(?),Ka(?)	72	20	0.09	516	163	6,820	1340	--	6540	6,170	4.3	-	--	20,900	1960	860	88	67	--	-
(S)8.3W.10.224	Laguna Pueblo	5-16-58	Qal	62	29	-	258	99	558	224	--	1530	344	-	3.6	--	3,020	1050	867	54	7.5	3,790	7.7
(S)8.3W.12.342	Laguna Pueblo	12- 7-57	Jm	--	30	0.26	270	109	609	222	0	1640	384	0.7	4.7	0.85	3,270	1120	940	54	7.8	4,030	7.7
20.211	Albert Harrington	2- 8-57	Qal	59	33	-	453	252	376	161	0	2240	364	-	8.3	--	3,810	2170	2030	27	3.5	4,500	7.4
(S)8.3W.35.100	Laguna Pueblo	9- 3-41	Trc	65	28	0.02	65	18	47	377	0	13	3.1	0.2	0.8	--	355	236	0	30	1.4	--	-

Location number designates location of sampling station (see well-numbering system, p.7).

(Analyzed by U. S. Geological Survey. Chemical constituents in parts per million)

Location number	Source	Date collected	Amount of flow	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na) (Sodium, Potassium as Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Boron (B)	Dissolved solids	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Noncarbonate	Per cent sodium	Sodium adsorption ratio (SAR)	Specific conductance (micromhos at 25°C)	pH
5.2.16.433	Rio Grande (Belen bridge)	1-14-43	--	--	--	58	12	5.5		153	0	62	11	-	0.6	-	--	194	68	6	0.2	374	-
.16.433	Rio Grande (Belen bridge)	8- 6-43	--	--	--	--	--	---		113	0	94	11	-	-	-	--	--	-	--	-	406	-
6.2.1.140	Tome Drain	4- 9-47	--	--	--	126	22	118		335	0	306	48	-	0.3	-	--	405	130	39	1.8	1150	-
3.144	San Fernandez Drain	9- 7-44	--	--	--	94	14	62		230	0	184	33	-	-	-	--	292	104	32	1.6	790	-
3.243	San Fernandez Lateral	9- 7-44	--	--	--	49	9.2	36		152	0	91	14	-	-	-	--	160	36	33	0.9	457	-
28.324	Peralta Main Canal	6-17-58	--	--	--	--	--	---		116	0	--	14	-	-	0.07	--	--	-	--	-	394	7.8
7.2.25.220	Tome Drain	4- 9-47	--	--	--	118	19	94		323	0	244	41	-	0.7	-	--	372	108	35	2.1	1030	-
7.1W.31.111	Rio Puerco (Rio Puerco)	1-16-56	--	18	0.00	183	89	475	13	251	0	1160	300	1.0	2.5	0.71	2420	822	617	55	7.2	3210	8.0
31.111	Rio Puerco (Rio Puerco)	7-16-57	--	--	--	194	33	140	--	189	0	--	38	-	-	-	1260	620	464	33	2.4	1590	7.3
31.111	Rio Puerco (Rio Puerco)	8-25-57	--	12	--	--	--	226	--	165	0	963	26	-	-	-	--	682	547	42	3.8	1950	7.5
8.3W.2.334	Suwanee Creek	5-16-58	--	22	--	264	105	---		222	0	--	356	-	1.3	-	--	1090	908	--	-	3890	8.1
9.3W.33.321	Rio San Jose	7-26-57	1000+ cfs	--	--	33	8.1	80	--	109	0	--	17	-	-	-	400	116	26	60	3.2	557	7.8
9.4W.35.443	Rio Colorado	7-16-57	10-15 cfs	--	--	23	3.3	56	--	147	0	--	10	-	-	-	287	71	0	63	2.9	384	7.7
35.443	Rio Colorado	7-26-57	1000+ cfs	--	--	17	8.1	81	--	105	0	--	14	-	-	-	400	76	0	70	4.0	448	7.8

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