



The occurrence of ground water in south-central New Mexico

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THE OCCURRENCE OF GROUND WATER IN SOUTH-CENTRAL NEW MEXICO

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INTRODUCTION

The value of ground water as a natural resource and the need for developing it efficiently and using it wisely, particularly in the arid and semiarid regions of the Southwestern United States, have become more apparent to the general public in recent years. This increasing awareness of the value of ground water is the result partly of personal experiences, partly of the publication of scientific and technical articles, and partly of the publicity given to ground water as a result of litigation and controversial legislation. For many years the U. S. Geological Survey, in cooperation with the New Mexico State Engineer, the New Mexico Bureau of Mines, other State agencies, and various Federal agencies, has been making ground-water studies in New Mexico. The results of many of these studies have been made available to the general public in the form of published or open-file reports, and much additional open-file information is available through State agencies and/or the U. S. Geological Survey in Albuquerque, New Mexico.

In south-central New Mexico detailed studies have been conducted in several small areas, and less detailed studies have been conducted in other areas, but for some areas data relating to the occurrence of ground water are almost completely lacking. The following discussion represents an attempt to consolidate the available data from many sources into a generalized description of the occurrence of ground water in the area indicated on the accompanying map. For more detailed information on the occurrence of ground water in specific parts of this area, the reader is referred to the reports listed at the back of this paper.

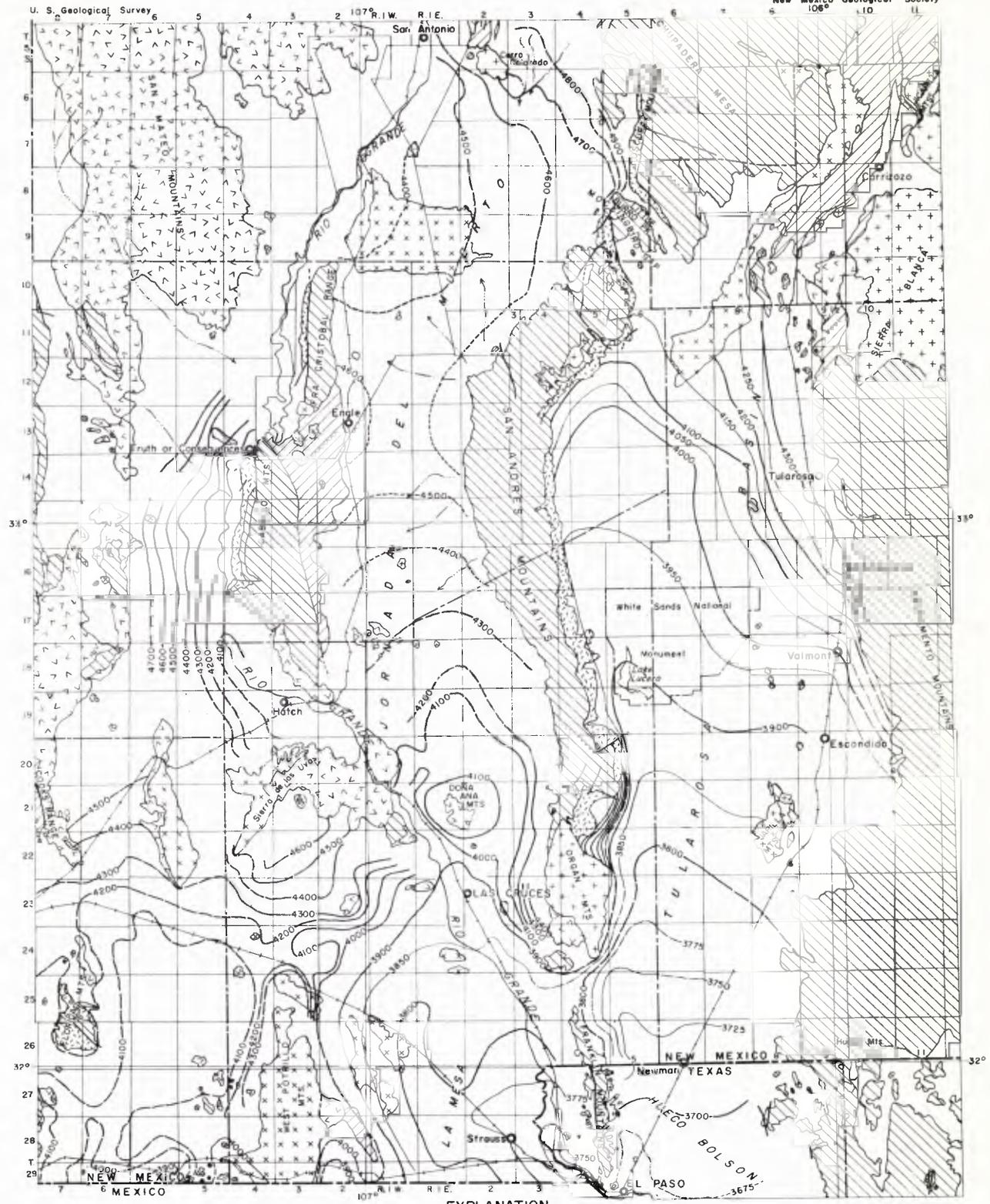
The geology on the accompanying map has been reproduced entirely from the geologic map of New Mexico by Darton (1928). Since the publication of Darton's map, detailed studies in some areas of the State have revealed errors and have resulted in the compilation of much more accurate data than were available to Darton, and a revised map is now being compiled. However, because of the small scale of the accompanying map and because only a short time was

available for the preparation of this discussion, no attempt was made to modify the original map, except to group the rocks as indicated for ease of reproduction and maximum legibility.

The ultimate source of essentially all the ground water in this area is precipitation. The part of the precipitation that reaches the zone of saturation is very small, ranging from perhaps as much as 25 percent where the surface materials are very permeable, as along the margins of the basins, to practically none in the playa areas where the surface is underlain by impermeable clay, silt, and evaporites. Precipitation in the area ranges from less than 7 inches in the Tularosa Basin to more than 25 inches in the higher mountains. Because of the range in climatic conditions in various parts of south-central New Mexico, and because the many kinds of rocks present differ greatly in their capacity to absorb, store, and yield water, the occurrence of ground water varies greatly in different parts of the area.

The water supply of south-central New Mexico is quite diverse. The Rio Grande valley south of Truth or Consequences contains one of the most dependable supplies of water in New Mexico, whereas large areas in the Jornada del Muerto and Tularosa Basin have no usable water supplies.

The intrusive igneous rocks generally are relatively impermeable and, consequently, are poor aquifers and act as barriers to the movement of water, except where they are fractured or weathered. The Precambrian granitic and metamorphic rocks exposed along the west-facing escarpment of the San Andres Mountains, and the Tertiary monzonites of Sierra Blanca and the Organ Mountains do not readily absorb precipitation but are important areas from which water runs off to adjacent areas where it becomes available for ground-water recharge. A few springs occur in those rocks, and the water from those springs generally is not highly mineralized. Most of the fine-grained igneous extrusives are similarly impermeable, but some basalt flows are extremely permeable and represent important recharge areas because precipitation is readily absorbed before



<p>HYDROLOGY</p> <p>4400</p> <p>Contour on water table; long dashes where approximate, short dashes where inferred. Datum is mean sea level.</p>	<p>EXPLANATION</p> <p>SEDIMENTARY ROCKS</p> <p>Quaternary and Tertiary alluvium</p> <p>Mesozoic</p> <p>Paleozoic</p>	<p>GEOLOGY</p> <p>IGNEOUS ROCKS</p> <p>Quaternary and Tertiary basalt</p> <p>Tertiary and Cretaceous extrusives, unclassified</p> <p>Post-Carboniferous intrusives</p> <p>Precambrian, unclassified</p>
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GENERALIZED GEOLOGY AND APPROXIMATE ALTITUDE OF THE WATER TABLE IN SOUTH-CENTRAL NEW MEXICO 1955



Geology after Darton (1928)

much of it evaporates. Also, the more recent basalt flows, such as those in the northern parts of the Tularosa Basin and the Jornada del Muerto, support very little vegetation which might intercept the precipitation before it reaches the water table. Almost all tuffs are impermeable.

The Bliss sandstone and the dense limestones of early Paleozoic age, exposed in the southern part of this area, mainly in the San Andres, Franklin, and Sacramento Mountains, are relatively impermeable and are not important aquifers. Springs issuing from those rocks in the mountains yield only small quantities of water, which generally is hard but potable. The Madera limestone of the Pennsylvanian Magdalena group yields small quantities of water to stock and domestic wells in the vicinity of Organ, along the east slope of the Oscura Mountains, and elsewhere. In some parts of New Mexico the Madera reportedly yields sufficient quantities of water for irrigation, although these occurrences are localized, as in the western part of the Estancia Valley. Ground water occurring in the Madera generally has a high carbonate hardness but is potable, unless it has dissolved other objectionable mineral matter from other rocks before reaching the Madera. The Bursum and Abo formations of Permian age yield relatively small quantities of water to a few stock and domestic wells in the northern part of the Tularosa Basin. A well at Mockingbird Gap, between the Oscura and San Andres Mountains, produces 30 gallons per minute from a fault zone in the Abo formation, but the ground-water storage is limited, and the well is not capable of producing this yield steadily for more than a few months.

The Permian Yeso formation is an aquifer in some areas, but generally the formation contributes calcium sulfate, and other minerals, to the ground water in objectionable quantities. Almost all the water occurring in the Yeso formation on Chupadera Mesa is impotable or nearly so. Much of the high sulfate content of the ground water occurring in the valley fill in the northern parts of the Tularosa Basin and the Jornada del Muerto has been derived from the gypsum and gypsiferous silts of the Yeso formation. The Glorieta sandstone member of the San Andres formation may furnish some water to wells on Chupadera Mesa, but, except where the sandstone is fractured, the member yields relatively small quantities of water.

The limestone member of the San Andres formation yields water to some wells on Chupadera Mesa and is a very important aquifer in the Roswell basin. In the southern part of Chupadera Mesa the limestone member contains a considerable amount of gyp-

sum; consequently, in that area the ground water in the limestone area is potable only locally where it has moved short distances. Gypsum, like limestone, is impermeable but extensive solution channels or fractures may exist. Ground water occurring in gypsum generally contains large quantities of sulfate and is impotable.

Most of the Mesozoic sedimentary rocks present in this area are not good aquifers, although some of the Cretaceous sandstones furnish small quantities of water to wells in the northeastern part of the Tularosa Basin in the vicinity of Carrizozo. Generally, the ground water obtained from these sandstones in this area is of only fair chemical quality or is impotable.

The Tertiary and Quaternary unconsolidated alluvial deposits contain the most important aquifers in south-central New Mexico. For the most part, these deposits are relatively very permeable—particularly the coarse stream-laid flood-plain deposits along the Rio Grande, where many irrigation wells yield more than 1,000 gallons per minute. The alluvial deposits generally contain water of good chemical quality along the margins of the basin, but the ground water becomes increasingly mineralized toward the centers of the basins. In some areas, as in the north-central part of the Tularosa Basin, the ground water even in the marginal deposits is highly mineralized, partly because the deposits have been derived from gypsiferous rocks and partly because the ground water has migrated from rocks containing readily soluble minerals.

As a guide in the classification of waters for various uses, the U. S. Public Health Service (1946) has indicated that, for interstate carriers, drinking water should contain not more than 1,000 ppm and preferably not more than 500 ppm of dissolved solids. Water containing several thousand ppm of dissolved solids, however, is often used for irrigation and for watering stock. Sulfate and chloride are the principal undesirable constituents of ground water in south-central New Mexico. Both, in association with calcium and magnesium, contribute so-called “permanent” hardness which is difficult and costly to remove. According to the standards adopted by the U. S. Public Health Service, water used for domestic purposes should not contain more than 250 ppm of either sulfate or chloride. In large parts of the Jornada del Muerto and Tularosa Basin the ground waters do not meet these standards. Many of the waters derived from the limestones contain bicarbonates of calcium and magnesium, causing the water to have a “temporary” hardness, which generally is inexpensive to remove, if present to an objectionable extent. Some wa-

ters contain less common mineral constituents, such as fluoride and nitrate, in objectionable quantities. These constituents are difficult to remove but, fortunately, are not usually present in large quantities.

In the following discussion, the occurrence of ground water in four principal areas in south-central New Mexico is described. Those areas are the Truth or Consequences area, the Rio Grande Valley south of Truth or Consequences, the Jornada del Muerto, and the Tularosa Basin.

THERMAL WATER IN THE TRUTH OR CONSEQUENCES AREA

The occurrence of ground water in the Truth or Consequences area has been described in some detail in a report by Theis and others (1941), from which the following material has been abstracted.

Thermal water occurs within the town limits of Truth or Consequences. The hot springs were responsible partly for the existence of the town as well as its former name of Hot Springs, and even today the hot water is one of the attractions for health-seekers and tourists. Two well-known springs are State Spring and Government (Geronimo) Spring. Because of a decline in artesian pressure, these springs do not now normally flow, and Government Spring is now equipped with a small pump.

The thermal water, whose temperature ranges from 98 to 114 degrees F., is obtained principally from the Magdalena group, in which it occurs in openings along bedding planes, solution cavities, and fractures near the fault zone between the Magdalena group and the Precambrian granite. Hot water occurs also in the alluvium overlying the limestone. The hot water is confined to a relatively small area south of the ridge of the Magdalena group that extends through the center of the town, and north of the Precambrian granite outcrop that underlies the low terrace south of Truth or Consequences on which the Carrie Tingley Hospital is situated. Water of the highest temperature in the area, 114 degrees F., occurs in a small area near the center of town, about one block south of State Spring which is at the base of the bluff. There apparently is little or no variation in temperature with depth, but outward from this locus temperatures decrease, though not uniformly. The temperature pattern is evidently related to the structure or distribution of the rocks of the Magdalena group in which the hot water is found. The locus of high temperature possibly occurs at the point of convergence or intersection of two or more minor faults which allow rapid circulation of the thermal waters.

The hot water within the town is remarkably uniform in chemical character, whether it comes from

the Magdalena or from the overlying sand and gravel. The sodium and potassium content is about 750 ppm, chloride about 1,270 ppm, calcium about 150 ppm, and magnesium about 195 ppm. There is no areal pattern of variation in the chemical content. The thermal water is entirely different in chemical character from any of the nonthermal waters near Truth or Consequences.

Study of the hydrologic and geologic features of the area indicates that the hot water apparently rises in the fault zone between the developed area and the Precambrian terrace on which the Carrie Tingley Hospital is situated. It apparently migrates up the dip of beds of the Magdalena group, which dip toward the fault at this locality. The overlying alluvium acts as an imperfect confining bed. The hot water escapes by slow upward penetration into the alluvium and by migration up the dip of the Magdalena group to the point where the alluvium pinches out against the hill of limestone of the Magdalena group in the center of town. The State and Government Springs, which are near the contact of alluvium and the Magdalena, represent the overflow from the Magdalena. The thermal water moves laterally through the alluvium to discharge to the Rio Grande. The quantity of water discharging in the area in 1940, largely by natural means, was about 3.5 cubic feet per second or about 2,260,000 gallons a day, and only about 140,000 gallons a day was discharged from artesian wells.

It is of interest to note that the amount of thermal water discharged at Truth or Consequences is about eight times that discharged by Old Faithful at Yellowstone Park, and the amount of heat brought to the surface is about two and one-half times as great.

It appears that the most probable source of the heat of the hot water is hot igneous rock at depth, either acting by conduction of heat through the rock or by yielding steam and hot gases that rise through fractures to mingle with circulating meteoric ground water. It appears that the rate at which heat is furnished to the water and the rate of flow of the water may be considered constant, and that no significant change in the amount or temperature of the hot water is to be expected under present climatic conditions. Excessive withdrawal of the thermal water could reduce the head; however, the amount of water used is only a fraction of the quantity discharging naturally to the Rio Grande.

RIO GRANDE VALLEY SOUTH OF TRUTH OR CONSEQUENCES

For the purposes of this discussion, the Rio

Grande Valley area extends along the Rio Grande from Truth or Consequences to the lower part of the Mesilla Valley north of El Paso and includes the adjoining higher surfaces. Ground-water conditions in this area have been described by Conover (1954), Murray (1949), Slichter (1905), and Lee (1907), from whose reports the following discussion has been taken.

The geology of the area is quite varied, particularly that of the consolidated rocks forming the mountains and underlying the valley-fill deposits. Because of this variability and the fact that significant quantities of ground water of usable quality occur, for the most part, in the valley-fill deposits, the discussion of the occurrence of ground water is confined to those deposits. In particular areas, such as at Truth or Consequences, where there is hot mineral water in the Magdalena group, ground water in consolidated rocks becomes important.

The valley-fill deposits consist essentially of unconsolidated or partly consolidated sediments of Tertiary and younger age which mantle much of the area. The deposits consist of varying proportions of clay, silt, sand, and gravel which partly fill the Rio Grande depression. These deposits can be separated into the older, slightly consolidated sediments that make up the greater part of the fill and the younger, unconsolidated deposits.

The older sediments are generally referred to as the Santa Fe formation. The younger sediments, deposited in the Quaternary period, overlie the older sediments as outwash-fan deposits and as alluvium deposited by the Rio Grande and tributaries in the flood plain during successive periods of scour and fill.

As both the younger and the older alluvial sediments were eroded from the same general rock formations and deposited in the same manner, they, as a consequence, have the same general character, and it is not always possible to differentiate them. Generally, the younger sediments, such as the flood-plain deposits in the valley, are unconsolidated and better sorted than the older sediments, and yield water more readily.

The thickness of the valley-fill deposits is variable, ranging from a feather-edge against the consolidated rock masses to several thousand feet. Valley-fill deposits west of the Rio Grande extend to depths greater than 2,100 feet, as shown by a well drilled to that depth in the Palomas River; about ten miles north of Caballo. A well drilled to 631 feet on the Jornada del Muerto about midway between the San Andres and Dona Ana Mountains encountered predominantly limestones and sandstones below 474

feet. Near the southern part of La Mesa the Southern Pacific Co. well at Strauss, depth 1,330 feet, was entirely in valley-fill deposits. The Lippencott well, in sec. 10, T. 28 S., R. 3 E., encountered limestone at 822 feet. A well drilled by the El Paso Electric Co. in sec. 27, T. 28 S., R. 3 E., about 50 feet above the valley floor, encountered typical valley-fill deposits with about 200 feet of basal conglomerate above black shaly limestone at 1,568 feet. Test drilling in the vicinity of Canutillo for the city of El Paso indicates that the underlying consolidated rock is step faulted downward to the west.

The flood-plain deposits of the Rio Grande in the Mesilla Valley are apparently thinnest at the upper and lower ends of the valley, where the river has eroded through consolidated rocks. At the narrows above El Paso, the depth of fill does not exceed 86 feet. The flood-plain deposits in the central part of the Mesilla Valley appear to range in thickness from 100 to possibly more than 200 feet. In the Rincon Valley, north of the Mesilla Valley and south of Caballo dam, the thickness of the flood-plain deposits appears to be rather uniformly less than 70 feet, somewhat less than in the Mesilla Valley.

The depth of water in the upland areas of Dona Ana County ranges from less than 25 feet to more than 400 feet. Generally the greatest depths to water, more than 300 feet, occur in the relatively thick alluvial deposits between the mountain fronts and the Rio Grande, such as the central part of La Mesa, T. 26 S., R. 1 W., where the depth to water exceeds 400 feet. In a narrow north-south strip in R. 3 E., under the Jornada del Muerto between the Dona Ana and San Andres Mountains, the depth to water also exceeds 400 feet. The depth to water generally decreases toward the east side of the Jornada del Muerto and the west side of La Mesa, where the sediments are relatively thin and the underlying relatively impermeable consolidated rocks hold the water at a relatively high level.

Abnormally high water levels in certain areas represent water perched on clay beds, like that tapped by some wells in tributary stream channels such as at the head of Mud Springs Draw, or are a reflection of bedrock at shallow depth, as in the Gold Dust area east of the Hillsboro Mountains. Water levels in the Gold Dust area are about 200 feet above the regional level.

From Truth or Consequences south about 18 miles to Arrey a number of flowing wells have been obtained in the valley-fill deposits within four miles west of the Rio Grande. The flowing wells are concentrated in three areas—Mud Springs Draw, Animas

Creek, and Percha Creek. Flowing wells are not obtained in the Palomas River and Seco Creek areas, probably because the valley floors are higher than the valley floors of Percha and Animas Creeks—that is, above the piezometric surface. The artesian flows generally are only a few gallons a minute, but some wells have large flows, such as in Mud Springs Draw where the Truth or Consequences city wells flowed about 300 gallons a minute on completion, and in Percha Creek where one well 215 feet deep flowed 125 gpm and yielded 850 gpm to the pump.

The artesian conditions are brought about by clay beds, acting as confining layers, that extend west of the Rio Grande, in some places for a number of miles. The existence of seeps along some bluffs, such as at the highway bend west of Truth or Consequences, testify to the continuity of some clay beds. The strata dip eastward, and the flowing wells result from the gradient of the stream valleys being greater than the piezometric surface. Impounding of water in Caballo Reservoir may have increased the piezometric head by imposing a back pressure on the discharge of the ground water to the Rio Grande.

The direction of movement of the ground water in the Rio Grande Valley area is shown by the contours on the water table on the accompanying map. Generally, the water moves from the higher to the lower elevations along the Rio Grande. The movement of some of the ground water, however, is quite circuitous. Under La Mesa, for instance, the flow is generally eastward from the West Potrillo Mountains to the central part of La Mesa, then southeastward to discharge to the valley east of Strauss. A ground-water divide exists between the Sierra de las Uvas and the West Potrillo Mountains, separating ground water between the Rio Grande and Mimbres drainage basins.

Though the ground water moves from the highland areas to discharge to the Rio Grande, the amount is infinitesimal as compared to the flow of the Rio Grande. On the basis of the water-table gradient of about 55 feet per mile and the transmissibility of the aquifer of 11,000 gpd per foot, based on pumping tests on wells in Mud Springs Draw, the discharge to the Rio Grande in that vicinity is about one cubic foot per second per mile along the river. Measurements in 1936 on the gain in flow of the river from Truth or Consequences to Caballo dam showed essentially a gain of one cubic foot per second per mile. The ground-water flow to the Rio Grande in the vicinity of Strauss has been calculated to be about 800 acre-feet per year, or about 0.13 cubic foot per second per mile along the river. The total ground-water flow to

the Mesilla Valley is apparently less than one cfs per lineal mile, or less than 40,000 acre-feet a year for the 55 miles of valley.

The unit recharge to the ground-water body is small, on the average, as shown by comparing the contributing area to the accretion of ground water to the valley. The surface area contributing to the flow of about 800 acre-feet a year at Strauss is about 600,000 acres, indicating an average recharge of less than 0.02 inch annually. The low rate of recharge is to be expected, as the annual precipitation is less than ten inches and the evaporation is high. It is likely that here, as in many areas in the Southwest, the recharge occurs only after storms of considerable magnitude and that there is no recharge at all in most years.

The flood-plain deposits in the Rincon and Mesilla Valleys are relatively permeable, and irrigation wells capable of yielding 1,000 gpm or more are normally obtained. The older alluvial sediments are not as permeable, and wells normally are of small capacity. Many such small-capacity irrigation wells have been drilled in the tributary valleys, such as those of Tierra Blanca and Percha Creeks, to irrigate lands not furnished surface water.

Pumping of ground water for irrigation in the Rincon and Mesilla Valleys was practiced as early as 1896 because of the variable flow of the Rio Grande. After storage of water began in Elephant Butte Lake in 1915, irrigation wells were not needed. However, deficient flow of the Rio Grande caused by the current drought renewed interest in irrigation wells to supply lands under the Rio Grande project. About 60 privately owned irrigation wells were in existence by the end of 1947, to serve lands normally furnished surface water. Well-drilling activity has continued at such a pace since, that there are now nearly 2,000 irrigation wells below Caballo dam, including the Texas portion of the Rio Grande project. Sufficient wells exist to furnish nearly a full supply of water to the major portion of the irrigated lands. Because of the interrelation of the river and the ground-water body, one of the effects of pumping has been to decrease the surface flow by practically eliminating the flow of the drains and increasing the seepage from the river.

Because of the interrelation between the surface water and the ground water in the Rincon and Mesilla Valleys, pumping of ground water does not represent an additional supply or new source of water to the project, but rather essentially a change in method, time, and place of diversion of supplies already available. Depletion of ground-water storage is, in effect, borrowing upon future surface-water supplies.

JORNADA DEL MUERTO

The Jornada del Muerto, a broad, essentially flat synclinal basin, lies between the Oscura, San Andres, and Organ Mountains on the east and the Rio Grande and the Fra Cristobal and Caballo Mountains on the west. The Jornada ranges from 12 to 30 miles in width and is approximately 120 miles in length from north to south. This semiarid area was very aptly named by early Spanish explorers the Jornada del Muerto. Translated approximately this means "journey of death," a name that undoubtedly fitted this trek perfectly in the times of Coronado. Even today much may be said of the propriety of this designation, as water, the "giver of life," is exceedingly scarce in almost all parts of the 2,500 square-mile area.

The eastern boundary of the Jornada del Muerto is somewhat more distinct than the western boundary because of the continuous positive relief, whereas the western boundary consists of an element of negative relief, the Rio Grande Valley, over about half its length. Very few physiographic highs exist in the Jornada del Muerto to break the monotony of the slightly undulating, flat surface of the basin. The most important of these are in the northern half of the Jornada and are: The Hansonburg Hills along the eastern margin of the basin southwest of Bingham; the Cerro Colorado and surrounding volcanic hills southeast of San Antonio; and the basalt flow or malpais northeast of the Fra Cristobal Range.

Structurally the Jornada del Muerto is apparently a very shallow syncline bounded for the most part by fault-block mountain ranges. The rocks of the Oscura Mountains and Little Burro Peak dip eastward away from the basin, but the rocks of the other boundary ranges dip generally into the basin.

The surface of most of the central Jornada del Muerto is formed by Quaternary alluvium, composed mainly of gypsiferous silt and sand and some quartzose dune sand and many deposits of impure gypsum. Apparently much of the Quaternary alluvium has been deposited by sheet floods which originate in the boundary areas where rocks of Tertiary, Permian, Pennsylvanian, and Precambrian age crop out. Consequently, alternating layers of impure gypsum, sand, and silt occur in the alluvium of the central part of the basin. These sands, silts, and gypsites were derived principally from the Abo, Yeso, and San Andres formations of Permian age. The outcrops of alluvium on the margins of the Jornada del Muerto usually consist of fanglomerate and conglomerate containing materials composed of granite, limestone, sandstone, siltstone, and volcanic debris. The Quaternary alluvium may range up to 400 feet in thickness in some

parts of the Jornada del Muerto.

The Santa Fe formation and the somewhat older Datil formation, both of Tertiary age, crop out in the northwestern part of the Jornada. The Santa Fe formation consists of unconsolidated pinkish sands, silts, and gravels. The Datil formation in this area includes the volcanic rocks and associated conglomerates and agglomerates of Cerro Colorado. The Santa Fe formation is approximately 400 feet thick, and the Datil formation is about 500 feet thick in the Jornada del Muerto.

Reliable subsurface data for this area are meager, but apparently in the northeastern third of the basin the bedrock underlying the fill is Permian, and in the remaining two-thirds of the basin the bedrock is Cretaceous.

Ground water in sufficient quantities for watering stock can be obtained from wells in the Quaternary or Tertiary fill almost everywhere in the Jornada del Muerto. The depth to water in the fill ranges from 30 feet below the land surface in the west-central part of T. 5 S., R. 3 E., and eastern part of T. 5 S., R. 4 E., to about 400 feet below the land surface in the area around the south and west flanks of Cerro Colorado. In addition to the main ground-water body of the basin fill, bodies of shallower, perched water occur in many localities. The perched water zones usually furnish a less dependable supply than the principal ground-water body.

As the normal annual precipitation is about 7 to 9 inches, most of which is undoubtedly transpired or evaporated, the average recharge to the ground-water body from precipitation on the valley floor is small. Any appreciable recharge must occur as a result of freshets from higher lands during storms and infrequent wet periods. Because sediments in the central part of the Jornada are fine grained and contain much clay and silt, recharge water presumably enters the bordering alluvial fans and plains near the mountains. As shown by the water-level contours on the accompanying map, the water of the fill moves generally basinward away from the topographic highs of the area, and toward the Rio Grande, which receives the natural discharge from the fill of the Jornada del Muerto. There is no known natural discharge of ground water within the Jornada.

Two wells are known to furnish sufficient water for irrigation: a well drilled by the Sun Oil Co. as an oil test (SW $\frac{1}{4}$ sec. 25, T. 10 S., R. 1 W.) on the Diamond A Ranch about 20 miles north of Engle, and a well at the old JAC Ranch (NE $\frac{1}{4}$ sec. 3, T. 10 S., R. 2 E.), now in the northern part of the White Sands Proving Grounds. The Sun Oil Co.'s test yields water

from a depth of about 1,318 to 1,347 feet in the San Andres formation, and will flow about 800 to 1,000 gallons a minute. Water was reported also in the Dakota sandstone in this well. Water from the Dakota reportedly flowed at 200 gallons a minute. The well on the White Sands Proving Ground reservation, probably bottomed in the Dakota, reportedly encountered water at about 400 feet below the land surface, with sufficient hydraulic head to bring the level of water to within 35 feet of the surface. During a pumping test, the well reportedly yielded 300 gallons a minute with 180 feet of drawdown.

The water of the basin fill in the Jornada del Muerto is generally of poor chemical quality. Only a few wells in the area derive potable water from the fill, and some wells producing from the fill in an area northwest and south of the basalt flow northeast of the Fra Cristobal Range reportedly yield water that is unfit even for stock. Most water for drinking in the Jornada del Muerto is collected from rainfall in cisterns or is hauled from distant sources, usually outside the basin. Water of sufficiently good quality for watering stock may be obtained in most of the basin from relatively shallow wells that derive water from the fill. The main chemical constituent in the waters of the Jornada del Muerto is calcium sulfate, dissolved from the fill, San Andres formation, and other rocks.

The few known sources of potable water in the Jornada del Muerto are in the peripheral areas where wells derive water from alluvial-fan deposits. Potable water is known to occur in the northwestern part of the basin, in a well at the Fite Ranch Headquarters, seven miles east-southeast of San Antonio, which derives water from the Mesaverde formation of Cretaceous age; and a well four and one-half miles south of the Fite Ranch Headquarters, which derives water from the Santa Fe formation. These waters are potable, apparently because recharge is mainly by runoff from the volcanic hills of the Cerro Colorado. One other source of reportedly potable water occurs at the Aleman Ranch on the Santa Fe Railroad about 14 miles south of Engle. This water is from a well reported to be the oldest existing in the Jornada and the only source of water in the Jornada del Muerto in early days.

Artesian water from the San Andres formation, as shown by the Sun Oil test, is of such poor chemical quality that cattle reportedly will not drink it. Water from the Dakota sandstone, as demonstrated by the JAC Ranch irrigation well, is of sufficiently good chemical quality to be used for irrigation but apparently is not potable.

Relatively large supplies of water might be developed from deeper wells drilled to the Dakota sandstone or San Andres formation where these formations occur in the subsurface. However, it is believed that most of the water in the San Andres formation, and possibly the water in the Dakota, is of very poor chemical quality. The poor chemical quality of the water from the deeper sources in the area is probably due to the mineral character of the rocks and the lack of circulation.

Wells yielding water unfit for stock have been reported in the areas both north and south of the basalt flow northeast of the Fra Cristobal Range. Ranchers have built runoff-collection tanks in many areas within the basin in order to provide water for livestock.

Because of the scarcity of appreciable quantities of potable water, the Jornada del Muerto has been mainly a cattle- and sheep-ranching area for more than half a century. Since the early 1940's, the U. S. Government has used parts of this area for testing weapons. The first atomic bomb was detonated on the eastern side of this basin in an area known to the world as Trinity Site. The U. S. Army now uses a large area in the east-central part of the Jornada del Muerto for its guided-missile program.

TULAROSA BASIN

The Tularosa Basin was first explored by the Spanish, who shunned it because of its dry and forbidding appearance, long after the Rio Grande valley had been established as a route of travel. The basin was visited principally by parties seeking salt, until the 1840's, when United States military parties came into the area. About seven years after Fort Stanton was established in 1855, a group from the El Paso Valley established the present village of Tularosa, a few years later the present village of La Luz. Alamogordo, Carrizozo, and other smaller communities were established after the railroad was laid from El Paso through the basin in 1898. Farming developed around Tularosa, La Luz, and Alamogordo. The development of the basin is today essentially what it was at the turn of the century, the greatest development being along the eastern edge and in the adjacent mountains, with little or no development or population in the central and western parts of the basin. One real difference exists today. Owing to the isolated and unproductive nature of the central and western parts of the basin, a large area there is now used by the Armed Forces for testing guided missiles and similar war material.

Although numerous investigators have visited the basin, few investigated ground water. The prin-

cial source of ground-water information for the Tularosa Basin is a report by Meinzer and Hare (1915). Their coverage of the basin was relatively complete, and, other than detailed revision of geology and local ground-water conditions, their appraisal of ground water in the Tularosa Basin is essentially correct. Sayre and Livingston (1945), working in the Hueco bolson, provided information concerning the southern edge of the Tularosa Basin. More recently, unpublished work by the Geological Survey, done principally for military purposes, has provided rather complete information concerning ground-water supplies in small parts of the basin.

The Tularosa Basin is a long, narrow intermontane basin, and is part of a structural depression more than 200 miles long and from 24 to 60 miles wide. This larger depression extends from western Lincoln County southward through the eastern edges of Socorro and Dona Ana Counties and western Otero County, New Mexico, through parts of El Paso and Hudspeth Counties, Texas, and south of the Rio Grande into Chihuahua, Mexico. The larger depression was first called the Hueco bolson by Hill (1900) and was subsequently divided on the basis of topography by Richardson (1909) into the Tularosa Basin, or Tularosa Desert, on the north and the Hueco bolson on the south.

The Tularosa Basin is bounded on the south by a low topographic divide near the State line; on the west by the Organ, San Andres, and Oscura Mountains and Chupadera Mesa; on the north by the Mesa Jumanes; and on the east by the Jicarilla, Sierra Blanca, and Sacramento Mountains. The interior plain has low relief, with altitudes ranging from about 4,000 feet on the south and west sides to about 4,400 feet on the north and east sides. The surrounding mountains rise abruptly to altitudes of 7,000 to 12,000 feet.

Climatically, the Tularosa Basin has wide extremes. Precipitation in the interior basin is less than 10 inches per year; at the edges of the plain and in the foothills it is about 12 inches. In the higher mountains the annual precipitation may amount to more than 25 inches.

The role of consolidated rocks in supplying ground water in the Tularosa Basin is as varied as the geology of the mountains. The igneous rocks of the Organ Mountains, along the base of the San Andres Mountains, and in the Sierra Blanca-Jicarilla Mountains area yield little or no ground water. Where small supplies are developed locally in weathered zones, the quality of the ground water is excellent. The entire lower Paleozoic section up to and includ-

ing the Pennsylvanian in most areas yields ground water in very limited quantities locally. The dense limestones, shales, and well-cemented sandstones are impervious for the most part and yield water only where faulting or folding has provided permeability. Exposures of rock older than Pennsylvanian are generally limited to the steep sides of the cuestas in the San Andres and Sacramento Mountains, thereby limiting their intake areas to the floors of canyons dissecting the mountain fronts. In the San Andres and Sacramento Mountains a few small springs, mostly seeps, issue from rocks ranging in age from Ordovician to Pennsylvanian. The quality of water from these springs in the west side of the Sacramento Mountains is fair to poor. The principal chemical factors governing potability are hardness derived from the limestones, and sulfate probably originating in the overlying Permian rocks. In the Oscura Mountains, recent ground-water investigations indicate the Pennsylvanian limestones in that area may be important aquifers. However, where potable ground water is found in the Pennsylvanian in the Oscuras, the water is extremely hard.

Of all the consolidated rocks exposed in the Tularosa Basin, the Permian is by far the most important from the standpoint of quantity of ground water. This importance is due both to the extensive exposure of the Permian and to the large amounts of soluble minerals present, principally in the Yeso formation. The Yeso and the sandy parts of the Abo are the principal sources of nearly all the large springs in the Sacramento-Sierra Blanca portion of the Tularosa Basin. Cavernous zones in the San Andres limestone transmit appreciable quantities of water; however, the San Andres is more important as an aquifer in the Roswell basin, east of the Tularosa Basin. In the Chupadera Mesa area, the Yeso is the principal Permian aquifer.

With regard to quality, ground water in the Permian rocks generally ranges from fair to very poor but locally is good. The degree of mineralization of water obtained from the Yeso is more or less a function of the distance from the intake area. In the Chupadera Mesa area, nearly all water in the Yeso is highly mineralized. However, along the western face of the Sacramento Mountains, a number of springs, such as Alamo Springs, discharge water suitable for domestic consumption. Alamo Springs have long been a source of public supply for the town of Alamogordo, and produce from 1 to 2 million gallons per day, depending on the annual rainfall.

On the west and northwest sides of the Sierra Blanca are rocks assigned to the Triassic and Upper