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GEOLOGY

and

GROUND–WATER CONDITIONS

of the

Pecos River Valley

in the vicinity of Laguna Grande de la Sal, New Mexico, with special reference to the salt content of the river water

by

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Prepared by the Geological Survey
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in coperation with the State Engineer of New Mexico
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GEOLOGY AND GROUND-WATER CONDITIONS OF THE PECOS RIVER VALLEY IN THE VICINITY OF LAGUNA GRANDE DE LA SAL, NEW MEXICO, WITH SPECIAL REFERENCE TO THE SALT CONTENT OF THE RIVER WATER

By T. W. ROBINSON and W. B. LANG

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INTRODUCTION

At the request of and in cooperation with the State Engineer of New Mexico, a study of ground-water conditions in the Pecos River Valley southeast of Carlsbad, Eddy County, New Mexico, has been under way since the spring of 1937. The results of that study are presented in this report. The area involved lies largely in Townships 21, 22, 23 and 24 south, Ranges 26, 27, 28 and 29 east, New Mexico principal meridian. (See plate 1). Intensive work was done chiefly in the vicinty of the Laguna Grande de la Sal and the area lying between it and the Malaga Bend of the Pecos River, about five miles south. The area is crossed by the Pecos River flowing southeastward from Carlsbad. During the growing season, the entire flow of the Pecos River above Carlsbad is normally diverted for irrigation at Lake McMillan and Lake Avalon. During this period the Pecos River from Carlsbad south is fed chiefly by large springs. The largest spring, known as Carlsbad Spring, is located in the river channel just below Lake Avalon. The Black River enters the area from the west and flows eastward to its confluence with the Pecos River northeast of Malaga. It also is spring-fed, deriving most of its water from Blue Spring and Castle Spring, near Black River village. The drainage pattern is well developed on the west, and during rainy periods many normally dry arroyos and draws discharge flood water into the Pecos River. Drainage from the east is by poorly developed draws which carry water to the Pecos only during exceptionally heavy rainfall. A prominent feature east of the river is Laguna Grande de la Sal, which is a shallow salt lake in a playa covering about 3½ square miles.

Carlsbad, the largest town in the area and the county seat of Eddy County, had a population of 3,708 in 1930. However, owing largely to the development of the potash mines located about 20 miles east, the population in 1938 is about double that of 1930. Loving, located about 12 miles south, and Malaga, about 18 miles south of Carlsbad, each had less than 1,000 inhabitants in 1930. Carlsbad is served by the Atchison, Topeka and Santa Fe Railroad and by main highways leading north to Roswell, New Mexico, southwest to El Paso, Texas, south to Pecos, Texas, and east to Hobbs, New Mexico.

Cotton and hay are raised in the irrigated section along the Pecos River, while cattle, sheep and goat raising predominate in the unirrigated upland areas to the east and west. The principal mineral industry is the mining and refining of potash. A large number of tourists are attracted annually to the famous Carlsbad Caverns, located about 25 miles southwest of Carlsbad, near the highway leading to El Paso, Texas.

A group of farmers who pump water from the river for irrigation report that in recent years the water, because of its salinity, has been injurious to their cotton crop. In September 1932 the U. S. Potash Company began operations, using the Laguna Grande de la Sal as a disposal area for the waste brine from their potash refining operations. The reported difficulty with salt, shortly after refinery operations began, naturally cast suspicion on the brine in the Laguna Grande. There is no visible outlet from the Laguna Grande, and therefore the problem arose as to whether the lake brine may be percolating underground to the Pecos River.

A study of the chemical character of the water of the Pecos River has been made by C. S. Howard and W. F. White, Jr., and numerous analyses were made of the surface and ground waters in this area (see report on chemical character of Pecos River under "Quality of Water," to be found elsewhere in this volume). The ground-water studies by T. W. Robinson were begun on April 13, 1937, and the geologic studies by W. B. Lang on October 15, 1937.

GEOLOGY OF THE PECOS RIVER BETWEEN LAGUNA GRANDE DE LA SAL AND PIERCE CANYON

By Walter B. Lang

GENERAL GEOLOGY

The area of the Pecos River under consideration lies in the geologic province of the Delaware basin near its northern rim, which is composed of reef limestones that trend northeasterly across the Pecos River at Carlsbad, New Mexico. West of Carlsbad the reef limestones are exposed at the surface, and rise both topographically and in relief southwestward from Carlsbad. East of the Pecos River the reef limestones dip beneath younger formations which increase in total thickness eastward. This reef is composed of the Capitan and Carlsbad limestones of the Permian, the stratigraphic equivalent of the upper Delaware Mountain formation which underlies the Delaware basin. The Delaware Mountain formation is composed essentially of fine grained sandstone, at the top of which is the Lamar limestone member. At the base of the reef this sandstone grades into the reef limestones which rise 700 to 1000 feet above the general level of the adjacent floor of the Delaware basin. Upon the Delaware Mountain formation was deposited the Castile anhydrite, above which in turn lie the Salado halite and Rustler formations, both of which extended beyond the margin of the Delaware basin. All of these formations are Permian. Subsequently they were covered by Triassic, Cretaceous, and Tertiary deposits; which in the area under consideration were more or less completely removed by erosion in the early Tertiary. Quaternary modifications were aggradational as well as degradational.

There is evidence that the Pecos Valley began in the mid-Tertiary but the greatest amount of erosional development, that has made it what it now is, occurred during the Quaternary, when all of the rocks of the Pecos Valley south of Carlsbad were stripped off to the middle part of the Rustler formation, and the Pecos River then cut an entrenched course in the lower Rustler forming a small canyon. Tributary streams also incised their channels to meet the Pecos. Lone Tree, Indian, and Nash Draws and Dark and Black Canyons then drained their respective areas at lower levels. A later period of refilling softened the rugged aspect of the topography. East of this area the upper Rustler section is exposed and this in turn is covered farther east by younger rocks. Thus, in this area, the rocks that are exposed or are covered only by very late deposits lie in the mid-section of the Rustler formation. The general geologic relations are shown in plate 2.

STRUCTURAL ATTITUDE OF THE FORMATIONS

Since the formation and filling of the Delaware basin with the Delaware Mountain sandstones, and the deposition of the correlative reef limestones and back-reef deposits,[1] there has been a tendency toward progressive tilting of this basin to the east and southeast. A very minor amount of tilt occurred during upper Permian time, but the present altitude of the beds is largely due to the combined effects of the regional Rocky Mountain uplift and of the more local block tilting which caused the basin and range type of structure west of the Pecos. On a 25-mile line, south 45° east, across Nash Draw at the Nash well, the base of the Rustler formation has a dip southeastward of 13 feet to the mile. On a parallel trend (S 45° E), the Rustler limestone on the western side of the Pecos from the Fontier Hills, west of Dark Canyon Draw, to Red Bluff has a dip of 27 feet to the mile. West of Quahada Ridge the Salado halite has been truncated and the overlying beds show a local flattening of dip. The area of Laguna Grande de la Sal lies in a sag in the Rustler formation, for the Rustler rises from here both to the northwest and the southwest.

GEOLOGIC FORMATIONS WITH REFERENCE TO WATER

Formations Lying Below the Rustler Formation

Salado halite.—The Salado is essentially a salt formation with supplementary beds of anhydrite and polyhalite. It is divisible into two parts, an upper section which locally carries rich beds of soluble potash salts, and a lower section that has only anhydrite and some polyhalite beds as accessories to the main mass of stratified salt. The Salado is usually 1,000 to 1,500 feet thick in the eastern part of the Delaware basin, but in the area of Malaga Bend most of the upper section has been removed by erosion in pre-Rustler time. The Salado halite in this area is devoid of aquifers, and no instance is known where circulation of water occurs in it. Water coming in contact with solid rock salt can dissolve salt only up to the point of saturation, after which no further solution takes place. If, however, circulation is established bringing unsaturated water into contact with the salt, the rate of removal of the salt becomes a function of what might be called the saturation deficit of the circulating water. This is also true of anhydrite but in addition ground water permeating the anhydrite gradually alters it to gypsum and mechanically disrupts it, thus permitting ingress of more water to continue the process but without mass removal of the rock in the initial stages of ground-water circulation. Later, if the circulation continues, gypsum is removed by solution. This difference in the behavior of these two types of rock, characteristic of this area, is of importance to the study of ground-water circulation. Also, ground water circulating in a gypsum bed may be turned from a normal structural course by the unaltered anhydrite portion of the bed.

Castile anhydrite.—The Castile anhydrite underlies the Salado halite and fills the Delaware basin. It attains a thickness of more than 2,500 feet, and is composed essentially of anhydrite, with thick beds and lenses of salt, and beds of calcitic limestone and sandstone. Water is occasion-

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[1]The Permian formations of the Pecos Valley of New Mexico and Texas, by Walter B. Lang; Bull. Amer. Assoc. Pet. Geol., vol. 21, No. 7, pp. 833-898, 1937.

ally found in the sandstone and anhydrite members at depth and, in the outcrop of the Castile far to the west of the Pecos shallow water may be encountered in the altered gypsum.

Lamar limestone member of Delaware Mountain formation.—The Lamar limestone member lies at the top of the Delaware Mountain formation and is the correlative of the top of the Carlsbad limestone of the reef zone. In many places it is a sandstone, but the sand grains are so fine and so thoroughly cemented with an approximately equal percentage of carbonate of lime that it appears more like a dense limestone. The petroleum of the Delaware Mountain formation occurs at this horizon and it is usually accompanied by sulphur water either in the Lamar or immediately below it.

Carlsbad and Capitan limestones.—The Carlsbad and Capitan limestones, or the limestones of the Barrera del Guadalupe, and their immediate correlatives of the back-reef area, are of great importance to the water supply of the Pecos River. They serve as the main source of supply of the ground waters that feed the numerous springs which issue from the river channel below Lake Avalon. The combined outflow from these springs is sufficient to maintain a sizeable stream of water even when all upstream water is impounded at Avalon dam. The outcropping Carlsbad limestone and the sandstone of Azotea Mesa serve as catchments for rain water that eventually finds its way to the Pecos by cavernous channels in the limestone. Part of the water of Azotea Mesa and of Dark Canyon serve to charge the surface fill and buried Rustler section between this mesa and the Pecos River. Waters issuing directly from the limestones of the Barrera are generally not highly mineralized but somewhat hard. As this water passes from the limestone into the fill and the Rustler section it gradually accumulates undesirable sulphate, chloride and additional carbonate salts in its passage southeastward. Before reaching the vicinity of Otis much of the water has become undesirable for domestic use. In all probability these limestones serve as the chief source of supply of water in the Rustler formation on the west side of the river.

Rustler Formation

The Rustler formation serves as a key marker of the upper Permian in the Pecos Valley of New Mexico and Texas. Though varying in thickness and lithology from place to place, it is nevertheless sufficiently distinct from associated formations to be readily recognizable in subsurface. On the surface, however, it is not always recognizable with certainty. This is due to the fact that exposures of the Rustler are nearly always ruptured and altered and where the gypsum and red bed sections appear in inliers of caliche it is often impossible to determine directly whether these interliers expose Rustler, Castile, or gypsiferous fill. The main dolomitic limestone of the Rustler is a distinct unit in the Delaware basin and where present serves to determine and locate the position of the section. But where this section comes into juxtaposition with the top reef limestones, their similarity is confusing and may cause error of determination.

The Rustler formation in this area is approximately 500 feet thick. It is divided into two sections: the upper part usually 200 feet thick, consisting of all beds lying above the main limestone to and including the top 30-foot anhydrite or gypsum member; and the lower part, a section that includes the 35-foot dolomitic limestone and everything down to the top of the Salado. The lower section usually approaches 300 feet in thickness but may vary considerably, depending in part upon the unevenness

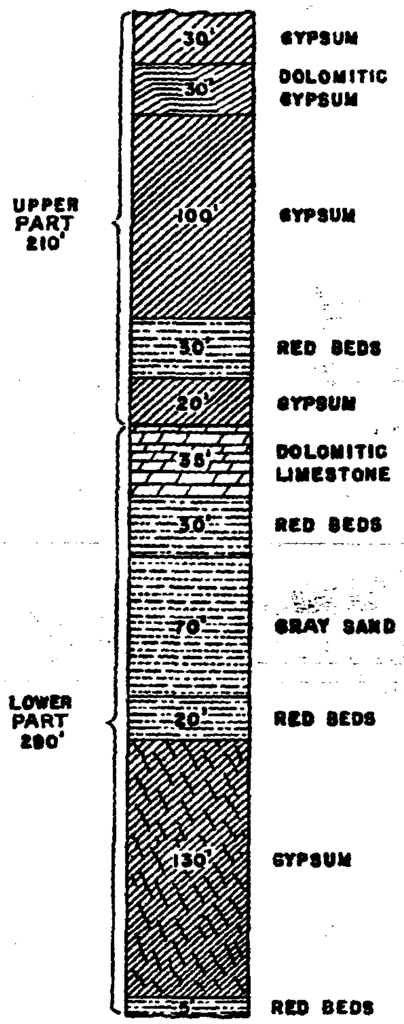

Figure 1. Generalized columnar section of the Rustler Formation in the Pecos Valley, New Mexico.

of the floor upon which these sediments were deposited. A generalized geologic columnar section of the Rustler formation is shown in figure 1.

The Rustler is largely composed of calcium sulphate, originally in the form of anhydrite but more often altered to gypsum and selenite where water has had access to the beds, and fine quartz sand. These two very nearly make up the bulk of the formation. The limestones are conspicuous in outcrop but quantitatively unimportant; in fact the limestone member in places changes to a sandstone. The red beds are either largely or partly composed of fine quartz sand. The grey sand section owes its color to the presence of carbonaceous residue adhering to the sand particles and also to the absence of the ferric aluminates.

The Rustler in outcrop usually presents a jumbled appearance, more especially where the limestone member is present at the surface. The limestone is often seen warped and broken into large blocks an acre or more in extent and tilted at various angles. This is caused by the partial solution of the gypsum beds and the removal of the underlying soft shales which induces a collapse of the harder and less soluble beds. This structural picture is superficial and is seldom representative of the true attitude of the beds 25 to 50 feet below the surface. Fundamental structures in the Rustler are mildly undulating, a condition seldom interrupted where these beds lie 200 to 300 feet below the surface. There are, however, local instances where solution and slump have affected these beds at considerable depth.

Deposits Overlying the Rustler Formation

Pierce Canyon redbeds.—The Triassic Pierce Canyon redbeds normally overlie the Rustler but in this area they are not exposed and are not important except that they provided material for the upbuilding of later formations. This formation, which may attain a thickness of 350 feet, is composed of earthy and fine sandy bedded red beds.

Gatuña formation.—The name Gatuña is here given to an assemblage of rocks of various kinds that were laid down in the Pecos Valley in post-High Plains time and apparently after the completion of the maximum cycle of erosion in this valley. The deposits are of terrestial origin and with them began the process of refilling the Pecos Valley. The dominant material of which they are composed is fine red sand. However the material is largely of local derivation and therefore the character of the source of the material has had a controlling influence on the composition and color of the resulting deposits. Conglomerates, stream gravels, gypsum, and limestone, as well as bedded and unconsolidated sands and silts, comprise this formation. They are gray, purplish, and yellow as well as red. The inclusion of caliche wash has in most places contributed to this formation a slightly paler reddish color than that of the Pierce Canyon redbeds. The name is derived from Gatuña Canyon in northeastern Eddy County, New Mexico. The formation is of Quaternary age.

The Gatuña formation mantles many places to a depth of only a few feet. In Pierce Canyon it is more than 100 feet thick and it may exceed 300 feet at the head of Cedar Canyon. On the eastern side of the Pecos Valley, it usually yields a very small quantity of water of good quality. In the Malaga Bend the Gatuña formation is found below the present level of the Pecos River and is more or less saturated with a solium chloride brine. The beds are here altered from red to black.

In this outline of the geology no attempt is made to elaborate upon the characteristics or distribution of the Gatuña formation or the physiographic history of the Pecos Valley.

Caliche of Pecos Valley.—The caliche of the Pecos Valley caps a surface younger than the Gatuña. It is here composed of calcium carbonate with enclosed sand and dull colored Triassic quartz pebbles and attains a thickness of 10 feet but is commonly not over 3 feet thick. Even where the caliche is less than a foot thick it has been mapped as caliche.

Fill of Laguna Grande de la Sal.—Laguna Grande de la Sal is a playa. It has been filled in to a depth of 55 feet or more (about 15 feet above the present lake level) with fine crystalline gypsum, that may in part be inwash of detrital material from the upper Rustler gypsum beds but the greater amount is more likely the result of precipitation of gypsum from gypsiferous waters from Nash Draw and the springs that discharge into the playa or perhaps from other sources. These gypsum deposits are slightly calcareous, but near the top of the deposit there is a 6-foot bed of soft pure white caliche overlain by 3 feet of white crystalline gypsum. On the surface of the lowest swales of the playa there is a thin black mud layer which is now mantled by a heavy crust of salt in some places as much as 2 feet thick.

Gravels of Pecos Valley.—The terrace gravels of the Pecos Valley are younger than the Gatuña formation. There are at least three stages of lime-cemented limestone gravels exposed at the surface. The high stage gravels on the west side of the river lie directly on the Rustler or Gatuña. These gravels are essentially composed of limestone cobbles and pebbles fed to the Pecos by the western tributary streams draining the limestone cuesta slopes of the Guadalupe and Sacramento Mountains. There are, however, intermixed with them in varying proportions the dark siliceous and igneous gravels of an earlier influx. The type of pebble present in a terrace gravel is not the only feature diagnostic of the age of a terrace, the position and relationship of the terrace gravels to the other formations are even more important than the composition of the gravel.

Alluvium.—Immediately preceding the present cycle of erosion the Pecos River passed through a period of alluviation during which it loaded its channel and flood plain with fine sand, silt, and adobe, and formed the Harroun flood plain. Also in the upland areas local drainage carried sands and silts into existing depressions.

Dune sand.—The work of the wind has slightly modified the topographic expression of the country here and there by working into dunes the loose sands deposited on flood plains or in washes. The larger accumulations of dune sands are usually found on the east side of the Pecos

River or of high hills and ridges. Although the dominant annual wind direction is from the south, the strong, hot, dry winds most effective in dune formations come from the west. The easterly winds commonly carry moisture and are therefore less effective as a transporter of sand.

GENERAL RELATION OF THE GEOLOGY TO THE OCCURRENCE OF BRINE AT THE BASE OF THE RUSTLER FORMATION

It was observed by the writer more than a decade ago, during the investigation for potash, that some of the test wells in the vicinity of T. 21 S., R. 30 E., indicated the presence of a strong sodium chloride brine just above the salt of the Salado halite. Some other test wells that were dry at this zone yielded salt core slightly cellular or cuttings with an uncommon appearance that was interpreted as having been caused by solution. Later, wells drilled farther south in Nash Draw yielded abundant sodium chloride brine in the basal Rustler, but those west of the draw were dry. Thus it seemed likely that the structural conditions that caused the development of Nash Draw might also control the position of a body of salt water beneath it in the basal Rustler. The investigation has confirmed this assumption. (See plate 3).

Water percolating into the ground in the vicinity of Bear Grass Draw (T. 18 S., R. 30 E.) may pass into the truncated edges of the lower Rustler formation and may migrate south and east as porosity and structure determine. This water in its early travel would first dissolve calcium carbonate and then calcium sulphate as it passed down to and along through the gypsum beds. The lower gypsum member of the Rustler is brecciated in many places, and the basal shale member is locally only a foot or two thick or is absent. If water migrates through this lower gypsum it may pick up salt in solution from veins and stringers of salt that are known to occur in it and also from the top of the underlying salt.

In the Eddy-Baker No. 1 well, a sodium chloride brine was encountered in the Castile formation at 530 feet. This brine rose to a height of 3,116 feet. (Surface elevation 3,145 feet.) Brines in the Rustler underlying Lone Tree or Indian Draws are apparently cut off from the Nash Draw brine in the lower Rustler by a dry area that underlies the central and northern parts of Quahada Ridge. Thus any outlet that these waters may have must be by direct outflow into the Pecos by underground channels north of Culebra Bluff or southward by means of the lower beds of the Rustler. In the latter case the water would be intercepted by the underflow of brine in Nash Draw or by ground water moving southeastward on the west side of the Pecos.

GROUND WATER

By Thomas W. Robinson

OCCURRENCE

For the purpose of this report, the ground water in the area under investigation has been divided into three main divisions according to its occurrence in the geological section. These are (1) water below the Rustler formation, (2) water in the Rustler formation and (3) water in the sediments overlying the Rustler formation. The water ranges in quality from relatively fresh to a concentrated brine. With the exception of some of the first water encountered in the sediments, all of the water is under artesian pressure. The artesian head, however, is not in all wells sufficient for the water to flow at the land surface.

SALADO HALITE, CASTILE ANHYDRITE AND DELAWARE MOUNTAIN FORMATION

The Salado halite which immediately underlies the Rustler formation is, at least in the area under investigation, devoid of ground water. This has been amply demonstrated by the numerous oil tests and potash core tests which have been drilled in the area.

In the next lower stratigraphic unit, the Castile anhydrite, water occurs locally in scattered areas. An example of this is afforded by two oil tests drilled in 1937 east and south of Laguna Grande de la Sal. In the first test drilled, 23-29-14N2 (Fogarty No. 1—X), (plate 1) no water was reported in the Castile anhydrite section; whereas in the second well, 24-29-3F2 (Kerr No. 1), located 3½ miles south, an exceptionally large yield of water was encountered at 1,725 feet. The water-bearing bed in this well was between 60 and 90 feet thick, and, as shown by the chemical analysis, it yielded a concentrated sodium chloride brine. The quality of water is also variable. This is shown by two wells drilled in search of water west of the Pecos River. In the Pardue well, 24-26-29F1, and in the Forehand well, 25-27-30Q1, located about 7.5 miles southeast, a concentrated solution of magnesium sodium sulphate was encountered. (See plate 1).

In the next lower stratigraphic unit, the Delaware Mountain formation, mineralized water is nearly always found in the Lamar limestone member.

The waters which occur in the Castile anhydrite and lower formations appear to be in no way connected with the immediate problem at hand. They occur at such depths and are overlain by so many hundred feet of impermeable material that it is improbable they serve as a source of the salt water contamination to the Pecos River. Hence no further discussion need be made of the ground water below the base of the Rustler formation.

RUSTLER FORMATION

Character, Extent, and Relations of the Brine Horizon at the Base of Rustler Formation

The water which occurs in the Rustler formation may be divided into two groups on the stratigraphic position of the water-bearing beds and the quality of the water. These two groups are (1) the water occurring in the brine horizon at the base of the Rustler formation, and (2) the water occurring above the brine horizon.

The brine horizon occurs at or very near the base of the Rustler formation, and as a rule it yields a strong sodium chloride brine. In some of the oil tests and potash core tests only weak to moderate solutions of sodium chloride were reported. This difference in concentration may be due to the occurrence of weaker brine in the locality of the well, to a dilution of strong brines by fresher water from a higher bed that was not shut out when the well was drilled, or to admixture of water used in drilling. At the seven test wells, described in the appendix, (not included with this report), the material of the brine horizon is composed almost entirely of granular and selenitic gypsum. In some of the wells the bottom of the bed that yields the sodium chloride brine is separated from the salt of the underlying Salado halite by a very few feet of clay and in others it appears to be in contact with the salt. Such close association of the water in this horizon with the salt is obviously favorable for the production of a sodium chloride brine.

The presence of a rather extensive bed yielding a sodium chloride brine at the base of the Rustler formation was not generally recognized until the first test well had been drilled. Previous to the start of the investigation, brine had occasionally been reported in oil tests and potash core tests just above the Salado halite. As the brine was not reported in all wells it was at first believed to occur only locally. However with the drilling of the first test well, 23-29-22C1, by the U. S. Potash Company with a sodium chloride brine reported in two nearby oil tests, 23-29-14N1 (Fogarty No. 1) and 24-29-3F2 (Kerr No. 1) (plate 1), it became evident that there is a continuous horizon yielding a sodium chloride brine east and south of Laguna Grande de la Sal. Subsequent drilling of the other test wells and oil tests, 22-31-30K1 (Texas Welch) (?) and 24-28-28L1 (C. J. Frederick Reed No. 1), has shown that this brine horizon extends over a considerable area. The approximate area underlain by this brine horizon, as it is known at present from all available test wells, oil tests and potash core tests, is outlined on the accompanying map, plate 3. The area shown on the map covers about 122 square miles, but it is approximate only and is subject to revision when more well data are available.

As shown on the map, the area extends as a narrow strip northeast from the vicinity of Willow Lake to Laguna Grande, and then northeast and north to the head of Nash Draw, a distance of approximately 30 miles. It ranges in width from 2 to 8 miles. It is interesting to note that north of Laguna Grande the brine horizon appears to lie within the confines of Nash Draw, suggesting that solution of the Salado halite may have had some influence in the development of this flat valley.

The thickness of the brine horizon based on the six test wells which penetrated to the Salado halite, ranges from 61 feet in well 23-29-28B6 (U. S. P. C. No. 2 Test) to 10½ feet in 22-30-17M1 (U. S. G. S. No. 5 Test), and averages about 36 feet. The seventh test well, 23-29-22C1, (U. S. P. C. No. 1) did not penetrate the Salado halite. The thickness appears to decrease to the north. The average thickness based on all available data of the oil tests, potash core tests and the six test wells, is about 24 feet.

Quantity of Salt in the Brine Horizon

It is possible to estimate roughly the quantity of salt that is in solution in the water of the brine horizon. There are no data as to the porosity of the material that contains the brine but it is believed that the assumption of a porosity of 33 1/3 per cent is not greatly in error. With this porosity and an average in thickness of 24 feet the brine in storage over the area would be equivalent to that of a reservoir 8 feep in depth covering 122 square miles, or to about 625,000 acre-feet.

The concentration of the brine decreases toward the north and also from well 24-29-16M1 (U. S. G. S. No. 1 Test) toward the west and south. The following table gives the average chloride content of the brine from the six test wells that penetrated the full thickness of the brine horizon and also of the water samples taken at four oil tests after the brine was encountered. The samples from the oil tests may be diluted with drilling water, or by water from an upper and fresher water-bearing bed which had not been sealed out of the well. Obviously sampling conditions could not be controlled as closely at the oil tests as at the test wells which were drilled in part for that purpose. The chloride content shown for the test wells is the average of those samples after the brine had been encountered and the well bailed vigorously at least once, and before the underlying salt had been penetrated by the drill. Thus they should represent approximately the average concentration of brine in the brine horizon at that locality.

Chloride Content and Specific Gravity of Water in the Brine Horizon at the Base of the Rustler Formation

Well Number	Chloride parts per million	Specific gravity
20-31-30K1	15,480	1.020
22-30-17M1 (U.S.G.S. No. 5 Test)	125,600	1.162
23-29-14N1	* 86,870	* 1.111
23-29-17B1 (U.S.G.S. No. 4 Test)	149,600	1.199
23-29-28B6 (U.S.P.C. No. 2 Test)	145,700	1.189
24-28-24C1 (U.S.G.S. No. 2 Test)	134,000	1.175
24-28-28L1	6,920	1.000
24-29-3F2	44,400	1.05
24-29-8D1 (U.S.G.S. No. 3 Test)	147,000	1.195
24-29-16M1 (U.S.G.S. No. 1 Test)	154,800	1.203
Average	101,000	1.130

* Determination by U. S. Potash Company. Ten bailers of water were removed, and the sample was taken from the 10th bailer.

A chloride content of 101,000 parts per million and a specific gravity of 1.13 is equivalent to 114,100 milligrams per liter. To convert chloride in milligrams per liter to ton equivalents of sodium chloride per acre-foot, it is necessary to multiply by the conversion factor 0.002242. Using these figures the quantity of sodium chloride in solution in the brine horizon as delimited is 160,000,000 tons.

Source of Water in the Brine Horizon

That the source of the water of the brine in the brine horizon is independent of the brine in Laguna Grande is suggested by the three test wells which were drilled in the vicinity of it, 23-29-17B1 (U. S. G. S. No. 4 Test), 23-29-22 C1 (U. S. P. C. No. 1 Test) and 23-29-28B6 (U. S. P. C. No. 2 Test). See plate 5.) In each of these tests the first water-bearing bed encountered was below the lake level, yet the water was much fresher than that in the lake, having about 85,000, 6,000 and 41,000 parts per million of chloride respectively, whereas brine in the lake is nearly always at or near the satuation point with respect to sodium chloride—that is from 150,000 to 160,000 parts per million of chloride. Moreover, at 90 feet in well 23-29-22C1 a relatively fresh water was encountered whose specific gravity, based on Twaddell reading, was about 1.007, and two similar fresh water strata were encountered in well 23-29-28B6, the first between 150 and 153 feet and the second at 174 feet. The specific gravity of the water from the first stratum in well 23-29-28B6, based on Twaddel readings, was 1.006 and that of the second, determined gravimetrically, was 1.006. A sample of water collected from the 174-foot stratum in well 23-29-28B6 had a chloride content of 6,240 parts per million, or only about one twenty-fifth that of the lake brine. Similarly the water stratum encountered in 23-29-17B1 between 75 and 86 feet, yielded water of less concentration than lake brine and of an entirely different type. If the brine in the Laguna Grande were percolating downward to the brine horizon at the base of the Rustler formation, the concentration and quality of the ground water above the brine horizon should not be dissimilar from the concentration and quality of the brine in the lake and in the brine horizon.

The study of the relationship of water levels in an artesian aquifer is a study of the relationship of pressures. Thus, the upward pressure exerted at the top of an artesian water-bearing bed is measured by the height to which a column of water will rise above the top of that bed. The height to which the water column will rise for any given pressure will depend upon the specific gravity of the water in the column. It will rise to its maximum height when the specific gravity is 1.00, but if the specific gravity is increased, the height to which the water column rises will decrease correspondingly. Therefore, to study the differences in head as shown by the water levels in the wells it is essential that all the water columns be corrected to the same specific gravity. In the study of the water levels of the brine horizon, the water columns have been corrected to a specific gravity of 1.20, as that is about the density of the sodium chloride brine encountered in most of the test wells.

The water level in well 22-30-17M1 (U. S. G. S. No. 5 Test), located about 6 miles north of Laguna Grande de la Sal, stands about 2,927 feet above sea level, which is higher than the water levels in either 23-29-17B1 or 23-29-28B6. The specific gravity of the water of 22-30-17M1 is somewhat less than that of the water in the other two wells. However, when a correction is made for this difference in gravity the head in well 22-30-17M1 still is higher, that is, a brine with a specific gravity of 1.20 would stand at an altitude of about 2,921 feet. Such a condition is indicative of a source of supply north of the lake.

The profile in figure 2 indicates the slope of the piezometric surface with the water columns in the wells corrected to a specific gravity of 1.20. The profile shows a pressure gradient from the north to the south, and hence indicates movement in that direction and a source of water to the north of well 22-30-17M1.

Evidence of Discharge of the Brine Into the Pecos River

As the slope of the hydraulic gradient and hence the direction of movement of the water is indicative of the area of recharge it is also indicative of the area of discharge. This area of discharge appears to be in the Malaga Bend of the Pecos River in the vicinity of well 24-29-16M1. Here the known conditions are more favorable for upward percolation from the salt brine horizon than in any other part of the area. The confining bed is much thinner than at any of the other tests and the static level of the brine stands higher than the land surface in the river channel and the adjacent flood plain.

In the drilling of well 24-29-16M1 (U. S. G. S. No. 1 Test), it was found that a large part of the Rustler formation had been eroded and replaced by alluvial fill. The thickness of the Rustler formation, below the top of the dolomitic limestone member, based on outcrops of the dolomite on the river bank above Fishing Rock, about one-half mile northwest, and at Livingston's Pump, about one-half mile southwest of 24-29-16M1, is estimated to be about 250 feet. Yet at the well an examination of the cuttings shows that only 99 feet of the basal Rustler formation is present. A generalized section of this well shows alluvial fill from the surface to a depth of 149 feet, Rustler formation from 149 to 248 feet and Salado halite from 248 feet to the bottom of the hole at 260 feet. Thus the Rustler formation to a depth of about 150 feet below the top of the dolomitic limestone member has been eroded away. The thickness of the confining bed, however, is much less than 99 feet. Its thickness at 24-29-16M1, that is from the point where the Rustler formation was encountered at the depth of 149 feet to the point where the salt brine was encountered, at a depth of 212 feet, is only 63 feet. The top of the permeable lower gypsum section lies at 175 feet, and from this level to the base of the alluvial fill there is an aggregate of 20 feet of sandy red beds. The exposures of the dolomitic member of the Rustler formation at Fishing Rock, and at Livingston's pump show that erosion has removed the top members so that thickness of the formation decreases rapidly from these points to the well.

Evidence of upward percolation of the sodium chloride brine was furnished in the drilling of U. S. G. S. No. 1 test. As shown by the drilling record, the hole from a depth of 149 to 210 feet caved badly during the overnight and week-end shutdown periods, and considerable sodium chloride brine accumulated in it. There was no indication of leakage around the casing seat at 149 feet. Rather in this 61 feet of hole the sodium chloride brine appeared to be percolating slowly through the side walls into the hole. The material penetrated was largely shale mixed with sand, silt and gypsum. When first drilled this material stood with but little if any caving, but seepage caused it to become unstable and to cave badly.

The depth to water measurements show that in well 24-29-16M1 the brine has a hydrostatic head sufficient to raise the brine to an altitude of between 2,900 feet and 2,901 feet. The topographic map indicates that the 2,900-foot contour crosses the river channel about three-quarters of a mile upstream from Fishing Rock. It is estimated that the altitude of the water surface in the river at Fishing Rock during normal flow is about 2,900 feet. Thus it can be seen that below Fishing Rock the hydrostatic head of the brine is sufficient to raise it above the level of the water in the river.

As is shown by Howard and White,[1] there is a rapid increase of the chloride content of the river water between Malaga and Pierce Canyon gaging stations. Surface features and analysis of spot samples indicate that most of this increase occurs between Fishing Rock and Livingston pump.

Water Above the Brine Horizon

Water-bearing beds occur in the Rustler formation above the brine horizon. In 22-30-17M1 (U. S. G. S. No. 5 Test) four such beds were encountered—from 80 to 85 feet, 110 to 117 feet, 156 to 161 feet and 225 to 231 feet (fig. 1). In addition a small seep was encountered between 197 and 208 feet. As a rule water is found in the dolomitic limestone member. Where the dolomite is at or near the surface this is the first water encountered, but where it lies at considerable depth there may be water-bearing beds above it, as in the case of well 22-30-17M1, in which two water-bearing beds were encountered above the dolomite. Water-bearing beds also occur below the dolomitic limestone member but generally they yield less than the dolomite or the beds above it. These lower beds are somewhat irregular, yielding water in some localities but not in others. Below the dolomite and separated from it by 30 to 60 feet of red sandy shale, there is a gray sand of variable thickness, which yields water in some places. As an example, no water was found in this sand in well 22-30-17M1, whereas, in 23-29-28B6 two seeps were encountered in it—the first near the middle and the second near the base of the gray sand member. There is no authentic report of a water-bearing bed between the base of the gray sand member and the top of the brine horizon.

In general the movement of the water appears to be toward the river, on both the east and west sides. Little is known about the movement of water in the beds below the base of the dolomitic limestone as there are no wells in which the water levels of these aquifers can be observed. A study of available well logs indicates that these lower aquifers are not continuous over a large area, and hence it is inferred that there is no very active movement.

[1]Howard, C. S. and White, W. F. Jr., Chemical character of Pecos River water in New Mexico: pp. 5, 13, 14, 1937-1938. Typewritten report released to the public by the Geological Survey, 1938. Also reported elsewhere in this volume under "Quality of Water."

The specific gravity of the water ranges from 1.059 in well 23-29-28B7 to 1.000 in well 22-30-17M1. The specific gravity of the water in the water column of a well may also range rather widely because of lack of casing or improper casing, allowing fresher water in overlying sediments to mix with the water in the dolomite. Notable examples are afforded by wells 23-29-32J1 and 23-29-28Q1. These two wells were drilled at the edges of small playas that receive detrital material and drainage from their surrounding drainage basins and may contain ponded water for two to three weeks after periods of heavy rainfall. The casing, especially in well 23-29-28Q1, did not shut out the fresh water percolating downward through the sedimentary material mantling the dolomite but allowed it to enter the well. As a result the water at the top of the water column is of different density than that at the bottom. Thus a sample taken from the top in well 23-29-28Q1 on May 4, 1938, had a specific gravity of 1.014, and a sample taken from the bottom of the water column at the same time had a specific gravity of 1.043. On the same date the specific gravity of a sample taken from the top of the water column in well 23-29-32J1 had a specific gravity of 1.016 and a sample taken from the bottom had a specific gravity of 1.020. The chemical analyses of samples taken at other dates, for which the specific gravity was not determined, indicate that the range in specific gravity may be even greater. Hence the level to which the water rises in these wells is lower than the level to which it would rise if it had the specific gravity of water that is entirely fresh.

Eight wells penetrating the Rustler formation have been drilled between Laguna Grande de la Sal and the Pecos River in which it is possible to measure water levels. Six of these wells penetrated the dolomite and in five (23-29-22C1, 23-29-28B7, 23-29-28Q1, 23-29-32J1 and 24-29-4P1) water is known to have been encountered in the dolomite. In the sixth well, 24-29-8D1 (U. S. G. S. No. 3 Test), the water level could not be measured.

Between wells 23-29-22C1 and 23-29-28B7 the hydraulic gradient is only about 0.2 foot per mile. South from 23-29-28B7 to 23-29-28Q1, the gradient, as computed from observed water levels, is about 3.7 feet per mile; if corrections were made for differences in specific gravity, the gradient would doubtless be even greater. The gradient from well 23-29-28Q1 southwest to 23-29-32J1, as computed from observed water levels, is about 0.9 foot per mile, and south to 24-29-4P1 it is about 4.3 feet per mile. If corrections were made for differences in specific gravity the gradient between 23-29-28Q1 and 23-29-32J1 would be decreased and might be reversed in direction, and the gradient between 23-29-28Q1 and 24-29-4P1 would also be decreased. The steepest apparent gradient is between 23-29-32J1 and 24-29-4P1, amounting to about 6.0 feet per mile, but if account were taken of differences in specific gravity the gradient would be flatter. At the present time there is some doubt as to whethehr the dolomite is continuous under the ridge between 23-29-28Q1 and 23-29-32J1 to 24-29-4P1, inasmuch as none was reported by the driller in 24-29-3F2 (Kerr No. 1 Oil Test). Unfortunately the samples from this well to a depth of 382 feet are missing and therefore the report cannot be verified. If the dolomite is not continuous there can be no direct movement of water from 28-29-28Q1 and 23-29-32J1 to 24-29-4P1. The hydraulic gradients and hence the movement of the water in the dolomite is in general southward from Laguna Grande de la Sal.

West of the Pecos River and east of the highway along the Atchison, Topeka and Santa Fe Railroad, between Cass Draw and Malaga, measurements have been made of depths to water levels in 20 wells at intervals beginning in March, 1938. All of these wells have been sunk to obtain water for domestic and stock purposes, but because of the mineral content of the water many of them have been abandoned. Some of these wells draw water from the Rustler formation and the rest from alluvial fill. In the absence of logs or samples of the water-bearing material, it is possible to state for only a few of the wells what is the formation from which they obtain water. However, the first water found in the alluvial fill and the first water found in the Rustler formation seem to be rather closely associated. This close association is doubtless due to a common source, that is, the irrigation water applied over this area. A study of the water levels indicates a movement eastward and southward toward the Pecos River. The hydraulic gradient is rather steep, ranging from 20 to 30 feet to the mile. Locally for about four miles above the mouth of the Black River, where this stream is deeply incised, the movement appears to be toward this stream from both the north and south. Measurements of depths to water levels in the few wells south and east of Malaga indicate a slope southeastward toward the Pecos River.

The numerous springs and seeps which occur on the west side of the Pecos River channel from the Harroun dam south to the Malaga Bend indicate that ground water from the west is discharging into the river.

East of the Pecos River, the ground water in the dolomite and in the water-bearing beds above it is believed to be derived in large part from rainfall. There are no active streams in this part of the area, and the drainage pattern is for the most part poorly developed. The sandy soil over most of this area has a high permeability and evidently permits rapid downward percolation. Rain falling on this area is disposed of in part by evaporation and transpiration but in part also by downward percolation to the water-bearing beds. Some water is doubtless also percolating to the area from adjacent territory. There are not sufficient data to state the source of the water in the water-bearing beds below the dolomite.

SEDIMENTS OVERLYING THE RUSTLER FORMATION

Water in the Fill of Laguna Grande de la Sal

(By T. W. Robinson and W. B. Lang)

Although sediments occur over much of the area under investigation, they do not everywhere contain beds of water-bearing material, especially where the sedimentary deposits are thin. The fill underlying the vicinity of the Laguna Grande de la Sal extends under the lake and playa and in many places well back from the present short line. It is lenticular in shape, ranging from feather edge, along the sides of the playa, to at least 68 feet at well 23-29-17B1, near the western end. In other parts of the playa the thickness of the fill may be greater than 68 feet, but data as to the maximum thickness are lacking as no other wells have been drilled to the bottom of the fill. In drilling well 23-29-17B1, which is located on a small tract of land rising about 10 feet above the surrounding playa, two bodies of ground water were encountered in the lake fill. The first between 11 and 51 feet and the second between 62 and 68 feet. Auger holes which were put down for observation wells along the south and west margin of the playa generally encountered water in the fill at depths of five feet or less.

All the waters encountered in the lake fill within the margin of the playa were weak to moderate sodium chloride brines, with specific gravities ranging from 1.035, at 23-29-28B2, to 1.149 at 23-29-17B1. The water with the highest specific gravity and hence the highest salt content was collected at the depth of 68 feet in 23-29-17B1.

The lake water is at present supplied from three sources: (1) Surface drainage during periods of rainfall, (2) spring discharge and ground-water inflow, and (3) the effluent from the United States Potash Refinery. W. T. Lee, in his paper "Erosion by solution and fill" (U. S. Geol. Survey Bulletin 760-C), gives an analysis of water from a salt lake which probably was the Laguna Grande. The sample was collected November 4, 1923. Records in the Water Resources laboratory of the Geological Survey show that it was collected by J. R. Yates and E. E. Teeter, of the Bureau of Reclamation. Doctor Lee states, " . . . . . reports as to this lake are conflicting. It is said that salt crystals are forming on the bottom, yet this analysis shows that the water is far from being saturated." Other analyses in the files of the Geological Survey represent samples collected by Lee from the lake in July 1924. Two samples collected on the west side of the lake showed total dissolved solids of 162,300 and 239,000 parts per million, respectively. Doctor Lee also collected a sample of salt from the bottom of the lake near the point where the most concentrated water sample was collected. This sample of salt consisted chiefly of sodium chloride. It is reported by persons who settled in this area as early as 1875 that at that time Mexicans came to the lake and picked off chunks of salt from the bottom, which they carried off in sacks by trail up the Pecos Valley.

According to Mr. T. M. Cramer, resident manager of the United States Potash Company, the effluent discharged into the lake at present from the refinery operations ranges between 1 and 3½ second-feet. It is approximately a 10 percent solution of sodium chloride. As a result of evaporation, however, the water in the lake is a concentrated brine that has a specific gravity of 1.20 or higher.

The ground water in the fill is derived in part from rainfall penetration and in part from ground-water inflow. During the winter and in the rainy periods, when evaporation is low, the sediments become saturated. In the summer ground water is discharged by evaporation.

In general the movement of the ground water in the fill is toward the lake. This is shown by the springs which discharge into the lake at or near the shore line. (See plate 4). The largest spring, 23-29-4P10 (Surprise Spring), has a rather uniform discharge of 115 to 125 gallons a minute. Further evidence of ground-water movement toward the lake is furnished by the observation wells. Thus at the west end of the lake the water level on June 3, 1938, stood 5.34 feet lower in well 23-29-17M1, at the margin of the lake, than in well 23-29-19C1, 0.8 mile west. On July 18, the water level in well 23-28-12N1, 2.3 miles northwest of well 23-29-17M1, stood at an altitude of 2960.50 feet above sea level, or about 16 feet above the water level in the lake. On June 21, 1938, the water level in well 23-29-3E1, located about 0.8 mile northeast of Surprise Spring at the north end of the lake, stood at an altitude of 2955.90 feet above sea level, or about 11.6 feet above the level of the lake at Surprise Spring.

At the south end of the playa six pairs of wells penetrating the fill furnish data of the lakeward slope of the water table (See plate 4). On June 21, 1937, measurements were made in all these wells within a period of a few hours. The following table gives the wells, their distances apart, and the drop in water level between the shoreward and lakeward well.

Differences of Water Levels in Pairs of Wells at the South End of Laguna Grande de la Sal

Wells		Distance between wells, in feet	Difference in water levels between shoreward and lakeward well (feet)
Shoreward	Lakeward		
23-29-22M1	23-29-21K2	2500	0.28
23-29-28B1	23-29-21Q1	1100	.47
23-29-21P2	23-29-21P1	80	.26
23-29-21M1	23-29-21M2	30	.36
23-29-20G1	23-29-20G2	1000	3.23

From the foregoing discussion and table it is evident that at least during June and July ground water in the fill was moving toward the lake. During the winter or after periods of heavy rains, when the lake level is rising, the slope of the ground water in parts of the playa close to the water's edge may be reversed temporarily until conditions of equilibrium are reestablished.

Nearly all the wells bored in the bed of the playa have a slight artesian head, and the head appears to increase with the depth of the well. Such a condition is demonstrated by well 23-29-21F1 (plate 4). This well, located in the bed of the playa, was bored to a depth of 13 feet, encountering a water-bearing bed between the depths of 8.7 and 9.7 feet below the top of the salt crust. After being thoroughly cleaned to remove all well cuttings, the water level on May 30, 1938, stood 0.70 foot above the salt crust, and 0.83 foot above the water level in the lake measured in a hole through the salt crust about 5 feet distant. This artesian condition indicates a source of water higher than the water level in the well.

As has been indicated, discharge of the ground water in the fill is by the flow of springs and seeps into the lake and by evaporation from the soil. Discharge into the lake is shown by Surprise Spring, Smith Spring, and other springs, and is also evident during dry periods in the summer in that part of the lake which is covered by a salt crust. Small vents through the salt crust were observed in the summer of 1937 and in the spring of 1938. These vents appear to be the result of unsaturated brine percolating upward through the fill and dissolving the salt to form small holes in the overlying salt crust. The vents were observed not only at the margin of the salt crust, where the crust was thin, but also away from the margin where the salt crust was from 4 to 6 inches thick and strong enough to carry the weight of an automobile.

On the margin of the playa, where the depth to the ground water is not great and the capillary fringe consequently extends to the land surface, ground water is discharged by evaporation of moisture from the soil. Ground water that is discharged into the lake mingles with the lake brine and eventually evaporates.

Water in the Alluvium Along the Pecos River in the Malaga Bend Locality

The Malaga Bend locality, as referred to in this report, is the locality lying adjacent to the Pecos River but largely within the pronounced bend of the river about four miles east and one mile south of Malaga. As shown by the geologic map, plate 2, the material in the Malaga Bend locality is almost entirely alluvium. The maximum known thickness of the alluvium is 149 feet.

The quality of the water in the alluvium ranges widely—from relatively fresh water to a concentrated brine. Thus at well 24-29-16M1 (U. S. G. S. No. 1 test) four water-bearing beds were encountered in the alluvium. The depths between which these water-bearing beds were encountered and the specific gravity of the water which they yielded are as follows: First bed, 22.5 to 46 feet, specific gravity 1.00; second bed, 54 to 68 feet, specific gravity 1.09; third bed, 76 to 84 feet, specific gravity 1.13 to 1.17; and fourth bed, 110 to 149 feet, specific gravity 1.20 to 1.21. It might be inferred from these specific gravities that water of the highest concentration is found only at the base of the alluvium. Such, however, is not the case.

Numerous shallow bored and driven wells have been sunk in the alluvium of the Malaga Bend locality to determine the quality of the ground water and its direction of movement. (See plate 5). In well 24-29-21D2 (plate 5) a sodium chloride brine with a specific gravity of 1.202 was encountered at 11.5 feet, in well 24-29-20A5 a sodium chloride brine with specific gravity of 1.195 was found at 21 feet while in the Grandson Spring area a sample of sodium chloride brine with a specific gravity of 1.189 was collected from a barrel sunk only 2 feet into the sand, and pools in the immediate vicinity of the barrel contained sodium chloride brine nearly as high in concentration. Weak to moderately strong sodium chloride brines were found nearly everywhere in the area, but concentrated sodium chloride brines, having a specific gravity of about 1.20, were found only in a narrow strip about 1 mile long, in and adjacent to the river channel, from the head of the Grandson Spring area south to the vicinity of Livingston's pump. It is in this section of the river that a large part of the total chloride influx in the Malaga Bend locality occurs.

The water in the alluvium of the Malaga Bend locality appears to be derived from the following sources: inflow of ground water from the west, rainfall penetration, penetration of irrigation water, and upward movement of brine from the brine horizon at the base of the Rustler formation. Irrigation recharge is undoubtedly a source. Mr. Dan Harroun, of the Valley Land Company, which controls the land in the Malaga Bend, estimated that in 1937 there was about 180 acres of land under irrigation and in 1938 about 165 acres. The duty of water according to Mr. Harroun is from 2.5 to 3.0 acre-feet per acre. Using these figures, the quantity of water applied to the cultivated land was between 450 and 540 acre-feet in 1937 and between 410 and 500 acre-feet in 1938. The land in the Salt Bend area was first irrigated in 1928, beginning on May 10 of that year, and has been irrigated each year since then. The irrigation season each year begins about April 15 and ends about September 15.

The soil of the irrigated land is largely sand that has a high permeability. Thus much of the irrigation water percolates downward to the water table, and thence laterally away from the irrigated areas, toward the river channel on the north, east and south. Movement in these directions as indicated by the slope of the water table, between well 24-29-16M5, which lies in the central part of the irrigated area, and shallow wells located on the flood plain of the river. On June 14, 1938, the water level in well 24-29-16M5 stood 0.82 feet higher than the water level in well 24-29-17H4, 1,000 feet north 4.19 feet higher than the water level in well 24-29-16K2, 3,300 feet east, 3.63 feet higher than the water level in well 24-29-16K1, 1,600 feet southeast, and 8.39 feet higher than the water level in well 24-29-20A2, 2,400 southwest.

The seasonal fluctuation of the Granddaddy Spring is chiefly the result of irrigation in the Malaga Bend locality. The discharge of this spring occurs largely in the form of small seeps over an area of about 40 acres, with the greatest concentration of them in the abandoned river channel paralleling the foot of the terrace at the south edge of the present flood plain. The northern limit of the irrigated area, as shown in plate 5, is about 600 feet south of the abandoned channel. In this channel during the height of the irrigation season, a series of pools separated by very low and flat divides, overflow from one to another to form a body of water about 1,500 feet long and about 100 feet in width. (See plate 5). Shortly after the end of the irrigation season, the discharge of the pools begins to diminish and in two to four months it ceases altogether. The shallower pools dry up entirely, whereas the larger pools persist until the next irrigation season but do not overflow.

The first irrigation water applied during the 1938 season was between April 5 and 19. As shown on the map, plate 6, about 15 acres of land closest to the spring pool on the south was not irrigated up to July 19. As shown by the measurements of depths to the water levels, the water level in well 24-29-17H1, located at the head of the spring pool, began to rise between April 5 and 19 and continued rising throughout April and May. There was no visible discharge from the pools into the river up to July 19. Readings on the No. 2 staff gage in Granddaddy Spring indicate that the water level in the pool rose 0.15 feet in the period April 19 to 26.

Observations of the discharge of the Granddaddy Spring pool, which are available as far back as October 12, 1934, are shown in the following table.

Discharge of the Granddaddy Spring Pool Into the Pecos River

Date	Granddaddy Spring pool discharging into the Pecos River	Discharge, in gallons a minute
1934		
Oct. 12	*yes	—
1936		
Dec. 10, 16, 26, 27, and 31	*yes	—
1937		
Jan. 15	*yes	—
Feb. 23	no	—
Mar. 19	no	—
May 29 and June 3	Under water-flood	—
July 30	*yes	—
Aug. 16	yes	70
Sept. 8 and 24	*yes	—
Oct. 5	yes	25-30
Oct. 12 and 14	*yes	—
Oct. 29	yes	—
Nov. 5	yes	5
Nov. 11	*no	—
Nov. 11 to July 19, 1938	No flow	—

* Observation by the United States Potash Company.

A similar fluctuation in the discharge of the Grandson Spring was observed from the long pool located at the base of the river terrace on the present flood plain. (See plate 5). It was not possible to measure the total discharge of the spring but measurements of the visible discharge into the river from the largest pool by means of a Cipolletti weir gave the following results: In December, 1937, the discharge into the Pecos River was 50 gallons a minute; January 18, 1938, it was 40 gallons a minute; on March 16, it was 30 gallons a minute and on March 25 it was about 22 gallons a minute. Between March 25 and April 26 it increased to about 35 gallons a minute.

The water discharged into the Pecos River from the pools just described in the Granddaddy and Grandson spring localities was a weak sodium chloride brine—presumably a mixture of the irrigation percolate with a small amount of the ascending concentrated sodium chloride brine. Many seeps and small spring pools located along the river bank in the two spring areas discharge a moderate to strong sodium chloride brine into the river. Here, as in the large pools referred to, the water is apparently a mixture of the irrigation percolate with the ascending sodium chloride brine, but with smaller proportion of the irrigation percolate.

LAGUNA GRANDE DE LA SAL AS A SOURCE OF SALT IN THE WATER OF THE PECOS RIVER

During the present investigation a careful study was made of the lake and of the area between the lake and the Malaga Bend to determine whether there is evidence of movement of the lake brine into the Malaga Bend locality. Some of the results of this study have been previously stated, but the entire subject will be briefly discussed here.

There is no surface outlet from Laguna Grande de la Sal; hence if there is a connection between the lake and the river it must occur underground. Laguna Grande is situated sufficiently high so that if an underground outlet exists the lake brine can flow by gravity to the river. The lake bottom at its deepest place, in the north end near Surprise Spring, lies at an altitude of 2,930 feet above sea level. (See plate 4). The discharge of the effluent from the refinery operations bgan on a small scale in the fall of 1932. As shown in figure 3, the level of the brine in the lake during the period May 20, 1933, to the present, for which staff gage readings are available, has fluctuated between 2,943.71 and 2,945.58 feet above sea level has averaged about 2,945 feet. That the lake level has been higher in previous years is shown in places by the wave-cut shore lines. According to an observation made by Mr. Dan Harroun,[1] of the Valley Land Co., in August, 1928, at the western end of the lake, the water level at that time was about 2 feet higher than the water level at the same place in July, 1938. This observation was made following a period of heavy rainfall. A study of the hydrograph indicates that the fluctuations in the lake level since 1933 were due largely to variations in discharge by evaporation and in recharge by surface inflow in rainy periods.

Three test wells were drilled in the vicinity of the lake—23-29-17B1 (U. S. G. S. No. 4 test), 23-29-22C1 (U. S. P. C. No. 1 Test), and 23-29-28B6 (U. S. P. C. No. 2 test). In each of these wells water of a different type and of a decidedly lower chloride content than that of the lake brine was encountered below the bottom of the lake, indicating that the lake brine is probably not penetrating down to the brine horizon at the bottom of the Rustler formation Moreover, in none of the wells located between the lake and the Malaga Bend which draw water from above this brine horizon was brine found with a concentration comparable to that of the brine in the lake or of the concentrated brines of some of the springs and shallow wells in the Malaga Bend. It appears improbable, therefore, that the lake brine is reaching the Malaga Bend through permeable beds above the brine horizon.

On pages 94 and 95 it is seen that the water in the fill has a gradient toward the lake, indicating ground-water movement toward the lake rather

[1]Oral communication.

than away from it. The artesian conditions in the lake, especially at well 23-29-21F1, where the head is sufficient to cause the water to flow above the top of the salt crust, is evidence of a source of water higher than the lake level. The second water encountered in well 23-29-17B1 (U. S. G. S. No. 4 test), between 62 and 68 feet, was also under artesian pressure. A further indication of artesian pressure is afforded by the vents in the salt crust, which are the result of upward percolation of fresh water which dissolves holes in the salt crust. The artesian conditions seem to indicate that there is little or no penetration of the lake brine downward to the underlying Rustler formation, as otherwise the artesian head would be dissipated. An examination of the lake failed to reveal any visible opening through which the brine could escape. Moreover, if the reports were correct that concentrated brine and solid salt occurred in the lake many years ago, before refinery operations contributed salt, these reports indicate that there has not been much opportunity for the lake water to escape by downward percolation.

CONCLUSIONS

By Thomas W. Robinson and Walter B. Lang

The discussion in the foregoing pages and the data presented in the appendix lead to the following conclusions: A body of concentrated solution of sodium chloride occurs at the base of the Rustler formation and overlies the extensive deposit of salt known as the Salado halite. This brine horizon extends from some locality north of Laguna Grande de la Sal to the vicinity of the Malaga Bend of the Pecos River. The brine in this horizon is under artesian pressure and has in general a southward hydraulic gradient. Below Fishing Rock, at the Malaga Bend, the artesian pressure is sufficient to raise the brine above the level of the river at normal stages. In the vicinity of the Malaga Bend the confining bed for the brine horizon is thin and incompetent. Salt water is percolating upward from the brine horizon and entering the Pecos River at the Malaga Bend locality.

It is believed that the salt in the brine of the brine horizon is derived chiefly from the underlying deposit of salt in the Salado halite. The available evidence points to the conclusion that the lake brine does not reach the Malaga Bend through the brine horizon or by any other route.

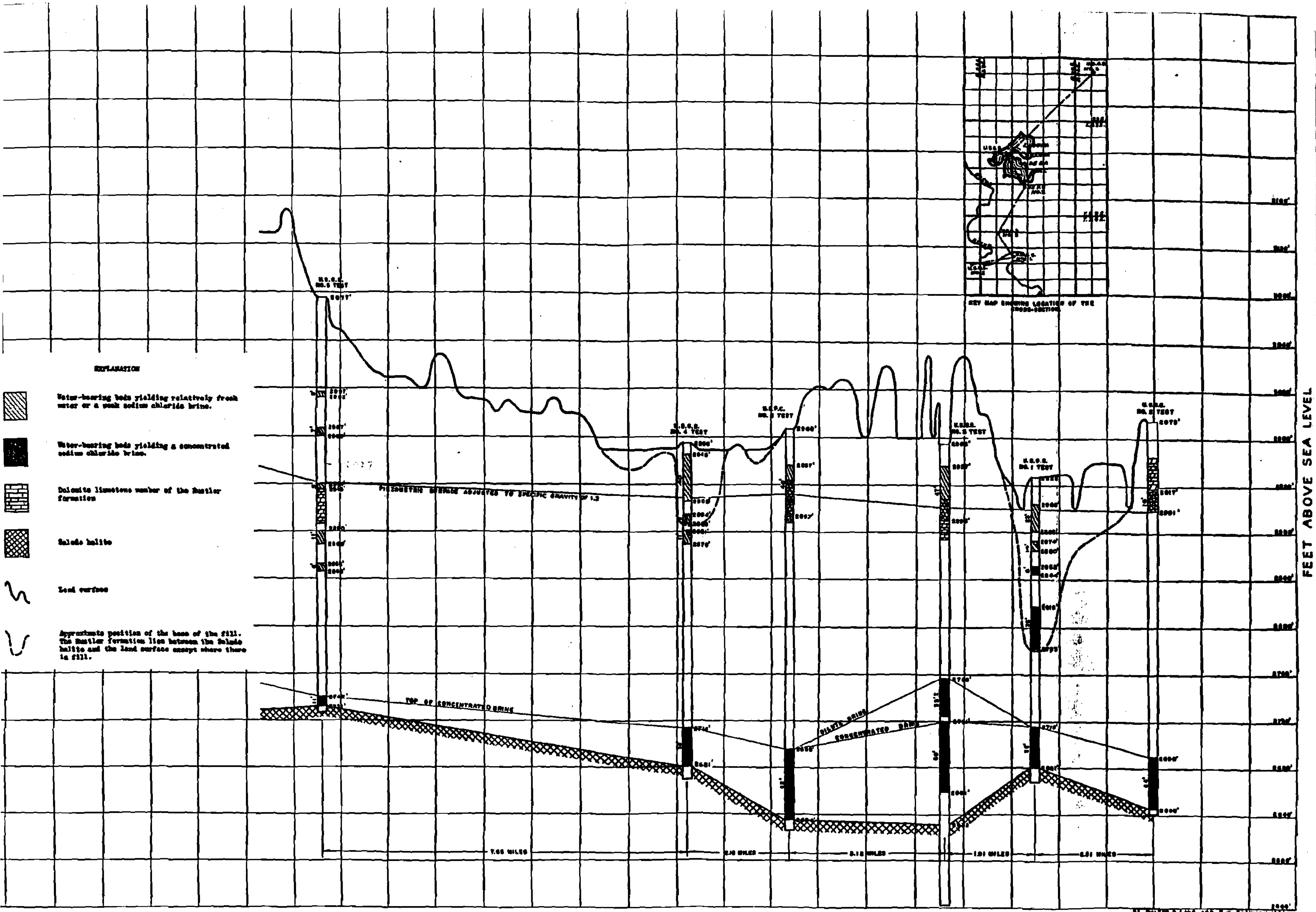

Figure 2. Cross section showing the water horizons encountered by test wells in the Rustler formation and slope of the piezometric surface of the brine at the base of the formation.

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cos River

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	5

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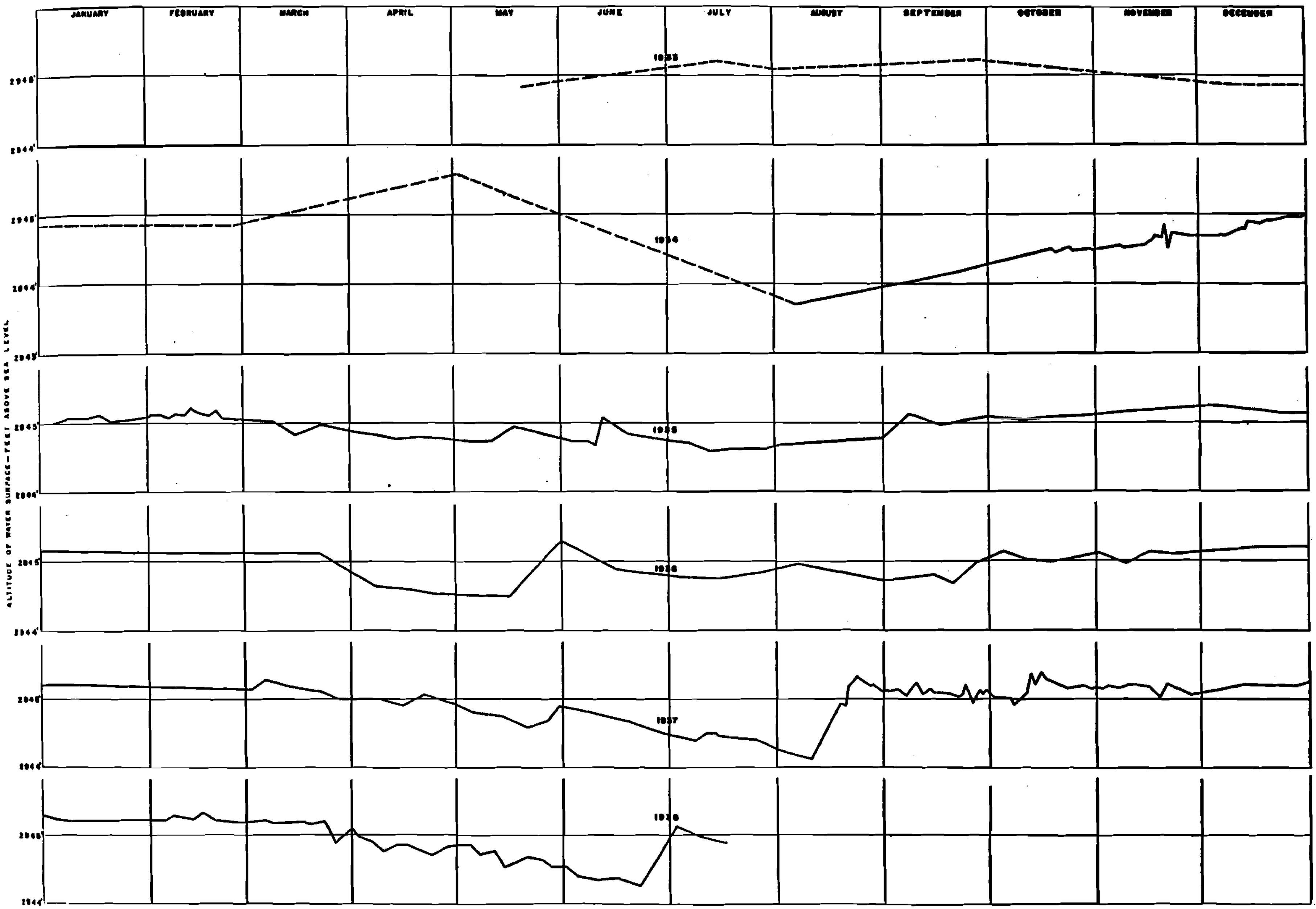

Figure 8. Hydrograph of Laguna Grande de la Sal based on staff gage readings at Surprise Spring.

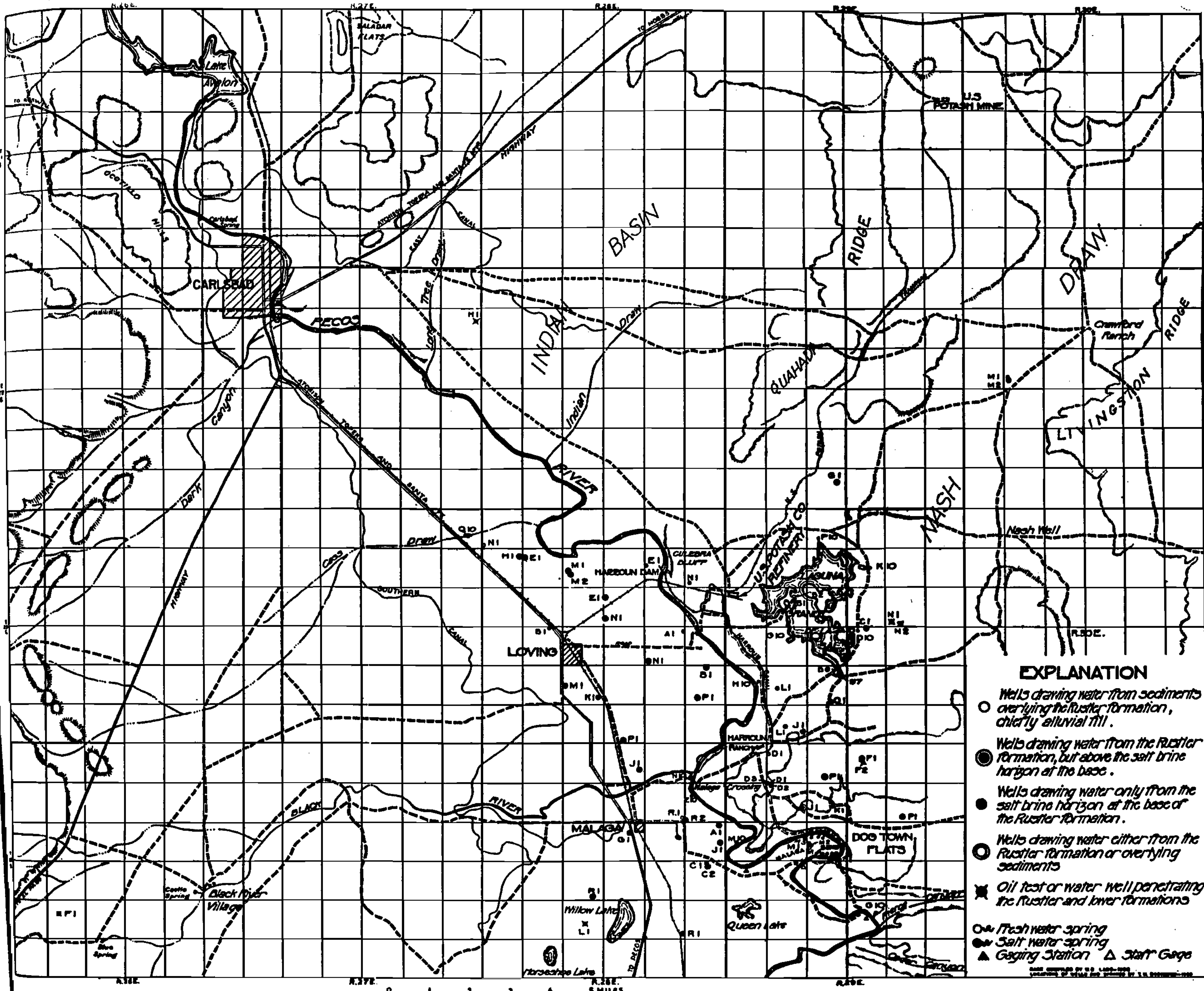

Plate 1. Map of the Pecos River area in the vicinity of Laguna Grande de La Sal showing wells and springs.

Robinson + Lang 1134 p. 83 Res. Grande

p. 86 "dryness" " " 55' deep to 15' along lake

p. 89 sand Canyon independent of Sprigs in Laguna Grande

p. 90 piezo - pressure gradient X

= F.W.H.

22-30-17 M1 (USGS #5 2927 W.L.)

(corrected to 2921 for SpG = 1.20)

p. 90 Upward percolation Level 7 floodplain

Dal 149 feet deep

2927
2742
(185' / 179) =

Brine head = 2900+ at Well 24-29-16A11

River at Fishing Lake : 2900'

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p. 91 USGS 5 Water in Rustler

50 · 85

110 · 161

156 - 161 197 - 208s

225 - 231

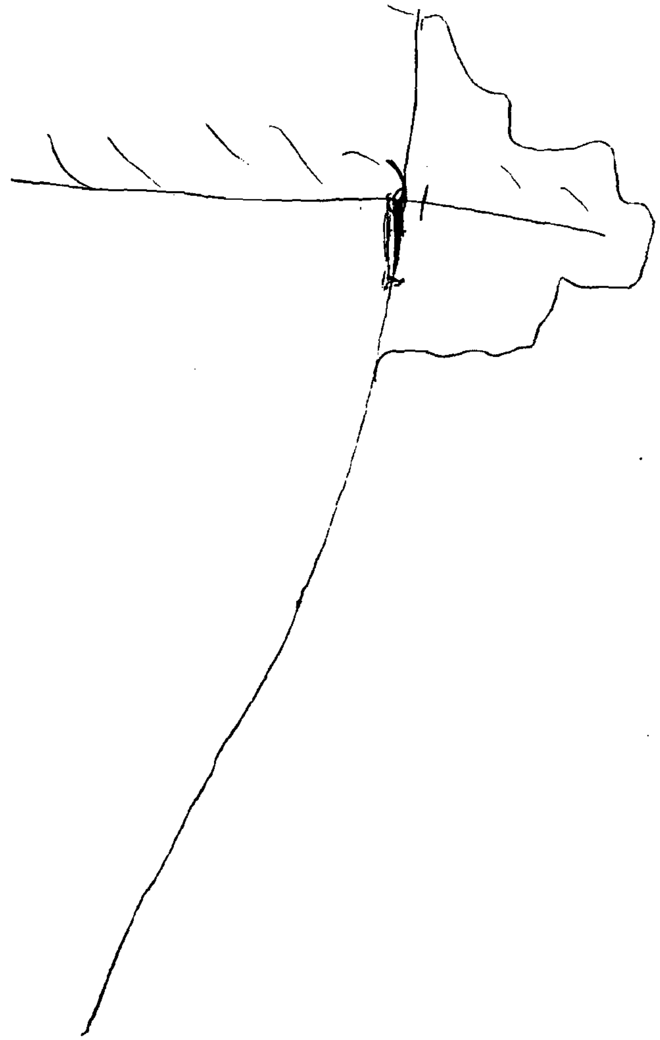
gray sd. below dol. (W.B.)

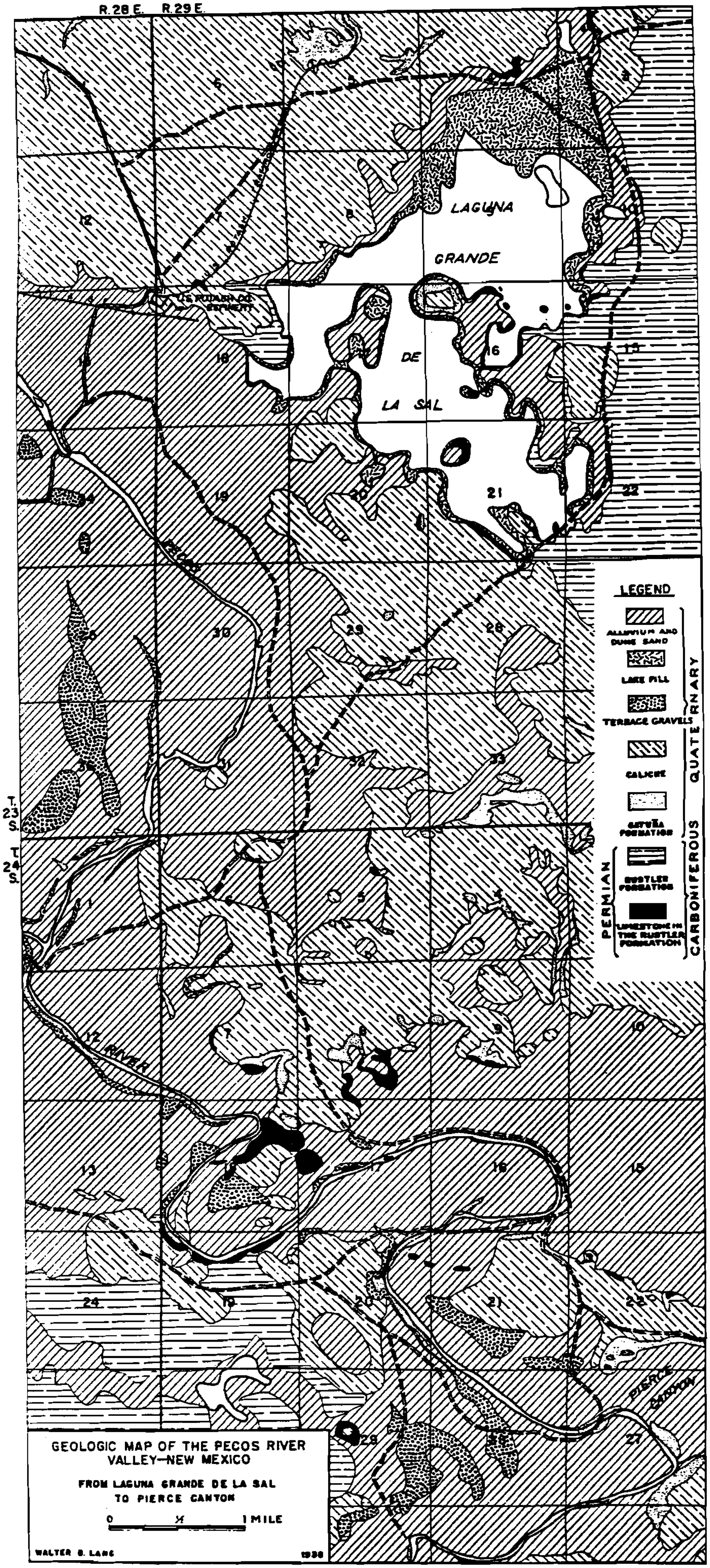
* "No water found" = "dry"

" "no very active movement"

p. 92 "No direct movement" (dolomite disc.)

93




R.28 E.
R.29 E.
LAGUNA
GRANDE
DE
LA SAL
PECOS
RIVER
PIERCE
CANYON
T. 23 S.
T. 24 S.
LEGEND
ALLUVIUM AND DUNE SAND
LAKE FILL
TERRACE GRAVELS
CALICHE
RUSTLER FORMATION
LIMESTONE IN THE RUSTLER FORMATION
QUATERNARY
PERMIAN
CARBONIFEROUS
GEOLOGIC MAP OF THE PECOS RIVER VALLEY—NEW MEXICO
FROM LAGUNA GRANDE DE LA SAL
TO PIERCE CANYON
0 ½ 1 MILE
WALTER B. LANG

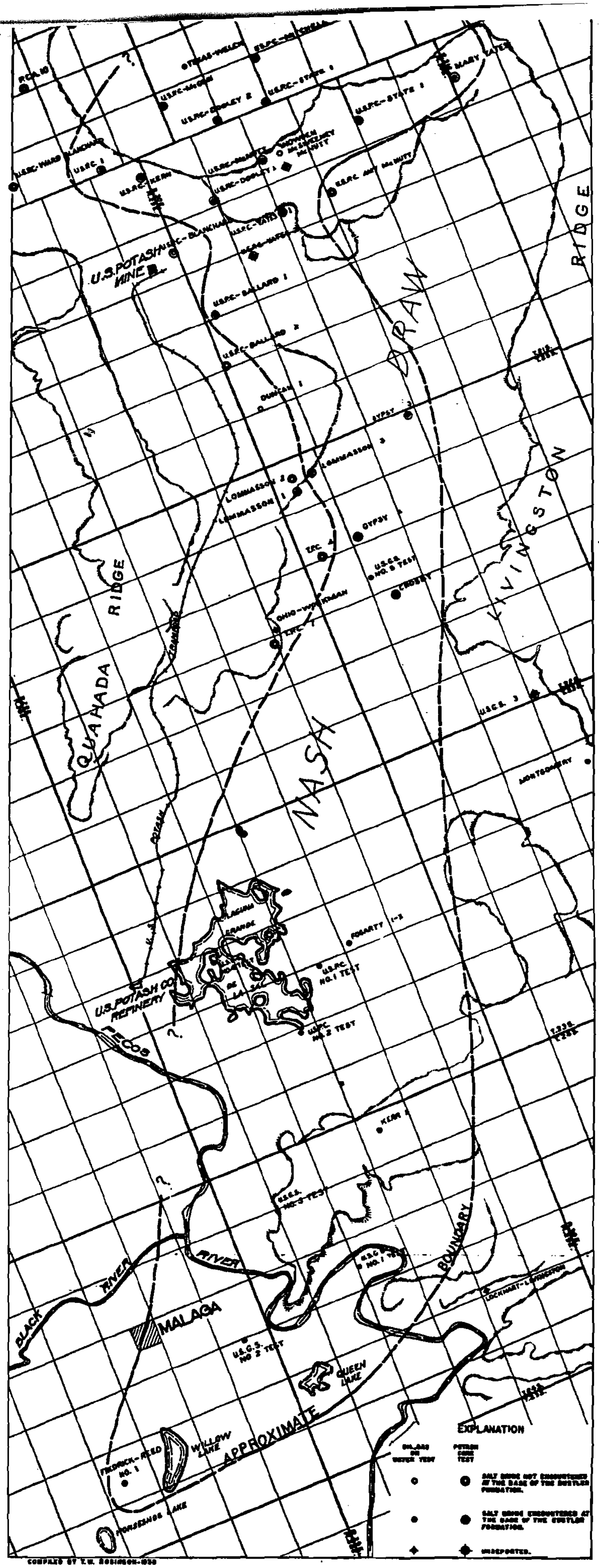


Plate 3. Map showing approximate area underlain by sodium chloride brine at the base of the Ru[illegible] formation, in the vicinity of Laguna Grande de la Sal and adjacent area.

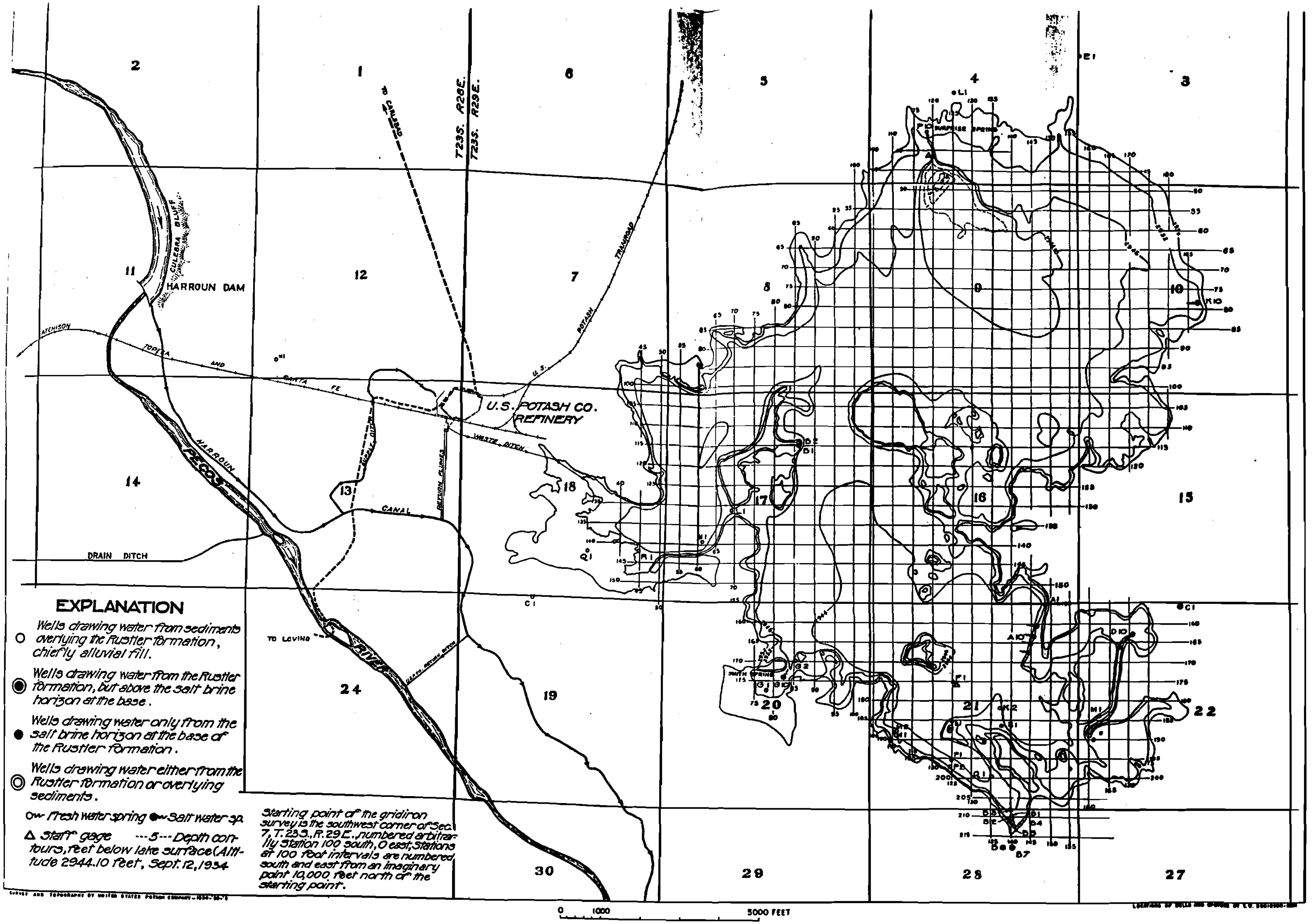


Plate 4. Map of Laguna Grande de la Sal and adjacent area showing locations of wells and springs.

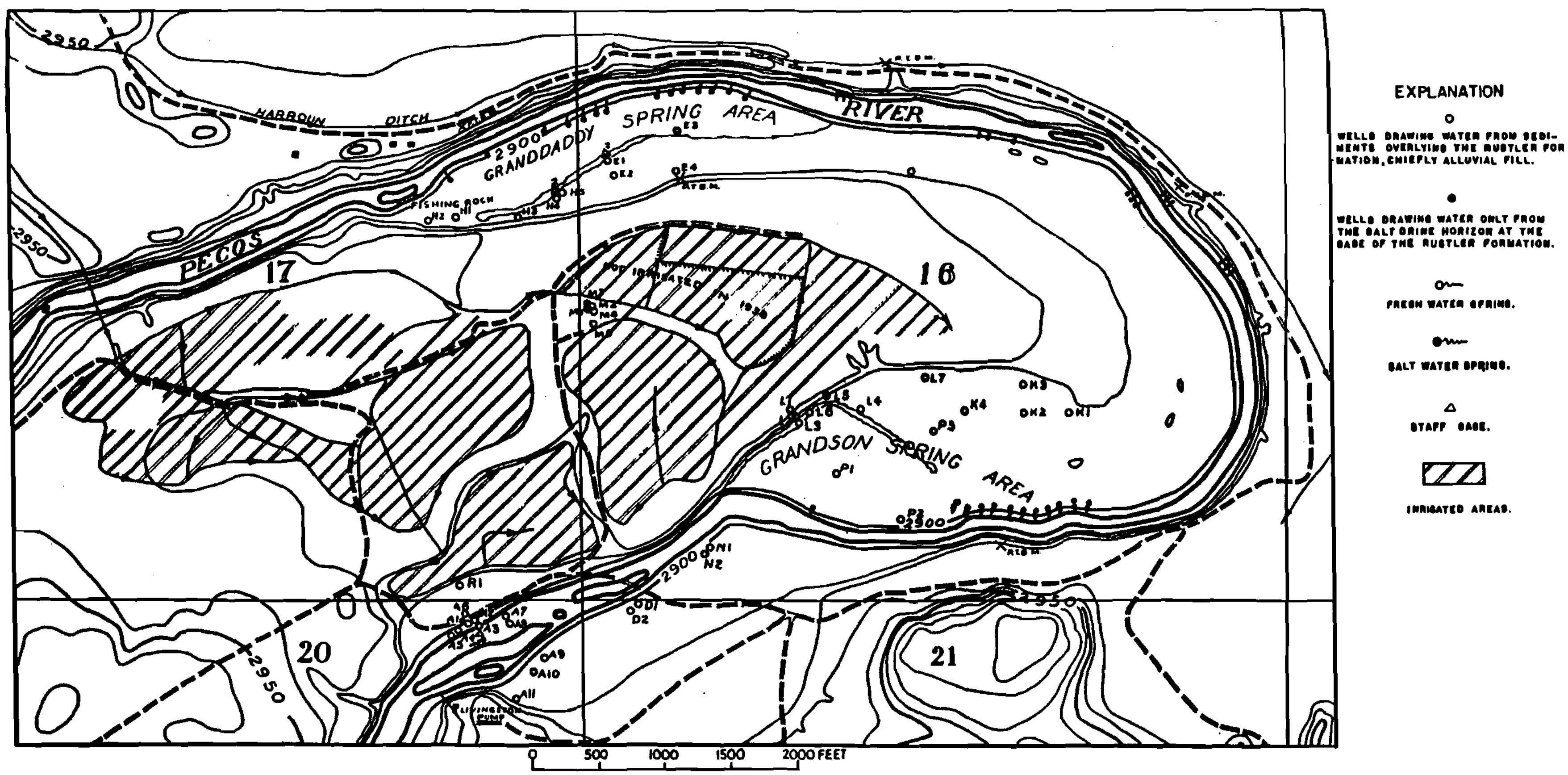


Plate 5. Map of the Malaga Bend locality along the Pecos River showing the irrigated areas and locations of wells and springs, 1938.