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F. D. Trauger
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GROUND WATER IN EAST-CENTRAL NEW MEXICO*

by

F. D. TRAUGER

INTRODUCTION

Water resources in east-central New Mexico are limited as to quality and quantity. It is the principal purpose of this paper to summarize available data and knowledge concerning the occurrence of potable ground water in the region, its general relation to surface water, and to provide selected references for those wishing more detail. For a discussion of the occurrence of saline ground water in New Mexico, the reader is referred to J. L. Kunkler, this Guidebook.

The area discussed in this paper includes most of Curry, Guadalupe, and Quay Counties, and much of De Baca, Harding, Roosevelt, San Miguel, and Torrance Counties. This large area, about 13,000 square miles, includes many geologic formations of great lithologic variety. None of the formations has exactly the same water-bearing characteristics, and the water-bearing characteristics of some formations, as for example, the Exeter Sandstone (Entrada Sandstone of U.S. Geological Survey usage) differs greatly from area to area.

Detailed lithologic descriptions and the stratigraphic relations of geologic formations found in outcrops, or occurring in the subsurface of the area, are abundant in the literature. Most are also described in considerable detail in one or more papers in this guidebook. This paper will be concerned mainly with the physical properties of the rocks as they relate to the occurrence of ground water and incidentally with problems of stratigraphy and lithology.

Ground-water reports for De Baca, Quay, San Miguel, Torrance, and Union Counties have been published by the New Mexico Bureau of Mines and Mineral Resources, and a U.S. Geological Survey open-file report for Guadalupe County is in press. The State Engineer has published a technical report on ground water near Tucumcari and numerous other technical reports touching on one or more aspects of ground water in the region. These and other reports, some open-file, are listed in the selected references and are the principal sources of the information given in this summary.

ROCK FORMATIONS AND THEIR WATER-BEARING CHARACTERISTICS

Precambrian rocks.—Igneous and metamorphic rocks of Precambrian age crop out in the Pedernal Hills in central Torrance County. The igneous rocks are mostly granitic and the metamorphic rocks are mostly gneiss; quartzite and schist occur locally (see Gonzales and Woodward, this guidebook). The Precambrian rocks are found at relatively shallow depth beneath younger rocks immediately adjacent to the Pedernal Hills, but at increasingly greater depth away from the hills. The relation is one of off-lapping sediments on a sloping crystalline basement complex.

The Precambrian crystalline rocks are almost everywhere poor aquifers. They locally yield small amounts—1 to 3 gpm (gallons per minute)—of water of fairly good quality to domestic and stock wells. Not all wells drilled into these rocks are successful in developing usable supplies of water, but in some places deeply weathered granitic rock or highly jointed and fractured rocks may yield as much as 100 gpm (Smith, 1957, p. 24), as near Negra in Torrance County, where wells owned by the A.T. & S.F. Railway Co. supply water for the towns of Encino and Vaughn.

Magadelena Group (Permian and Pennsylvanian).—Units of the Magdalena Group—the Sandia Formation, Madera Limestone, and Bursum Formation—do not crop out in the area. They may occur in the deep subsurface but nowhere in the area visited by the conference are they known to provide potable water to wells. To the west of the Pedernal Hills, in Estancia Valley, the Madera Limestone occurs beneath the Tertiary and Quaternary valley fill and furnishes water to some domestic and stock wells, and recharge to the overlying valley fill (Smith, 1957, p. 27).

Abo Formation (Permian).—Red shaly and sandstone of the Abo immediately underlies the valley fill in parts of Estancia Valley, and in the vicinity of Estancia, and near Punta de Agua. It may supply a small amount of water to a few domestic wells (Smith, 1957, p. 28). Elsewhere in the region to the east it lies far below land surface and is not a source of potable water.

Yeso Formation (Permian).—The predominantly orange to orange-red silty sandstone and shale beds of the Yeso are exposed on the north, east, and southern flanks of the Pedernal Hills, and to the south in the broad, shallow Pinos Wells basin (Smith, 1957, pl. 1). It also directly underlies the alluvial fill in parts of Estancia Valley. To the east, the Yeso, like the Abo, lies far beneath the surface and has not been used as a source of water for wells.

The Yeso generally will furnish adequate amounts of water to stock and domestic wells where it lies within practical drilling depths. However, the quality of the water is mostly poor to bad due to large concentrations of sulfate ion derived from gypsum beds in the formation. Locally, as at Mountainair, limestone beds in the Yeso furnish large quantities of water (as much as 500 gpm) of good quality.

Glorieta Sandstone (Permian).—The distinctive massive to bedded, white to light buff medium-grained Glorieta Sandstone crops out across the conference area in a south-southeast trending band, 2 to 10 miles wide, from just east of Clines Corners to just southwest of Vaughn. Because of the regional easterly dip, the Glorieta is located deeper and under successively younger formations to the east. It occurs at depths generally between 1,000 and 2,500 feet under most of De Baca and Guadalupe Counties. It thins to the east, and was questionably identified by drillers at a depth of 3,400 feet (Bates, in Dobrovolny, Summerson, and Bates, 1946, sheet 2) in only one oil-test well, near Ragland, about 25 miles south of Tucumcari, Quay County. A lithologic log of a CO_2 gas well in the Bueyeros gas field, Harding County, indicates the Glorieta in that area is about 100 feet thick and occurs at a depth of about 1,400 feet.

The Glorieta Sandstone is a principal aquifer only where it occurs underlying the surface of low ground. Where it caps the

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mesas or occurs in a sequence as part of high ground, it generally is drained. Where it is saturated in Torrance County, water yields to wells commonly are moderate and the quality of the water is poor to fair. Northeast of Moriarty the Glorieta furnishes irrigation water to a few wells (Smith, 1957, p. 34).

San Andres Limestone (Permian).—The San Andres Limestone in Torrance and De Baca Counties consists generally of an upper sequence of alternating thin beds of light gray dolomite and gypsum, and a lower sequence of alternating beds of anhydrite, limestone, and dolomite. In the western part of De Baca County the upper sequence contains appreciable amounts of red shale and red sandstone (Mourant and Shomaker, 1970, p. 14). According to Dinwiddie (1967, p. 26) the formation grades from primarily a limestone facies in the outcrop areas of western Guadalupe County to an anhydrite-gypsum-salt facies eastward into the Tucumcari structural basin.

Both the chiefly limestone facies of the formation and the overlying chiefly clastic facies are everywhere above the water table in Torrance County (Smith, 1957, p. 35-36); hence, neither is an aquifer. In most of De Baca County the formation lies deeply below the surface and is not tapped by wells. Where it is close enough to have been reached by wells the quality of water in the formation generally is poor and used only for stock. In Guadalupe County water in the San Andres ranges from fresh to moderately saline, and the best quality water comes from the predominantly limestone facies in areas of outcrop (Dinwiddie, 1967, p. 26).

The San Andres in western Guadalupe County furnishes as much as 2,500 gpm to irrigation wells, and flow from springs range from 10 to 3,000 gpm (Dinwiddie, 1967, p. 27).

Bernal Formation of Artesia Group (Permian).—Dinwiddie (1967, p. 28) considered the Bernal in Guadalupe County the lateral equivalent of beds of the Artesia Group, and Mourant and Shomaker (1970, p. 15) referred to equivalent beds in De Baca County as the Artesia Formation. Regardless of the nomenclature used, we are considering here all the beds of Permian age above the San Andres Limestone. In Guadalupe County they range from 50 to 250 feet thick and in De Baca County they are as much as 935 feet thick. They are widely exposed west of the Pecos River in the conference area; in the region east of the river they lie far below the surface and are not generally reached by domestic or stock wells.

The Bernal Formation and/or Artesia Group consist largely of alternating beds of salmon to orange-red to gray shale, siltstone, sandstone, gray limestone, dolomite, salt, and gypsum. In general the sequence thickens from west to east.

A characteristic of the Artesia beds that aids in their recognition is the occurrence of "Pecos Valley diamonds," commonly double-terminated quartz crystals that, according to Mourant and Shomaker (1970, p. 15) "are found nearly *everywhere* that the Artesia crops out."

The Artesia beds generally are poor aquifers. However, they underlie the surface of a large area and consequently furnish the only water available at reasonable depths to many domestic and stock wells. Yields to wells commonly are small—from ½ to 5 gpm—and the quality of the water generally is poor. Potable water is found only n those places where sandstone beds occur below the water table and are not overlain by beds of gypsum, anhydrite, or salt.

Santa Rosa Sandstone of Dockum Group (Triassic).—The Santa Rosa Sandstone crops out locally in northeastern Torrance County, broadly in Guadalupe County and adjacent parts of San Miguel County, only in the valleys of Yeso and Salado Creeks in De Baca County, and questionably in Quay County. The relation of the Santa Rosa to the overlying Chinle Formation in Quay County is not clear at this time.

The Santa Rosa is primarily a sequence of sandstone beds, silty to fairly clean, fine-grained to coarse, massive to cross-bedded, gray, locally conglomeratic, and thin to thick beds of red shale, silty shale, and siltstone. Beds of carbonaceous shale containing fossil plant imprints are locally common (See S. R. Ash, this guidebook). All the beds are more or less discontinuous and commonly thin and thicken over short distances so that few beds can be traced with certainty for more than a few miles. The formation ranges in thickness from about 110 feet to about 400 feet, depending on where the contact with the overlying Chinle Formation is picked. Griggs and Hendrickson (1951, p. 26) noted the similarity between the Santa Rosa and the Chinle and the problem of distinguishing between them.

No type locality was originally designated for the Santa Rosa; probably no section can be said to be truly typical. V. C. Kelley (1972, p. 21) has designated a type locality but it is safe to assume it will be found to be "typical" of the Santa Rosa only in that immediate area.

The Santa Rosa generally does not yield much water to wells—commonly less than 10 gpm, and less than 1/8 gpm locally—in central and western Guadalupe County (Dinwiddie, 1967, p. 30). Mourant and Shomaker (1970, p. 16) report yields of as much as 1,000 gpm between Truchas Creek and Arroyo de Anil in De Baca County. Griggs and Hendrickson (1951, p. 46) report the Santa Rosa is an important aquifer for stock and domestic wells in much of San Miguel County. If sandstone beds near Logan, Quay County, are Santa Rosa, then the formation in that area furnishes water to domestic and stock wells, and probably some water to irrigation wells.

The quality of water from the Santa Rosa varies from good to poor (slightly saline), depending on whether it comes mostly from sandstone beds in or near the outcrop areas recharged by precipitation, or from deeper lying beds of shale and sandstone. The water commonly contains large concentrations of sulfate ion, and, locally, objectionable amounts of fluoride.

Chinle Formation of Dockum Group (Triassic).—The Chinle underlies the surface of most of Guadalupe County east of the Pecos River and of much of Quay County. In large areas of Quay County where it is not exposed, it lies near the surface, veneered by sand and gravel of Tertiary and Quaternary age. It is exposed also over broad areas in the valley of Ute Creek in Harding County, and in eastern De Baca County, particularly in the valley of the Pecos River. To the southeast, in Curry and northern Roosevelt Counties, it lies near the surface, being generally covered only by the Ogallala Formation, dune sands, and pediment gravel.

The Chinle is lithologically much like the Santa Rosa and the two formations are properly included in the Dockum Group, a name that should be used more extensively. The Chinle consists of three relatively well defined members, each highly variable within itself. The lower and upper units consist of sequences of red shale beds and lensing beds of red siltstone and gray sandstone; the shale and siltstone predominate. Griggs and Hendrickson (1951, p. 48) noted that the middle member was "a sandstone which is identical in lithology with the Santa Rosa Sandstone." They noted thicknesses of 200 to 350 feet for the lower shale member, 45 to 165 for the

sandstone member, and 350 feet for the upper shale. To the east, in Quay County, the Chinle attains thicknesses of about 1,000 feet in the general area of the Tucumcari structural basin. The formation continues to be divisible into three members as recognized to the west. However, the middle sandstone member tends to split into lensing beds of varying thickness separated by beds of red shale and silty shale and siltstone. It is doubtful if any particular sandstone in the middle member is continuous across the region between Tucumcari and Santa Rosa. Northeast of Tucumcari one thick bed, well exposed near Logan, appears to develop strongly and to extend east into Texas.

The Chinle is an important aquifer in all the areas in which it crops out, or where it underlies thin deposits of Tertiary-Quaternary age, because in most places it can be depended upon to yield small quantities of water of fair to poor quality from the numerous though discontinuous beds of sandstone. Where wells are started near the top of either the upper or the lower shale unit it may be necessary to drill 300 to 400 feet to get even 1 to 2 gpm. A few wells fail to find useable amounts of water even at these depths. The middle sandstone member generally yields more water of better quality than either of the shale members. Water from wells completed in the lower shale and middle sandstone members tends to be of better quality than that in the upper shale member. The quality of water in the Chinle in Quay, Harding, Curry, and Roosevelt Counties generally is better than in the areas in the counties to the west.

Redonda Formation (Triassic).—The Redonda Formation has been formally recognized only in Quay and San Miguel Counties, but certainly is present also in Harding County. The Redonda as originally described is "—25 to 425 feet of variegated and red shale, purplish-red or gray, argillaceous limestone, and red or buff sandstone and siltstone" (Dobrovolny and Summerson *in* Dobrovolny, Summerson, and Bates 1956, sheet 2). Many subsequent workers, unfamiliar with the type section, have failed to include the variegated beds and limestones in the Redonda, and have, instead improperly considered them part of the underlying Chinle. Admittedly, they appear to be more closely related to the Chinle beds than to the overlying orange-red siltstones and sandstones.

The Redonda Formation is not known to yield water to any wells in the region. The beds commonly are above the regional water table, and where they are below it, they generally are too dense to transmit water. They serve instead to perch water locally in overlying formations.

Entrada Sandstone and Bell Ranch Formation (Jurassic).—The Entrada Sandstone (Exeter Sandstone) is well exposed in central and western Quay County, along the Canadian escarpment in Harding County, and over limited areas of northeast Guadalupe and southeast San Miguel Counties. It wedges out to the south and is missing from the section under the Llano Estacado. In all other parts of the conference area it has been removed by the extensive late Tertiary and Quaternary erosion cycle.

The Entrada in most of the conference area is of remarkably uniform lithology. It consists of a lower and upper sequence of sandstone beds that attains a maximum known thickness of about 228 feet in the vicinity of Metropolitan Park, west of Tucumcari. The lower sequence is comprised largely of weakly cemented beds of white to buff, massive to crossbedded, very fine to fine quartz sandstone. The grains for the most part are rounded to subround, and many appear frosted as the result of wind action. However, C. V. Mankin (this Guidebook) suggests the "frosting" may be due to silica overgrowth.

The lower sandstone sequence ranges from a few tens of feet thick in some areas to as much as 140 feet in the exposure in the north face of Tucumcari Mountain. A particularly persistent massive to thin-bedded fine sandstone, about 40 feet thick, near the top of the sequence, can be recognized throughout the region.

The upper part of the Entrada Sandstone is characterized by a sequence of relatively thin alternating beds of fine to very fine grained buff sandstone and clayey to silty fine sandstone. This sequence was named the Bell Ranch Formation by Griggs and Read (1959, p. 2006). It is about 35 feet thick in Tucumcari Mountain where it is considered to be the sequence of beds occurring above the 40-foot thick sandstone. It is about 50 feet thick in a well in Metropolitan Park. The unit is especially well exposed in cliffs seen on David Hill, mile 84 of the first-day road log. There the unit represents clearly a gradational transition from the sandstones of the Entrada into the predominantly shale beds of the Morrison, leading to some question as to the validity of, or the need for, the Bell Ranch Formation designation of Griggs and Read.

The Entrada is an important aquifer in Quay County and is the principal water-bearing formation west and southwest of Tucumcari, and in the area east and southeast of Bueyeros, Harding County. Where it occurs beneath the high mesas, it has been largely drained. In all areas where it is an aquifer, the quality of the water obtained is good. Yields to wells tapping the Entrada range from about 5 to as much as 260 gpm depending on the saturated thickness penetrated and the capacity of the pump.

Morrison Formation (Jurassic).—The Morrison crops out in virtually the same areas as the Entrada in the conference area. In this region it consists of three distinct members—a lower sequence of variegated shales and red mudstone as much as 80 feet thick (locally absent); a middle sequence of light-green to gray soft shale, soft silty and shaly sandstone, variegated shale and mudstone, and interbedded thin hard gray sandstone, locally as much as 250 feet thick; and an upper sequence of interbedded sandy shale and massive to crossbedded, light-gray to yellow-buff and orange-mottled hard, fine-textured to very coarse conglomeratic sandstone as much as 100 feet thick (locally absent). In the region south of Mosquero, and east and north of Conchas Dam, a soft white sandstone occurs in the upper sandstone member that can be confused with overlying beds of Cretaceous age.

About 300 feet of Morrison beds were penetrated in a well in Tucumcari's Metropolitan Park well field, and an estimated 50 feet of the upper sandstone member, exposed in surrounding cliffs, had been removed by erosion. Locally the upper sandstone member and much of the middle shale member is absent beneath overlying Lower Cretaceous formations. In southeastern Quay County all three members are present but the total thickness of the section is probably less than 80 feet.

The Morrison Formation is not a good aquifer anywhere in the conference area because of the general low permeability of both the shale and sandstone beds, and partly because the formation generally lies above the regional water table. The lower variegated beds locally confine water in the underlying Entrada Sandstone.

It is reported by E. G. Lappala (oral communi. 1972) that the upper sandstone of the Morrison in southwestern Union

County may be the source of part of the water pumped from some irrigation wells.

Tucumcari Shale (Cretaceous).—The Tucumcari Shale primarily is a fine to very fine-grained shaly sandstone and siltstone that crops out mainly in Quay County and southeastern San Miguel County. It may be present in southwestern Harding County, but if so, it is thin, discontinuous, and not easily recognized. The shale generally forms a narrow grayish-yellow band on the hillsides at or near the base of the overlying cliff-forming Mesa Rica Sandstone. Slump from the Mesa Rica commonly conceals the unit. It is best observed in road cuts, especially west of Tucumcari, and in a few places, as at the Kilgore Ranch, sec. 9, T. 10 N., R. 29 E., where erosion has largely stripped the Mesa Rica and left the Tucumcari Shale exposed in low knolls on which rest residual blocks of Mesa Rica.

The Tucumcari Shale carries a fossil assemblage characterized by locally abundant shells of Exogyra and Gryphea (oysters). Fossils generally are more common in the upper than in the lower part of the sequence (See Brand and Mattox, and R. K. Deford, this guidebook).

The formation lies above the water table nearly everywhere in the region and is not known to yield water to any wells.

Mesa Rica Sandstone (Cretaceous).—The Mesa Rica Sandstone was correlated with the Dakota by Darton (1928a, p. 40), then referred to as a member of the Purgatoire Formation by Dobrovolney and Summerson (*in* Dobrovolny, Summerson, and Bates, 1946), and elevated to formational rank by Griggs and Read (1959, p. 2007). Dane and Bachman (1965) included it again with the Dakota on their revision of the State geologic map. It crops out widely in Quay, Harding, and San Miguel Counties where it forms most of the prominent rimrock of the Canadian escarpment. It is missing under the Llano Estacado south and southeast of Tucumcari, having been removed by post-depositional, pre-Ogallala erosion.

The Mesa Rica is primarily a sequence of massive to crossbedded, well-cemented sandstone beds 10 to 60 feet thick, having an aggregate thickness of as much as 140 feet. It is commonly white to brownish buff, grayish-yellow, or mottled orange, and medium to coarse grained. A quartz-pebble conglomerate occurs locally at the base. A distinctive white, soft, clean, quartz sandstone forms a prominent marker bed at the base of the unit over much of the area north of the Canadian River, and to a lesser extent in the immediate vicinity of Tucumcari.

The basal white sandstone may be the equivalent of Cragin's (1889, p. 65) Cheyenne Sandstone (Lower Cretaceous, Comanchean). The massive to crossbedded buff upper sandstone beds were found to overlie it unconformably at numerous places, and a pebble conglomerate commonly occurs at the base of the overlying beds.

The Mesa Rica Sandstone is not an important aquifer in Quay County because it is generally above the regional water table. Some perched water may occur in the sandstone on Mesa Rica and Luciana Mesa. To the northwest, under the Las Vegas Plateau in San Miguel County, the Mesa Rica Sandstone (and including possible Dakota Sandstone beds) is the best source of ground water for domestic and stock supplies. The old railroad well at Campana reportedly would yield 66 gpm from the lower part of the formation, presumably from the clean white sandstone.

Pajarito Shale (Cretaceous).—The Pajarito Shale is found only in northwestern Quay and southeastern San Miguel Counties where it overlies the Mesa Rica Sandstone on Mesa Rica, Liberty Mesa, and adjacent outliers, and in a narrow band of outcrop along the downthrown side of the Bonita Fault in southeastern Quay County. The Pajarito is mostly a sequence of soft brown shaly siltstone and fine sandstone beds and gray shale that contains *Ostrea quadriplicata* Shumard. The basal unit of the sequence locally consists of a coarse, sandy, quartzose conglomerate. The whole unit may be as much as 100 feet thick in sec. 22, T. 11 N., R. 29 E., on Liberty Mesa, west of Tucumcari.

The Pajarito Shale is not known to be an aquifer at any place.

Purgatoire Formation (Cretaceous).—Abandonment of the name "Purgatoire Formation" in the Tucumcari-Sabinoso area was recommended by Griggs and Read (1959, p. 2007) and the recommendation was subsequently adopted by the U.S. Geological Survey. This causes problems of reference. The Mesa Rica Sandstone, formerly a member of the Purgatoire, is traceable in outcrops northward into Union County where the Purgatoire still is recognized as a proper formational name.

Dakota Sandstone (Cretaceous).—The existence of the Dakota Sandstone in the conference area is questionable and subject to debate. It is considered present in Union County by Cooper and Davis (1967, p. 7) on the basis of mapping by Baldwin and Muehlberger (1959). Griggs and Hendrickson (1957, p. 29) indicate it probably is present in northern San Miguel County but point out the cap rock of Mesa Rica is "undoubtedly" Purgatoire. In Harding County, in exposures in the Canadian River Canyon where State Highway 120 crosses, and in the vicinity of Mosquero, there is evident to the observer an obvious delineation between two massive sandstones comprising the cap rock. One distinction is color, but more significantly, there appears to be some truncation of beds at the top of the lower, lighter colored unit; locally a pebble conglomerate can be found at the base of the upper sequence. This obvious division of the cap rock becomes indistinct and is largely lost southward from Mosquero. It is suggested that the upper sandstone unit represents the Dakota Sandstone in this region, and that it thins rapidly southward of a northeast-trending line drawn through Mosquero and is not present, except possibly as scattered remnants, south of Campana.

The Dakota in central Harding County is a buff to yellow-orange, massive to bedded, medium to coarse grained, shaly to relatively clean, firmly to well endurated sandstone. It commonly furnishes ½ to 5 gpm of good quality water to domestic and stock wells, but may yield no water to wells near the edge of the Canadian escarpment.

Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation, of Colorado Group (Upper Cretaceous).—The Graneros Shale and Greenhorn Limestone are exposed in limited outcrops on the downthrown side of the Bonita fault, southeastern Quay County, and is extensively exposed in northwestern Harding County and in the vicinity of Las Vegas, Watrous, and Wagon Mound. Small outcrops of dark-gray shale found locally overlying Dakota-like sandstones in the vicinity of Mosquero may be remnants of the Graneros Shale. Collectively, units of the Colorado Group are a poor aquifer. A few stock and domestic wells obtain from ¼ to 1 gpm of water from silty beds in the shales, but the water generally is of poor quality.

Ogallala Formation (Tertiary).—The Ogallala underlies the

surface of northeastern Quay County and southeastern Union County and all of the Llano Estacado, which is to say, nearly all of Curry County and the adjacent parts of southern Quay and northwestern Roosevelt Counties. Outliers of the Ogallala cap Mesa Rica, Luciana Mesa, and Liberty Mesa west of Tucumcari, and the isolated High Plains surface of western Harding County. Some thick deposits of caliche and gravel that underlie broad surfaces in Guadalupe and De Baca Counties resemble closely the Ogallala but they are younger deposits. Much, if not most, of the material was derived from the Ogallala, and some may be remnants of the Ogallala, but they have not been positively identified as such.

The Ogallala is a sequence of poorly sorted to well sorted sand and gravel generally more or less cemented with calcium carbonate. The carbonate development generally increases greatly upward in the formation and commonly forms a thick capping of caliche that may be as much as 100 feet thick. The formation as a whole ranges from a feather edge, as near Roy and Mosquero, to as much as 260 feet in southeastern Quay County. It thickens to the east, and reportedly may be as much as 600 or more in Palmer County, Texas, east of Curry County.

The Ogallala is the principal aquifer of the High Plains, and in most places in New Mexico it will supply adequate water for stock and domestic wells. It furnishes water to irrigation wells near House in southern Quay County, the Clovis-Portales region of Curry County, and the northeast part of Quay County and southeastern Union County.

Quaternary sedimentary deposits.—Much of the surface of east-central New Mexico is underlain by alluvium, wind-blown sand, and pediment, terrace, and lake deposits. They are irregularly distributed throughout the area of the conference and they vary greatly in character, but if a single character is common to all, it is that they are unconsolidated or nearly so. They range in thickness from a few feet on pediment slopes to as much as 600 feet in collapse structures at Tucumcari. Lithologically they range from clay to coarse conglomerate.

In general the Quaternary deposits are thin and occur above the regional water table but in some areas they are important aquifers.

In the Estancia Valley, west of the Pedernal Hills, the valley fill is as much as 300 feet thick and is the aquifer tapped by irrigation wells. Quaternary fill in the vicinity of Tucumcari is the aquifer that for many years supplied both the City of Tucumcari and the Southern Pacific and Rock Island Railroads with water. The aquifer was mostly dewatered in the period 1900 to 1940 and most of the wells were abandoned after development of the Metropolitan Park well field that tapped the Entrada Sandstone. The aquifer has since been fully recharged and ground water now discharges to Tucumcari Lake. The quality of the water is now inferior to that originally in the aquifer because the recharge has been derived largely from irrigation and canal seepage.

The alluvium in the valleys of major rivers such as the Mora, Pecos, and Canadian generally yields small but dependable quantities of water. Irrigation wells tap the older alluvium in the Pecos Valley west of the Pecos River and south of Fort Sumner. The younger alluvium furnishes water to irrigation wells in the Mora River Valley near Watrous, and Griggs and Hendrickson suggest irrigation water might be obtained from the alluvium east of Rociada.

The pediment and old channel gravels, and dune sands, generally are not aquifers in themselves. However, because of their high porosity they serve as excellent catchments for recharge. Locally, where they overlie impermeable beds such as commonly are found in the Dockum Group, they may contain perched water at shallow depth. Such an occurrence may supply the water developed for irrigation near Nara Visa and Porter in Quay County (Trauger, 1953).

Some of the old lake beds have strata of sand below an upper sequence of clay and silt. The sands probably represent early sedimentation when the lakes were receiving considerable inflow during pluvial cycles of the Pleistocene. The uppermost clays and silts, and local beds of gypsum and salt represent the sedimentation that occurred in the drying-out period toward the close of the Pleistocene. The sand strata can be the source of small amounts of potable water for stock and domestic wells but the quality also may be poor. A well drilled in the floor of Black Lake basin northeast of Mosquero produced about 20 gpm from a black sand underlying blue clay, but the water contained 3,890 mg/1 (milligrams per liter) of dissolved solids of which 2,320 mg/1 was sulfate and 5.1 mg/1 was fluoride ion.

REGIONAL MOVEMENT OF GROUND WATER

The direction of movement of ground water is controlled to a large extent by the three factors of topography, regional structure, and lithologic character of the rocks. Water moves through permeable rocks from high ground to low ground, and, in this region, the movement commonly parallels the regional dip of the beds. The shape of the water table has often been described as being generally a subdued or smoothed version of the land surface, and that characterization holds true for east-central New Mexico.

The two main river systems—the Pecos and the Canadian, and their tributaries—are the discharge lines for most ground water moving through the various formations. However, in Torrance County, ground water in general moves toward the axial playa of Estancia Valley. East of the Pedernal Hills movement is toward the Pecos River.

The Pecos is a gaining stream through most of its course in the conference area. It loses water to the cavernous San Andres Limestone and Artesia Formation above Colonias, where it trends along the north side of the Esteritos dome. Ground water is discharged to the river from all formations exposed along its course south of Colonias, and water is discharged upward from deeper-lying formations, through overlying beds, to the river. Water derived from saline aquifers at depth is largely responsible for the generally poor quality of water in the Pecos River in its course south from Colonias.

The topographic divide between the Canadian and Pecos River drainage basins coincides approximately with the ground water divide. The Canadian River and its larger perennial tributaries maintain flow from ground-water discharge. In the area between the Canadian River and the Llano Estacado, ground water moves northward to the Canadian. Ground water moves south toward the river in San Miguel, Harding, northern Quay, and southeastern Union Counties.

The direction of movement of water under the Llano Estacado is southeast. The water in the Ogallala moves eastward down gradient over the eastward-dipping buried bedrock surface. That pre-Ogallala surface was locally deeply channeled by streams that trended southeast. Ogallala sediments backfilled the channels and they now serve as "conduits" for water moving into Texas.

USE OF WATER AND DEVELOPMENT POTENTIAL

The pattern of water use in the region as established is not likely to change appreciably in the foreseeable future. Ground-water studies have been made for most of the region and the occurrence and distribution of ground water is fairly well understood. Supplies of water for domestic, stock, and municipal use are generally available throughout the region although it may be necessary for communities to go farther afield than they desire to develop potable supplies to meet increased needs. [It is the editors' opinion that the supplies may be beyond the economic reach of small communities, and consideration should be given by the Federal, State, and local governments to extending assistance. In this manner some measure of help may be given to slowing the decline of the small communities, and controlling the too-rapid growth of some large communities that have abundant water to supply both domestic and industrial needs.]

Ground water in areas of heavy pumping are being depleted but no regional general decline of the water table has been detected. Some shallow wells that extended only a few feet into alluvial aquifers along stream channels are known to have gone dry in recent years, probably as a result of drought, but no general "drying up" of wells is occurring, nor should such "drying up" be anticipated. Small-yield domestic and stock wells can continue to be developed as needed. The potential is poor, however, for developing additional large supplies of ground water in east-central New Mexico. The ground-water studies made to date have defined the principal large bodies of ground water and have determined their general chemical character and yield characteristics. Further studies may define additional small areas that have a limited potential for irrigation supplies, but discovery of large areas is not likely.

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