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GROUND-WATER CONDITIONS
IN THE
VICINITY OF CARLSBAD, NEW MEXICO

1945

By

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In cooperation with United States Geological Survey

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By

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ABSTRACT

The area included in this investigation lies in Eddy County, New Mexico, largely between the foothills of the Guadalupe Mountains on the west, and the Pecos River on the east, and extends from Carlsbad southward to Black River. The Pecos River drains the entire area and in the growing season, when water is diverted at Avalon Dam for irrigation, its flow in this locality is maintained largely by the numerous springs emerging in the river channel north of Carlsbad. Carlsbad and vicinity depend on ground water for a domestic water supply, as the waters of the Pecos River are too highly mineralized for domestic use. About 1,120 acres of land were irrigated by ground water in the vicinity of Carlsbad in 1940.

Valley fill, of Quaternary age, extends over most of the area, largely as a thin veneer, but it has a maximum known thickness of 256 feet. It is made up largely of clay with lenses of conglomerate, gravel, and sand. The Rustler formation, of Upper Permian age, underlies the fill, and is composed of gypsum and red beds with one persistent bed of limestone. The Salado formation, which is composed chiefly of halite (common salt), underlies the Rustler formation elsewhere but is absent over most of the area described in this paper. The Castile formation, which is predominantely anhydrite, underlies the Salado and overlies the Delaware Mountain group, of Middle Permian age, which is deeply buried in most of the area. The upper part of the Delaware Mountain group grades into the Capitan and Carlsbad limestones to the north, east and west, the latter being exposed near Carlsbad and in the foothills of the Guadalupe mountains. The Carlsbad limestone, in turn, grades into the upper part of the Chalk Bluff formation.

Ground water apparently moves eastward from the Guadalupe Mountains through the Carlsbad limestone to recharge the aquifers in the Delaware Mountain, Castile, and Salado units. In these formations the water soon becomes too highly mineralized for domestic or irrigation use. A large part of the water in the Carlsbad lime-

stone emerges in the spring area north of Carlsbad, and part of it moves into the valley fill in Dark Canyon Arroyo. The water in the fill of Dark Canyon Arroyo moves laterally into the limestone of the Rustler formation. The water moving eastward in the valley fill and Rustler limestone becomes progressively more mineralized, and in the farmland area in the Carlsbad Irrigation District it is unfit for domestic use. In addition, highly mineralized water seeping from the farmlands and canals in the Carlsbad Irrigation District commingles with the water from the east, and the resulting mixture is undesirable even for watering stock although, of necessity, it is much used for that purpose.

Water occurs in channels of the Carlsbad limestone and wells drilled into it generally obtain large yields of hard but potable water. The municipal supply of the city of Carlsbad is derived from four wells (1940) in the Carlsbad limestone. The aquifer has a high transmissibility in the vicinity of Carlsbad, as was shown by a test on one of the wells owned by Southwestern Public Service Company. This well has a specific capacity of 275 gallons per minute per foot of drawdown. The present withdrawal of water from wells penetrating the aquifers in the Carlsbad limestone averages about 4 second-feet (about 2,600,000 gallons a day). The average flow, emerging in the spring area in the Pecos River north of Carlsbad, is about 60 second-feet (about 40 million gallons a day). It appears that about 12 second-feet of this flow (about 8 million gallons a day) comes from aquifers in the Carlsbad limestone, and that the remainder represents leakage from Lake Avalon and the canal system.

The valley fill is less permeable than the Carlsbad limestone, but, in some places, sufficient yields are obtained for irrigation purposes. A test made on a well in the fill just south of Carlsbad showed the aquifer in that locality to have a transmissibility of about 60,000.

Contamination of the household wells in West Carlsbad does not appear to be taking place at the present time, although the juxtaposition of cesspools and outhouses, on the one hand, and poorly cased wells for domestic water supply, on the other, make the situation dangerous.

INTRODUCTION

SCOPE, PURPOSE, AND ACKNOWLEDGMENTS

Carlsbad and vicinity depend upon ground water for a potable water supply as the water of the Pecos River is too highly mineralized for domestic use. With the rapid growth of the city, there has been some concern as to whether there are sufficient potable ground-

water supplies to meet the future needs of the city. The public water supply of Carlsbad in 1940 was derived from 4 wells. Communities outside the city limits have no public water supply, and therefore have developed private ground-water supplies, or where potable ground water does not occur, they obtain water from city taps or distant wells. Farmlands outside the Carlsbad Irrigation District irrigate with water derived from wells. A greater diversity of crops may be grown where the quality of water obtained from these wells is better than that used by the Carlsbad Irrigation District. Thus, a study of both the quality and the quantity of ground water available for development in the vicinity of Carlsbad was desirable. Also, there is some concern as to whether contamination of the potable ground-water supply in West Carlsbad can take place. This community has no sewer system, and the conditions are such that there is a possibility of contamination.

With the foregoing objectives and problems in mind, the Geological Survey has compiled the data available on ground-water conditions in this area, the results of which are presented in this report. The investigation was carried on in cooperation with T. M. McClure, State Engineer of New Mexico, and under the supervision of C. V. Theis, geologist in charge of ground-water investigations in New Mexico. V. L. Minter, secretary of the Carlsbad Chamber of Commerce, gave valuable assistance in outlining the needs of the community in this type of investigation. The geological sections of this report are based in large part on the work of A. M. Morgan, of the Geological Survey. All of the water analyses were made by chemists in the Geological Survey laboratory in Roswell, New Mexico, unless otherwise stated. The Southwestern Public Service Company allowed pumping tests to be run on their water wells, and also gave permission to install a recorder on one of their less frequently used wells. Well owners and drillers in the area were cooperative.

The area included in the investigation lies mostly west of the Pecos River in the stretch of land between T. 21 S. and T. 24 S., and R. 25 E. and R. 28 E. The most intensive work covered the period from September 1939 to June 1940. Additional data were obtained from July 1940 to September 1941, and various times in early 1942. A memorandum[1] was prepared in April 1942, giving well logs, water analyses, and other data, part of which are repeated in this report.

[1] Hale, W. E. and Theis, C. V., *Memorandum of Ground-water Conditions in the Vicinity of the City Airport Southwest of Carlsbad, New Mexico*: New Mexico State Engineer, 14th and 15th Bienn. Rept., 1938-42.

METHOD OF DESIGNATING WELLS

The system of numbering the wells in this area is based upon the common land subdivisions, and serves the dual purpose of designating and locating the well. The number of the well is separated into segments by decimal points. The first segment denotes township, the second the range, the third the section, and the fourth the 10-acre tract in the section. The section is divided into quarters numbered 1, 2, 3, and 4 for the NW, NE, SW, and SE quarters respectively, and each quarter is subdivided in a similar manner so that the first digit in the fourth segment represents the quarter section of 160 acres, and the second the 40-acre tract; similarly, each 40-acre tract is divided into 10-acre tracts, which are denoted by the third digit in the fourth segment. Thus, a well located in the NW¼ SE¼ NE¼ of sec. 35, T. 21 S., R. 26 E., would be designated as 21.26.35.241. If two or more wells are located in the same 10-acre-tract, a letter, a, b, c, or d is added to the number designated. All of the townships are south of the base line, and the ranges are all east of the New Mexico Principal Meridian.

INDUSTRIES AND COMMERCE

Carlsbad, the county seat of Eddy County, is located on the Pecos River in southeastern New Mexico. This city is a stop-over for a large number of tourists visiting the famous Carlsbad Caverns, 25 miles to the southwest, and is the center for a number of industries such as farming, cattle raising, and the mining and refining of potash ores. In 1930 Carlsbad had a population of 3,708, but with the opening of the nearby potash mines and refineries since 1932, the city has grown rapidly. According to the 1940 census, Carlsbad proper had a population of 7,048, and greater Carlsbad a population of 10,000.

The future steady growth of the city seems assured by the permanent nature of the potash industry. The two companies in operation in New Mexico in 1940 were the Potash Company of America and the United States Potash Company which, together with a company operating at Searles Lake, Calif., produced 98 percent of the potash mined in the United States. The present known reserves of high grade potash ore in New Mexico are much greater than those in Searles Lake, and it is estimated that the New Mexico reserves alone could supply the United States at the rate of 500,000 tons, figured as K_2O, annually for 150 years. The current consumption (1940) is about 430,000 tons, figured as K_2O, per year. A third company, the Union Potash and Chemical Company, located near Carlsbad, began production in 1941.

The farming district is made up mainly of lands included in the Carlsbad Irrigation District, which is operated by the United States Bureau of Reclamation. This project extends from Avalon Dam, a diversion and storage dam 5 miles north of Carlsbad, to 2 miles south of Black River, or about 17 miles south of Carlsbad, and lies largely between the Southern Canal on the west and the Pecos River on the east. About 25,000 acres of farmland are included in the district. Two storage reservoirs above Avalon Dam, on the Pecos River, supply water to the project; namely, Alamogordo Reservoir, near Fort Sumner, and Lake McMillan, located southeast of Artesia. Lake Avalon supplies water to the Eastern Canal, which serves La Huerta, a community north of Carlsbad, and the Southern Canal, which serves the larger portion of the district, which is south of Carlsbad. The growing season is from March to October. The two main crops are cotton and alfalfa. Outside the Carlsbad Irrigation District there are several farms that have developed ground-water supplies sufficient for irrigation purposes.

Carlsbad and vicinity are served by a branch line of the Atchison, Topeka and Santa Fe Railway. This line extends from Clovis, through Roswell and Artesia, to Carlsbad, and thence south through Loving, a small town 12 miles south of Carlsbad, to Pecos, Tex. Highways lead north to Artesia and Roswell, N. Mex., east to Hobbs, N. Mex., south to Pecos, Tex., and southwest to the Carlsbad Caverns and El Paso, Tex. Numerous truck lines serve the city from all points. The Continental Airlines, Inc., maintains airmail and passenger service to El Paso, Tex., and to Albuquerque, N. Mex.

TOPOGRAPHY

The Guadalupe Mountains extend northward in a V-shape from just inside the Texas border at a point about 50 miles southwest of Carlsbad. The west limb of the V forms the Guadalupe Mountains proper, and the east limb forms the foothills. This eastern limb has been named La Barrera del Guadalupe, by Lang.[2] The Barrera extends northeastward to a point about 15 miles southwest of Carlsbad, and from there swings to the north in an unbroken line to Hackberry Draw, due west of Carlsbad. (See map of Eddy County, Fig. 1, and map of Carlsbad and vicinity, Fig. 2.) North of Hackberry Draw there is a small group of hills which has been named the Ocotillo Hills. Still further north across the Pecos River, there are two small hills without names which are a continuation of the Barrera. There is usually a sharp break between the Barrera and the adjacent valley floor. North of Black River a row of hills parallels

[2] Lang, W. F., *The Permian Formations of the Pecos Valley of New Mexico and Texas*: Am. Assoc. Petroleum Geologists Bull., Vol. 21, p. 839, 1937.

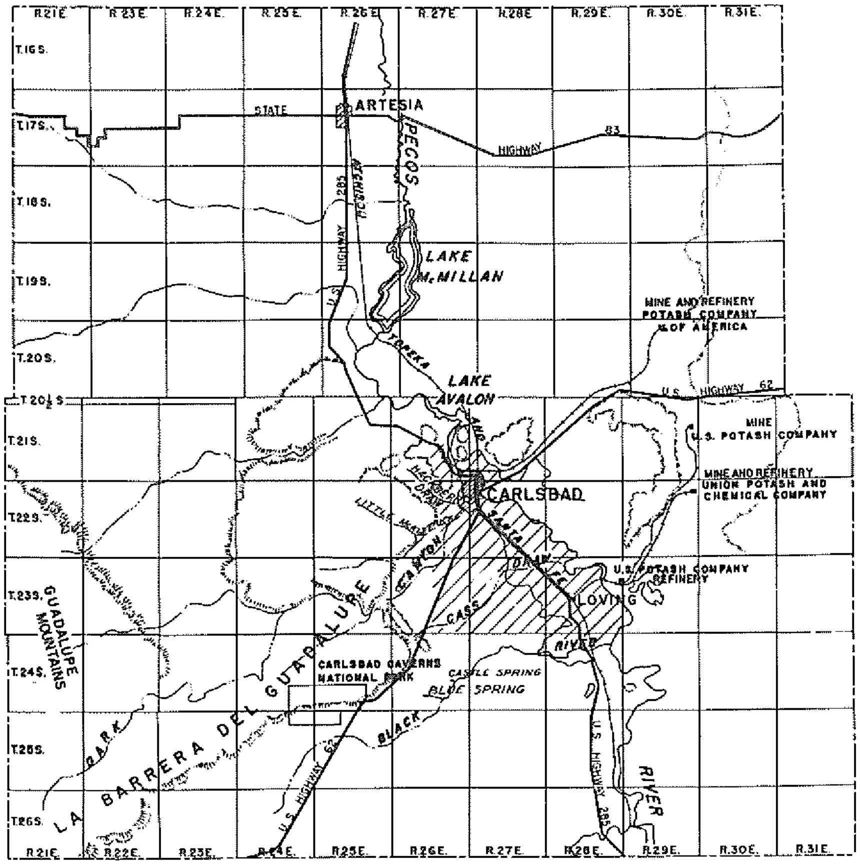

FIGURE 1
MAP OF EDDY COUNTY, NEW MEXICO, SHOWING AREA DISCUSSED IN THIS REPORT (SHADED)

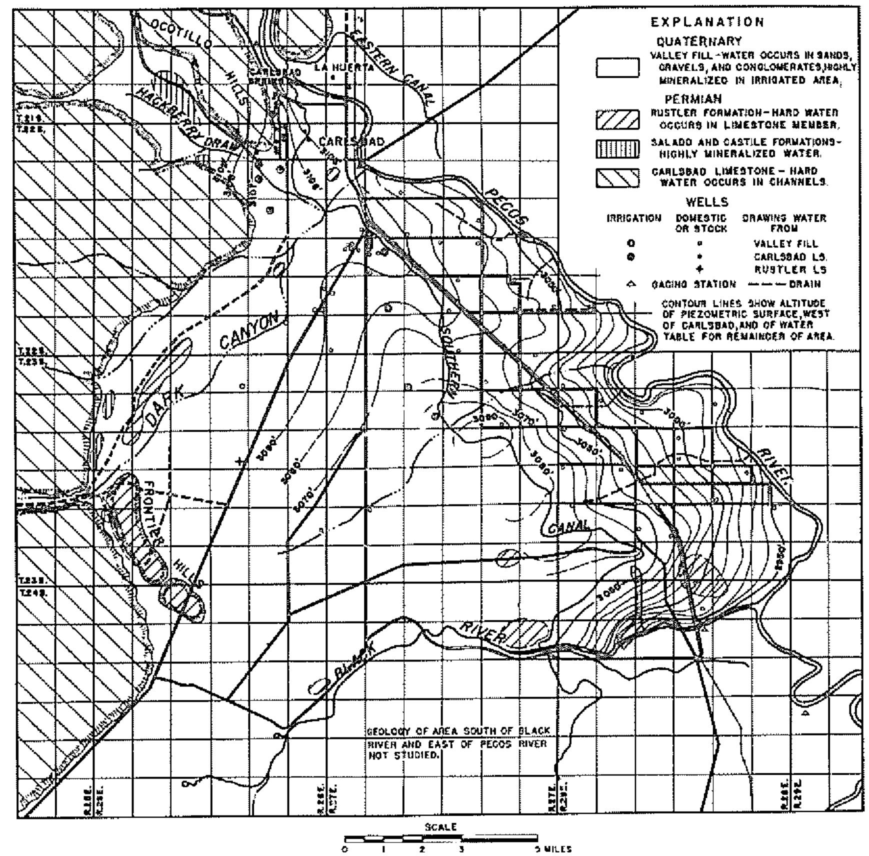

FIGURE 2
CARLSBAD AND VICINITY SHOWING GEOLOGY AND CONTOURS OF THE WATER TABLE AND PIEZOMETRIC SURFACE

the Barrera as far north as Carlsbad. These hills are more prominent near the southern end and have been named the Frontier Hills. Further north the relief diminishes until at Carlsbad the hills disappear altogether. Eastward from this row of hills, the surface slopes gently to the Pecos River and is broken only by occasional knolls.

In the expanded part of the Pecos River Valley, south of Carlsbad, there are three distinct terraces. The lowest terrace is adjacent to the river and covers a small area. The next terrace covers the larger part of the valley and includes most of the farmlands and some of the rangeland west of the farmland. Small knolls that contain gravels covered by a caliche cap are all that remain of a third terrace. These terraces have probably the same ages as the terraces in the Roswell Artesian Basin to the north:[3] that is, the lowest terrace is probably the Lakewood terrace; the intermediate, extensive terrace, the Orchard Park terrace; and the third terrace, the Blackdom terrace.

DRAINAGE

The Pecos River flows southeastward in this locality and drains the entire area. During the irrigation season, from February to November, the entire flow of the Pecos River is normally diverted for irrigation at Avalon Dam. The river channel is usually nearly dry between the dam and Carlsbad, where a large number of springs emerge along the banks and in the channel of the river. Carlsbad Spring, one of the largest springs, has been developed by building a concrete tank which maintains the water level about 5.5 feet above the adjacent river water level. This spring has a flow of about 5 second-feet. A dam in the river, on the east side of Carlsbad, backs up the water from these springs to a point about 2½ miles above the dam and opposite the Carlsbad Spring. The combined flow of the Carlsbad Spring and numerous other springs varies between 50 and 80 second-feet as measured at Green Street Bridge Gaging Station on the east side of Carlsbad, below the dam. Southeast from Carlsbad, a few small springs are found along the banks of the river. Black River and Dark Canyon Arroyo are the only tributaries to the Pecos River in this area of any size. A few drains and Cass Draw, deriving water from return irrigation water, contribute about 12 second-feet, on the average, to the flow of the Pecos River.

[3] Fiedler, A. G. and Nye, S. S., *Geology and Ground-Water Resources of the Roswell Artesian Basin, New Mexico*: U. S. Geol. Survey Water-Supply Paper 639, p. 10-12, 1933.
Morgan, A. M., *Geology and Shallow-Water Resources of the Roswell Artesian Basin, New Mexico*: 12th and 13th Bienn. Rept. of State Engineer of N. Mex., p. 167-168, 1938.

Black River flows generally in an eastward direction and enters the Pecos River at a point about 16 miles southeast of Carlsbad. The stream has a perennial flow below Blue Spring, which is about 15 miles west of the mouth of Black River. Blue Spring maintains a flow of from 10 to 15 second-feet, and Castle Spring, about 2 miles to the northeast, flows somewhat less than 1 second-foot. Some of the water is diverted for irrigation near Blue Spring for the farmlands located near Castle Spring. The Southern Canal intersects Black River above a diversion dam about 5.5 miles from its mouth. When no water is required for irrigation south of Black River, the water from the river and canal is spilled to the Pecos River.

Dark Canyon Arroyo heads in the Guadalupe Mountains, about 36 miles to the southwest of Carlsbad. This normally dry arroyo drains a considerable area in the foothills of the Guadalupe Mountains, and when heavy rains occur in that region flash floods rush to the Pecos River. The arroyo emerges from the foothills of the Guadalupes, about 11 miles southwest of Carlsbad, and flows to the northeast, entering the Pecos River just south of Carlsbad. Hackberry Draw and Little McKittrick, two small ephemeral streams in the area, enter Dark Canyon Arroyo from the west near its mouth.

CLIMATE

The climate of Carlsbad is semiarid. Summers are hot and winters are mild, as a rule. All farming is carried on by means of irrigation. The rangelands support growths of greasewood, mesquite, some grasses, and cacti. The table below gives the normal monthly rainfall at Carlsbad, as determined from a precipitation record which has been continuous since 1895. The heavier rainfall occurs in the summer and fall months.

Jan.	.32	May	.77	Sept.	1.92
Feb.	.44	June	1.73	Oct.	1.44
Mar.	.56	July	2.42	Nov.	.62
April	.95	Aug.	1.77	Dec.	.65
				Total	13.59

OUTLINE OF GEOLOGIC HISTORY

Ground water moves through openings in the rocks. These openings may be large or minute in size depending upon the nature of the rocks and are largely interconnected to form conduits. The velocity of movement and the quality of the water flowing through these conduits are determined, to a large extent, by the character of the rocks through which the water must pass. In the vicinity of Carlsbad, ground water occurs in openings of two types. In the valley fill, which yields the water to domestic and some irrigation wells south of Carlsbad, the water occurs in the pores between grains of sand and gravel. In the limestone west of Carlsbad, which supplies the wells of the public water works of Carlsbad and also the Carlsbad Springs, and in the gypsiferous rocks in the area, the water occurs in comparatively large solution passages. The chemical character of the water and the ease with which the water is obtained from wells are generally quite different in the two types of rocks.

Rocks of Middle and Upper Permian and Quaternary age crop out in and underlie Carlsbad and vicinity. Rocks of early Permian age and older formations crop out in the Sacramento Mountains to the northwest and probably underlie the Carlsbad area at great depths, but as they have no bearing on the ground-water problems in this area, they will not be discussed. Rocks of Triassic and possibly Cretaceous age which were laid down over the area have been stripped off during the long erosion period preceding deposition of Quaternary deposits. The geologic map (Fig. 2) shows areal distribution of formations in the vicinity of Carlsbad.

The Permian formations in the vicinity of Carlsbad differ greatly from place to place, some being confined to a part of the area and others changing rapidly from limestone to anhydrite, or to clay and shale. The great diversity of the rocks results from the unusual conditions of sedimentation under which they were laid down. The following brief discussion of these conditions, taken largely from Lang,[4] will help to explain the changes in lithology, to be described later.

The vicinity of Carlsbad lies geologically near the northwest rim of the Permian Delaware Basin. During Middle Permian time an arm of the sea occupied the Delaware Basin and extended beyond. In shallower water near the margin of the Delaware Basin, reef limestones, composed of the massive Capitan and the well-bedded Carlsbad limestone, were laid down in the shape of a horseshoe with the open end to the south. This reef development served to divide the area into three sedimentary provinces, which Lang named: 1) the Delaware Basin, or fore-reef province; 2) the reef-zone province; and 3) the back-reef province. In the fore-reef province marine deposits of sandstone and limestone, which now form the Delaware Mountain group, were laid down. In the back-reef area, where the waters were more saline, anhydrite and clastics from the lowland area, around the margin of the sea were deposited. These back-reef deposits form the Chalk Bluff formation. The deposits of the reef-zone province, namely the Capitan and Carlsbad limestones, grade rapidly into the Chalk Bluff formation in the back-reef area, and into the Delaware Mountain formation in the fore-reef area. A gradual downward movement of the land, which kept pace with deposition, allowed these formations to attain a great thickness.

[4] Lang, W. B., *The Permian Formations of the Pecos Valley of New Mexico and Texas*: Am. Assoc. Petroleum Geologists Bull., Vol. 21, p. 833-898, 1937.

The period of reef-building was brought to a close by a change from normal sea-water conditions to highly saline conditions, possibly as a result of an uplift between the Delaware Basin and the open sea to the southeast, which restricted the amount of water coming into the basin. The incoming water barely kept pace with evaporation, with the result that a thick series of anhydrite beds, namely the Castile formation, were laid down until they almost filled the Delaware Basin. Later the sea overlapped the reef deposits of limestone but still remained highly saline. In it were deposited the thick beds of halite making up the Salado formation which now extends beyond the Delaware Basin over a large area in southeastern New Mexico. The succeeding Rustler formation was deposited under less saline conditions.

After Rustler time, the sea retreated southward. Any deposits which may have been laid down over the Rustler formation, prior to Pleistocene time, were eroded away before the Pleistocene epoch, when the valley fill was deposited over much of the area. The Guadalupe Mountains were formed and the Permian formations in this area tilted eastward at the time the Rocky Mountains were uplifted. The western part of the reef limestones is now exposed in La Barrera del Guadalupe. Younger Permian formations, the Castile, Salado, and Rustler, crop out to the east of the Barrera in this locality, but most of the area is covered by the valley fill.

WATER IN THE VALLEY FILL

NATURE OF THE AQUIFER

Most of the area discussed in this report is covered by the valley fill of Quaternary age, which extends from La Huerta on the north to Black River on the south, and from the hills east of the Barrera to the Pecos River (Fig. 2). Thickness of the fill varies greatly in short distances, owing to pronounced irregularities in the surface on which it was deposited, caused by solution and collapse of underlying rocks. In the interstream areas it appears to be generally only a thin veneer. In the area between the Barrera and Dark Canyon, few wells have been drilled and no accurate measurement of the thickness of the fill can be obtained, but numerous exposures of Permian formations lead to the conclusion that the fill here is relatively thin. In the divide between Dark Canyon and Cass Draw, in sec. 18, T. 23 S., R. 27 E., and adjacent sections to the north and east, there is a prominent knob in which gypsum of Permian age is covered only by a thin layer of alluvium. The fill, for some distance from this knob, is probably thin, although there are no wells to show that this is so. The fill apparently increases in average thickness eastward from Dark Canyon to a maximum just west of and parallel to the Pecos River.

The thickest part of the fill is under the present drainage system. The maximum known depth of the fill near the Pecos River is 206 feet in a well in sec. 20, T. 22 S., R. 27 E., which went through a conglomerate into limestone at this depth. In La Huerta, the fill varies in thickness in existing wells from 80 to 116 feet. A well drilled in Cass Draw in sec. 25, T. 23 S., R. 26 E., went through a conglomerate at 176 feet into limestone. A well drilled near Dark Canyon in sec. 3, T. 23 S., R. 26 E., went through a conglomerate at 93 feet into red beds. A well at the Carlsbad Air Base near Dark Canyon, in sec. 35, T. 22 S., R. 26 E., penetrated valley fill to a depth of 256 feet, and another, nearby, reached a depth of 260 feet, but the lower 8 feet of red clay in this hole may be of Rustler age.

The fill in most of the area is made up chiefly of buff to red clays, with lenses of conglomerate, gravel, and sand, and is similar to the quartzose conglomerate of the Roswell Basin. According to well drillers, the fill in this locality changes rapidly in character from place to place. This is characteristic of stream deposits, as the stream channels shift rapidly and deposit different types of material. Near Dark Canyon the fill contains beds of boulders and pebbles, chiefly limestone, firmly and densely cemented by calcite to form limestone conglomerate. These beds are essentially limestone, and they have no original porosity. In some localities solution cavities in these beds have furnished supplies of several hundred gallons of water a minute with little drawdown. Drill cuttings from these conglomerates show the variegated colors and textures of their component pebbles and their matrix. In the absence of cuttings, it is frequently impossible to tell from drillers' logs whether the "limestone" found in a well is one of these Quaternary conglomerates or the limestone in the Rustler formation. To the east of the area studied in this report, the fill is made up largely of clays and fine red sand, which have been named the Gatuna formation by Lang.[5] The Gatuna formation is the same age as the quartzose conglomerate on the west side of the Pecos in this locality. Some logs of wells in the fill west of the river are listed below:

HELLYER WELL

SW¼NW¼ sec. 20, T. 22 S., R. 27 E.

Material	Thickness *(feet)*	Depth *(feet)*
Silt, sand, gravel	50	50
Conglomerate	20	70
Yellow clay	40	110
Sand (water)	15	125

MATTHEWS WELL

SW¼NW¼ sec. 24, T. 22 S., R. 27 E.

Material	Thickness *(feet)*	Depth *(feet)*
Silt, sand, gravel	45	45
Conglomerate	10	55
Clay	95	150
Conglomerate	6	156
Pink clay	39	195
Conglomerate (water)	11	206

HANSON WELL

SW¼SW¼ sec. 17, T. 22 S., R. 27 E.

Material	Thickness *(feet)*	Depth *(feet)*
Silt, sand, gravel	20	20
Conglomerate	50	70
Soft conglomerate	10	80
Cavity or very loose sand (water)	10	90

[5] Robinson, T. W., and Lang, W. B., *Geology and Ground-Water Conditions of the Pecos Valley in the Vicinity of Laguna Grande de la Sal, New Mexico, With Special Reference to the Salt Content of the River Water*: New Mexico State Engineer, 12th and 13th Bienn. Rept., p. 84-85, 1938.

WELL NO. 2, ARMY AIR BASE

Sec. 35, T. 22 S., R. 26 E. (Driller's log from 0 to 166 feet; from cuttings by J. P. Smith, United States Potash Co., 166 to 260 feet.)

Material	Thickness (feet)	Depth (feet)
Soil	5	5
Gravel	10	15
Clay	4	19
Gravel	31	50
Pink, sandy shale	102	152
Limestone conglomerate (water, 50 gpm)	14	166
Conglomerate, medium coarse limestone, siliceous pebbles with occasional fragments of gypsite	29	195
Limestone conglomerate, small pebbles	5	200
Conglomerate, medium coarse limestone, siliceous pebbles with a few fragments of rounded, re-worked gypsum. Increase of water, 195-215 feet.	15	215
Buff and fawn-colored clay	15	230
Medium coarse limestone conglomerate, streaks of fawn-colored clay, fragments of gypsum	22	252
Brick-red clay, streaks of lighter clay, some fine gravel embedded in clay	8	260

WELL NO. 3, ARMY AIR BASE

Sec. 35, T. 22 S., R. 26 E. (Approximately 200 feet west of Well No. 2. Driller's log to 166 feet; cuttings by J. P. Smith, from 166 to 256 feet.)

Material	Thickness (feet)	Depth (feet)
Soil	12	12
Gravel	68	80
Pink, sandy clay	82	162
Conglomerate (seep of water)	2	164
Pink, sandy shale	10	174
Hard, indurated, buff, limey sand and fine gravel conglomerate	3	177

WELL NO. 3, ARMY AIR BASE *Cont.*

Material	Thickness (feet)	Depth (feet)
Conglomerate; matrix yellow limestone, medium-coarse dolomitic and siliceous pebbles (water at 180 ft.)	16	193
Hard, buff, fine gravel and sand conglomerate	7	200
Hard, indurated, buff, limey sand	10	210
Medium-coarse limestone conglomerate	5	215
Buff, greenish and pink, calcareous shale with a few pebbles and a few sandy laminae	10	225
Very hard, indurated, limey sand	10	235
Medium-coarse, gray and buff conglomerate. Increase of water	10	245
Hard, fine-textured, buff conglomerate	11	256

MARTIN WELL

SE¼ SE¼ sec. 25, T. 22 S., R. 26 E. Drilled in June 1941. Cased with 10-inch casing. (Logged from cuttings by R. H. King, Geological Survey.)

Material	Thickness (feet)	Depth (feet)
Missing	10	10
Gravel, coarse, poorly sorted, composed of sub- to well-rounded pebbles of limestone & dolomite, white, tan, gray, and some reddish	10	20
Missing	10	30
Clay, tan, and gravel, moderately well sorted, mostly subangular pebbles of limestone & dolomite, white to dark gray	5	35
Gravel, poorly sorted, composed of pebbles of limestone & dolomite, mostly white and light gray, some tan and dark gray, trace of reddish mostly subrounded	5	40
Missing	15	55
Gravel, poorly sorted, composed of limestone and dolomite pebbles, white to dark gray, some tan, sub- to well-rounded	15	70
Clay, light tan, very calcareous, and gravel, as in preceding samples	10	80
Missing	10	90
About like material between 70 and 80 feet	5	95

MARTIN WELL *Cont.*

Material	Thickness (feet)	Depth (feet)
Conglomerate, limestone & dolomite pebbles as in preceding samples, bound by pinkish, calcareous cementing material	5	100
Same, very little, weak cementing material; virtually a gravel	5	105
Same, but considerable tan, clayey, calcareous cementing material	15	120
Same, ground very fine and containing some crystaline calcite and some quartz, in crystals and angular to well-rounded grains	5	125
Same, fairly numerous quartz grains	5	130
Conglomerate, very poorly sorted, firmly cemented, consisting of pebbles of limestone & dolomite, seemingly rounded to well-rounded, white, tan, gray, pinkish, light brown, and yellowish; some quartz in crystals and angular to well-rounded grains; some calcite	5	135
Clay, brown; some conglomerate as in preceding samples	5	140*

* Total depth 140 feet.

MERCHANT WELL

SW¼ SW¼ NW¼ sec. 30, T. 22 S., R. 27 E.

Material	Thickness (feet)	Depth (feet)
Soil	5	5
Gravel	15	20
Clay, yellow	70	90
Clay, red, sandy	58	148
Conglomerate (limestone), water - cased off	12	160
Clay, red	10	170
Limestone (conglomerate?)	7	177
Sand	6	183
Limestone, broken up (conglomerate?) (water)	24	207

GOAT ROPERS CLUB WELL

NE¼ SW¼ sec. 30, T. 22 S., R. 27 E.

Material	Thickness (feet)	Depth (feet)
Soil	5	5
Gravel	50	55
Conglomerate, limestone, yellow	18	73
Clay, yellow	37	110
Sand, white (water)	10	120
Clay and broken-up material	40	160
Conglomerate, limestone (water)	30+	190+

The fill is capped by caliche along the slopes of the valley, just east of the Barrera, and in remnants of an old terrace that occurs throughout the valley. East and south of the Ocotillo Hills the caliche is from 10 to 15 feet thick and rests, in some places, directly on the fill and in others on the Carlsbad limestone.

Water occurs in the conglomerates, sands, and gravels, and is found in the deep fill adjacent to the Pecos River, and the deeper part of the fill in Cass Draw and Dark Canyon. Elsewhere, the fill does not extend deep enough to intersect the water table. Ground water probably enters the fill from the Carlsbad limestone to the west and from parts of the Rustler formation below. Surface water enters the fill by seepage of flood waters in Dark Canyon, and by seepage from the canals and irrigated lands in the area.

The quality of water varies from place to place, depending on its source. It is, therefore, desirable to discuss water in the valley fill under three headings: 1) that between the Southern Canal and the Pecos River from Carlsbad to Black River; 2) that in the fill in La Huerta; and 3) that west of the Southern Canal.

WATER BETWEEN THE SOUTHERN CANAL AND THE PECOS RIVER

The area from Carlsbad south to Black River, and between the Southern Canal and the Pecos River, includes the major part of the farmlands in the Carlsbad Irrigation District and, as no irrigation wells are needed, all of the wells are dug or drilled to obtain water for stock or domestic use. The dug wells are generally from 15 to 25 feet deep, and the drilled wells from 18 to 45 feet. A few wells have been drilled 100 or more feet deep in the search for good water. The water table is from 5 to 35 feet below the general land surface and slopes from the Southern Canal to the Pecos River (see Fig. 2).

The water table in the southern part of the area slopes from 15 to 25 feet to the mile, and in the northern part about 10 feet to the mile.

As shown by Table 4 on page 254, water levels in wells in this area rise markedly in summer, during the irrigation season, and fall during the winter, when irrigation canals are dry. It is evident that the canal losses and the return of water from the irrigated farmlands are the sources of a large part of the water found in the valley fill in this area. Very little water appears to be moving into the area from west of the Southern Canal.

The quality of water in the fill in this area reflects the character of the irrigation water supplied to the Carlsbad Irrigation District. As the soil is gypsiferous and contains other soluble minerals, the mineral content of the ground water obtained from shallow wells is somewhat higher in general than that of the already highly mineralized irrigation water supplied to the district. It is impotable, but of necessity it is used to water stock. A better quality of water is obtained from well 23.28.15.131, which has the first water sealed off, but even this lower water is too highly mineralized to be suitable for drinking. This better quality of water indicates that some water is moving in from west of the Carlsbad Canal. A table showing the quality of water obtained from various wells in the area appears on page 243.

WATER IN THE FILL IN LA HUERTA

The Eastern Canal borders La Huerta on the north and water seeping from it and from the irrigated lands down to the water table renders the shallow ground water in this locality impotable. Also, ground water probably moves from Lake Avalon through the fill material in La Huerta. Deeper wells in the area probably pass out of the fill into gypsum and red beds in the Rustler formation. The water table slope is from north to south. Depth to water below the land surface is between 11 and 35 feet.

A table beginning on page 243 gives the analyses of water found in various wells not deriving water from the Carlsbad limestone. The water found in the fill is slightly more mineralized than the irrigation water used in La Huerta. The water from well 21.27.30.322 has about the same sulfate content as the water from other wells in La Huerta, but is low in chloride. This water is different in type from the canal water and probably has another source.

WATER IN THE FILL WEST OF THE SOUTHERN CANAL

Most of the wells drilled in the valley fill west of the Southern Canal are located in a rather small area from 2 to 5 miles south of

Carlsbad. They may be divided into two groups: 1) those within a mile of Dark Canyon, which have been drilled for domestic purposes and which yield a calcium bicarbonate water with little other mineralization, and 2) those near the Canal, which have been drilled for irrigation as well as domestic purposes and which yield highly mineralized water approaching the character of the water east of the Canal.

The wells near the Southern Canal are from 60 to over 200 feet deep and derive water from conglomeratic or sandy zones in the fill. The water generally rises in the hole after being struck by the drill, but the water level in all wells, deep and shallow alike, stands at about the same local level, indicating a common origin for all the water. Wells near Dark Canyon obtain water from solution passages in dense limestone conglomerates at depths of from 150 to 250 feet. The depths to aquifers in this area vary widely in short distances due to abrupt distortions of the valley fill caused by solution and collapse in the underlying Permian beds.

The slope of the water table near the Southern Canal (Fig. 2) is from east to west. In September 1939 the water level in well 22.27.18.444, 200 feet southwest of the Canal, was at an altitude of 3,096.60 feet; and in well 22.27.19.214b, 2,000 feet to the southwest along the same line, the water level was at an altitude of 3,095.06 feet. This condition probably exists along the entire length of the Canal. Some miles west of the Canal the water table slopes gently from west to east. Thus, there is a shallow trough in the water table paralleling the Canal on the west, down which water from the west tends to move south. However, as water of better quality than canal water was encountered in well 23.28.15.131, east of the Southern Canal, some of the water must move to the east through aquifers in the fill separated from the upper water by confining beds of clay.

The water obtained from wells near the Southern Canal contains typically from 1,000 to 1,800 parts per million sulfate, and from 400 to 900 parts chloride. The water is hard and generally nearly impotable, although about half of the persons in the locality, of necessity, drink it. The deepest well, well 22.27.20.133, drilled 206 feet deep, yields water of only about half the mineralization of the other shallower wells. This water is intermediate in character between that of the shallower wells in the vicinity and that of the wells near Dark Canyon, and seems to indicate that the better water from the west may be present at depth in this locality, although admixed with the highly mineralized, shallower water.

$$T = (264\ Q/v')\ \log\ (t/t')$$

in which

T = coefficient of transmissibility (gpd/ft)
Q = rate of pumping in gpm
t = time since pumping started
t' = time since pumping stopped
v' = residual drawdown, in feet

The following table shows the data obtained from the pumping test:

RECOVERY MEASUREMENTS AND CALCULATIONS
FOR WELL 22.27.20.143, MARCH 26, 1940

Time pumping started: 9:00 a.m. Pumping rate, gallons per minute: 675
Time pumping stopped: 3:55 p.m. Depth to static water level, feet: 50.02

Time	Depth to water *(feet)*	Time since pumping started, t *(minutes)*	Time since pumping stopped, t' *(minutes)*	$\frac{t}{t'}$
4:03 p.m.	53.23	423	8	52.9
4:05	52.94	425	10	42.5
4:10	52.65	430	15	28.65
4:15	52.42	435	20	21.75
4:20	52.19	440	25	17.60
4:25	52.02	445	30	14.83
4:30	51.84	450	35	12.86
4:35	51.70	455	40	11.37
4:40	51.58	460	45	10.22
4:45	51.50	465	50	9.30
5:05	51.25	485	70	6.93

According to the formula, if the log of t/t' is plotted against the water level in the well, the points should fall in a straight line and the slope of the line, together with the pumping rate, should indicate the transmissibility of the formation. The coefficient of transmissibility, obtained from data from the pumping test on March 26, was 56,100.

A second pumping test was begun on September 15, 1941, in order to check the first pumping test results as the recovery measurements were for such a short period that the conclusions might well be in error. At the time of the second pumping test the water was discharged into a circular tank 115 feet in diameter and 6 feet high. The static water-level measurement was made and the pump started at 6:13 a.m. The rate of rise of water in the tank was measured for some time before the water was released from the tank in order to

obtain the discharge rate. The pump was shut down at 6:18 a.m., September 16, 1941. Recovery measurements were made until 9:30 a.m., September 17, 1941. In addition to water-level measurements, variations in atmospheric pressure were measured by an aneroid barometer.

The barometric efficiency of the well appeared to be about 100 percent for the time of the pumping test. All water-level measurements were corrected for barometric pressure effects. Figure 3 is a recovery curve in which the corrected depth to water is plotted against the log of t/t'.

The pumping rate was determined to be 515 gallons a minute. The ratio (log t/t')/v' is represented by the slope of the recovery curve (Fig. 3). Using the interval between log (t/t') = 10 and 100, the value for the ratio (log t/t')/v' was determined to be $\frac{1}{2.23}$. The coefficient of transmissibility was then calculated to be 60,900 gpd/ft.

Wells tapping solution passages in the dense limestone conglomerates near Dark Canyon are very productive. During a 24-hour pumping test, well 22.26.35.220 at the airport produced 600 gallons a minute with a drawdown of 10.75 feet. As in wells tapping solution passages in the limestone in the Roswell Basin, the drawdown in this well was not directly proportional to the pumping rate. At pumping rates of 300, 400, and 500 gallons a minute, the respective drawdowns were 3.5, 5.25, and 7.6 feet. The discharge in gallons a minute was equal to 136 times the drawdown in feet to the 0.629 power ($Q = 136D^{0.629}$, in which Q is the discharge in gallons a minute and D is the drawdown in feet). As nearly as could be determined from measurements made with an airline, the water level returned instantaneously to its original position when pumping ceased.

WATER IN THE CARLSBAD LIMESTONE

NATURE OF THE AQUIFER

The Carlsbad limestone is exposed in and extends over all of La Barrera del Guadalupe, the Ocotillo Hills, and smaller hills further north. Near the margin of the Delaware Basin, beneath the surface in the area considered in this report, it interfingers with and overlaps upon the massive Capitan limestone which, in turn, grades below the surface into the Delaware Mountain group. In a northerly direction, away from the Delaware Basin, the Carlsbad limestone grades into the upper part of the Chalk Bluff formation

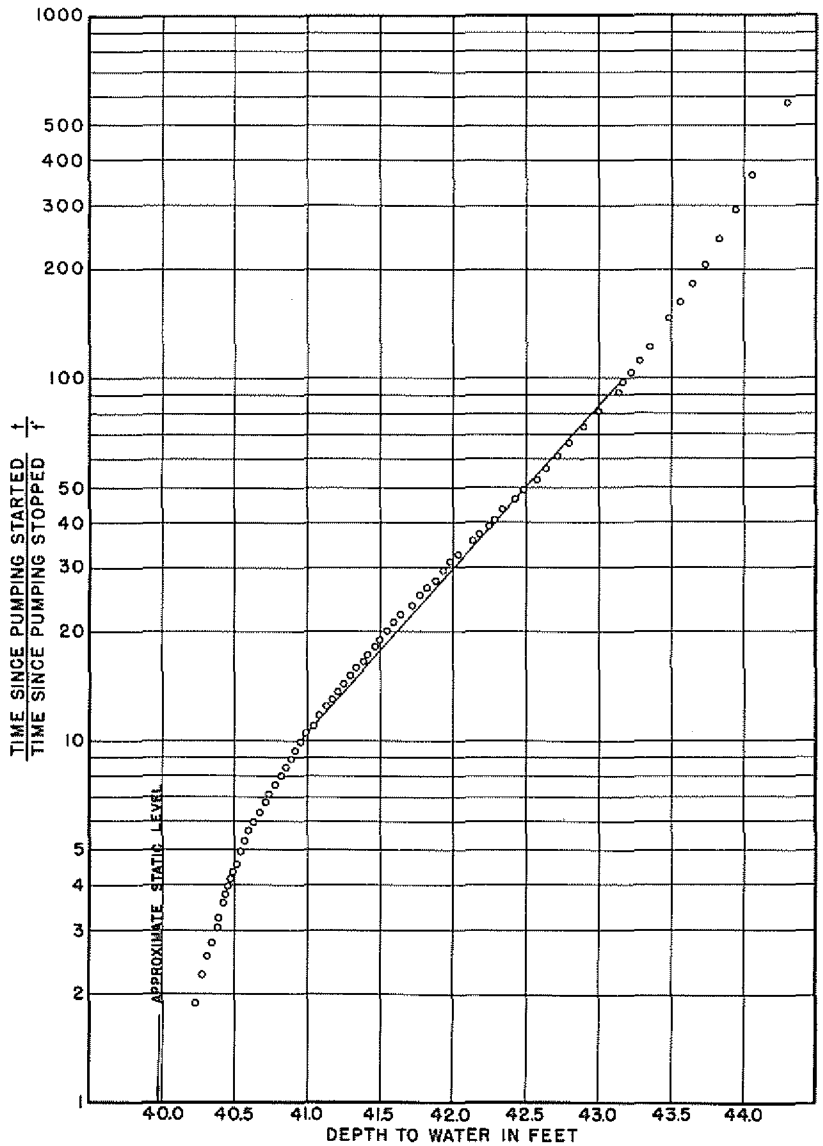

FIGURE 3
RECOVERY OF WATER LEVEL AFTER PUMPING IN GIBSON WELL (20.27.20.143b) SEPTEMBER 16-17, 1941

except for one persistent tongue, the Azotea tongue[7] of the Carlsbad limestone which extends for some miles into the back-reef area.

The Carlsbad limestone is well bedded, a feature distinguishing it from the Capitan limestone. West of Carlsbad the beds range from a half inch to a foot in thickness. Here the limestone is fine-grained and dolomitic. Farther to the south, in the Dark Canyon region, the limestone is buff-colored, coarse-grained, and more massive in appearance.

The Chalk Bluff formation is made up, for the most part, of gypsum and red beds, but contains some persistent sandy zones that form useful marker beds. One of the most persistent and extensive sandstone beds is the Queen sandstone member, which extends into the Guadalupe Mountains proper and separates Carlsbad limestone from the Goat Seep limestone (Dog Canyon limestone of former reports), which is the equivalent of the lower part of the Chalk Bluff.

Part of the rainfall and surface drainage in the Guadalupe Mountains percolates downward into the Carlsbad limestone, which is well exposed in the Guadalupe Mountains proper. Water moves eastward in the numerous channels developed in the limestone. It is possible, also, that some water may move into the Carlsbad limestone from the Queen sandstone. This water, in passing out of the limestone, recharges aquifers in the Castile and Rustler formations and parts of the valley fill. Part of the rainfall may also percolate downward in the fill in the Dark Canyon drainage area and move through the fill eastward to recharge aquifers in the same manner as the water in the limestone. Water occurring in the limestone and fill in Dark Canyon is usually hard but not otherwise highly mineralized.

OCCURRENCE OF WATER

Most of the wells deriving water from the Carlsbad limestone are located in West Carlsbad, a community just east of the Ocotillo Hills (Fig. 2). Domestic wells, usually drilled from 60 to 115 feet deep, encounter the limestone from 15 to 50 feet below the surface. The water is found under slight pressure and rises from 10 to 15 feet in the wells. The numerous wells drilled in this locality, to the same relative depths, indicate the presence of a zone of considerable porosity in the limestone. Other domestic wells deriving water from the limestone are located in a community 2 miles south of West Carlsbad and here water is encountered under similar conditions. Although most of the wells in and near West Carlsbad are

[7] Lang, W. B., *The Permian Formations of the Pecos Valley of New Mexico and Texas*: Am. Assoc. Petroleum Geologists Bull., Vol. 21, p. 868, 1937.

drilled to the water-bearing bed, occurring between 50 and 115 feet below the surface, there is evidence that there are other water-bearing beds below this one. An oil test well, now used as an irrigation well located in sec. 3, T. 22 S., R. 26 E., encountered a second water in a cavity between 320 and 345 feet. The water rose in the well to approximately the same level as the first water. One of the wells furnishing the city supply, located along the Southern Canal on the west side of Carlsbad, went through the first water horizon in the limestone at 120 feet, a second at 151 feet, and a third at 192 feet. Near La Huerta, just north of Carlsbad, the limestone interfingers with the Chalk Bluff formation and wells drilled in this locality have hit these limestone fingers at depths of 80 feet, 180 feet, and 300 feet, obtaining water at each of these levels.

All of the wells drilled into Carlsbad limestone are confined to a rather narrow strip along the east edge of the Barrera and associated hills to the north. This limited area of development is controlled by the geologic structure, for the limestone dips sharply into the valley and within a short distance is so deeply buried that cost of drilling to it is generally prohibitive. One of the deeper wells deriving water from the limestone, located in sec. 31, T. 21 S., R. 27 E., encountered the limestone at a depth of 300 feet.

The piezometric surface, that is the imaginary surface showing the level to which water will rise in wells tapping a confined or artesian aquifer, slopes gently from west to east in the vicinity of West Carlsbad (Fig. 2). The exact shape of the piezometric surface could not be determined because most of the wells tapping the aquifer are located along the strike of the surface. The gentle slope of the piezometric surface, together with the results of the pumping test, indicates that water moves freely through the aquifer.

IRRIGATION AND MUNICIPAL USE

The four wells which furnished water to the city of Carlsbad in 1939 were located near the Southern Canal on the west side of town (Fig. 4). These wells were from 150 to 237 feet deep and derived water from the Carlsbad limestone. Combined output of these wells in 1939 was about 2,000 gallons a minute, the largest well being pumped at the rate of about 850 gallons a minute. All the pumps were driven directly by electric motors.

After the main body of data for this report was assembled in 1939 and 1940, the City of Carlsbad purchased the water system and extended it. Wells 1, 2, and 3, on which observations were made during a pumping test discussed in the report, have been filled and other wells drilled. The new wells, Nos. 6, 7, and 8, are also shown in Figure 4. Logs of wells producing in 1945 are given below:

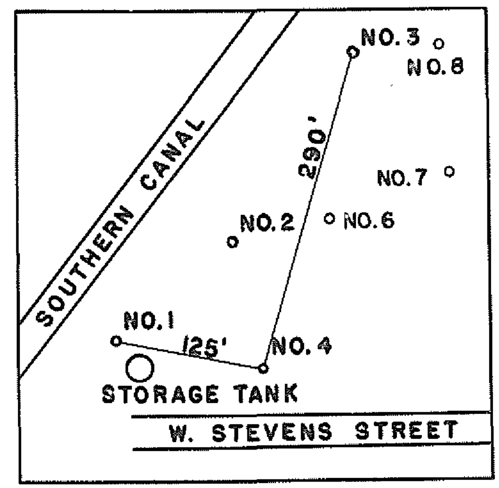

FIGURE 4

LOCATION OF MUNICIPAL WELLS, CARLSBAD, NEW MEXICO

WELL NO. 4, CITY OF CARLSBAD

Drilled July 1935; 12-inch casing to depth of 116 feet.

Material	Thickness (*feet*)	Depth (*feet*)
Surface conglomerate	2	2
Gray gypsum	25	27
Yellow gypsum (good water flow)	10	37
Gray gypsum (water)	16	53
Sandstone	5	58
Yellow gypsum	4	62
Gray shale	13	75
Gray gypsum	4	79
Gray sandstone - soda (i.e. alkali) water	18	97
Gypsum and shale	11	108
Hard limestone (casing bottom)	8	116
Soft limestone	4	120
Shale, limestone - some soda water	31	151
Blue limestone - good water flow	42	193
Yellow limestone - good water flow	32	225
Blue limestone	8	233

WELL NO. 6, CITY OF CARLSBAD

Drilled December 1942; casing set at 120 feet.

Material	Thickness (feet)	Depth (feet)
Caliche	7	7
Conglomerated rock (water at 38 ft.)	31	38
Sand and lime rock mixture (water at 70 feet in sand)	32	70
Lime rock	10	80
Shale	5	85
Sand	25	110
Lime rock	13	123
Water		128

WELL NO. 7, CITY OF CARLSBAD

Casing set at 118 feet.

Material	Thickness (feet)	Depth (feet)
Caliche	15	15
Clay and gravel	20	35
Boulders	5	40
Gravel and sand	30	70
Yellow clay	5	75
Gravel and sand	44	119
Yellow limestone	10	129
Gray limestone	14	143

WELL NO. 8, CITY OF CARLSBAD

Drilled March 1944; 7-foot drawdown at 1,200 gallons a minute; 10-foot drawdown at estimated 1,700 gallons a minute; lower joint of pipe perforated.

Material	Thickness (feet)	Depth (feet)
Surface	1	1
Yellow clay	19	20
Sand and gravel	17	37
Water, sand	3	40
Boulders and gravel	13	53
Sand and gravel	43	96
Clay	4	100
Water, sand, and gravel	15	115
Lime-lots of water (?)	3	118

WELL NO. 8, CITY OF CARLSBAD *Cont.*

Material	Thickness (feet)	Depth (feet)
Gravel	1	119
Lime-water	6	125
Lime and gravel	10	135
Yellow clay and gravel	17	152
Bottom of hole	1	153

Wells 4 and 6 definitely obtain water in the Carlsbad limestone, whereas Well 8 obtains its water in Quaternary gravels. Without much doubt, the site of the wells lies at the edge of an old channel of the Pecos River. This position, relative to the old channel, suggests the probability that water is drawn, in part, from the Carlsbad limestone and, in part, from the water of much poorer quality in the alluvial deposits of the Pecos Valley.

The average pumpage for the year 1944 was slightly over 2 million gallons a day. Maximum daily pumpage was 3.858 million gallons.

In 1939 there were eight irrigation wells in Hackberry Draw, and one north of the Draw that derived water from the Carlsbad limestone. These wells have fairly large yields. The Marquess well, 22.26.11.223,[6] is pumped at the rate of 1,000 gallons a minute, the Stephenson well, 22.26.14.213, at the reported rate of 1,000 gallons a minute, and the Taylor well, 22.26.11.143, at the rate of 1,630 gallons a minute. The largest yield is obtained from the Happy Valley Farms well, 22.26.3.232, which is pumped at the rate of 2,000 gallons a minute. Although no drawdown measurements can be made on the wells at the present time, only small drawdowns were reported at the time pumps were installed. The estimated amount of water pumped annually from aquifers in the Carlsbad limestone is shown in the following table. The duty of water for Happy Valley Farms was calculated from the record of the number of hours the well was pumped. The duty of water for the S. A. Taylor farm was based upon the farm operator's estimate of the number of hours it took to irrigate the farmland for one watering, and the number of times it was irrigated in the year 1939. The duty of water for other farms was computed from estimates of the duty of water for Happy Valley Farms and the S. A. Taylor farm.

[6] Well numbers represent the location of the well.

ESTIMATED PUMPAGE FROM AQUIFERS IN CARLSBAD LIMESTONE, 1939

Well Number	Owner	Pumping Rate *g. p. m.*	Use	Acres Irrigated	Duty of Water *ac.-ft./ac.*	Annual Pumpage *ac.-ft.*
22.26.3.232	Happy Valley Farms	2,000*	Irrigation	275	1.87 §	517
22.26.11.221	T. Marquess	1,000	Irrigation	65	1.80 †	118
22.26.11.121	S.A. Taylor	725	Irrigation	60	1.75 ‡	105
22.26.11.143	S.A. Taylor	1,630	Irrigation	86	1.75 ‡	151
22.26.14.213	H.E. Stephenson	1,000*	Irrigation	100	1.80 †	181
21.26.35.432	Dickson	850*	Irrigation	57	1.80 †	103
22.26.1.233	S.W. Public Service Co.	2,000	Public supply			921
....	Sev. small farms in W. Carlsbad	2,200 †	Irrigation	90 †	1.80 †	162
....	Wells in/near W. Carlsbad	750 †	Domestic			230
Total		11,655		733		2,488

* = Reported pumping rate.
§ = Figure obtained from record of number of hours pumped.
† = Estimated.
‡ = Figure obtained from farm operator.

The estimated average discharge throughout the year from all pumps drawing water from the Carlsbad limestone was about 4 second-feet, or 2,584,000 gallons a day, in 1939. However, the maximum withdrawal rate occurs during summer months and may be as high as 26 second-feet (11,670 gallons a minute or 16,800,000 gallons a day) when all the wells are operating simultaneously.

PUMPING TESTS

On October 29, 1939, a pumping test was made on Well 4 of the municipal group. Prior to starting the test, all pumps were shut down for a period of 1¼ hours while recovery measurements were made in the water levels in Wells 1, 3, and 4. Because of limited storage in the water tanks and heavy demand for water, the pumps could not be shut down for a longer period. At 3:27 p.m. the pump on Well 4 was started and drawdown measurements were made on the three wells about every 30 minutes during the pumping period. A water meter in the Well 4 discharge pipe, read at the beginning and end of the pumping period, indicated an average pumping rate of 833 gallons a minute. At 8:15 p.m. the pump was shut down, after which recovery measurements were made until 10:00 p.m.

The graphs of water levels in the three wells throughout the test are shown in Figure 5. The water level in the well being pumped

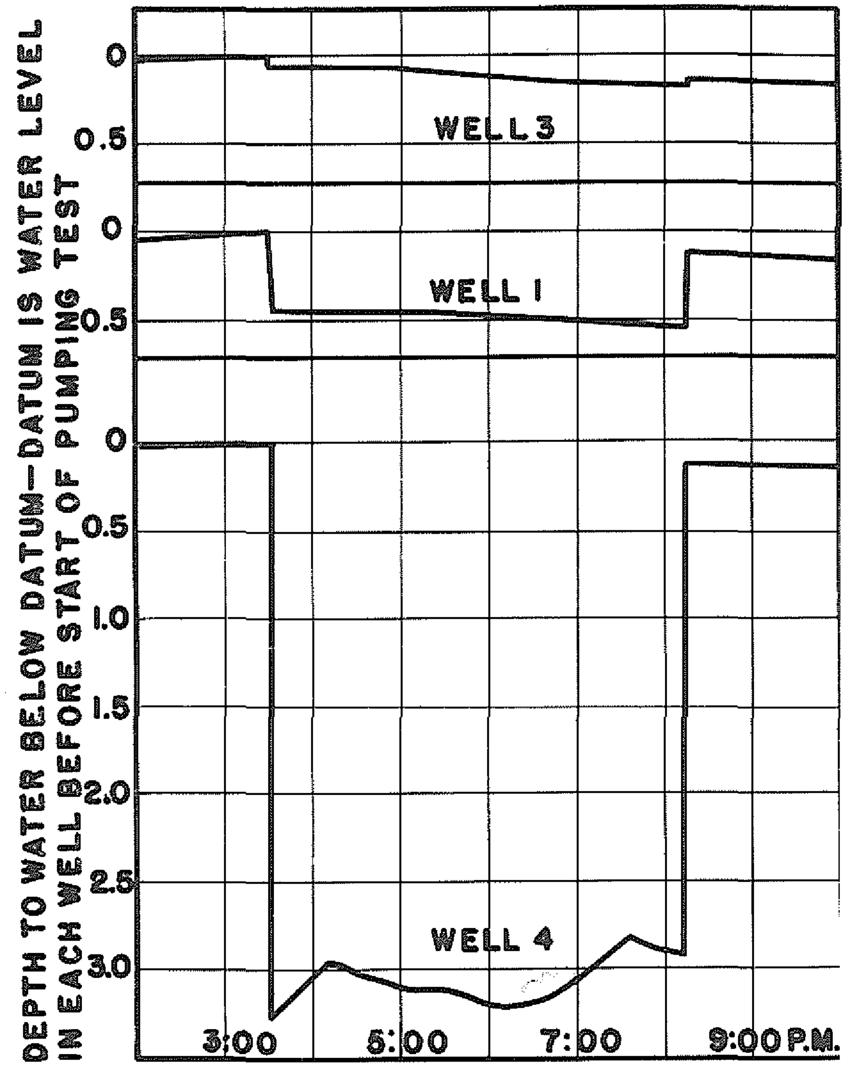

FIGURE 5
HYDROGRAPHS OF MUNICIPAL WELLS DURING PUMPING TEST OF WELL 4, OCTOBER 29, 1939

(No. 4) dropped practically instantaneously to a fairly constant position. The slight decrease in drawdown was due to decrease in discharge caused by the increasing head, against which water was being pumped as the storage tanks were filled.

In the other two wells (Nos. 1 and 3) water levels also dropped almost instantaneously when pumping began, about 0.5 foot in the near well and about 0.05 foot in the far well. When the Well 4 pump was stopped, water levels in all three wells rose practically instantaneously about as much as they fell at the beginning of pumping. However, during the period of pumping the water levels in Wells 1 and 3 fell gradually a few hundredths of a foot and water levels in all three wells were a few hundredths of a foot lower after the test than before. As water levels in the wells continued to decline after the pump had stopped, the gradual decline in Wells 1 and 3 during the test, and the difference in level in all three before and after the test, were doubtless caused by changes in atmospheric pressure.

The specific capacity of Well 4 was 275 gallons a minute for each foot of drawdown. Such a high value indicated great ease of movement of the water through the limestone. The practically instantaneous drawdown in all three wells shows also great ease of movement and suggests further that the aquifer contains no very compressible members. Figure 6 shows part of the record obtained from a water-stage recorder installed on Well 1 from the latter part of December 1939 until March 1940. It shows that the water level of Well 1 surges when the Well 4 pump is stopped, rising about 0.2 of a foot above its equilibrium position. Such an effect is uncommon in wells and indicates that movement of water in the limestone is so free that the water attains an appreciable momentum. The freedom of movement indicates rather clearly that the water moves through the limestone in fairly open channels.

The coefficient of transmissibility usually can be obtained from pumping test data in several ways. The rate of fall of water levels in observation wells near pumped wells, and the rate of recovery of the water level in a well after it has been pumped, can usually be used.[9] These methods could not be used in the present case because drawdown and recovery were so nearly instantaneous that they could not be measured. However, the data show that the coefficient is very large.

[9] Theis, C.V., *The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage:* Am. Geophys. Union Trans. 16th Ann. Meeting, p. 522, 1935.
Jacob, C.E., *On the Flow of Water in an Elastic Artesian Aquifer:* Am. Geophys. Union Trans. 21st Ann. Meeting, p. 574, 1940.

Another method of ascertaining coefficient of transmissibility is that known as Thiem's method,[10] which utilizes the drawdown difference in wells near the pumped well. The theory of this method, like that of the other methods, presupposes that the water can move with equal ease in every direction and in every place in the aquifer in the vicinity of the pumped well. Ideally, there should be a considerable number of observation wells in order to determine to what extent this condition is fulfilled. In this test only two observation wells were available and these were, unfortunately, not in line with the pumped well. However, as this method is the only one available, the data were used to compute coefficient of transmissibility.

The Thiem formula is as follows:

$$T = \frac{527.7\ Q \log r_2/r_1}{(h_1-h_2)}$$

in which:

T = coefficient of transmissibility, gpd/ft.
Q = discharge, gpm.
r_1 and r_2 = distances of observation wells from pumped well, in feet.
h_1 and h_2 = drawdowns in observation wells at distances r_1 and r_2, respectively, from pumped well, in feet.

In the Carlsbad pumping test, the distance from the pumped well to Well 1 was 125 feet, and the drawdown in that well was 0.43 foot. The distance to Well 3 was 290 feet, and the drawdown in it was 0.055 foot. The pumping rate was 833 gallons per minute. Substituting these values in the equation, the coefficient of transmissibility is determined as 428,000 gpd/ft. This is a high value and checks well with the high specific capacities observed and other test data. It is indicated that this aquifer probably carries water more easily at this locality than any other known aquifer in New Mexico, with the probable exception of some parts of the artesian aquifer in the Roswell Basin.

Figure 6 is a reproduction of the record obtained on February 4 and 5, 1940, from the recorder installed on Well 1 of the Southwestern Public Service Company. Sharp fluctuations that are at once observed are due to the starting and stopping of pumps on Wells 2, 3, and 4. The largest fluctuation is due to Well 4 being pumped; as the pump is set to shut down automatically when storage tank water

[10] Wenzel, L.K., *The Thiem Method for Determining Permeability of Water-Bearing Materials:* U.S. Geol. Survey Water-Supply Paper 679-A, p.10,1936.

level reaches a certain height, numerous fluctuations result. The drawdown and recovery of water level take place almost instantaneously. The chart also shows that a surge occurs at the beginning of both drawdown and recovery. Drawdown is practically constant, although, as pointed out in discussion of the pumping test, the water level rises slightly during the pumping period. The similar fluctuations on a much smaller scale are caused by Well 3, which is pumped almost constantly, and by Well 2, which is occasionally used.

Another type of fluctuation, not sharp but quite variable in nature, is due to changes in atmospheric pressure acting on the water in the wells. The magnitude of the water level fluctuations in a well caused by variations in atmospheric pressure depends upon the nature of the aquifer and distance of the well from the discharge or recharge area. Wells in an artesian or confined aquifer act as manometers and respond to changes in atmospheric pressure. The barometric efficiency of a well is the ratio of fluctuation of the water level produced in it by changes in atmospheric pressure to the equivalent variation of atmospheric pressure, as it would be expressed in a water barometer. Well 1 of the Southwestern Public Service Company has a barometric efficiency of about 40 percent. Wells in limestone aquifers commonly have barometric efficiencies approaching 100 percent. The deviation from 100 percent in the city wells no doubt is due to their proximity to the valley fill deposits of the Pecos River.

Records of depth to water in Well 1 of the Southwestern Public Service Company, kept since 1935, show that a fluctuation of about 3 feet occurs annually. High-water level occurs generally in February and the low-water level generally in October.

QUALITY OF WATER

As is shown in a table beginning on page 243, the uppermost water found in the limestone is somewhat hard, but not highly mineralized. The hardness is calculated as equivalent calcium carbonate, and is determined by multiplying the calcium content of the water by 2.5, the magnesium content by 4.1, and adding the result. A typical water found in this area is represented by that in well 21.26.35.234, which has a hardness of 651, a chloride content of 148, a bicarbonate content of 266, and a sulfate content of 386 parts per million. Water in the aquifers lower in the formation is apt to be more highly mineralized, as shown by analysis of water from the oil test well, 22.26.3.232. The McKinney well, 22.26.1.122, which is located near the Southern Canal and is poorly cased, allows canal water to seep into the well, thus accounting for the high mineral content of the water.

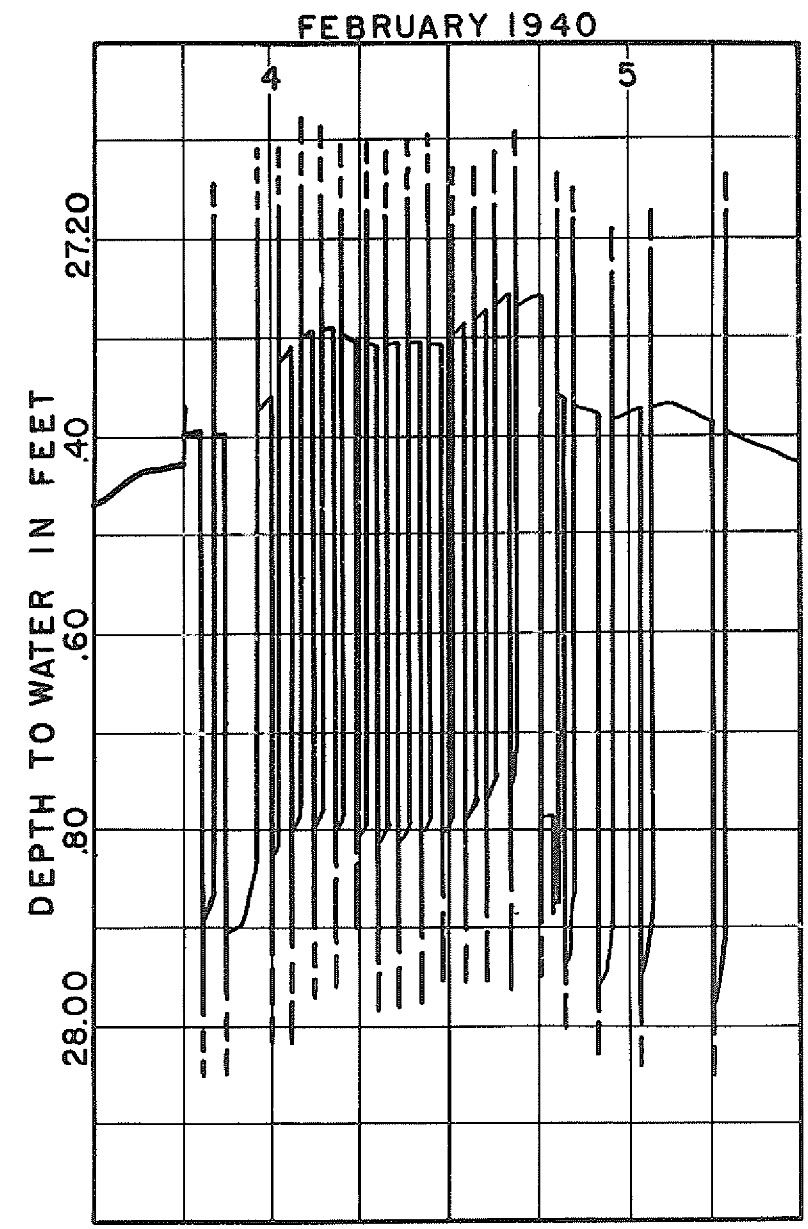

FIGURE 6

FLUCTUATIONS OF WATER LEVEL IN WELL 1 OF MUNICIPAL WATER PLANT, CARLSBAD, NEW MEXICO, CAUSED BY PUMPING NEARBY WELLS

SOURCES OF WATER IN CARLSBAD SPRINGS

The Carlsbad Spring area is comprised of a group of springs emerging along the banks and in the channel of the Pecos River from Tansill Dam, east of the city, to slightly beyond Carlsbad Spring, about 2½ miles upstream from the Dam. During a large part of the year the river channel is practically dry between Lake Avalon and the spring area. At such times of the year the stream gaging station at the Green Street bridge below the Dam, operated by the Bureau of Reclamation and, since 1937, by the Geological Survey, measures the spring flow. Between February 1940 and January 1, 1941, a gaging station was operated by the Surface Water Division of the Geological Survey, just above the spring area, so the spring flow could be determined throughout the year. The low-water flow past the Green Street bridge gaging station, which represents the spring flow, appears to have fluctuated slowly over a period of years between 50 and 80 second-feet (between 32 and 52 million gallons a day). During the period of operation of the gaging station above the spring area the flow of the springs appeared to vary between 52 and 68 second-feet (between 34 and 44 million gallons per day).

As is shown in Figure 2, the piezometric surface in West Carlsbad in the area in which wells have been drilled into the Carlsbad limestone, slopes toward the Carlsbad Spring area in a northeastward direction, and therefore shows that water in the Carlsbad limestone is moving toward the spring area. Unfortunately, there are no wells in the Carlsbad limestone between the city wells and the spring area, and hence the flow cannot be definitely shown to be into the springs. However, as there are no other areas of large increase of flow in the Pecos River in the vicinity and apparently no other possible localities of discharge for the water in the Carlsbad limestone, the locality of natural discharge for the water in the limestone is doubtless the spring area.

The piezometric surface, where it is known, slopes at a rate of about 2 feet to the mile. The coefficient of transmissibility is of the order of 400,000 gpd/ft. If this last value is approximately correct, about 800,000 gallons of water a day move through each mile of the limestone. At this rate, it would take a section of the limestone about 40 miles long to transmit the minimum discharge in the spring area. Even if the coefficient of transmissibility is considerably larger than indicated by the pumping test, it is unlikely that all the water emerging in the spring area can be delivered to the springs through the limestone and it appears that there must be another source for part of the water discharged in the spring area.

Again, the water emerging in the Carlsbad Spring area is more

highly mineralized than that found in the wells in the limestone. The average mineral contents shown by the analyses of water from wells in the Carlsbad limestone are about 157 parts per million of calcium, 63 parts of magnesium, 266 parts of bicarbonate, 352 parts of sulfate, and 153 parts of chloride. The specific conductance indicates an average content of total dissolved solids of about 975 parts per million. A table on page 248 gives analyses of various sources of water in the Carlsbad Spring area and indicates a discharge in that area of water much more highly mineralized than that found in wells in the Carlsbad limestone.

The average mineral content of the water of the combined spring flow was determined from analyses of water samples collected daily at the Green Street bridge gaging station by the Quality of Water Division of the U.S. Geological Survey, for the period October 1, 1938, to September 30, 1940. Analyses of samples collected when there was an appreciable inflow above the spring area were eliminated from the calculations. The average water passing the gaging station for the water year 1940, during periods when the entire flow was probably derived from the springs, contained about 400 parts per million calcium, 143 parts magnesium, 1,366 parts sulfate, 579 parts chloride, and 3,142 parts per million total solids. These averages are in line with the average constituents given in the analyses of individual sources. The fact that water issuing from the springs is much more highly mineralized than that from wells in the limestone indicates that water more highly mineralized than the spring water is commingling with the water coming in from the west in the Carlsbad limestone.

The two directions from which more highly mineralized water may be moving into the spring area are the east and north. Ground water, east of the Pecos River, occurs principally in the limestone of the Rustler formation. The yield of water obtained from it is usually so small that water coming in from the east can probably be eliminated as a major source of the more highly mineralized water. To the north there are three probable sources of the highly mineralized water, namely: leakage from Lake Avalon, leakage from the canal system on the left bank of the Pecos River, and return flow from irrigated lands in La Huerta. The relationships of these different sources to the spring flow have been discussed in another publication.[11] A brief discussion of these various sources contributing water to the Carlsbad Springs will be presented here. The

[11] National Resources Planning Board, *The Pecos River Joint Investigation, Reports of the Participating Agencies*, p. 59-62, 1942.

conclusions stated are those of the report of the Pecos River Joint Investigation.

Although it had been recognized that there was some leakage from Lake Avalon,[12] it was not until R. L. Lowry made a study of the available discharge records of the lake inflow and outflow during the course of the Pecos River Joint Investigation that it was suspected the leakage was large.

The inflow into Lake Avalon is measured at the gaging station at Reservoir Site No. 3, not far from the head of Lake Avalon. The outflow into the Main Canal is measured at the head of the Canal. In February 1940 a gaging station was installed in the river channel just below Lake Avalon to measure the spill from the lake. With the installation of the channel station below the dam, a continuous record of reservoir losses was obtainable.

The computations of leakage from Lake Avalon, made in the report of the Pecos River Joint Investigation, covered the period from February 6, 1940, to August 31, 1940, the latest period for which records were available at the time the report was prepared. In addition, an old capacity curve for Lake Avalon computed for conditions in 1907, was used. Since preparation of that report, stream-flow records to December 31, 1940, have become available and a new capacity curve, reflecting present conditions in the reservoir, has been completed. Present computations, using the longer record and new capacity curve, follow the methods described in the previous report, and the quantities arrived at are not essentially different.

Daily leakage from Lake Avalon was computed as the inflow of the Pecos River, as measured at Reservoir Site No.3, minus measured discharge from Avalon Reservoir into the stream and into the canal, minus the estimated evaporation, a minor quantity, and plus the loss of storage, or minus the gain in storage. Days in which rainfall occurred were not considered because direct runoff into Lake Avalon could not be determined. Days in which the flow into the reservoir exceeded 400 second-feet were also not considered, inasmuch as the rating curve for the gaging station was not well defined for such flows.

Figure 7 is a plot of the average leakage over 2-day periods against the average gage height during the respective periods. It will be noted that the arrowed lines joining consecutive points show, in general, a zigzag pattern. This pattern is due to small, inherent

[12] Meinzer, O. E., Renick, B. C., and Bryan, Kirk, *Geology of No. 3 Reservoir Site of the Carlsbad Irrigation Project*: U. S. Geol. Survey Water-Supply Paper 580, p. 28, 1926.

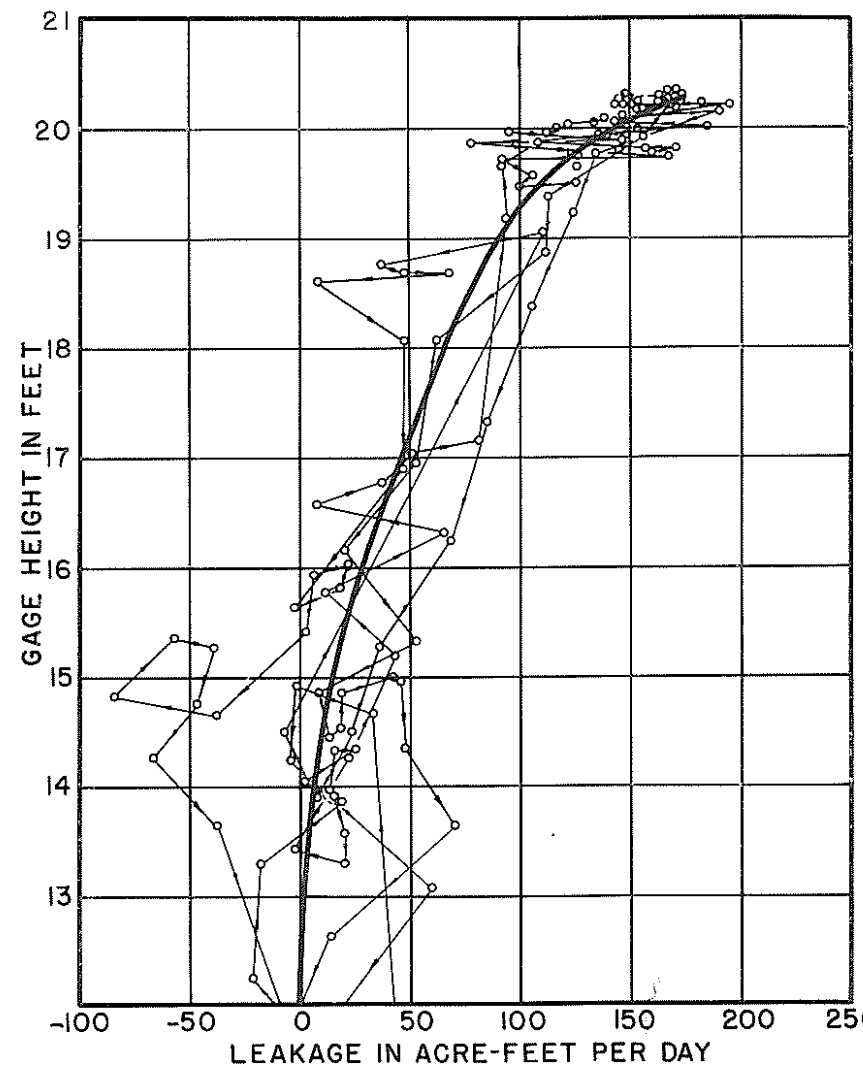

FIGURE 7

RELATION BETWEEN LEAKAGE AND GAGE HEIGHT AT LAKE AVALON, FEBRUARY 6, 1940, TO DECEMBER 31, 1940 errors in reading gage height, which make significant errors in the computed leakage, but such errors are compensated in succeeding periods. Criss-crossing of the lines, across the mean position of the points, indicates such balancing of errors. The heavy line drawn through the mean position of the points is, in effect, a rating curve for leakage from the reservoir.

By the application of the rating curve shown in Figure 7 to the record of gage height in the reservoir, it is computed that average leakage from Lake Avalon, in the water year ending September 30, 1940, was 27 second-feet (17,500,000 gallons a day). The amount computed from the rating curve, published in the Pecos River Joint Investigation report and based on the shorter period of record, was 26 second-feet.

Leakage from the Main Canal, between the intake at Lake Avalon and the flume across the Pecos near the Carlsbad Spring area, was computed as the inflow into the Main Canal, minus discharge at the flume minus diversions and loss by evaporation. Loss in the East Canal and laterals was computed as the discharge at the head of the canal, minus the waste at the lower end of the canal, minus diversions to the land. Total leakage in the canal system amounted to about 20 second-feet (12,900,000 gallons a day) in the water year ending September 30, 1940. An estimated 1 second-foot was returned to the spring area from the irrigated lands. These quantities are given in the report of the Pecos River Joint Investigation.

Total leakage from Lake Avalon and the canals, and the return from farmlands in La Huerta during the water year ending September 30, 1940, appears, therefore, to amount to about 48 second-feet (31,000,000 gallons a day). As the average flow of the Carlsbad Springs amounted to about 60 second-feet (38,750,000 gallons a day) during the period, it is indicated that ground-water flow to the springs through the limestone to the west of Carlsbad probably amounted to 12 second-feet (7,750,000 gallons a day), or about 20 percent of the flow.

If computations of the quantities of water from the various sources making up the spring flow are sufficiently accurate, the chemical content of the water emerging in the springs should represent the mixture of the chemical constituents of the various source waters in their respective proportions, except as leakage water may be modified in the passage underground. Such a comparison was made between the source waters and waters emerging in the Carlsbad Springs in the Pecos River Joint Investigation report. The average chemical composition of water in the Carlsbad limestone was obtained by averaging analyses from several samples of water collected

from wells deriving water from that source. The average composition of water leaking from Lake Avalon and the canals was obtained by weighting the analyses available from February 11, 1939, to February 10, 1940, according to the rate of leakage from Lake Avalon and the canals. The average composition of this water in the river, above the spring area, was assumed to be similar to the one available analysis of a water sample collected February 19, 1940. The average composition of water in the Carlsbad Springs was determined by weighting the analyses of water samples collected during the water year ending September 30, 1940, according to the time interval represented by each sample. About 1 second-foot is coming in as return flow from the farmlands of La Huerta. The composition of this water was assumed to be the same as the spring water and is not shown in the table mentioned below.

The average composition of water from the various sources, the observed composition of water from the Carlsbad Spring area, and its computed composition as a mixture of the other waters in the proportions indicated, are shown in the following table. Values given are not essentially different from those previously tabulated in the report of the Pecos River Joint Investigation.

COMPARISON OF AVERAGE CHEMICAL CONTENT OF WATER IN THE CARLSBAD AREA

	Carlsbad Limestone	Leakage from Lake Avalon	Leakage from Canals	Inflow above Carlsbad Springs	River below Carlsbad Springs		
					Computed	Observed	Percent Error
Estimated Discharge *Sec.-ft.*	12	27	20	1.8		61.8	
Chemical Content p.p.m.							
Calcium	157	562	538	592	475	400	+18.7
Magnesium	63	137	130	212	122	143	−14.7
Sulfate	352	1775	1684	2114	1474	1366	+ 7.9
Chloride	153	662	671	940	573	579	− 1.0
Total solids	975	3849	3732	4810	3271	3142	+ 4.1

POTENTIAL CONTAMINATION OF WATER SUPPLY IN WEST CARLSBAD

The populated area immediately west of the Carlsbad city limits has no sewer system and contains numerous privies and cesspools. The fill which overlies the Carlsbad limestone and from which the domestic water supply is derived, varies in thickness from 10 to 60 feet. The top 10 to 15 feet is made up of caliche and the lower part is made up of conglomerate, gravel, and buff clay. The cesspools are dug into the caliche and generally do not penetrate below it. No shallow body of water occurs in this locality above the limestone except, that near the eastern side of the community. This body of ground water is fed by seepage from the Southern Canal. As the water in the limestone is encountered under 10 or 15 feet of artesian pressure, the limestone itself must be practically impermeable but there may locally be joints or cavities through which upper water may percolate down to the aquifer. Further, it is possible that water from the privies and cesspools may move laterally to the walls of domestic wells, which are generally cased only down to the limestone, no attempt being made to obtain a watertight shutoff. Thus, water moving laterally to the wells may flow down the walls into the drinking water.

Water samples were collected from several wells in this locality in October and November 1939 and were sent to the State Public Health Laboratory, Albuquerque, N. Mex., for bacterial analyses. None of the analyzed samples showed *B. coli*, the indicator of animal excreta, including human sewage. Later, in March 1940, uranine, which is a harmless dye, was introduced into as many cesspools and privies in this locality as possible. The dye is red when concentrated but in weak solutions has a greenish color, which can be easily seen in concentrations of 1 part per million parts of water. Dye was mixed ¼ of a pound with 2½ gallons of water and put in each privy or cesspool. Householders were urged to report any coloring that they observed in the drinking water. No reports of any coloring of the water were received by the Health Department or by the U.S. Geological Survey.

On the basis of this evidence it is concluded that contamination of the water supply in West Carlsbad was not taking place at the time of the investigation; however, the danger always exists. Wells should be properly cased down into the limestone and a watertight seal should be obtained at the casing seat. Sampling of water in this locality should be carried on periodically for a check of conditions.

WATER IN OTHER FORMATIONS

RUSTLER FORMATION

The Rustler formation, of Permian age, takes its name from the type section in the Rustler Hills in Culbertson County, Tex., where the formation is made up of limestones and sandstones. It changes in character farther north, and near Carlsbad is composed of gypsum and red beds with one persistent bed of limestone near the middle

of the section. The best outcrops of the Rustler occur in the line of foothills parallel to the Barerra. The limestone exposed in the Frontier Hills is from 80 to 100 feet thick, but farther north erosion and gradation have left only scattered remnants from 5 to 6 feet thick. Eastward from these foothills the limestone grades largely into gypsum, leaving only thin beds of limestone which may be seen in outcrops along Black River and in some of the small hills surrounded by the valley fill. A series of alternating gypsum and red beds is exposed in a 15-foot-deep drain ditch south of Loving, which runs southward into Black River. These gypsum and red beds have been greatly distorted and lie almost in a vertical position in some places. These beds are probably Rustler, as Rustler limestone is found at about the same elevation about 0.7 mile from these exposures, but the limestone is so warped it could not be determined whether it overlies or underlies the gypsum and red beds exposed in the ditch. The Rustler formation in this area is warped and faulted because of solution that has taken place in the lower Rustler and formations below.

The key bed for the Rustler formation in the vicinity of Carlsbad is the easily recognized, fine-grained, dolomitic limestone. Without this marker it is difficult to identify the numerous gypsum and red beds in the section. Erosion has removed most of the beds above the limestone. The formation has a general eastward dip, but locally the numerous sinks developed in the formation give rise to dips in every direction.

Water is found in the limestone and in some of the solution passages developed in the gypsum beds of the Rustler formation. Water may pass out of the limestone into the gypsum beds or the fill above, but the thick red beds in the section are practically impervious. The recharge area for water occurring in the Rustler is probably along hills parallel to the Barrera and along the limestone adjacent to the fill in Dark Canyon Arroyo.

Most of the wells drilled west of Dark Canyon Arroyo and east of the Barrera in the Rustler formation are dry. This indicates, as might be expected, that there is not much water moving eastward from the Barrera through the Castile and Salado formations into the Rustler formation. Eastward from Dark Canyon Arroyo water occurs in some beds of the Rustler formation. One aquifer occurs in the gypsum bed immediately overlying the Salado and in close association with it. Near the Pecos River the water in the aquifer is a strong brine, as shown by a test well drilled in sec. 24, T. 24 S., R. 28 E., that encountered a water having 134,000 parts per million chloride and a specific gravity of 1.175.[13] According to reports of local farmers, some wells drilled west of the Pecos River and just north of Black River encountered a weak brine in the Rustler formation. This horizon is probably a continuation of the brine horizon in the Rustler formation near the Pecos River. It may continue west to Dark Canyon Arroyo where, near the recharge area, the water may contain less salt in solution, but there are no wells that would demonstrate this.

Water also would probably be found in the limestone member of the Rustler formation east of Dark Canyon Arroyo. A well located in sec. 15, T. 23 S., R. 26 E., encountered water in a limestone at a depth of 320 feet, the water rising 48 feet in the well. Because no log of the well is available, there is a possibility that the limestone aquifer may be one of the Quaternary limestone conglomerates, but well depth suggests the aquifer lies below the Quaternary.

In most of the area the Rustler formation has been stripped off down to the limestone and the valley fill commonly rests directly on the limestone. As a consequence, ground water may pass out of the limestone into the fill, in some places, and from the fill into the limestone, in others. The limestone apparently grades intc gypsum to the east, in some parts of the area. A well drilled in the NW¼SW¼SW¼ sec. 35, T. 22 S., R. 26 E., tc a depth of 300 feet encountered limestone at 70 feet, passed out of the limestone at 77 feet into 20 feet of clay, and then went into gypsum. No water was encountered. Wells drilled in secs. 7, 8, 17, and 18 to a depth of about 300 feet, went through a large amount of gypsum and encountered no water; thus, it appears that unless limestone stringers are encountered below the saturation zone, dry holes will result, with the exception of brine encountered in gypsum at the base of the Rustler formation in some parts of the area. However, few wells have been drilled in this area and too little information is at hand to reach any definite conclusions. As shown in the table of analyses beginning on page 243, the water obtained from the one well believed to obtain water from the limestone member is too low in sulfate to have passed through extensive gypsum beds, thus indicating further that no appreciable amount of water passes from the Barrera through the Castile and Salado formations into the Rustler formation. This points to the fill of Dark Canyon Arroyo as the chief source of water found in the Rustler formation. As the water moves eastward through the

[13] Robinson, T. W., and Lang, W. B., *Geology and Ground-Water Conditions of the Pecos River Valley in the Vicinity of Laguna Grande de la Sal, N. Mex., with Special Reference to the Salt Content of the River Water:* N. Mex. State Eng., 12th and 13th Bienn. Rept., p. 89, 1938.

limestone and fill material, undesirable sulfate and other minerals are picked up in solution until, in the farmland area somewhat farther west, the water is undesirable for drinking. In addition, highly mineralized water percolating downward from the farmlands and canals in the farmed area commingles with water from the west.

SALADO FORMATION

The Salado formation[14] of Permian age, sometimes referred to as the "Upper Castile," rests upon the Castile formation ("Lower Castile") and is overlain by the Rustler formation. The bulk of the Salado is made up of stratified beds of halite (common salt) with included beds of anhydrite. Beds of potash occur throughout the Salado section, the richer beds occurring in the upper part of the formation.

Rather extensive beds of gypsum outcrop in upper Hackberry Draw and along the face of the Barrera, between the Barrera and the Frontier Hills, and associated hills to the north. The gypsum in Hackberry Draw appears to be too high, stratigraphically, to be Castile, and it may be the equivalent of the Salado halite farther east, although it is equally possible that it represents the lower part of the Rustler. Some gypsum between the Barrera and the Frontier Hills may be of Salado age, but most of the deposit appears to be Castile.

Water has never been found in the halite beds of the Salado, anc any water coming in contact with the salt would soon become highly saline. Water occurs sparsely in channels in the anhydrite and ir the altered anhydrite in the outcrop area, where it is sometimes used to water stock even though highly charged with sulfates. Elsewhere, the water is too highly mineralized to be suitable for stocl or domestic use. The thick red beds occurring in the lower Rustle do not allow much water to percolate downward from the Rustle limestone or the valley fill. It is, therefore, inadvisable to dril into the Salado formation in search of potable water.

CASTILE FORMATION

The Castile formation consists, for the most part, of banded an hydrite, with included lenses of halite and thin beds of sandston and limestone. The upper beds of the formation crop out against th Barrera between the Barrera and the Frontier Hills. The Castil

[14] Lang, W. B., *Upper Permian Formation of Delaware Basin of Texas and New Mexico:* Am. Assoc. Petroleum Geologists Bull., Vol. 19, p. 262–270, 1935.

———, *Salado Formation of the Permian Basin:* Am. Assoc. Petroleum Geologists Bull., Vol. 23, No. 10, 1939.

rests upon the formations of the Delaware Mountain group and laps up against the Capitan and Carlsbad limestones. It is overlain by the Salado east of the Pecos River. Occasionally, water is found in channels in the anhydrite and in thin limestone and sandstone beds but, as in the Salado, the water is always highly mineralized. Water may move into the Castile formation from the Carlsbad limestone. It is inadvisable to drill into the Castile in search of potable water.

TABLE 1—CHEMICAL ANALYSES OF WATER FROM WELLS IN THE VICINITY OF CARLSBAD

Well Number*	Owner	Depth of Well (feet)	Use **	Date Sample Collected	Analyses (p. p. m.)						Specific Conductance $K \times 10^5$ (25° C)	Analyzed By†
					Calcium Ca	Magnesium Mg	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Hardness		
Wells in the valley fill east of the Southern Canal and south of Carlsbad												
1938												
23.28.6.333	W.W. Galton	18	S	May 11	1,106	162	278	1,834	2,150	.....	966	W. F. W.
23.28.8.131	Unknown	25	S,D	May 5	672	186	138	2,222	1,045	.....	639	Do.
23.28.9.314	Unknown	23	S	May 11	660	197	207	2,100	933	.....	590	Do.
23.28.11.131	Pardue & Guitar	18	S	May 11	668	...	134	2,364	1,153	.....	690	Do.
23.28.15.131	F. Nymeyer	80	S,D	Mar. 17	274	100	99	749	526	1,097	296	Do.
23.28.15.331	Unknown	24	S	May 11	668	181	144	2,041	939	.....	574	Do.
23.28.20.212	Rich Carter	16	S	May 11	740	206	106	2,053	1,560	2,695	760	Do.
23.28.23.224	Unknown	20	S	May 11	718	315	130	2,495	1,550	.....	824	Do.
23.28.23.333	Pardue & Guitar	24	S	May 11	.....	...	...	.....	1,532	.....	735	Do.
23.28.28.312	Cole	42	S	May 11	720	192	122	2,064	1,235	.....	641	Do.
23.28.28.442	T.W. Yarbo	18	S	May 11	.....	...	...	.....	2,072	.....	855	Do.
Wells in the valley fill near La Huerta												
1940												
21.27.19.411	Spencer	43	D	Apr. 26	584	197	105‡	1,972	895	.....	546	B. S.
21.27.29.321	H.C. Petree	40	D	Apr. 26	628	230	199‡	2,337	1,102	.....	673	Do.
21.27.30.141	J.W. Potter	80	S	Apr. 26	613	161	118	1,993	755	.....	508	Do.
21.27.30.142	Wayne Evrage	60	D	Apr. 26	572	183	139‡	1,872	866	.....	528	Do.
Wells in the valley fill west of the Carlsbad Canal												
1939												
22.26.25.242	K. Gass	150	D	Dec. 15	113	54	...	254	65	504	102	H.M.

See footnotes at end of table

Table 1. Chemical analyses of water from wells in the vicinity of Carlsbad *(continued)*

Well Number*	Owner	Depth of Well (feet)	Use **	Date Sample Collected	Analyses (p. p. m.) Calcium Ca	Magnesium Mg	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Hardness	Specific Conductance $K \times 10^5$ (25°C)	Analyzed By†
1942												
22.26.25.430	R.V. Barfield	140	D	Feb. 28	84	37	380	79	15	362	...	.....
22.26.25.440	W.M. Martin	140	D	Feb. 26	88	37	326	104	28	372	...	.....
22.26.35.220	City Airport	155	D	Mar. 9	88	31	350	42	5	347	...	.....
1939												
22.27.17.333	O.W. Hanson	90	I	Sep. 18	524	169	138	1,692	744	2,003	481	B. S.
22.27.18.414	J.E. Nabors	83	D	Sep. 14	404	135	183	1,314	533	1,564	381	Do.
22.27.18.444	Tom Ernest	60	D	Sep. 17	541	179	156	1,802	777	2,086	505	Do.
22.27.19.213a	D.B. Fuson	82	D	Sep. 15	346	112	189	1,082	425	1,324	320	Do.
22.27.19.213b	L.W. Warren	80	D	Sep. 14	.....	...	...	.....	515	.....	372	Do.
22.27.19.213e	Miles Black	80	D	Sep. 15	.....	...	...	.....	493	.....	361	Do.
22.27.19.214b	Joe Carlton	65	D	Sep. 14	468	148	158	1,524	611	1,777	425	Do.
22.27.19.214c	W.L. Nance	60	D	Sep. 15	.....	...	...	.....	640	.....	436	Do.
22.27.19.231	Harve Mayfield	68	D	Sep. 15	320	113	129	1,083	428	1,263	318	Do.
22.27.19.232a	A.A. Gorrell	85	D	Sep. 17	359	118	175	1,162	455	1,381	336	Do.
22.27.19.232b	C.C. Russell	72	D	Sep. 18	.....	...	...	.....	487	.....	356	Do.
22.27.20.111	E.C. Waltersheid	146	I	Sep. 17	.....	...	...	.....	797	.....	514	Do.
22.27.20.113	T.M. Neal, Jr.	110	I	Sep. 17	598	238	166	1,880	951	2,471	562	Do.
22.27.20.131	W.E. Hellyer	125	D	Sep. 17	436	154	138	1,455	603	1,721	411	Do.
22.27.20.133	Matthews	206	D	Dec. 14	100	74	...	506	281	553	185	H. M.
1940												
22.27.20.143	Gibson	127	I	Mar. 26	370	128	196‡	1,146	530	1,450	354	B. S.

See footnotes at end of table

Table 1. Chemical analyses of water from wells in the vicinity of Carlsbad *(continued)*

Well Number*	Owner	Depth of Well (feet)	Use **	Date Sample Collected	Analyses (p. p. m.) Calcium Ca	Magnesium Mg	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Hardness	Specific Conductance $K \times 10^5$ (25°C)	Analyzed By†
1939												
22.27.20.333	F. Gentry	195	D	Sep. 17	384	134	171	1,244	515	1,509	364	B. S.
1942												
22.27.30.133	W.H. Merchant	207	D	Feb. 28	138	56	252	354	79	575	...	....
1939												
22.27.31.331	K. Cass	160	S	Dec. 15	164	106	...	498	205	845	174	H. M.
1940												
23.26.3.400	K. Cass	300	D	May 14	60	37	243	117	28	302	...	B. S.
23.26.25.421	Nymeyer	176	D	Apr. 9	82	35	288‡	115	10	348	65.2	Do.
23.27.20.334	Forehand	136	S	Apr. 9	78	44	284‡	130	22	375	73.3	Do.
Wells deriving water from the Carlsbad limestone												
1939												
21.26.35.214	R.L. Pipkin	62	D	Sep. 25	165	62	256	394	156	667	151	B. S.
21.26.35.223b	Edwards	84	D	Sep. 25	.....	...	...	.....	262	.....	214	W. F. W.
21.26.35.232a	Sam Jones	83	D	Sep. 25	.....	...	...	.....	154	.....	146	Do.
21.26.35.232b	M.H. Holley	84	D	Sep. 25	245	79	244	672	257	936	222	B. S.
21.26.35.234a	E.L. Rupert	71	D	Sep. 25	.....	...	...	.....	156	.....	137	W. F. W.
21.26.35.234b	W.C. Brandon	86	D	Sep. 25	157	63	266	386	152	651	148	B. S.
21.26.35.241	Frank Cox	62	D	Sep. 25	.....	...	...	.....	233	.....	194	W. F. W.
21.26.35.412	Paul Kennedy	...	D	Sep. 25	.....	...	...	.....	151	.....	143	Do.
				Sep. 25								

See footnotes at end of table

Table 1. Chemical analyses of water from wells in the vicinity of Carlsbad *(continued)*

Well Number*	Owner	Depth of Well (feet)	Use **	Date Sample Collected	Analyses (p. p. m.) Calcium Ca	Magnesium Mg	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Hardness	Specific Conductance $K \times 10^5$ (25°C)	Analyzed By†
21.26.35.414	Harvey Buse	92	D	Sep. 25	.....	...	...	.....	302	.....	221	W.F.W.
21.26.35.432	Dickson	114	I	Sep. 25	159	67	148	500	196	672	169	B. S.
21.26.35.444	Tom McKinney	71	D	Sep. 26	.....	...	...	.....	134	.....	125	W. F. W.
				1940								
21.27.31.211	W.H. Merchant	302	D	Apr. 26	157	57	231‡	429	180	626	166	B. S.
				1939								
22.26.1.121a	E.E. Walthall	84	D	Oct. 24	.....	...	...	.....	144	.....	139	W. F. W.
22.26.1.121b	M.C. Cathcart	74	D	Oct. 24	.....	...	...	.....	152	.....	144	Do.
22.26.1.122	McKinney	60	...	Oct. 24	.....	...	...	.....	755	.....	452	Do.
22.26.1.124	Lea Mays	...	D	Oct. 24	.....	...	...	.....	166	.....	148	Do.
22.26.1.233a	Southwestern Public Service Co.	150	PS	Oct. 6	.....	...	...	.....	165	.....	147	Do.
22.26.1.233b	Carlsbad, N.Mex.	150	PS	Oct. 6	125	55	214	331	144	538	136	B. S.
22.26.1.233c		237	PS	Oct. 6	.....	...	...	.....	169	.....	144	W. F. W.
22.26.1.233d		230	PS	Oct. 6	133	64	162	398	170	595	148	B. S.
22.26.1.321a	I.C. Austin	...	D	Oct. 24	.....	...	...	.....	158	.....	148	W. F. W.
22.26.1.321b	J. Bryan	81	D	Oct. 24	212	84	250	583	284	874	219	B. I.
22.26.2.221a	D.C. Neel	104	D	Sep. 26	76	60	146	336	52	436	102	Do.
22.26.2.221b	John Cooper	115	D	Sep. 26	80	56	190	223	109	430	105	Do.
22.26.2.221c	G. Cooper	100	D	Oct. 24	70	52	258	147	73	388	91.8	Do.
22.26.2.223a	C.C. West	113	D	Sep. 26	.....	...	...	.....	160	.....	136	W. F. W.
22.26.2.223b	W. Karchner	94	D	Sep. 26	72	47	226‡	159	89	373	93.0	B. I.
22.26.2.223c	L.L. Grenillian	86	D	Sep. 26	.....	...	...	.....	98	.....	93.5	W. F. W.
22.26.2.243a	J.C. Todd	89	D	Sep. 26	65	33	224‡	98	64	298	74.6	B. I.

See footnotes at end of table

Table 1. Chemical analyses of water from wells in the vicinity of Carlsbad *(continued)*

Well Number*	Owner	Depth of Well (feet)	Use **	Date Sample Collected	Analyses (p. p. m.) Calcium Ca	Magnesium Mg	Bicarbonate HCO_3	Sulfate SO_4	Chloride Cl	Hardness	Specific Conductance $K \times 10^5$ (25°C)	Analyzed By †
22.26.2.243b	T.D. Pierce	115	D	Sep. 26	.....	...	...	.....	82	.....	85.6	W. F. W.
22.26.2.243c	Fred Hudson	145	D	Sep. 26	.....	...	...	.....	79	.....	79.6	Do.
22.26.2.423	Briggs	86	D	Oct. 9	.....	...	...	.....	96	.....	101	Do.
22.26.2.441	Q.E. Bural	80	D	Sep. 26	.....	...	...	.....	122	.....	111	Do.
				1938								
22.26.2.334	J.F. Hunick	105	D	Apr. 15	.....	...	258	.....	78	.....	98.9	.....
22.26.3.232	Happy Valley Farms	345	I	Aug. 10	214	63	198‡	709	264	793	.....	.....
22.26.11.143	S.H. Taylor	172	I	Aug. 10	145	52	272‡	342	135	576	.....	§
22.26.14.213	Stephenson	130	I	Aug. 10	89	32	282‡	171	78	354	.....	§
22.26.23.222	Hart	...	D	Aug. 10	126	39	289	183	5	475	.....	§
	Well probably in limestone of the Rustler Formation											
				1939								
23.26.15.4	T.J. Lovejoy	315		Dec. 15	109	42	228‡	249	14	445	84.7	.....

* For description of system of numbering wells see "Method of Designating Wells."

** D=Domestic; I=Irrigation; S=Stock; PS=Public Supply.

† All analyses by U.S. Geological Survey except as otherwise noted. Names of analysts: Burdge Ireland, Harry Mauger, Benton Stone, Jr., Walter F. White.

‡ Includes a small amount of normal carbonate.

§ Water analyses obtained from Southwestern Public Service Company.

TABLE 2. ANALYSES OF WATER FROM THE CARLSBAD SPRING AREA NEAR CARLSBAD

Sample No.*	Date	Parts per Million						Spec. Cond. $K \times 10^5$ (25° C)	Analyzed By**
		Calcium (Ca)	Magnesium (Mg)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Total Solids		
		Carlsbad Spring							
1.	Mar. 15, 1938	468	128	...	1,505	565	.....	414	H.M.
2.	Apr. 26, 1938	493	128	...	1,500	570	.....	416	Do.
3.	July 6, 1938	512	126	...	1,477	560	.....	413	Do.
4.	July 11, 1938	...	...	141	.....	573	.....	412	W.F.W.
5.	Nov. 5, 1938	...	...	...	.....	570	.....	403	W.W.H.
6.	June 3, 1939	...	...	...	.....	605	.....	420	H.F.B.
7.	Aug. 25, 1939	466	136	184	1,498	608	3,312	421	B.S.
8.	Oct. 28, 1939	488	128	158	1,490	590	.....	414	Do.
9.	Feb. 19, 1940	502	137	...	1,570	620	3,480	433	H.M.
10.	Mar. 14, 1940	510	138	164	1,588	625	3,520	438	B.I.
11.	Apr. 8, 1940	...	...	...	.....	595	.....	430	B.S.
12.	May 21, 1940	498	128	143†	1,526	585	3,358	420	Do.
		Small springs on right side of Pecos (looking downstream)							
13.	Mar. 7, 1940	171	60	262	419	172	1,070	164	B.I.
14.	Feb. 19, 1940	415	118	...	1,245	500	.....	362	H.M.
15.	May 28, 1938	548	143	178	1,640	651	.....	447	W.F.W.
16.	July 6, 1938	558	136	...	1,628	620	.....	447	H.M.
17.	Aug. 1, 1938	570	138	...	1,633	630	.....	445	Do.
18.	Nov. 5, 1938	...	...	...	.....	628	.....	432	W.W.H.
19.	Aug. 25, 1939	...	...	...	.....	675	.....	462	B.S.
20.	Aug. 1, 1938	563	140	...	1,620	630	.....	445	H.M.
21.	Nov. 5, 1938	...	...	...	.....	628	.....	429	W.W.H.
22.	Aug. 25, 1939	536	150	162	1,686	675	3,802	462	B.S.
23.	Feb. 19, 1940	...	...	...	.....	650	.....	451	H.M.
		Small springs on left side of Pecos (looking downstream)							
24.	July 11, 1938	297	90	228	888	355	.....	277	W.F.W.
25.	Mar. 7, 1940	334	105	158	1,029	425	2,340	316	B.I.
26.	Mar. 7, 1940	376	112	146	1,190	490	2,670	350	Do.
27.	Mar. 7, 1940	450	128	134	1,398	570	3,140	399	Do.
28.	Oct. 28, 1939	410	120	202	1,180	467	.....	345	B.S.
29.	Aug. 25, 1939	396	122	189	1,236	500	2,836	360	Do.
30.	Mar. 7, 1940	...	...	...	.....	430	.....	327	B.I.

* The following are brief explanations regarding locations where samples were taken (right and left are relative to downstream view).

**Names of Geological Survey analysts whose initials are shown: Harry Mauger, Walter F. White, Warren W. Hastings, Harry F. Burkstaller, Benton Stone, Burdge Ireland.

† Includes small equivalent of carbonate (CO_3), 8.9 parts per million.

1\. to 12. Carlsbad Spring sampled from water passing over weir.

13\. One of three "boils" in small arroyo on right bank of Pecos below island, between Carlsbad Spring and Canal Street bridge. Farm house south of here.

Table 2. Analyses of water from the Carlsbad Spring area near Carlsbad *(continued)*

14. Spring 200 yards below Carlsbad Spring. Right bank. (One of several "boils" near right bank.)

15. to 19. Small stream flowing into pool under lower end of flume above Carlsbad Springs.

20. Stream underneath flume. Flow controlled by wooden trough. No water in canal, but water standing in flume.

21. to 23. Water in wooden trough under flume.

24. Spring in Carlsbad Spring area. North side of Pecos River. Temp. 69° F.

25. Spring at head of small inlet below the first arroyo. This inlet has hundreds of small sand "boils."

26. Spring sampled at head of second arroyo below the Carlsbad flume on the left bank of the Pecos.

27. Spring on left bank (north) of Pecos River. This spring issues from the first arroyo below the Carlsbad flume.

28. North Carlsbad Spring at head, just below ditch crossing.

29. Spring in Carlsbad Spring area in first arroyo below the flume. Sampled about 25 yards from the river.

30. Spring on left bank near head of small inlet about midway between the first and second arroyos below the Carlsbad flume.

TABLE 3. WELL RECORDS

Well Number*	Owner	Well Depth Reptd. feet	Diam. inches	Use **	Measuring Point Altitude feet	Measuring Point Feet Above LS	Date	Depth to Water Below LS feet	Date	Depth to Water Below LS feet
		Wells deriving water from the valley fill								
22.26.25.242	K. Cass	150	6	D	3185.0†	flush	Dec. 15, 1939	94.82	....	.....
22.27.8.442	Anthony	17	6	S	3091.82†	1.82	....	.....	Apr. 30, 1940	11.26
22.27.15.244	...(unknown)	...	10	S	3072.0†	flush	....	.....	Apr. 30, 1940	7.96
22.27.16.333	Brickley & Smith	44	6	S	3117.57†	0.57	Mar. 11, 1940	32.61	Apr. 30, 1940	28.41
22.27.17.333	O.W. Hanson	90	8	I	3134.06	2.06	Sep. 20, 1939	35.43	....	.....
22.27.18.444	Tom Ernest	60	6	D	3131.08	1.63	Sep. 17, 1939	32.85	May 2, 1940	35.80
22.27.19.213	Miles Black	80	6	D	3140.60	0.70	Sep. 14, 1939	43.51	May 4, 1940	47.43
22.27.19.214	Joe Carlton	65	6	D	3133.40	flush	Sep. 14, 1939	38.34	May 4, 1940	41.02
22.27.19.231	Harve Mayfield	68	6	D	3145.13	1.70	Sep. 14, 1939	47.85	May 4, 1940	51.34
22.27.19.232a	A.A. Gorell	85	6	D	3143.03	1.70	Sep. 15, 1939	45.85	May 4, 1940	48.91
22.27.19.232b	C.C. Russell	72	6	D	3145.25	0.81	Sep. 18, 1939	48.99	May 4, 1940	52.16
22.27.20.131	W.E. Hellyer	125	6	D	3143.57	1.00	Sep. 12, 1939	49.17	May 3, 1940	52.16
22.27.20.133	Matthews	206	6	D	3146.52	1.50	....	.....	May 3, 1940	54.04
22.27.20.134	J. Autry	126	8	D	3142.66	flush	Sep. 17, 1939	49.04	May 3, 1940	50.57
22.27.20.143b	Gibson	127	8	I	3140.82	0.20	....	.....	Mar. 26, 1940	49.82
22.27.20.333	F. Gentry	195	..	D	3154.37†	1.37	....	.....	May 3, 1940	64.26
22.27.21.222	Waltersheid	...	6	S	3106.97†	1.97	Mar. 11, 1940	31.83	Apr. 30, 1940	28.73
22.27.22.224	W. D. Bales	37	6	S	3093.82†	0.82	Mar. 11, 1940	21.81	Apr. 30, 1940	21.28
22.27.25.441	Gadbury	16	72	S	3062.00†	flush	Mar. 11, 1940	12.59	Apr. 30, 1940	10.97
22.27.26.223	J.C. Ewers	40	6	S	3076.64†	0.64	Mar. 11, 1940	19.52	Apr. 30, 1940	18.60
22.27.26.444	...(unknown)	...	6	S	3074.40†	0.40	Mar. 11, 1940	13.02	Apr. 30, 1940	10.72
22.27.27.122	J.C. West	40	6	S	3106.54†	0.54	Mar. 11, 1940	29.00	Apr. 30, 1940	27.53
22.27.27.333	Lopez	140	6	S	3118.40†	0.40	Mar. 12. 1940	34.79	Apr. 30, 1940	30.67

See footnotes at end of table

Table 3. Well records (*continued*

Well Number*	Owner	Well Depth Reptd. feet	Diam. inches	Use **	Measuring Point Altitude feet	Measuring Point Feet Above LS	Date	Depth to Water Below LS feet	Date	Depth to Water Below LS feet
22.27.31.331	K. Cass	160	6	S	3207.10†	1.10	Dec. 12, 1939	117.78	May 3, 1940	116.60
22.27.34.344	A.J. Crawford	61	6	S	3106.0†	flush	Mar. 12, 1940	42.77	Apr. 30, 1940	38.83
23.26.3.	Snyder & Cass	290	6	D	....	....	May 14, 1940	225.60	....	.....
23.26.25.421	Nymeyer	176	6	S	3205.7†	0.7	....	.....	May 3, 1940	139.82
23.27.1.122	...(unknown)	20	48	S	3065.8†	0.8	Mar. 11, 1940	15.80	Apr. 30, 1940	9.18
23.27.2.331	H. Hopper	63	6	S	3087.5†	1.5	Mar. 12, 1940	20.88	Apr. 30, 1940	22.86
23.27.11.433	A.M. Hoose	14	60	S	3102.0†	flush	Mar. 12, 1940	8.43	Apr. 30, 1940	6.29
23.27.20.334	Forehand	125	6	S	3182.0†	1.0	....	.....	May 3, 1940	118.20
23.28.6.333	W.W. Galton	See Table 4 for record.								
23.28.8.131	...(unknown)		do.							
23.28.9.314	...(unknown)		do.							
23.28.11.131	Pardue & Guitar		do.							
23.28.15.331	...(unknown)		do.							
23.28.18.111	J.M. Jose	18	48	S	3060.0	1.0	Mar. 12, 1940	13.02	Apr. 30, 1940	9.55
23.28.19.111	...(unknown)	16.5	60	N	3087.0	flush	Mar. 12, 1940	14.06	Apr. 30, 1940	11.36
23.28.20.212	R. Carter	See Table 4 for record.								
23.28.23.224	...(unknown)		do.							
23.28.23.333	Pardue & Guitar		do.							
23.28.25.211	L.W. Arthur		do.							
23.28.28.312	Cole		do.							
23.28.28.442	T.W. Yarbro		do.							
23.28.30.122	...(unknown)	...	..	S	3082.4	0.4	Mar. 12, 1940	10.97	Apr. 30, 1940	11.59
24.28.3.211	C.W. Beeman	See Table 4 for record.								
24.28.3.423	do.		do.							

See footnotes at end of table

Table 3. Well records *(continued)*

Well Number*	Owner	Well Depth Reptd. feet	Diam. inches	Use **	Measuring Point Altitude feet	Measuring Point Feet Above LS	Date	Depth to Water Below LS feet	Date	Depth to Water Below LS feet
		Wells deriving water from the Carlsbad limestone								
21.26.35.214	L.R. Pipkin	62	6	D	3156.24	1.50	Sep. 25, 1939	49.17	May 6, 1940	48.60
21.26.35.223a	Norman Harris	80	6	D	3162.48	flush	Sep. 25, 1939	56.94	May 6, 1940	58.34
21.26.35.232	S. Jones	83	6	D	3165.42	1.83	Sep. 25, 1939	57.85	May 6, 1940	57.77
21.26.35.241	F. Cox	62	6	D	3157.22	1.04	Sep. 25, 1939	50.54	May 6, 1940	49.96
21.26.35.234	W.C. Brandon	86	6	D	3169.56	1.96	Sep. 25, 1939	61.38	May 6, 1940	61.13
21.26.35.412	Paul Kennedy	...	6	D	3172.50	1.56	Sep. 25, 1939	64.83	....	.....
21.26.35.432	Dickson	114	8	I	......	....	....	.....	(reported)	73.00
21.27.30.334	L.R. Mott	80	6	D	3121.89†	0.89	....	.....	Apr. 26, 1940	18.43
21.27.31.211	W.H. Merchant	302	6	D	3115.23†	1.23	....	.....	Apr. 26, 1940	13.65
22.26.1.124	Lea Mays	...	..	D	3144.23	0.80	Oct. 24, 1939	41.08	May 6, 1940	38.80
22.26.1.233a	Southwestern Public Service Co.	150	5	PS	3108.42	‡	Oct. 29, 1939	29.93	Feb. 26, 1940	26.77
22.26.1.233b	do.	150	..	PS	......	....	....	.....	....	.....
22.26.1.233c	do.	150	5	PS	......	....	....	.....	....	.....
22.26.1.233d	do.	237	12	PS	......	....	....	.....	....	.....
22.26.2.221a	O.C. Neel	104	6	D	3172.77	0.64	Sep. 26, 1939	65.76	May 6, 1940	65.34
22.26.2.221b	J. Cooper	115	8	D	3175.06	0.61	Sep. 26, 1939	68.17	....	.....
22.26.2.223a	C.C. West	113	6	D	......	....	....	.....	....	.....
22.26.2.223b	W. Karchner	94	6	D	3171.55	0.60	Sep. 26, 1939	64.46	....	.....
22.26.2.243a	J.C. Todd	80	6	D	3179.32	3.00	Sep. 26, 1939	66.53	....	.....
22.26.2.243c	F. Hudson	145	6	D	3187.51	0.30	Sep. 26, 1939	80.52	....	.....
22.26.2.334	Hunick	105	6	D	3190.87	2.90	Dec. 1939	81.15	....	.....
22.26.2.423	Briggs	86	6	D	3167.14	1.30	Oct. 9, 1939	59.53	May 6, 1940	62.44

See footnotes at end of table

Table 3. Well records *(continued)*

Well Number*	Owner	Well Depth Reptd. feet	Diam. inches	Use **	Measuring Point Altitude feet	Measuring Point Feet Above LS	Date	Depth to Water Below LS feet	Date	Depth to Water Below LS feet
22.26.2.441	Q.E. Bural	80	6	D	3166.52	0.50	Sep. 26, 1939	59.48	May 6, 1940	58.95
22.26.3.232	Happy Valley Farms	345	..	I	3252.52	flush	....	.....	Mar. 15, 1940	143.52
22.26.11.121	Taylor	152	..	I	......	....	....	.....	....	.....
22.26.11.143	do.	262	..	I	......	flush	....	.....	Jan. 15, 1940	59.82
22.26.11.223	T. Marquess	116	..	I	......	....	....	.....	(reported)	35.40
22.26.14.213	Stephenson	206	..	I	......	....	....	.....	....	.....
		Well deriving water from limestone of the Rustler formation								
23.26.15.4	J.T. Lovejoy	315	6	D	......	....	....	.....	(reported)	267.0

* For description of system of numbering wells, see "Method of Designating Wells."

** D=Domestic; I=Irrigation; S=Stock; PS=Public Supply; N=None.

† Altitude of land surface estimated from topographic map of Carlsbad quadrangle to closest foot.

‡ Measuring point 26.77 feet below land surface.

TABLE 4. DEPTH TO WATER IN OBSERVATION WELLS DRAWING WATER FROM THE VALLEY FILL

23.28.6.333. W. W. Galton. Stock well, dug 3 feet square, 17½ feet deep. Cased with concrete to 4 feet, uncased remainder of depth. Measuring point, top of 2- by 4-inch wood pipe clamp, north side at copper nail with washer, 0.5 foot above land surface altitude 3,047.5 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 11, 1938	15.49	Aug. 23, 1938	10.15	July 27, 1939	12.33
Mar. 26	14.25	Sept. 15	8.02	Sept. 5	7.60
Apr. 1	13.50	Oct. 6	10.44	Sept. 19	10.22
Apr. 11	12.91	Oct. 26	10.35	Oct. 2	8.56
Apr. 21	12.80	Dec. 3	12.84	Oct. 20	9.50
May 1	11.71	Dec. 21	13.33	Nov. 6	10.61
May 11	11.02	Jan. 7, 1939	13.22	Nov. 17	11.65
May 21	11.17	Jan. 21	14.35	Dec. 11	13.12
June 1	12.59	Mar. 8	14.05	Jan. 4, 1940	13.67
June 11	13.90	Mar. 30	14.51	Jan. 29	14.55
June 21	13.54	Apr. 13	11.38	Feb. 17	15.64
July 1	12.69	May 2	10.04	Mar. 28	15.03
July 16	13.42	June 1	11.14	Apr. 30	11.48
Aug. 3	12.74	July 18	13.27		

23.28.8.131. Owner unknown. Stock well dug 3 feet square, 25 feet deep. Cased with horizontal wood cribbing. Measuring point, top of 4- by 4-inch post at northwest corner of curb, 1 foot above general land surface altitude 3,033 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 15, 1938	21.65	Sept. 15, 1938	9.49	July 27, 1939	8.38
Apr. 1	20.42	Oct. 6	10.93	Sept. 5	3.82
Apr. 11	13.18	Oct. 26	10.86	Sept. 19	7.32
Apr. 21	14.05	Dec. 3	14.09	Oct. 2	7.16
May 1	14.20	Dec. 21	14.76	Oct. 20	7.39
May 11	14.68	Jan. 7, 1939	16.42	Nov. 6	9.07
May 21	15.17	Jan 21	16.81	Nov. 17	10.17
June 1	16.20	Feb. 11	17.31	Dec. 11	11.45
June 11	17.09	Mar. 8	17.45	Jan. 4, 1940	8.33
June 21	17.52	Mar. 30	16.35	Jan. 29	15.02
July 1	17.24	Apr. 13	13.93	Feb. 17	14.95
July 16	12.12	May 2	15.29	Mar. 28	13.94
Aug. 3	14.05	June 1	10.69	Apr. 30	9.56
Aug. 23	10.10	July 18	7.66		

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

23.28.9.314. Owner unknown. Stock well dug 6 feet in diameter, 23 feet deep. Uncased. Measuring point, top of 2- by 4-inch timber at southeast corner of well opening at copper nail with washer, at land surface altitude 3,027 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938-1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 17, 1938	21.74	July 1, 1938	19.50	Oct. 20, 1939	16.49
Apr. 1	21.26	July 16	17.19	Nov. 6	17.41
Apr. 11	21.32	Aug. 3	18.50	Nov. 17	18.19
Apr. 21	19.79	Aug. 23	16.09	Dec. 11	18.93
May 1	20.12	Sept. 15	15.07	Jan. 4, 1940	19.79
May 11	19.52	Oct. 6	well filled	Jan. 29	20.58
May 21	19.59	July 27, 1939	17.53	Feb. 17	21.89
June 1	18.83	Sept. 5	15.77	Mar. 28	21.57
June 11	19.12	Sept. 19	15.80	Apr. 30	20.23
June 21	18.90	Oct. 2	16.62		

23.28.11.131. Pardue and Guitar. Stock well drilled 8 inches in diameter, 18 feet deep. Iron casing. Measuring point, top of casing 3.4 feet above land surface altitude 2,996.4 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 15, 1938	12.18	Sept. 15, 1938	7.25	July 27, 1939	6.98
Apr. 1	11.31	Oct. 6	6.59	Sept. 5	5.04
Apr. 11	10.25	Oct. 26	8.06	Sept. 19	6.92
Apr. 21	9.15	Dec. 3	11.50	Oct. 2	7.88
May 1	9.67	Dec. 21	10.10	Oct. 20	7.07
May 11	9.96	Jan. 7, 1939	10.36	Nov. 6	7.86
May 21	9.44	Jan. 21	10.69	Nov. 17	8.22
June 1	9.69	Feb. 11	10.79	Dec. 11	8.84
June 11	10.37	Mar. 8	11.00	Jan. 4, 1940	9.42
June 21	9.62	Mar. 30	10.85	Jan. 29	10.16
July 1	10.52	Apr. 13	9.35	Feb. 17	10.42
July 16	8.32	May 2	9.18	Mar. 28	6.92
Aug. 3	9.59	June 1	9.89	Apr. 30	6.31
Aug. 23	7.94	July 18	7.22		

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

23.28.15.331. Owner unknown. Stock well dug 3- by 6-feet, 23.7 feet deep. Uncased. Measuring point, top of 2- by 12-inch timber, northwest corner at copper nail with washer, at land surface altitude 3,025 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 17, 1938	21.43	Sept. 15, 1938	17.61	July 27, 1939	19.46
Apr. 1	21.56	Oct. 6	18.20	Sept. 5	18.63
Apr. 11	21.61	Oct. 26	18.76	Sept. 19	18.13
Apr. 21	19.55	Dec. 3	19.59	Oct. 2	18.21
May 1	19.56	Dec. 21	19.90	Oct. 19	18.31
May 11	19.88	Jan. 7, 1939	20.22	Nov. 6	18.60
May 21	20.07	Jan. 21	20.52	Nov. 17	18.83
June 1	20.01	Feb. 11	20.94	Dec. 11	19.28
June 11	20.14	Mar. 8	21.51	Jan. 4, 1940	19.79
June 21	20.23	Mar. 30	21.17	Jan. 29	20.72
July 1	19.25	Apr. 13	21.10	Feb. 17	20.82
July 16	19.52	May 2	20.80	Apr. 30	20.84
Aug. 3	18.74	June 1	20.68		
Aug. 23	17.73	July 18	19.54		

23.28.20.212. Rich Carter. Stock well dug 5 feet square, 16 feet deep. Uncased. Measuring point, top of 2- by 4-inch timber upright, southwest corner of well curb at copper nail with washer, 2.0 feet above land surface altitude 3,042 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 17, 1938	10.91	Aug. 3, 1938	5.35	Sept. 5, 1939	2.28
Apr. 1	9.71	Oct. 8	4.83	Sept. 19	4.42
Apr. 11	9.05	Oct. 25	5.22	Oct. 2	4.83
Apr. 21	8.21	Nov. 8	6.01	Oct. 19	5.22
May 1	7.21	Dec. 3	6.86	Nov. 6	6.74
May 11	7.47	Dec. 21	6.56	Nov. 17	7.42
May 21	7.15	Jan. 7, 1939	7.71	Dec. 12	9.74
June 1	5.75	Feb. 11	8.51	Dec. 28	9.21
June 11	6.55	Mar. 9	9.65	Mar. 28, 1940	8.30
June 21	6.49	Apr. 14	7.41	Apr. 30	5.69
July 1	7.24	July 27	4.64		
July 16	4.62	Aug. 15	3.88		

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

23.28.23.224. Owner unknown. Abandoned well dug 6 feet in diameter, 20 feet deep. Uncased. Measuring point, top of wood platform over well at northwest corner of trapdoor, at land surface altitude 2,986 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 15, 1938	17.87	Sept. 15, 1938	14.60	July 27, 1939	13.31
Apr. 1	17.12	Oct. 6	13.55	Sept. 5	13.25
Apr. 11	13.34	Oct. 26	14.26	Sept. 19	12.62
Apr. 21	14.90	Dec. 3	15.82	Oct. 2	11.52
May 1	14.80	Dec. 21	15.79	Oct. 19	12.62
May 11	14.95	Jan. 7, 1939	16.26	Nov. 6	13.88
May 21	15.33	Jan. 21	16.76	Nov. 17	14.43
June 1	16.74	Feb. 11	17.42	Dec. 11	15.35
June 11	16.21	Mar. 8	18.00	Jan. 21, 1940	16.18
June 21	16.31	Mar. 30	17.65	Jan. 29	16.95
July 1	16.27	Apr. 13	16.94	Feb. 17	17.54
July 16	15.58	May 2	16.19	Mar. 28	17.66
Aug. 3	14.47	June 1	14.08	Apr. 30	15.12
Aug. 23	14.44	July 18	13.87		

23.28.23.333. Pardue and Guitar. Stock well dug 4 feet in diameter, 24.4 feet deep. Uncased. Measuring point, top of timber spanning well, near center at copper nail with washer, at land surface altitude 3,020 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 15, 1938	21.48	Sept. 15, 1938	13.67	July 27, 1939	14.87
Apr. 1	21.89	Oct. 6	15.31	Sept. 5	13.69
Apr. 11	18.90	Oct. 25	16.49	Sept. 19	12.95
Apr. 21	18.02	Nov. 8	17.34	Oct. 2	13.82
May 1	18.19	Dec. 3	18.46	Oct. 19	15.17
May 11	18.02	Dec. 21	19.22	Nov. 6	16.13
May 21	18.02	Jan. 7, 1939	19.74	Nov. 17	17.06
June 1	18.30	Jan. 21	20.38	Dec. 11	17.89
June 11	18.68	Feb. 11	21.17	Jan. 4, 1940	18.93
June 21	17.80	Mar. 7	21.32	Jan. 29	20.12
July 1	16.98	Apr. 13	17.89	Feb. 17	20.85
July 16	16.02	May 2	18.30	Mar. 28	21.62
Aug. 3	15.50	June 1	18.10	Apr. 30	17.46
Aug. 23	13.94	July 18	14.45		

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

23.28.25.211. L. W. Arthur. Stock well drilled 6 inches in diameter, 45.4 feet deep. Cased with iron casing to an unknown depth. Measuring point, top of 6-inch casing, 0.8 foot above land surface, altitude 2,984.8 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 15, 1938	37.21	Sept. 15, 1938	34.64	July 27, 1939	34.03
Apr. 1	37.48	Oct. 6	34.20	Sept. 5	34.51
Apr. 11	37.09	Oct. 25	33.96	Sept. 19	32.19
Apr. 21	33.39	Nov. 8	34.39	Oct. 2	32.05
May 1	36.50	Dec. 3	35.05	Oct. 19	31.83
May 11	36.51	Dec. 21	35.41	Nov. 6	32.31
May 21	36.41	Jan. 7, 1939	35.76	Nov. 17	32.78
June 1	35.53	Jan. 21	36.11	Dec. 11	33.71
June 11	36.15	Feb. 11	36.58	Jan. 4, 1940	34.60
June 21	36.20	Mar. 7	37.01	Jan. 29	36.44
July 1	36.20	Apr. 13	36.84	Feb. 17	36.00
July 16	37.05	May 2	36.42	Mar. 28	36.39
Aug. 3	34.71	June 1	35.59	Apr. 30	36.10
Aug. 23	35.00	July 18	34.34		

23.28.28.312. Mr. Cole. Stock well drilled 6 inches in diameter, 42 feet deep. Iron casing. The water level in this well is for the second water-bearing bed encountered in this locality. Measuring point, top of casing, 1.0 foot above land surface altitude 3,071 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 17, 1938	15.49	Aug. 3, 1938	12.67	July 18, 1939	11.00
Apr. 1	14.77	Sept. 15	10.56	July 27	11.41
Apr. 11	14.06	Oct. 6	11.80	Aug. 15	12.41
Apr. 21	13.30	Oct. 25	12.56	Sept. 5	13.00
May 1	12.70	Nov. 8	13.13	Sept. 19	11.60
May 11	13.06	Dec. 3	13.85	Oct. 2	11.85
May 21	13.30	Dec. 21	14.04	Oct. 19	12.02
June 1	13.26	Jan. 7, 1939	14.29	Nov. 6	12.84
June 11	13.76	Feb. 11	14.91	Dec. 12	13.85
June 21	12.65	Mar. 8	15.17	Dec. 28	14.12
July 1	13.22	Apr. 14	13.21	Mar. 28, 1940	13.46
July 16	12.03	June 2	10.15	Apr. 30	12.21

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

23.28.28.442. T. W. Yarbro. Stock well dug 6 feet in diameter, 18 feet deep. Uncased. Measuring point, top of 6- by 12-inch timber at southeast corner of well at copper nail with washer, at land surface altitude 3,051 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 17, 1938	9.05	Sept. 15, 1938	3.37	July 27, 1939	5.80
Apr. 1	8.62	Oct. 6	5.31	Sept. 5	5.30
Apr. 11	9.08	Oct. 25	5.76	Sept. 19	6.20
Apr. 21	4.00	Nov. 8	6.36	Oct. 2	7.00
May 1	4.10	Dec. 3	7.24	Oct. 19	7.70
May 11	5.27	Dec. 21	7.72	Nov. 6	8.33
May 21	5.80	Jan. 7, 1939	7.57	Nov. 17	8.45
June 1	6.00	Jan. 21	7.93	Dec. 11	8.89
June 11	6.44	Feb. 11	8.39	Jan. 4, 1940	9.32
June 21	7.29	Mar. 7	8.80	Jan. 29	9.37
July 1	7.25	Apr. 13	6.12	Feb. 17	9.38
July 16	5.00	May 2	6.65	Mar. 28	9.60
Aug. 3	6.22	June 1	6.68	Apr. 30	6.05
Aug. 23	6.22	July 18	5.39		

24.28.3.211. C. W. Beeman. Stock well dug 6 feet in diameter, 24.5 feet deep. Uncased. Measuring point, top of timber at southeast corner at copper nail with washer, at land surface altitude 3,028 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 18, 1938	17.83	Sept. 15, 1938	16.08	July 27, 1939	17.43
Apr. 1	17.25	Oct. 6	15.24	Sept. 5	17.60
Apr. 11	16.80	Oct. 25	15.92	Sept. 19	15.77
Apr. 21	15.80	Nov. 8	16.86	Oct. 2	17.13
May 1	15.85	Dec. 3	17.77	Oct. 19	18.44
May 11	16.59	Dec. 21	18.30	Nov. 6	19.31
May 21	17.38	Jan. 7, 1939	18.70	Nov. 17	19.76
June 1	17.98	Jan. 21	18.94	Dec. 11	20.47
June 11	18.32	Feb. 11	19.52	Jan. 4, 1940	20.94
June 21	17.40	Mar. 7	19.69	Jan. 29	21.56
July 1	16.70	Apr. 13	18.94	Feb. 17	21.80
July 16	16.26	May 2	19.05	Mar. 28	22.40
Aug. 3	16.38	June 1	16.10	Apr. 30	21.48
Aug. 23	15.35	July 18	17.30		

Table 4. Depth to water in observation wells drawing water from the valley fill *(continued)*

24.28.3.423. C. W. Beeman Stock well dug 8 feet in diameter, 21.5 feet deep. Uncased. Measuring point is top of timber at southwest corner of well at copper nail with washer, at land surface altitude 3,000 feet, estimated from topographic map.

Water level, in feet below land surface datum, 1938–1940

Date	Water Level	Date	Water Level	Date	Water Level
Mar. 18, 1938	10.30	Sept. 15, 1938	8.59	July 27, 1939	10.94
Apr. 1	9.68	Oct. 6	9.00	Sept. 5	10.73
Apr. 11	9.90	Oct. 25	9.38	Sept. 19	10.68
Apr. 21	9.63	Nov. 8	9.86	Oct. 2	10.86
May 1	9.58	Dec. 3	10.23	Oct. 19	11.28
May 11	9.90	Dec. 21	10.37	Nov. 6	11.60
May 21	10.03	Jan. 7, 1939	10.49	Nov. 17	11.79
June 1	9.47	Jan. 21	10.53	Dec. 11	12.02
June 11	9.74	Feb. 11	10.87	Jan. 4, 1940	12.29
June 21	9.95	Mar. 7	10.98	Jan. 29	12.60
July 1	9.98	Apr. 13	11.24	Feb. 17	12.79
July 16	10.78	May 2	11.02	Mar. 28	14.00
Aug. 3	9.93	June 1	11.06	Apr. 30	14.10
Aug. 23	8.65	July 18	11.05		