Waste Isolation Pilot Plant

Compliance Certification Application

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The Pecos River Commission
New Mexico and Texas

POSSIBLE IMPROVEMENT OF QUALITY OF WATER OF THE PECOS RIVER BY DIVERSION OF BRINE AT MALAGA BEND, EDDY COUNTY, NEW MEXICO

BY

W. E. Hale, Engineer
L. S. Hughes, Chemist
and
E. R. Cox, Geologist

Prepared cooperatively by

United States
Department of the Interior
Geological Survey
Water Resources Division

December 1954

U. S. GEOLOGICAL SURVEY
WATER RESOURCES DIVISION
P. O. BOX 842
CARLSBAD, NEW MEXICO

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THE PECOS RIVER COMMISSION
NEW MEXICO AND TEXAS

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PECOS RIVER COMMISSION
NEW MEXICO AND TEXAS

In 1951 the Geological Survey, in cooperation with the Pecos River Commission, began the investigation of the feasibility of eliminating the inflow of brine in the Malaga Bend reach of the Pecos River. This is an interim report prepared for the Pecos River Commission covering investigations to date. A more complete and comprehensive report is planned for later publication by the Geological Survey.

The report was released to the public by the Secretary of the Interior on December 27, 1954. In his release announcement Secretary McKay noted the Pecos River Commission would reproduce the report.

Office of the Secretary
P. O. Box 842, Carlsbad, New Mexico

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POSSIBLE IMPROVEMENT OF QUALITY OF WATER OF THE PECOS RIVER BY DIVERSION OF BRINE AT MALAGA BEND, EDDY COUNTY, NEW MEXICO

By
W. E. Hale, L. S. Hughes, and E. R. Cox

ABSTRACT

About 420 tons of dissolved minerals of which about 370 tons is common salt is added daily to the mineral load of the Pecos River through seeps and springs along a stretch of about 3 miles in the Malaga Bend of the river in T24 S., R 29 E., which is 17 miles southeast of Carlsbad in southern Eddy County, N. Mex. In this reach, the river gains on the average approximately 2-1/2 cfs, a mixture of water of which about 2 cfs is return from irrigation water applied to nearby lands and about 0.4 cfs (200 gpm) is a concentrated brine. Elimination of the small inflow of concentrated brine would result in substantial improvement in the quality of the water reaching the Red Bluff reservoir, the water from which is used for irrigation in the valley farther downstream in Texas.

Brine, almost saturated with sodium chloride, occurs at shallow depth in the alluvium in the Grandson Spring area on the inside of the Malaga Bend and between Livingston's Ford and the Lower Wading station on the outside and lower end of the Malaga Bend. Elsewhere at shallow depth in the Malaga Bend area, the ground water present is a mixture of brine and water derived from application of water to nearby farm lands. The chloride content of the water in the alluvium increases with depth and, in the lower part of the alluvium, the water is saturated with common salt.

The source of the concentrated brine in the alluvium at Malaga Bend is a brine aquifer that underlies the area at a depth of about 200 feet. The aquifer is developed mostly in gypsum near the base of the Rustler formation and in places directly overlies the thick sequence of impermeable salt and anhydrite beds of the Salado formation. The brine is under sufficient head in the brine aquifer to percolate upward through thin and incompetent beds of gypsum and clay into the overlying beds of sand, clay, and silt and thence into the river. The Malaga Bend area is the only known discharge area for this concentrated brine.

The basal brine aquifer extends northward from the Malaga Bend area in a strip 3 to 5 miles wide into Nash Draw. The known length of the aquifer containing brine is about 25 miles. The principal area of recharge is inferred to be in the vicinity of Bear Grass Draw in T. 18 N., R. 30 E., several miles north of Nash Draw. In the recharge area truncated beds of the Rustler formation are exposed or immediately underlie the alluvium in

the area. Some recharge to the brine aquifer occurs at times through sinkholes in the area about 2 miles west of the Malaga Bend. The source of the dissolved salt in the basal brine aquifer is undoubtedly the salt in the underlying Salado formation.

The transmissibility of the brine aquifer obtained from aquifer tests appears to be about 60,000 gallons a day per foot, and on the basis of the width of the aquifer of 5 miles and a gradient of 1.4 feet per mile the aquifer is estimated to be transmitting about 0.6 cfs toward the discharge area in the Malaga Bend. This value is of the same order of magnitude as the rate of discharge (0.4 cfs) calculated on the basis of the observed gain in salt load of the river in the Malaga Bend area. The latter method of determining the discharge from the aquifer is considered to be more precise.

Some consideration was given to elimination of the brine from the Pecos River by means of a bypass channel across the Malaga Bend. This channel, about 1 mile long, and retaining dams in the cutoff section would be very costly; the surface area in the cutoff sections required to evaporate the return irrigation water and brine would need to be large; and the brine might break into the constructed channel. For these reasons, this method of elimination of the brine inflow was not given further consideration. The most feasible method of preventing the brine from entering the river appears to be by pumping the brine at such a rate as to maintain the head of the brine below river level. The pumped brine would have to be disposed of by injecting it into deeper-lying aquifers or by pumping it to surface basins where it could be evaporated. Meager data from nearby oil test wells indicate that deeper aquifers are not sufficiently permeable to receive the quantity of brine that would need to be pumped. The most favorable nearby surface-disposal area appears to be the Queen Lake depression about 2 miles southwest of the Malaga Bend. The investigation of the feasibility of improving the water of the Pecos River passing the Malaga Bend thus has centered around methods of pumping the brine and the determination insofar as possible of the suitability of Queen Lake as a disposal area.

The alluvium in the Malaga Bend area extends to a depth of 150 feet below the Pecos River in places. It is composed of silt, sand, clay, and some gravel. The transmissibility of the alluvium appears to be small, of the order of 10,000 gallons a day per foot. Pumping of shallow wells constructed in the alluvium and finished only a few feet into the saturated brine would have the most immediate effect in eliminating the brine inflow to the Pecos River. The number of wells required would be large and, unless careful regulation of the discharge were maintained, considerable overlying fresh water would be drawn into the wells, which would diminish the efficiency of the pumping system. Wells finished and open only in the basal part of the alluvium probably could be pumped at rates greater than the shallower wells, and the number of wells required to effectively lower the head of the brine below river level throughout the bend area would be

less than that required for a shallow-well system. Again, however, careful observations would need to be maintained and the pumping rate from each well regulated to prevent drawing in of fresher water in the upper part of the alluvium.

Aquifer tests indicate that the basal brine aquifer has a high coefficient of transmissibility and low coefficient of storage. One or two properly located wells in the basal brine aquifer could be pumped at such a rate as to lower the head of the brine below river level over the entire discharge area. There is little likelihood that the fresh water in the overlying alluvium would be drawn into the wells. An initial pumping rate of 600 to 700 gallons a minute from the deeper wells would lower the head of the brine to about river level in a few days. The pumping rate could be lowered in time and eventually could be reduced to approximately 200 gallons a minute, the natural discharge rate from the aquifer. Some additional water may be induced into the basal brine aquifer in the recharge area as a result of lowering of the head on the brine aquifer, but the amount probably would be small. A high initial rate of withdrawal of brine from the basal brine aquifer would induce the brine to move from the alluvium into the basal brine aquifer, hastening the diminution of flow of brine to the river.

The brine stored in the alluvium will continue to drain to the river for several years, but if brine is prevented from entering the alluvium by diverting it through wells penetrating the basal brine aquifer, improvement in the quality of the river water moving past the Malaga Bend should occur within a few years. The efficiency of any pumping system in eliminating the flow of brine into the river may never reach 100 percent.

The Queen Lake depression is a sink developed by solution and collapse of rocks in the Rustler and underlying Salado formations. The depression has since been filled partially with alluvium. The playa covers an area of about 60 acres and is underlain by silt and clay. Exposures of gypsum and dolomite of the Rustler formation occur in the adjacent slopes of the depression, but most of the Rustler formation in the depression is mantled by silt, clay, and sand. Ground water moves in a general eastward direction toward the Pecos River through the fill and upper beds of the Rustler formation in the vicinity of Queen Lake. The playa sediments are not absolutely watertight but water moves only slowly through them. Storm runoff into the playa is lost almost entirely by evaporation. Tests of samples of the playa deposits indicate an initial permeability of about 1 gallon a day per foot. Continued tests with brine on some samples resulted in the material becoming essentially tight to passage of brine. The cause of the decrease in permeability is not known. If the depression were used for storage of brine, deposition of salt together with inwash of silt along the margins probably will make the depression tighter than it now is. Some leakage from the lake will occur but it may diminish under natural conditions in time. Some remedial measures might be necessary, however, to retard leakage from the

lake, the brine from which would move east and south and eventually enter the river. The storage capacity of the Queen Lake depression is about 5,500 acre-feet and would provide storage for pumped brine and the salt precipitated from it for approximately 100 years. A dam placed on a draw on the west side of the Queen Lake depression would prevent much of the surface runoff from entering the lake, so as to permit maintaining more concentrated brine in the lake and hence faster precipitation of salts.

Although an action program which involves pumping of brine from the basal brine aquifer in the Malaga Bend area and storage of the brine in Queen Lake appears to have a fair chance of success hydraulically, such a program should be considered as experimental. An observation program should be maintained to provide data on the effects of pumping on the quality of the water in the Pecos River and the movement and quality of water in the Queen Lake area. The data obtained would aid in making changes in the pumping regimen and would provide a basis for any remedial measures needed to retard the leakage from the Queen Lake depression. It may be advisable to attempt the development of wells in the basal part of the alluvium in the Malaga Bend area to hasten the required debrining of the alluvium. Some consideration should be given to plugging active sinkholes in the recharge area about 2 miles west of Malaga Bend.

INTRODUCTION

Highly mineralized water enters the Pecos River through seeps and springs in the Malaga Bend stretch of the river, about 20 miles southeast of Carlsbad in Eddy County, New Mexico (pl. 1), adding greatly to the already high mineral load (averaging something like 2,000 tons per day) carried by the river when it enters that stretch. In a reach of about 3 miles around the Malaga Bend, approximately 430 tons of salts, of which about 370 tons is common salt, is added daily to the river water moving past the bend. The river flows southward from the Malaga Bend into the Red Bluff reservoir just south of the State line in Texas. The water is stored here for use in seven irrigation districts along the valley from Mentone, Tex., south to Girvin, Tex. As much as 45,884 acres have been irrigated in these districts in favorable years but during the past few years there has been a marked decrease in irrigated acreage as a result of inadequate water and the high mineralization of the available water. Improvement of the quality of the river water would improve crop yields and the crops would require less water.

Usually, dissolved minerals are added to a river system through long stretches of a river and the volume of water involved is appreciable. Conditions such as this makes it impractical to improve the quality of a river water by preventing the contaminating water from entering the river. In the Malaga Bend reach of the Pecos River, however, the area of inflow of water of poor quality is relatively small and the quantity of mineralized water - a highly concentrated brine - entering the river is only

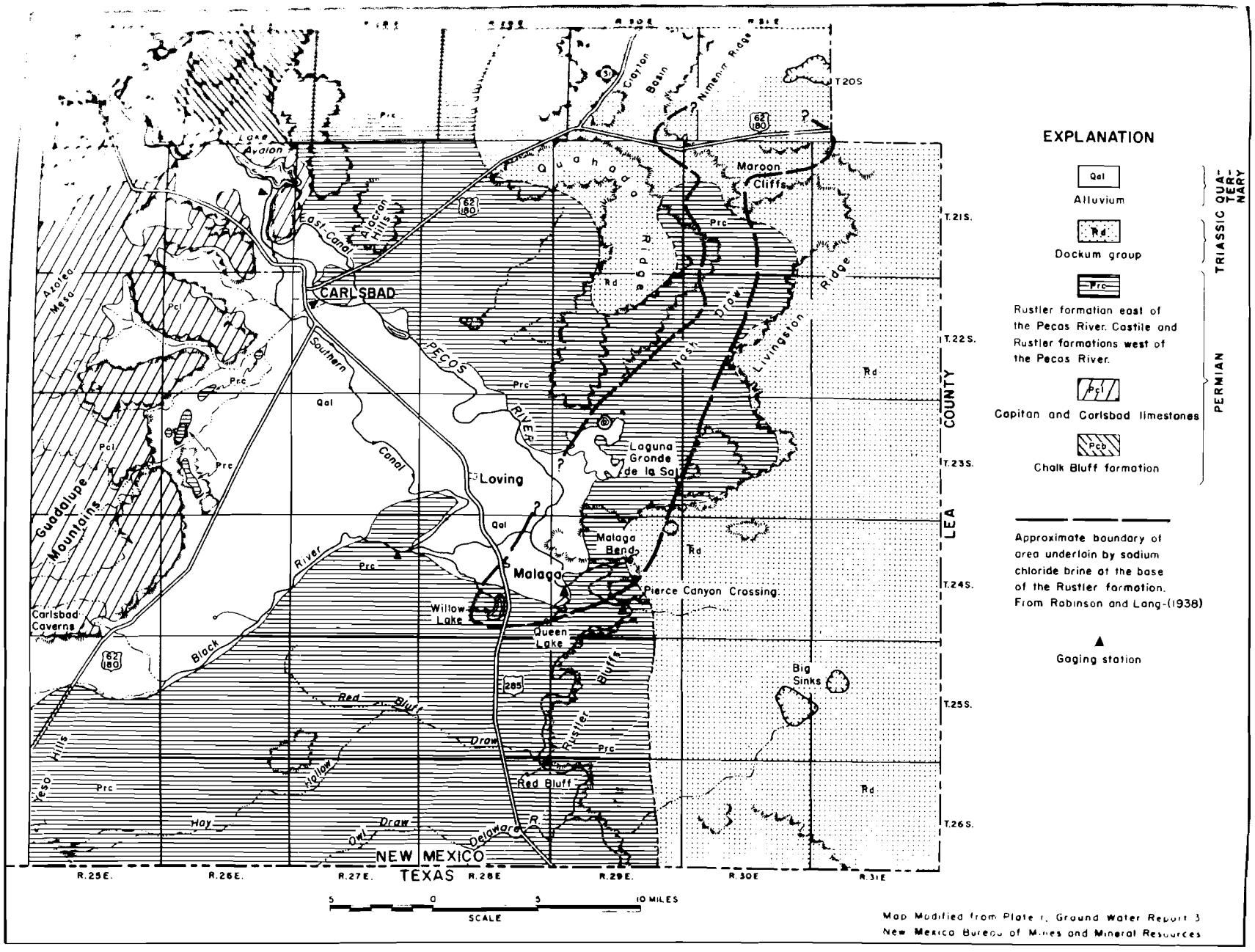

PLATE I. GEOLOGIC AND LOCATION MAP OF SOUTHEASTERN EDDY COUNTY, NEW MEXICO

about 0.4 cfs. Under these conditions the question arose, therefore, as to whether there might be some method within economic reach that might be found to keep the contaminating water from entering the river, thus improving substantially the quality of the water reaching the Red Bluff reservoir.

One of the specific responsibilities of the Pecos River Commission in carrying out the terms of the Pecos River Compact is to investigate means of improving the quality of water in the Pecos River, particularly in the Malaga Bend stretch, and if improvement is feasible to recommend a program for improving the quality of the water.

Scope of the Investigation

The Pecos River Commission entered into a cooperative agreement with the Geological Survey in 1951 to investigate the hydrologic feasibility of eliminating the inflow of brine in the Malaga Bend reach of the Pecos River. The investigation was made by the Water Resources Division. Some phases of the work were begun in July 1951 and parts of the investigative phase will continue through at least July 1955.

This report represents a preliminary compilation and discussion of the results of the study prepared for the Pecos River Commission for the purpose of presenting a summary of investigations to date. A more complete and comprehensive report is planned for later publication by the Geological Survey.

Two general methods of eliminating the inflow of brine to the river were given initial consideration: (1) Inasmuch as the influx of highly mineralized water takes place along the Malaga Bend, some consideration was given to the possibility of constructing a cutoff channel connecting the head of the bend with the toe of the bend, a distance of about 1 mile, and thus bypassing the stretch in which the brine springs are emerging. Dams would have to be built to retain the brine in the cutoff section. However, it would be difficult if not impossible to confine the brine to the storage pool, as the increased head brought about by the storage of brine in the cutoff section probably would cause the brine to break out in the cutoff channel or other areas. Further the storage pool in the cutoff section would have to be quite large to permit the evaporation of not only the brine but also the return water from nearby irrigated land. The inflow into the storage pool of course could be reduced by taking the nearby lands out of cultivation. The cost of the cutoff channel, retaining dams, and purchase of irrigated lands for the purpose of taking them out of production probably would be excessive. For these reasons, this approach to the elimination of the brine inflow was not given further consideration. (2) An alternative method of improving the quality of the river water would be to pump the brine at such a rate as to maintain the head of the brine in the water-bearing bed below river level, thus preventing it from entering the

river. The pumped brine could be disposed of (a) by injection into much deeper brine-bearing beds through wells or (b) by pumping it through a pipeline to nearby basins where it would evaporate.

Meager data obtained on nearby oil and oil-test wells suggest that deeper brine-bearing beds, which are at depths of more than 3,000 feet, are not sufficiently permeable to take the amount of brine that would be pumped. The intervening beds of salt and anhydrite are impermeable. For these reasons, the disposal of the brine into deeper brine-bearing beds does not appear to be feasible.

The most feasible method of eliminating the brine inflow therefore appears to be by pumping the brine into nearby evaporation basins. The largest nearby basin is Queen Lake, between 1 and 2 miles southwest of the Malaga Bend (pl. 2). The investigation thus has centered around means of pumping the brine from the Malaga Bend area and determining insofar as possible the suitability of Queen Lake as a disposal area.

Location of the Area

The principal area investigated is the southwest part of T.24 S., R. 29 E., which includes the Malaga Bend area and most of the Queen Lake area. The Malaga Bend of the Pecos River is about 5 miles east of Malaga which in turn is on U.S. Highway 285 about 17 miles southeast of Carlsbad. Improved roads lead to the Malaga Bend but only trails provide access to much of the area. Lands are irrigated in the Malaga Bend area on both sides of the river. Water is brought to the inside of the bend by means of a flume (pl. 2). The Pecos River is the source of the irrigation water, which is diverted through a canal system that originates several miles upstream from the bend. The study was extended to the Nash Draw area and other areas to the north of Malaga Bend (pl. 1) in connection with the source of the brine.

Previous Investigations

Although the occurrence of brine springs in the Malaga Bend has been known for many years, Robinson and Lang (1938) were the first to make a detailed study of the spring area, in 1937-38. Personnel of the U.S. Potash Co. also worked on the problem at the same time. Although the results of their work were not published, many of their data were made available to Robinson and Lang, who incorporated the data in their report on the area. Robinson and Lang concluded that the source of the brine was the brine aquifer in the basal part of the Rustler formation, from which the brine percolated through a thin and incompetent confining bed of the Rustler formation into the alluvium and thence into the river in the Malaga Bend locality. Additional work was done on the occurrence of brine in the Malaga Bend area from 1939 to 1941. The results of this additional work were presented in the "Reports of the participating agencies, the

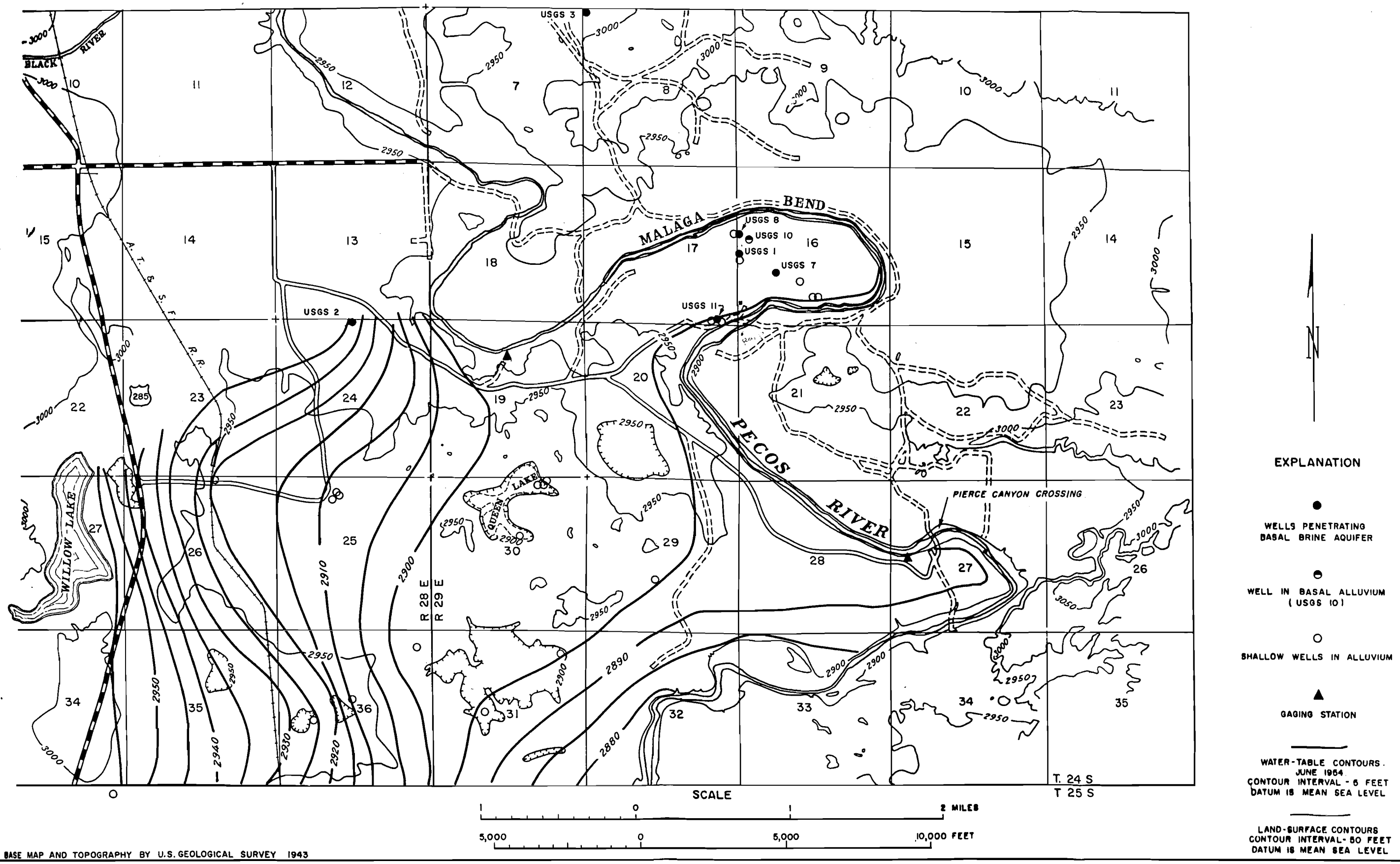

PLATE 2. GENERAL TOPOGRAPHIC MAP OF THE MALAGA BEND LOCALITY, EDDY COUNTY, NEW MEXICO, SHOWING WELL LOCATIONS AND WATER-TABLE CONTOURS

Pecos River Joint Investigation." In this report, Theis (Theis, Morgan, and others, 1942, p. 69) infers that if all the salt entering the river in the Malaga Bend area were coming from the brine aquifer at the base of the Rustler formation, the brine is emerging at the rate of 0.44 cfs. During the period from 1941 to 1952 periodic measurements of water levels were made in the brine test holes and in a few shallow wells used in the previous investigations of the occurrence of the brine.

Concurrent with the above investigations, data were obtained on the flow of the Pecos River at the gaging stations near Malaga, at Pierce Canyon Crossing, and at Red Bluff (pl. 1). The station was discontinued at Pierce Canyon Crossing in September 1941.

Water samples were collected daily for chemical analyses at these three stations for the periods of operation of the stream-gaging stations. Also data were collected by Howard, White, and Hastings on the chemical quality of the water in the brine aquifer and the shallow ground water in the Malaga Bend area. Results of this work appear in the 12th and 13th Biennial Reports of the State Engineer of New Mexico, and in the "Reports of the participating agencies, the Pecos River Joint Investigation."

The geology of the Malaga Bend and Queen Lake areas was studied, and consideration given to the watertightness of the bottom of Queen Lake, by R. S. Jones of the Geological Survey in 1948. Data obtained during his study and some of his conclusions are incorporated in this report.

Present Investigation

The present investigation was begun in 1951. The data collected during previous investigations were reviewed and utilized to provide the background for this investigation. Three brine test wells in the Malaga Bend area that had been drilled in connection with previous investigations were cleaned out and tested for casing leaks. The casings were found to be in satisfactory condition and perforated liners were inserted in the previously uncased lower parts of the test holes. Recorders were installed on the brine test wells in the Malaga Bend area and other brine test wells outside the area. Several shallow observation wells were constructed in the Malaga Bend area and in the vicinity of Queen Lake to observe fluctuations of the water level of the shallow water. Two additional moderately deep test holes were drilled in the Malaga Bend area. One, test well 24.29.16.133a (USGS 10), was drilled to the basal part of the alluvium to obtain information on the relation of the brine in the basal alluvium to that in the underlying brine aquifer in the basal part of the Rustler formation. Another test well, 24.29.17.444 (USGS 11), in the south part of the bend area was drilled to obtain information on water-bearing beds in the alluvium and was intended to be developed as a production well in the basal brine aquifer in the Rustler formation. The well did not yield sufficient water to be used as a production well and was finished as an observation

well in the basal brine aquifer. Two aquifer tests were made, one in May 1953 for a period of 2 weeks, one in January-March 1954 for a period of 6 weeks, to determine the aquifer characteristics of the basal brine aquifer and the effect of pumping, if any, on the inflow of brine to the river.

The work in the vicinity of Queen Lake included establishing a recording gage on the lake to aid in determining whether there was leakage from the lake of storm waters that drained into the lake. A few shallow wells were augered in the lake bed and along the margin to obtain further data on the behavior of the water table in the locality. A general inventory of wells in the locality was made to obtain data on the position of the water table. The geology of the area was reexamined and a detailed topographic map was prepared in order to calculate the potential storage capacity of the Queen Lake depression.

Records of surface-water flow were obtained at the Malaga, Pierce Canyon Crossing and Red Bluff gaging stations. The Pierce Canyon Crossing gaging station was reestablished in August 1951 to measure the gain or loss in the river in the Malaga Bend stretch. In addition periodic measurements were made of the flow of the Pecos River at 5 temporary stations* in the Malaga Bend area in connection with pumping tests and seepage runs.

Quality-of-water data were obtained on the Pecos River by collection of daily samples east of Malaga, at the Pierce Canyon Crossing gaging station, and near Red Bluff. The sampling point east of Malaga is about 1.5 miles upstream from the gaging station near Malaga. Near Red Bluff, the sampling point is at the pipeline bridge, about 2.5 miles downstream from the gaging station at Red Bluff. Analyses have indicated that there is little change in quality of the water between the sampling points and the respective gaging stations. In addition, intensive sampling of the Pecos River at the 5 temporary stations during the aquifer tests was done to determine the change in the salt load in this stretch of the river. Also, analyses were obtained of water from seep areas in the Malaga Bend. Samples were collected as needed from shallow and brine wells in the area of interest. The analyses were made by the Geological Survey.

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* Identified as the Fishing Rock station, Corral station, Head of Grandson Spring station, Livingston's Ford station, and Lower Wading station. The gaging point for the gaging station near Malaga is referred to as the Upper Wading station.

Personnel and Acknowledgments

This investigation was a cooperative effort of three branches of the Water Resources Division. The Ground Water Branch was responsible for the planning and programming of the study and the collection and interpretation of the geological and ground-water data connected with the study. Stream flow records at permanent stations and one project station along the Pecos River in New Mexico, together with miscellaneous discharge measurements at temporary stations around the Malaga Bend, were obtained by the Surface Water Branch. This phase of the work was done under the general supervision of Berkeley Johnson, District Engineer, and under the direct supervision of S.O. Decker, with the exception that the streamflow records at the Red Bluff station were obtained under the general supervision of Trigg Twitchell, District Engineer for the Texas district. Quality-of-water data on surface and ground water in the area were collected by the Quality of Water Branch under the general supervision of J. D. Hem, District Chemist until October 1953. After that date J. M. Stow became District Chemist and assumed general direction of the work. The quality-of-water phase of the investigation was under the direct supervision of L. S. Hughes. The work of the Ground Water Branch was under the general supervision of C. S. Conover, District Engineer, and under the direct supervision of W. E. Hale, who also was responsible for the over-all coordination of the various phases of the project. E. R. Cox was project geologist for the ground-water phase of the investigation.

Special acknowledgment is given D. S. Harroun for permitting access to his lands in the Malaga Bend area and the drilling of test wells on his property. Mr. Harroun and other landowners using river water for irrigation were very helpful by providing diversion and irrigation schedules, which were necessary in making the two aquifer tests. The Red Bluff Water Power Control District provided the pump and power unit used during the second aquifer test, as well as the personnel to operate the pump. Commissioners of the Pecos River Commission and members of its Engineering Advisory Committee gave assistance and made valuable suggestions during the course of the investigation. The commissioners are J. H. Bliss, commissioner for the State of New Mexico, J. C. Wilson, commissioner for the State of Texas, and Berkeley Johnson, chairman and commissioner representing the United States. Members of the Engineering Advisory Committee include R. J. Tipton, engineer advisor to the Pecos River Commission and chairman of the committee, R. L. Lowry and C. J. Anderson, engineering advisors to the commissioner for the State of Texas, and J. R. Erickson and J.J. Vandertulip, engineering advisors to the commissioner for the State of New Mexico. R. T. Lingle, director, Action Program, Pecos River Commission, contributed suggestions and participated in many of the discussions concerning the investigation.

Well-Numbering-System

The system used by the Geological Survey of numbering wells in New Mexico is based on the common system of subdivision of public lands into sections. By means of it the well number, in addition to designating the well, locates its position to the nearest 10-acre tract in the land net. The well number is divided by periods into four segments. The first segment denotes the township north or south of the New Mexico base line; the second denotes the range east or west of the New Mexico principal meridian; and the third denotes the section.

The fourth segment of the number, which consists of three digits, denotes the particular 10-acre tract in which the well is situated. For this purpose, the section is divided into four quarters, numbered 1, 2, 3, and 4, in the normal reading order, for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus, a well in the SW1/4SW1/4NW1/4 sec. 16, T. 24 S., R. 29 E., in Eddy County is designated as 24.29.16.133. If a well cannot be located accurately within a 10-acre tract, a zero is used as the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the section, the fourth segment of the well number is omitted. When it becomes possible to locate more accurately a well in whose number zeros have been used, the proper digit or digits are substituted for the zeros. Letters a, b, c, ... are added to the last segment to designate the second, third, fourth and succeeding wells in the same 10-acre tract.

Figure 1 shows the method of numbering sections within a township and tracts within a section.

TOPOGRAPHY AND DRAINAGE

The chief topographic feature of the region is the valley of the Pecos River. The river flows generally south-southeast through Eddy County, N. Mex. Although the width of the area considered to be in the Pecos River drainage extends more than 100 miles from the Guadalupe Mountains on the west to the High Plains on the east, the actual valley floor in this region generally is only a few miles wide. An exception is the broad valley west of the Pecos River extending from Carlsbad southward about 12 miles to the vicinity of the Black River. The surface of this broad valley is a terrace, well above the flood plain of the Pecos River. Bordering the flood plain and higher terraces are areas which are best described as having a modified karst topography of low relief. One of the largest depressions developed in this area is Laguna Grande

METHOD OF NUMBERING SECTIONS WITHIN A TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

← 6 miles →

METHOD OF NUMBERING TRACTS WITHIN A SECTION

111	112	121	122	211	212	221	222
(110)		(120)		(210)		(220)	
113	114	123	124	213	214	223	224
[100]				[200]			
131	132	141	142	231	232	241	242
(130)		(140)		(230)		(240)	
133	134	143	144	233	234	243	244
311	312	321	322	411	412	421	422
(310)		(320)		(410)		(420)	
313	314	323	324	413	414	423	424
[300]				[400]			
331	332	341	342	431	432	441	442
(330)		(340)		(430)		(440)	
333	334	343	344	433	434	443	444

← 1 mile →

Figure 1. Sketch illustrating well-numbering system.

de la Sal about 5 miles north of the Malaga Bend. Another moderately large depression is Queen Lake about 1 mile southwest of the Malaga Bend area in parts of secs. 19 and 30, T. 24 S., R. 29 E. The playa area covers about 60 acres and the tributary area covers about 4 square miles. Queen Lake receives only storm waters and at times is dry. Several smaller partially filled depressions are now the sites of farms and together with parts of the terrace areas and flood plains compose the farmland of the area. All the cultivated lands are under irrigation.

The principal drainageway is the Pecos River. Tributaries to the Pecos River in this area are developed principally westward from the river and rise in the Guadalupe Mountains several miles to the west. Of these tributaries only the Black River, which joins the Pecos River a few miles northwest of Malaga Bend, is perennial near its mouth. However, other normally dry arroyos in the area contribute much floodwater on occasions. The drainage pattern east of the Pecos River is poorly developed. Tributary draws extend for only a few miles to the east and only at time of heavy rains do they contribute any surface water to the river.

The Malaga Bend of the Pecos River is that reach of the river beginning in the SW1/4 sec. 17, T. 24 S., R. 29 E., and continuing east into sec. 16 then south then west to the NW1/4 sec. 20, T. 24 S., R. 29 E., a distance of about 4 miles. (See pl. 2.) Within this stretch the river flows through a large partially filled depression that is oval in shape about 1.5 miles across from north to south, and about 2.5 miles from east to west. The main floor of the depression which is also the river terrace is between 20 and 30 feet above the normal river level. The approximate altitude of the river is 2,900 feet at the upper end of the bend and 2,890 feet at the lower end. About 800 acres of land are under irrigation in flats along the outer side of the bend and about 200 acres are irrigated inside the bend.

DISCHARGE OF THE PECOS RIVER

Under normal conditions the Pecos River is dry between Carlsbad and Lake Avalon about 5 miles north of Carlsbad. Perennial flow starts at Carlsbad in a series of springs known as the Carlsbad Springs area. The stream gains in flow from here southward, largely from return flow of irrigation water in the Carlsbad Irrigation District. The Black River and, at times, the Delaware River also contribute to the dry-weather flow of the river. The principal diversion from the river in this stretch between Carlsbad and Red Bluff reservoir is through the Harroun canal. Included among the other, minor, diversions in this reach are those at two pumping plants, one in the Malaga Bend area and the other south of the bend in sec. 6, T. 25 S., R. 29 E.

Records of discharge of the Pecos River at the gaging station

near Malaga, N. Mex., in the NW1/4NW1/4 sec. 19, T. 24 S., R. 29 E., for the periods May 1920 to September 1925 and October 1931 to September 1951 are published in annual reports of the Geological Survey entitled, "Surface water supply of the United States." Data for the period January 1921 to December 1931 have been published in reports of the State Engineer of New Mexico. Discharges at the station have ranged from no flow on August 20 and 22, 1934, to 63,700 cfs on September 21, 1941.

Records of discharge at Red Bluff, N. Mex., in sec. 1, T. 26 S., R. 28 E., for the period October 1937 to September 1951 are published in reports of the Geological Survey. Published extremes at this station range from a minimum of 14 cfs on August 19, 1946, to a maximum of 52,600 cfs on May 24, 1941. Provisional records for the 1952 and 1953 water years show a new low of 5.4 cfs on August 30, 1953.

Records of discharge at the Pierce Canyon Crossing near Malaga, in the SE1/4 sec. 28, T. 24 S., R. 29 E., have been published by the Geological Survey for the period July 1938 to September 1941. The station was re-established in August 1951 for the present investigation, and provisional records are available through December 1953. The maximum gage height of the period of record at the station occurred on May 22, 1941; the discharge was not determined. The minimum flow of record was 6.6 cfs on August 14, 1953.

During the period of the Pecos River Joint Investigation from 1938 through 1941, several temporary stations were in operation on tributary streams and diversion canals between Carlsbad and Red Bluff reservoir.

Except during heavy local rains, inflow to the Pecos River between the gaging stations near Malaga and at Pierce Canyon Crossing is limited to spill from the Harroun canal, irrigation return flow, and the brine from seeps and springs in the Malaga Bend. Water is diverted by means of Livingston's pump on the south side of the bend. Discharge records were kept in the 1940 water year of spill from Harroun canal, when 2,800 acre-feet of water was returned to the river. Records of diversions at Livingston's pump are available for the 1940 water year, when 575 acre-feet was diverted.

The gain in flow between Fishing Rock near the upper end of the Malaga Bend and the Lower Wading station near the lower end of the bend was measured in February 1954 and again in September 1954. In February 1954 the gain appeared to be about 2 cfs and in September 1954 the gain was about 3 cfs, taking into account a loss of about 0.6 cfs due to evaporation from the river in September. The average gain in this reach is about 2.5 cfs, of which approximately 2.0 cfs is attributable to return from irrigation water.

There is apparently very little surface inflow to the river between the Pierce Canyon Crossing and Red Bluff stations, other than direct runoff resulting from local rainfall. During some years an apparent loss in flow has been reported between the two stations.

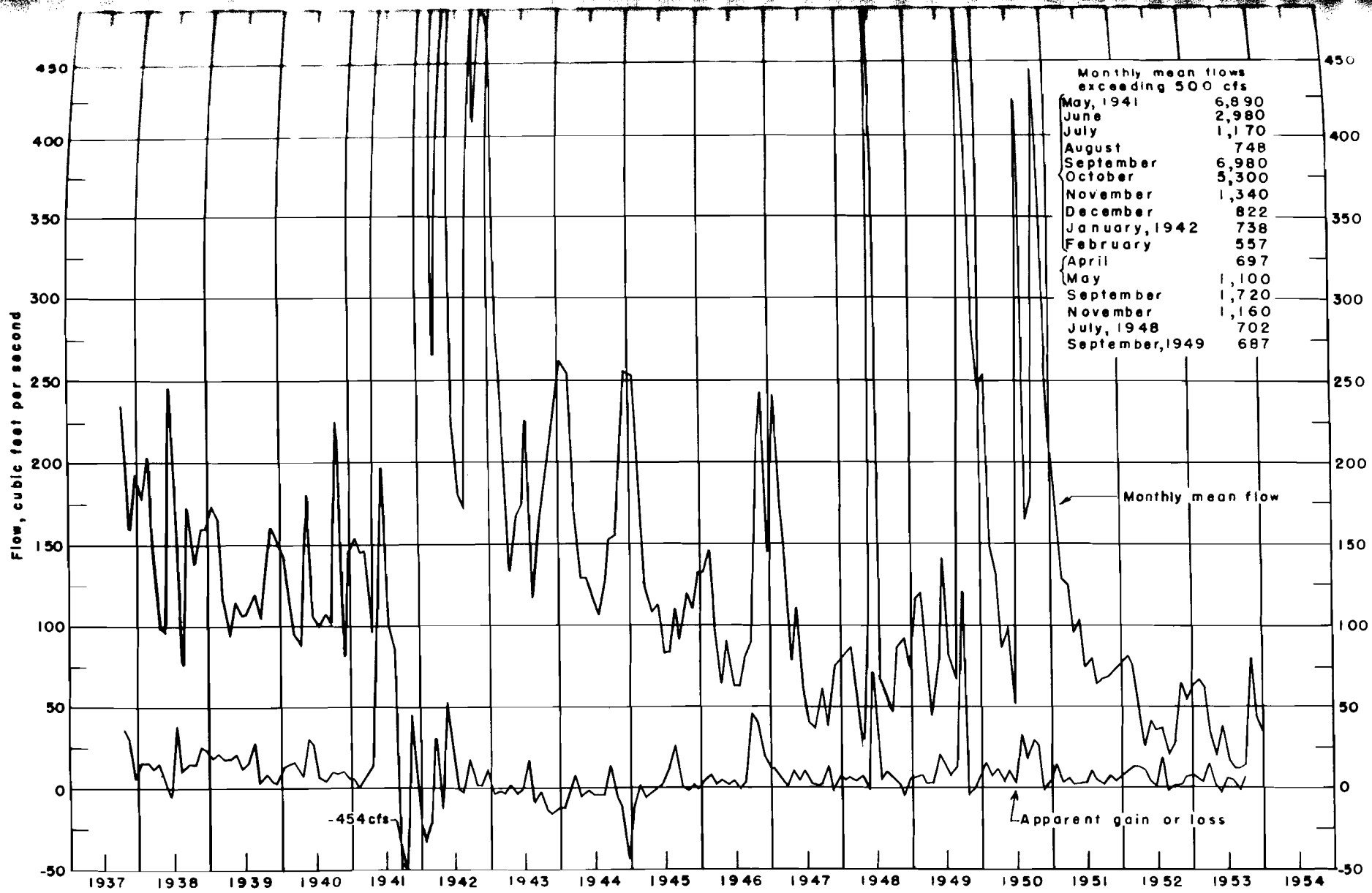


PLATE 3. MONTHLY MEAN FLOW OF PECOS RIVER AT MALAGA GAGING STATION, AND APPARENT GAIN OR LOSS IN FLOW BETWEEN MALAGA AND RED BLUFF GAGING STATIONS, N. MEX.

Monthly mean discharges for the gaging station near Malaga for the water years 1938 to 1953 are shown in plate 3. Also shown is the monthly gain or loss between the Malaga and Red Bluff gages. Yearly mean discharges for these two stations and for Pierce Canyon Crossing are shown in tables 1 to 3, in connection with the chemical analyses.

CHEMICAL QUALITY OF THE PECOS RIVER

Studies of the chemical character of water in the Pecos River basin in New Mexico began in 1937. During the entire period samples have been taken daily from the river at or near the gaging stations near Malaga and at Red Bluff. Sampling at Pierce Canyon Crossing, which had been done from 1938 to 1941, was resumed in October 1951. From March 1938 to December 1940, daily samples were collected from the Refinery intake canal in sec. 13, T. 23 S., R. 28 E., representing water in the Harroun canal diverted from the Pecos River at a dam in sec. 11, T. 23 S., R. 28 E. Weekly samples have been collected since January 1941. On the basis of the specific conductance of the daily samples, composite samples were made for complete chemical analysis. The composite samples usually included ten consecutive daily samples, but when daily conductance values showed excessive day-to-day variation, the composites were made for shorter periods in order that only daily samples of similar conductance be included in any composite sample. Analyses of the composite samples for the water years 1941 to 1950 are published in annual reports of the Geological Survey entitled "Quality of the surface waters of the United States."

Water of the Pecos River near Malaga contains large quantities of calcium, magnesium, sodium, sulfate, and chloride. Between Malaga and Pierce Canyon Crossing a large increase in dissolved solids occurs in the river water. The chief constituents added to the river in this reach are sodium and chloride, with smaller amounts of sulfate and magnesium. The mineralization of the water increases only slightly between Pierce Canyon and Red Bluff.

The weighted averages of the analyses of samples collected at the Malaga, Pierce Canyon Crossing, and Red Bluff gaging stations for the period of record are given in tables 1 to 3. A weighted average represents approximately the composition of water that would be found in a reservoir containing all the water passing a given station during the year after thorough mixing. The weighted average is computed by multiplying the discharge for the sampling period by the quantities of the individual constituents for the corresponding period and dividing the sum of the products by the sum of the discharges. These averages indicate that as the Pecos River enters the Malaga Bend area its waters are already so highly mineralized as to be limited in their usefulness for irrigation. Only salt-tolerant crops can be grown successfully, and large amounts of water must be used and drainage provided to prevent accumulation of harmful quantities of salts in the soil.

Comparison of loads of dissolved solids at the Malaga and Red Bluff stations for 14 years (omitting the high flow years of 1941 and 1942) show an increase in average load of 510 tons per day between the two stations. During the four years (omitting 1941) when records were also available at Pierce Canyon Crossing the average increase of dissolved solids from Malaga to Red Bluff was 520 tons per day of which 430 tons per day was contributed to the river between Malaga and Pierce Canyon Crossing. In recent years of low flow the addition of this quantity of salts to an already saline stream has had the result that the water is so concentrated in Red Bluff reservoir as to be unusable for successful irrigation.

The gain in chloride load between the Malaga and Pierce Canyon Crossing and Malaga and Red Bluff gaging stations for the period of record is shown in plate 4. The high gain in chloride load shown for the years 1941-43 is associated with the high flows which resulted from unusually heavy rainfall in 1941 and 1942. The records indicate that, for the period of record, the gain in chloride load between Malaga gage and Red Bluff, omitting periods of high water, has averaged about 230 tons per day. Most of this increased chloride comes into the river between Malaga and Pierce Canyon Crossing.

To determine more precisely the location and magnitude of the increase in dissolved solids in the river in the Malaga Bend area, continuous sampling runs of varying duration were made during the present investigation. Two of these were made in connection with aquifer tests and will be considered in the discussion of the aquifer tests.

On June 12 and 13, 1952, for a 36-hour period, samples were collected hourly from the river at the Upper and Lower Wading stations. During this period samples also were taken at 4-hour intervals at four intermediate points: Fishing Rock station, Corral station below Granddaddy Spring, Head of Grandson Spring station, and Livingston's Ford station. Locations of the sampling points are shown on the map (pl.5). Computations based on the analyses of the samples collected during this sampling period indicate that chloride was entering the river between the Upper and Lower Wading stations at the rate of 7.5 tons per hour, and that more than 60 percent of the chloride inflow occurred in the reach from the head of Grandson Spring area to the Lower Wading station.

During September 13 to 15, 1954, a similar sampling run was made. Results obtained from these samples indicated that the increase in chloride between the Upper and Lower Wading stations was approximately 9.8 tons per hour. The increased inflow of chloride during the September run is believed to be due to the seasonal rise in the ground-water level in the bend as a result of application of irrigation water during the summer. As this was near the end of the irrigation season, near-maximum rises of ground-water levels would have occurred. The manner in which irrigation in the area affects water levels in the auger holes and test wells was observed by Howard, White, and Hastings (1942, p. 125), and they

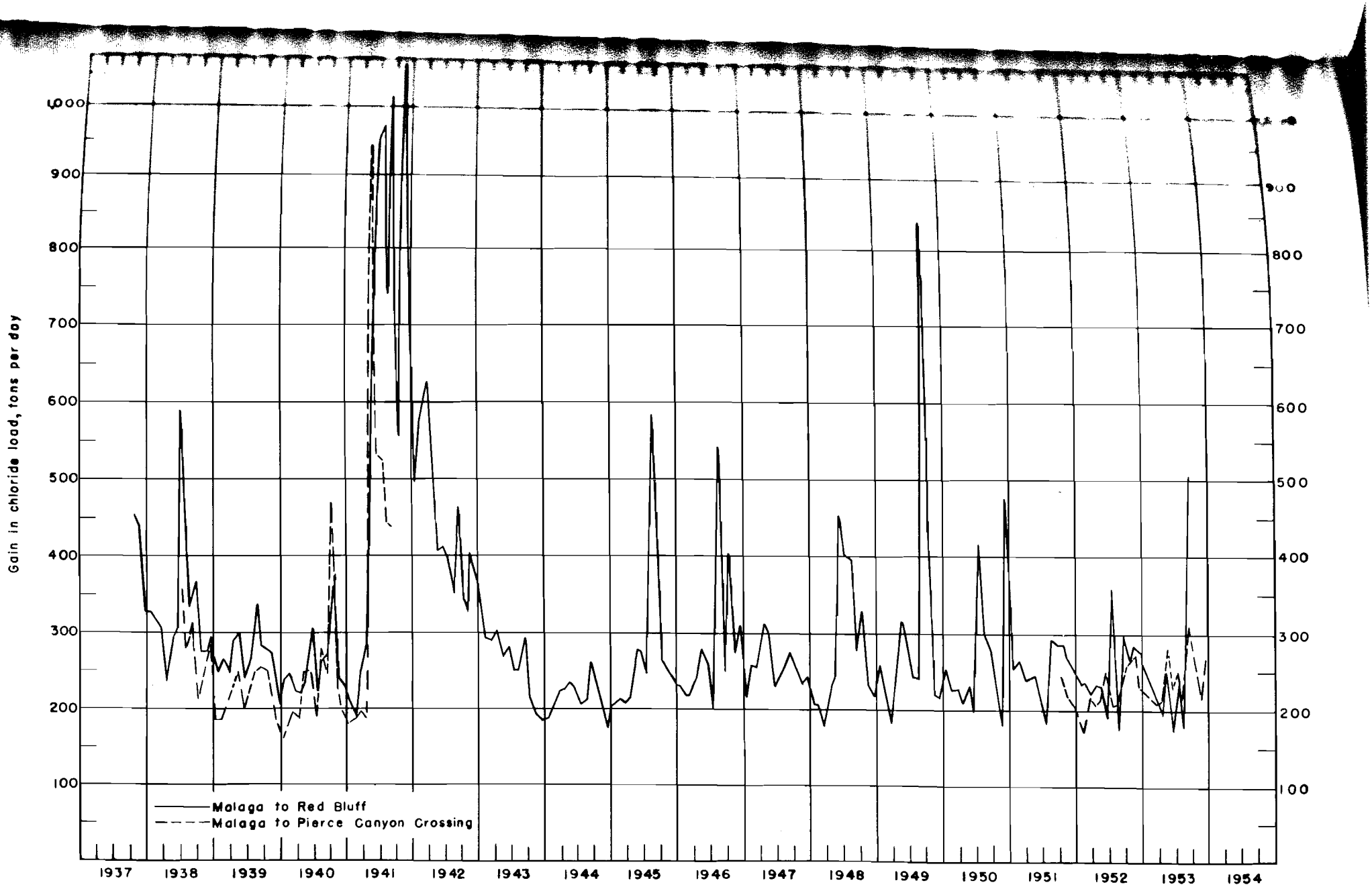


PLATE 4. GAIN IN CHLORIDE LOAD OF PECOS RIVER, BETWEEN MALAGA AND PIERCE CANYON CROSSING GAGING STATIONS, AND BETWEEN MALAGA AND RED BLUFF GAGING STATIONS, NEW MEXICO.

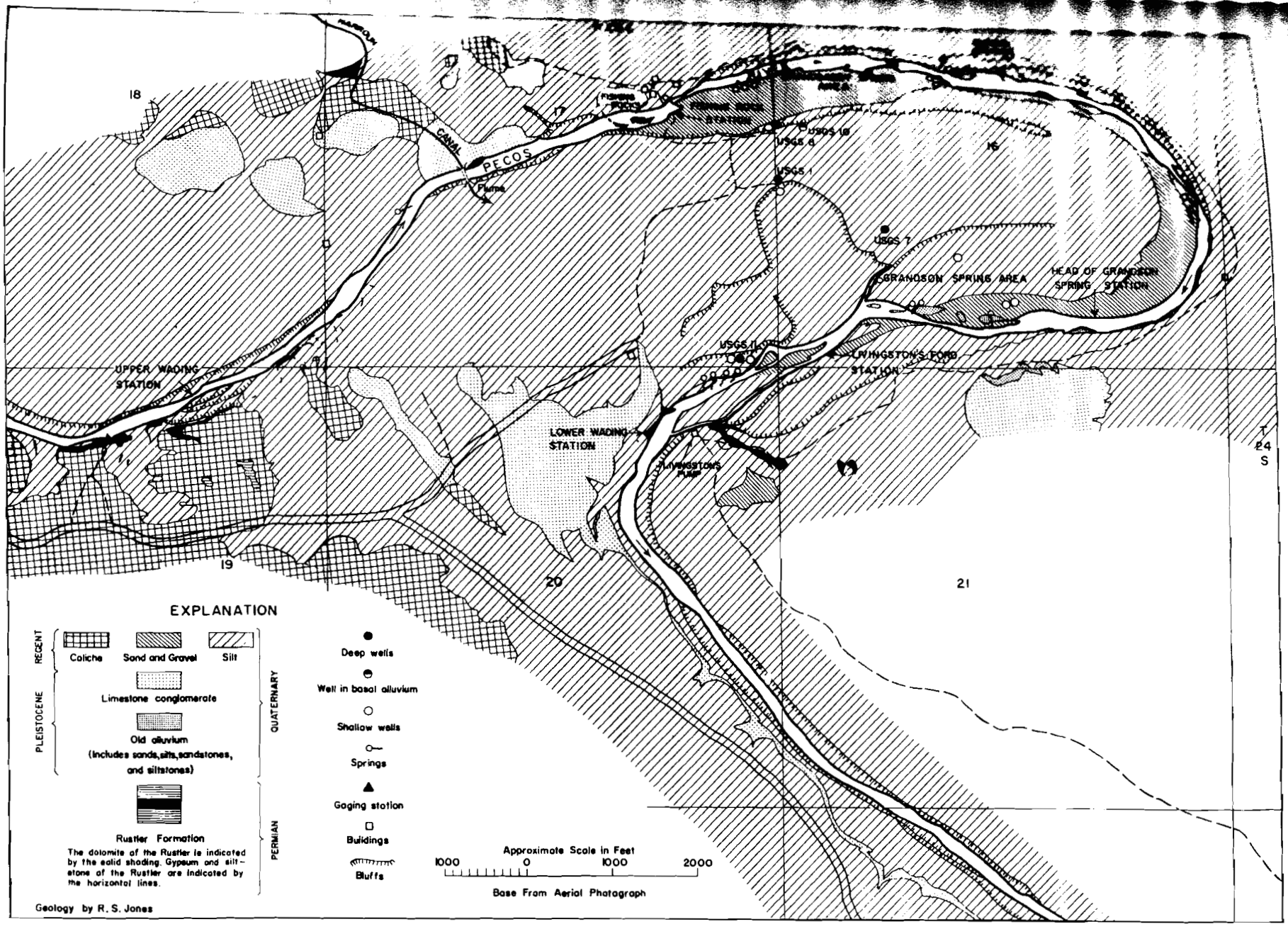


PLATE 5. GEOLOGY OF MALAGA BEND AREA, EDDY COUNTY, NEW MEXICO

believed that changes in the flow of seeps along the river and in load of dissolved solids are related to the irrigation practices in this section of the river.

Data on gain in loads in terms of chloride, sodium chloride, and dissolved solids are summarized in table 4. Records for the water years 1941 and 1942, when abnormally high flows occurred, have been omitted from the computations of the average gains. Shown are chloride gains for several reaches of river around the Malaga Bend, computed from data obtained during the June 1952 and September 1954 continuous sampling runs. An estimate is given for the quantity of chloride contributed to the river between Malaga and Pierce Canyon Crossing gaging stations by return flows of irrigation water applied to the lands in the bend area. The chloride concentration of the irrigation water was determined by analysis of weekly samples collected from the Refinery intake canal near Loving, a diversion from the Harroun canal. The chloride concentration of the canal water for the irrigation period, March through September, for the years 1938 to 1953 averaged 675 ppm. It is believed that most of the dissolved solids from about 4,500 acre-feet of irrigation water are returned to the river in the bend area.

As shown in table 4, the chloride load added to the river between the Malaga and Pierce Canyon Crossing gaging stations for 4 years of record averaged 9.3 tons per hour. Of this amount about 0.5 ton per hour is believed to have been supplied by return irrigation water, and an average of 8.8 tons chloride per hour by the inflow of approximately 0.4 cfs of brine.

CHEMICAL QUALITY OF THE GROUND WATER

During the earlier investigations in the Malaga Bend area, analyses were made of a large number of water samples from seeps, pools, test wells, and auger holes. This earlier work has been summarized in the 12th and 13th Biennial Reports of the State Engineer of New Mexico, (p. 58-75), and in the "Reports of the participating agencies, the Pecos River Joint Investigation" (Howard, White, and Hastings, p. 121-125). Both reports include tabulations of typical analyses.

As a part of the present investigation, samples were collected from the more active seeps and springs, from the test wells remaining from the previous study, from the new test and observation wells as they were constructed, and from private wells in the area.

Typical analyses of samples from the seeps and springs are given in table 5. The data indicate that, as during the earlier studies, small quantities of water ranging in quality from relatively fresh water to water nearly saturated with sodium chloride enters the river from seeps and springs in the Malaga Bend area. The quantity of inflow that could be observed was not sufficient to account for the increase in measured dissolved

solids that occurs in the river in the area. Therefore, additional brine must enter the river by means of seeps and springs in the bed of the river. This point was definitely established by the previous investigations of Howard and White (1938, p. 73) and is illustrated by analyses in table 5 of the present report.

Analyses of samples from the wells and test holes are given in table 6. Analysis 8, collected from well USGS 8 at the end of the 1954 aquifer test is typical of analyses of the saturated brine obtained from the basal brine aquifer. No apparent change occurred in the composition of brine from well USGS 8 during 28 days of pumping at about 300 gpm. Analyses 11 to 15, from well USGS 1, illustrates the different concentrations of minerals in water found at different depths in the alluvium within the bend. Analyses 23 to 25 show the concentration of minerals in shallow ground waters in the Queen Lake depression. Analyses 1-7, 24, 28, and 29 are of samples from private wells in the area west and south of Queen Lake.

GENERAL GEOLOGY

The region under investigation is in the geologic province known as the Delaware basin. The northwestern border of the basin is marked by the limestones of reef origin exposed in the Guadalupe Mountains in the western part of Eddy County and marked approximately by limestones developed in the shelf or back reef area and exposed in the hills in and west of Carlsbad. Eastward from Carlsbad the reef and nonreef limestones are covered by younger rocks which increase in thickness to the east. The Delaware basin extends eastward into Lea County and southward for many miles in Texas. The reef limestones and associated talus beds that border the Delaware basin grade basinward into predominantly fine-grained sandstones of the Delaware Mountain group.

The sandstones of the Delaware Mountain group are overlain by anhydrite and salt of the Castile and Salado formations. The evaporites comprising the Castile formation largely filled the basin, and the succeeding evaporites of the Salado formation were deposited not only in the basin but in the back reef or shelf area to the north and east. After deposition of the Salado formation, tilting of the basin began which resulted in giving the beds a slight regional eastward dip. Much of the western part of the Salado was removed by solution and abrasion prior to deposition of the sediments of the Rustler formation, which overlapped the area occupied by the Salado formation. All the strata described so far are of Permian age.

Subsequent deposition of sediments occurred during the Triassic, Cretaceous, Tertiary, and Quarternary periods, but during intervening epochs of erosion the beds of Triassic age were removed west of the Pecos River in Eddy County, the rocks of Cretaceous age were removed from essentially the entire area, and probably a large volume of sands, clays, and gravels laid

down in Tertiary and Quaternary time also were removed. Only a veneer of sediments mantles the older rocks over a large part of the basin in Eddy County.

In the Malaga Bend area the sandstones of the Delaware Mountain group are overlain by approximately 3,000 feet of relatively impermeable evaporites of the Castile and Salado formations. Other than being considered as a possible reservoir for disposal of brine, the sandstones of the Delaware Mountain group have no bearing on the problem and hence will not be considered further.

The Castile formation crops out in the area south of the Black River between the Guadalupe Mountains and a general north-south line several miles west of the Pecos River. In the area of outcrop the upper beds have been altered from anhydrite to gypsum and contain ground water in solution passages. Eastward from the outcrop area where the Castile formation is covered by the Rustler formation, and still farther east where the Salado formation intervenes, the Castile formation has not been subject to erosion. In the Malaga Bend area the Castile formation is more than 1,000 feet thick and the beds of anhydrite and salt are essentially impermeable. Therefore, the Castile formation has no bearing on the brine-disposal problem other than in connection with possible movement of water from the Castile formation into the Rustler formation in the general area where the Castile formation borders the Rustler formation.

Salado Formation

The Salado formation was defined by Lang (1935, p. 962-970) as the Salado halite. It was defined as including the dominantly rock-salt strata between the Castile formation and the Rustler formation. Contact of the Castile and Salado formations probably in part is gradational and is placed at the horizon below which the beds of anhydrite and salt do not extend beyond the Delaware basin. The Salado is overlain unconformably by the Rustler formation. There are no known outcrops of the Salado formation, but reworked remnants of gypsum laid down in Salado time probably are exposed in places.

Originally the Salado formation extended westward nearly to the Guadalupe Mountains. Erosion in pre-Rustler time removed the Salado from the area west of a line a few miles west of the present course of the Pecos River. Removal of the salt by solution, and alteration of the anhydrite gypsum, beneath the Rustler formation has occurred in places, at least at intervals, up to the present time. The resulting residue of gypsum and clay, referred to as residuum of the Salado, is included for convenience in the Rustler formation. This residue ranges in age from pre-Rustler to Recent. The Salado thickens rapidly to the east and is present eastward over a large part of the Delaware basin and areas to the north. No water is known to occur in the salt and anhydrite beds of the Salado.

The western limit of the Salado formation is not known precisely in the vicinity of the Malaga Bend area but probably is not more than a few miles west of the Pecos River. In an oil test about 2 miles northeast of the Malaga Bend in the SE1/4 sec. 3, T. 24 S., R. 29 E., the Salado formation was encountered at a depth of 575 feet and had a thickness of 735 feet. An oil test 2 miles southeast of the Malaga Bend in the SE1/4 sec. 23, T. 24 S., R. 29 E., penetrated approximately 500 feet of strata assigned to the Salado formation. The various brine test wells drilled in the Malaga Bend area in secs. 16 and 17, T. 24 S., R. 29 E., encountered the top of the salt of the Salado formation at depths ranging between 230 and 250 feet but at approximately the same altitude of 2,680 feet. The top of the Salado formation is fairly rugged. Local relief amounts to more than 200 feet. The top of the formation in the Malaga Bend area is apparently dome shaped, with gentle relief.

Rustler Formation

The Rustler formation was named by Richardson (1904, p. 44) for the strata overlying the Castile and Salado formations that were clearly older than the red beds of Triassic age. (Not considered here are the still younger Dewey Lake red beds which occur in the subsurface farther east and which are thought to be Permian in age.) In the type locality in the Rustler Hills in Culberson County, Tex., the Rustler is dominantly limestone and sandstone. To the north, in Eddy County, N. Mex., gypsum, anhydrite, and sandstone compose the bulk of the formation. There are, however, two persistent dolomitic limestone members, referred to by Adams (1944, p. 1614) as the Culebra and Magenta members, which serve as excellent markers in the formation. The formation contains also a minor amount of siltstone and gray and red shale, and in eastern Eddy County it contains considerable salt.

In southern Eddy County the Rustler formation extends westward to the vicinity of the upper Black River valley. Farther north, exposures of the formation occur within a mile or so of the eastern limb of the Guadalupe Mountains. The Rustler crops out also in a strip 6 to 10 miles wide east of the Pecos River north from the Black River for several miles. In the area of outcrop much of the formation is badly contorted from solution of the rocks within the formation and of underlying rocks. The effects of solution of underlying beds is shown particularly by large blocks of the dolomitic limestone beds, an acre or more in extent, that have different dips. Eastward from the Pecos River, where the formation is covered by rocks of Triassic age the beds of the Rustler formation have not been subjected to as much solution, and the formation has a more regular structure. East of the Pecos River where the formation is protected by the overlying red beds, the Rustler formation attains a thickness of about 500 feet.

In the Malaga Bend and Queen Lake areas the Rustler formation either crops out or immediately underlies the alluvium, (pls. 5 and 6). Along the western rim of the depression in the Malaga Bend area, the lower dolomitic limestone member (Culebra dolomite member) is exposed in the low bluff that marks the rim of the depression and also in the river on the north and south sides of the bend area. Within the large depression in the bend area, the Rustler formation is covered with alluvium that ranges in thickness from a featheredge to 170 feet at the site of test hole USGS 8 in the SW1/4NW1/4 sec. 16, T. 24 S., R. 29 E. At this test hole the clays and gypsum of the Rustler formation are only 60 feet thick. In the surrounding upland, the Rustler formation is between 250 and 350 feet thick.

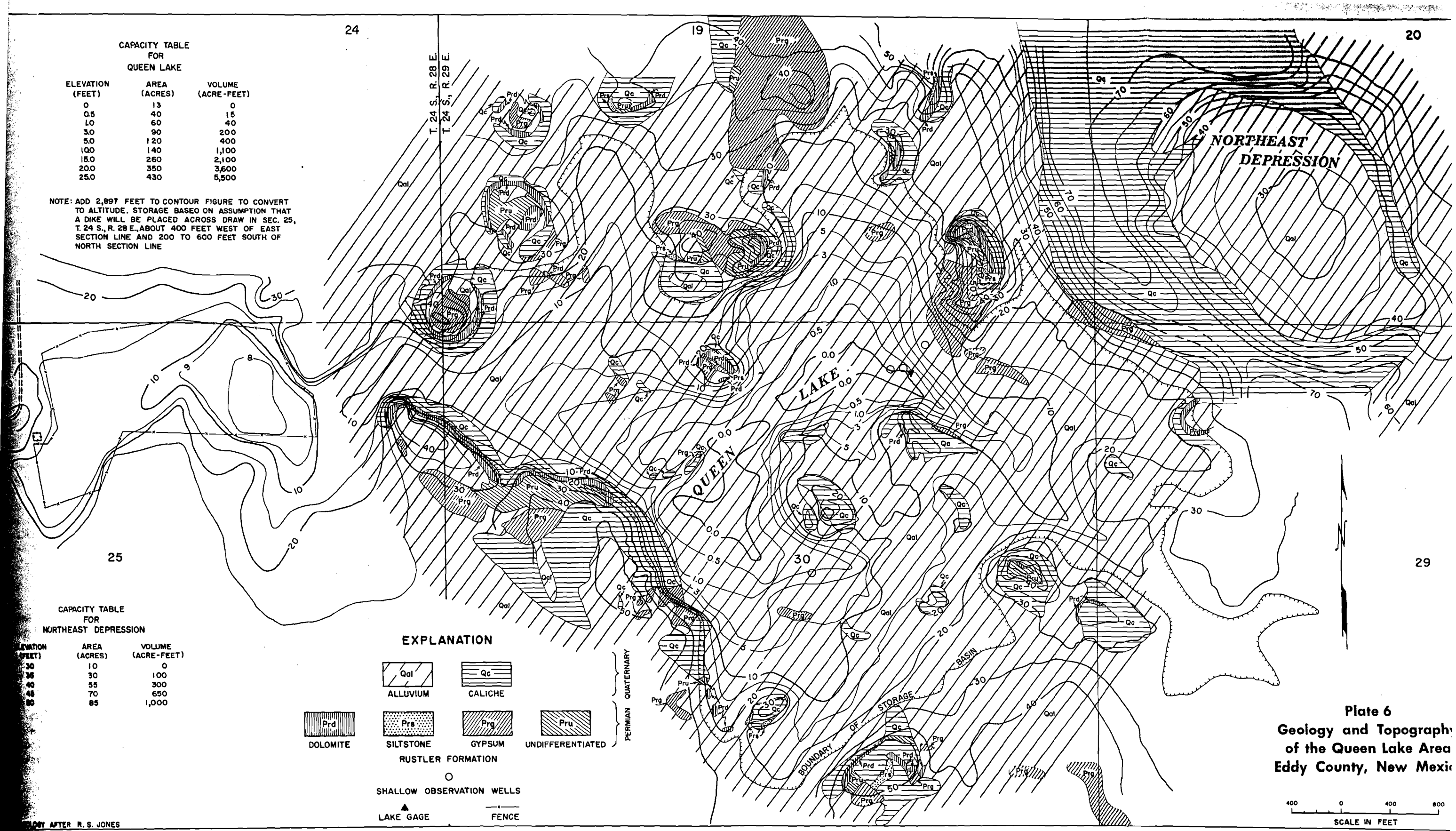
The Queen Lake depression has been formed by solution and collapse of rocks in the Rustler and Salado formations. Remnants of the Culebra member of the Rustler are exposed in places in the knobs and hills bordering the Queen Lake depression. (See pl. 6.) The depression has been partially filled by silts, sands, and clays washed in from the surrounding area. No test holes have been drilled to determine the thickness of the fill or character of the Rustler formation in the Queen Lake area.

In spite of the intensive solution of the rocks in the Rustler formation in the area of outcrop in Eddy County there are no known areas in which large yields of water are developed from the Rustler formation. Water occurs locally at many places in the Rustler, the most persistent water-bearing beds being the dolomitic limestone strata. The brine aquifer in the basal part of the Rustler formation in Nash Draw and the Malaga Bend area probably is the most highly permeable aquifer in the formation in Eddy County. It appears that, in general, with the leaching of soluble rocks in the Rustler formation, the clays and residue in the formation together with recementation of the remaining gypsum has made the formation relatively watertight.

Post-Rustler Deposits

Eastward from the Pecos River in Eddy County red sandy clays and sandstones belonging to the Dockum group of Triassic age cover the Rustler formation. The extent and thickness of these beds are not known and are relatively unimportant to the present investigation, but these beds probably have an indirect bearing on the quantity of water moving through the brine aquifer. The red beds of Triassic age in this area appear to be only slightly permeable and, hence, impede recharge to the Rustler formation in the area of their occurrence.

Alluvial deposits occur almost everywhere in the region but are only a veneer over the area south of the Black River and west of the Pecos River. In the Black River valley and the valley west of the Pecos River between Carlsbad and the Black River, the alluvium in places is as much as



CAPACITY TABLE
FOR
QUEEN LAKE

ELEVATION (FEET)	AREA (ACRES)	VOLUME (ACRE-FEET)
0	13	0
0.5	40	15
1.0	60	40
3.0	90	200
5.0	120	400
10.0	140	1,100
15.0	260	2,100
20.0	350	3,600
25.0	430	5,500

NOTE: ADD 2,897 FEET TO CONTOUR FIGURE TO CONVERT TO ALTITUDE. STORAGE BASED ON ASSUMPTION THAT A DIKE WILL BE PLACED ACROSS DRAW IN SEC. 25, T. 24 S., R. 28 E., ABOUT 400 FEET WEST OF EAST SECTION LINE AND 200 TO 600 FEET SOUTH OF NORTH SECTION LINE

CAPACITY TABLE
FOR
NORTHEAST DEPRESSION

ELEVATION (FEET)	AREA (ACRES)	VOLUME (ACRE-FEET)
30	10	0
35	30	100
40	55	300
45	70	650
50	85	1,000

GEOLOGY AFTER R. S. JONES

Plate 6
Geology and Topography of the Queen Lake Area Eddy County, New Mexico

PLATE 6 GEOLOGY AND TOPOGRAPHY OF THE QUEEN LAKE AREA, EDDY COUNTY, NEW MEXICO

200 feet thick. The materials composing the alluvium are the usual sands, gravels, silts, and clays, plus conglomerates. The conglomerate beds, where they are fractured, are the most productive aquifers in the alluvium. The sands and gravels contain much silt and clay and, hence, are only moderately to poorly permeable over much of the valley area.

One of the notable features of the alluvium is its large variation in thickness from place to place. The present channel of the Pecos River is cut through strata older than the alluvium at Carlsbad and near the head and toe of the Malaga Bend. At many places in the valley south of Carlsbad and in the Malaga Bend, the alluvium extends to appreciably lower elevations than at the places where the river channel has been cut in the older rocks. This overthickening of the alluvium in places suggests that either the river at one time was at a lower elevation and followed a different course or, as is more likely, the places where the alluvium is thickest are the places where the underlying rocks of the Rustler, Salado, and Castile formations have been removed, in part, by solution and the resulting depressions filled with alluvium.

Alluvium in the Malaga Bend area

In the Malaga Bend area, the alluvium extends in one place to a depth of about 150 feet below the adjacent bedrock in the river channel, but over a large part of the alluvial flats the base of the alluvium is probably between 50 and 75 feet below the river level. The alluvium in the Malaga Bend area appears to contain lenticular beds of sand, sandy clay, gravel, silt, and clay. In the five test holes drilled through the alluvium, the sequence of alluvial material at any one site could not be correlated in detail with that at any other site. Coarse gravels do occur at depth in places and could probably be developed to yield moderate quantities of the brine encountered in the alluvium in depth. In the southwest part of the bend area at the site of test well USGS 11 the alluvium, 81 feet thick, consisted mostly of fine sand with some gravel and silt and yielded only a small amount of water to the test well.

Alluvium in the Queen Lake area

Material consisting of sand, silt, clay, gypsum crystals, and some pieces of dolomitic limestone compose the alluvium in the Queen Lake depression. Sandy material occurs generally in the channel of the few short gullies that drain toward the playa but much of the material that covers the slopes of the depression is a silty clay. The playa floor is composed of silty clay that contains many selenite crystals. The selenite crystals either developed in the playa deposits or were washed in from the surrounding exposures of gypsum of the Rustler formation. When the playa is dry the clays fracture into a dense pattern of mud cracks which extend to a depth of about a foot. The cracks close when the playa is again flooded. The thickness of the alluvial material is not known but except under the playa probably is no more than 15 to 20 feet. In places in the

Queen Lake depression there are exposures of gypsum, red silty clay, and dolomitic limestone belonging to the Rustler formation.

THE BRINE-AQUIFER SYSTEM

The springs and seeps along the banks of the Pecos River in the Malaga Bend stretch discharge water having a chloride content generally ranging between 4,000 and 155,000 ppm. The brine spring area is confined almost entirely between the outcrop of the dolomitic limestone of the Rustler formation in the river channel at Fishing Rock Ford, NE1/4 sec. 17, T. 24 S., R. 29 E., near the head of the Malaga Bend, and the outcrop of limestone near the Lower Wading station, NE1/4 sec. 20, T. 24 S., R. 29 E., at the lower end of the Malaga Bend. The total accretion to the river in this stretch appears to range between 2 and 3 cfs. A large part of the spring flow is probably irrigation return from the irrigated lands located both inside and outside the bend. On the inside of the bend in the Grandson Spring area, and on the outside of the bend between Livingston's Ford and the Lower Wading station ground water at a depth of only a few feet contains as much as 155,000 ppm of chloride. Elsewhere in the alluvium in the bend the chloride content of the water at shallow depth is lower and increases with depth until a saturation point is reached, which is about 158,000 ppm. In the lower part of the alluvium the brine is under a head which is higher than the normal river level around all except the upper part of the bend.

At places in the area north of the Malaga Bend and south of Laguna Grande de la Sal (pl. 1) water containing approximately 10,000 to 20,000 ppm of chloride occurs at shallow depth in the alluvium and in the Rustler formation above the Culebra limestone member. Part of this water could be moving toward the fill in the Malaga Bend area. Water with a concentration of 20,000 ppm in chloride would need to enter the river at a rate approaching 5 cfs to account for the chloride gain in the Malaga Bend reach if this were the principal source for the brine inflow. Inasmuch as the inflow in this stretch can be accounted for by irrigation return and brine inflow, and further, as concentrated brine occurs near the surface in the bend area, it is concluded that very little water containing the 10,000 to 20,000 ppm of chloride is moving into the fill in the Malaga Bend area and discharging into the river in the bend. Thus, irrigation return water and the brine constitute the normal inflow in the Malaga Bend and daily add approximately 430 tons of dissolved minerals, mostly common salt, to the Pecos River.

Robinson and Lang (1938, p. 79-100) concluded that the source of the brine in the alluvium in the Malaga Bend was a brine aquifer in the basal part of the Rustler formation, and further work in the area has substantiated this conclusion. This aquifer underlies the bend area and appears to extend in a northward direction up Nash Draw. The brine in the aquifer in the basal part of the Rustler formation is under sufficient head in the Malaga Bend area to rise above the river level in the bend, and the clay and gypsum beds are so thin and disrupted in places in the

bend area that the brine moves upward through them into the alluvium and thence into the river. The brine aquifer in the basal part of the Rustler formation will henceforth be referred to informally as the basal brine aquifer. The basal brine aquifer, and the alluvium in the Malaga Bend area containing brine and irrigation return water, compose the brine-aquifer system.

The Basal Brine Aquifer

Extent

Lang (Robinson and Lang, 1938, p. 86) noted the occurrence of brine in the basal part of the Rustler formation in test wells in the vicinity of T. 21 S., R. 30 E., 15 to 20 miles north of the Malaga Bend, several years prior to the investigation of the brine aquifer by Robinson and Lang (1938). Wells drilled in Nash Draw yielded a sodium chloride drine in the basal Rustler while wells drilled on topographic highs to the west and east of Nash Draw were dry in this section. Lang (Robinson and Lang, 1938, p. 86) inferred that the structural conditions that caused the development of Nash Draw might also control the occurrence of the brine in the basal part of the Rustler formation. In 1938 test holes were drilled specifically for the purpose of further defining this brine area in conjunction with the investigation by Robinson and Lang. The results of the test drilling indicated the presence of brine in the basal part of the Rustler formation in the vicinity of Laguna Grande de la Sal and southward to the Malaga Bend area. The known area underlain by brine in the Rustler formation as outlined by Robinson and Lang (1938, pl. 3) is confined to Nash Draw and southward to the general vicinity of the Malaga Bend and is shown on plate 1.

That the brine aquifer is continuous and is an active system is shown by a number of facts. The brine level in the test wells fluctuates seasonally in phase with the irrigation season (see fig. 2), in that the brine head rises during the irrigation season and declines afterward to essentially the same level. Water levels in test wells farther from the bend area, as far north as Laguna Grande de la Sal, fluctuate in phase with the irrigation season but the fluctuations are less pronounced. The pumping done as a part of aquifer tests affected the water levels in brine test wells 2 miles from the pumped well on Malaga Bend in less than 1 hour. The level of the brine in test holes from Malaga Bend northward up Nash Draw, when corrected to the density of the brine in the Malaga Bend area, rise in elevation to the north from Malaga Bend.

Aquifer tests indicate that the brine aquifer has a coefficient of transmissibility of about 60,000 gallons a day per foot in the Malaga Bend area. (See p. 29). (The coefficient of transmissibility is here expressed as the flow in gallons a day that would move through a strip of the aquifer 1 foot wide extending the height of the aquifer under a unit hydraulic gradient.) The average gradient of the brine along the aquifer between the Malaga Bend and Laguna Grande de la Sal is about 1.4 feet per

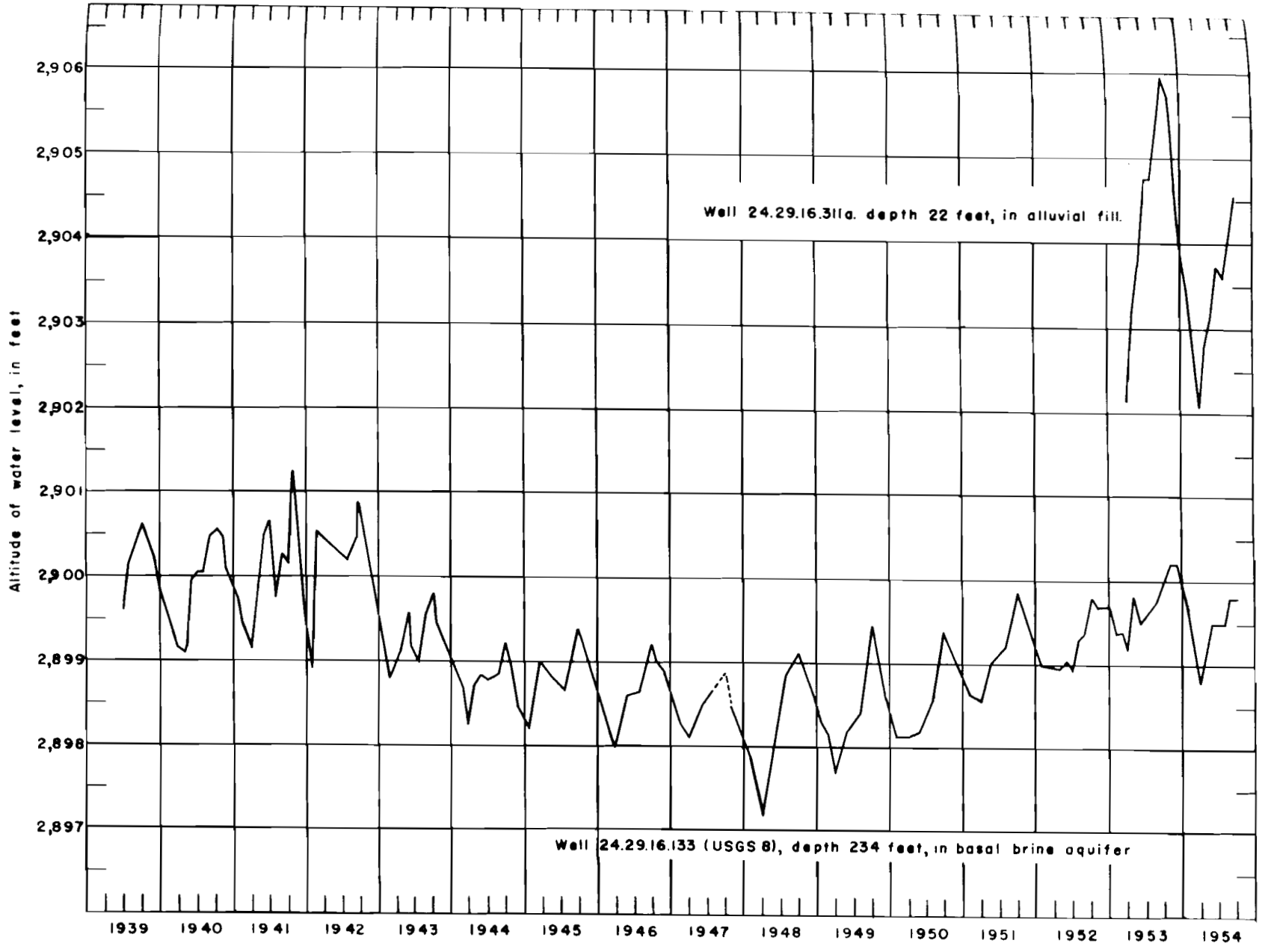


FIGURE 2. HYDROGRAPHS OF REPRESENTATIVE WELLS IN MALAGA BEND AREA, EDDY COUNTY, N. MEX.

mile. Assuming that the average width of the brine aquifer is about 5 miles and that the transmissibility averages 60,000, then the amount of brine being transmitted toward the bend past a given cross section would be about 420,000 gallons a day or about 0.6 cfs. This value is slightly greater than 0.4 to 0.44 cfs. of brine discharge calculated from the pickup of salt in the river in the Malaga Bend (see p. 6 and 15) but within the same order of magnitude. This suggests that most of the brine moving toward the Malaga Bend is confined to Nash Draw and the area to the south between Laguna Grande de la Sal and the Malaga Bend (pl. 1).

Discharge area

As mentioned, the brine in the basal brine aquifer between the Malaga Bend area and upper Nash Draw is under a progressively higher head northward from the bend and hence the brine is moving from Nash Draw toward Malaga Bend. The beds of clay, gypsum, and sandstone in the Rustler formation which confine the brine north of the Malaga Bend have been largely removed by erosion and solution in places in the depression at Malaga Bend. In test hole 24.29.16.133 (USGS 8) the clay and gypsum beds in the Rustler formation between the basal aquifer and the base of the alluvium are only 20 feet thick. These beds may also be somewhat fractured, permitting easier movement of brine into the basal part of the alluvium. Another path the brine may take from the basal brine aquifer into the alluvium is along the contact between the Rustler formation and the alluvium around the margin of the depression in the Malaga Bend area. That a connection definitely exists between the basal brine aquifer and the alluvium in the Malaga Bend is established by the fact that pumping of well USGS 8, finished in the basal brine aquifer, affects the water level in test well USGS 10, finished in the lower part of the alluvium. (See p. 31). Other effects such as annual rises and declines in the water table in the Malaga Bend area of 3 to 4 feet, causing an annual rise and decline of 1 to 1.5 feet in the head of the brine in the adjacent test wells finished in the basal brine aquifer, and changes in river stage in the Malaga Bend acting through the alluvium to cause changes in head in the basal brine aquifer, give further evidence of a connection between the basal brine aquifer and the alluvium in the Malaga Bend.

The head of the brine in the basal brine aquifer is somewhat higher than that in the basal alluvium in the Malaga Bend area, and both heads are several feet higher than the normal river level at the lower end of the Malaga Bend. The brine migrates upward through the fill, commingles with return irrigation water in the upper part of the fill, and discharges into the Pecos River. As no other area of discharge for the brine in the basal brine aquifer is known to occur, it is inferred that the discharge of brine in the Malaga Bend area probably represents the total discharge from the basal brine aquifer.

The determination of the rate of discharge of brine based on the observed increase in the chloride load of the Pecos River in the Malaga Bend

and the chloride concentration of the brine in the basal brine aquifer probably is the most accurate method of computing the discharge rate of the brine. The discharge computed by this method is between 0.41 and 0.44 cfs, or about 200 gallons a minute. Inasmuch as the aquifer has not been disturbed by artificial diversions, and the application of irrigation water within the bend area has been practiced for many years, the discharge should be in equilibrium with the recharge to the aquifer.

Water in the fill of the Malaga Bend area

About 1,000 acres of land are irrigated in the Malaga Bend area of which about 200 acres are cultivated on the inside of the bend. The principal crops grown are cotton and alfalfa. It is estimated that about 4,500 acre-feet of water is applied annually to these lands including the water lost in the ditches. It is further estimated that about one-third of the water applied seeps downward to the water table and moves laterally into the river. If this is approximately correct, then the average gain in this stretch of the river from irrigation return is about 2.0 cfs. The inflow of brine from the fill in this reach of the river is approximately 0.4 cfs. The total inflow from the brine and return irrigation water accounts for essentially all the observed gain in the flow of the Pecos River in the Malaga Bend.

The water table in the area on the inside of the Malaga Bend slopes toward the river to the north, east, and south from shallow well 24.29.16.311a near the center of the bend area. The altitude of the water table at well 24.29.16.311a was 2,905 feet on October 1, 1953, at the end of the irrigation season, and had declined to 2,901 feet above sea level at the end of March 1954, a period of 6 months. Near the river on the south side, water levels declined from an altitude of about 2,894.9 to 2,894.1 feet during the same period. The distance between well 24.29.16.311a and the south side of the bend is approximately 1,800 feet. Assuming that the specific yield* of the sediments is about 25 percent, the volume of water discharged from a half-mile section of the alluvium on the south side of the bend from October 1953 through March 1954 was approximately 3,000,000 cubic-feet, or an average of about 0.2 cfs. The average gradient of the water table in this strip on the south side of the bend was about 29 feet per mile during this period. The coefficient of transmissibility of the fill on the basis of these estimates is approximately 10,000 gallons a day per foot.

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* The specific yield of a water-bearing material is the ratio of (1) the volume of water which, after being saturated, it will yield by gravity to (2) its own volume.

Figure 3 shows by means of a north-south section through the Malaga Bend area the general relation of the brine in the basal brine aquifer and the lower part of the alluvium to the overlying fresh water. The brine in the basal brine aquifer is saturated with sodium chloride (common salt); the chloride content of the brine is about 158,000 ppm and the brine has a specific gravity of approximately 1.21. The brine in the lower part of the fill is also saturated. The movement of this saturated brine upward through the fill is influenced by the fresh water returned from irrigation of the lands in the bend area. The contact between the saturated brine and the fresh water is not sharp. This may be explained by the manner in which the fresh water is added to the fill. The total head operating on the brine in the lowest part of the fill is due largely to the weight of the overlying brine and fresh water. As irrigation water is added to the fill during the irrigation season part of it percolates to the ground-water body and the total head is increased, displacing the brine downward and outward. The brine does not move down uniformly; a part of it is trapped and mixes with the return irrigation water, which here is termed fresh water. This combination of brine and fresh water in turn mixes with brine trapped during the next irrigation season, becoming slightly more dense in comparison with the fresh water during each cycle of irrigation. The same type of mixing also occurs as the brine moves upward when the water table begins to decline after the end of the irrigation period. Thus, over the many years in which the lands in the bend have been irrigated, there has developed a thick lens containing an increasing concentration of chlorides with depth, until a depth is reached at which the upward movement of brine prevents any deeper mixing of unsaturated brines. It is largely the mixture of brine and fresh water that is discharged at the seeps and springs. The discharge of the springs is increased as the head of the water in the alluvium is increased by the addition of irrigation water, and hence the salt load contributed to the river increases during the irrigation season and declines again during the nonirrigation season. Accretion of salt to the river reaches a low of about 7 tons of chloride per hour in March and increases to approximately 10 tons of chloride per hour in September. Details of the gain in dissolved minerals in the Pecos River in the Malaga Bend stretch are given in the section on the quality of the water in the Pecos River, and in the section on results of the river sampling done in connection with the aquifer tests.

Source of the brine

The lower confining bed of the basal brine aquifer in many places is the rock salt of the Salado formation, and it is from this source that the originally fresh water entering the basal brine aquifer acquires its salt load. From the Malaga Bend northward in Nash Draw the brine contains progressively less dissolved salt. Lang (Robinson and Lang, 1938, p. 86) suggests that water percolating into the ground in the vicinity of Bear Grass Draw (T. 18 N., R. 30 E.) some 30 miles north of Malaga Bend may pass into the truncated beds of the lower Rustler formation and

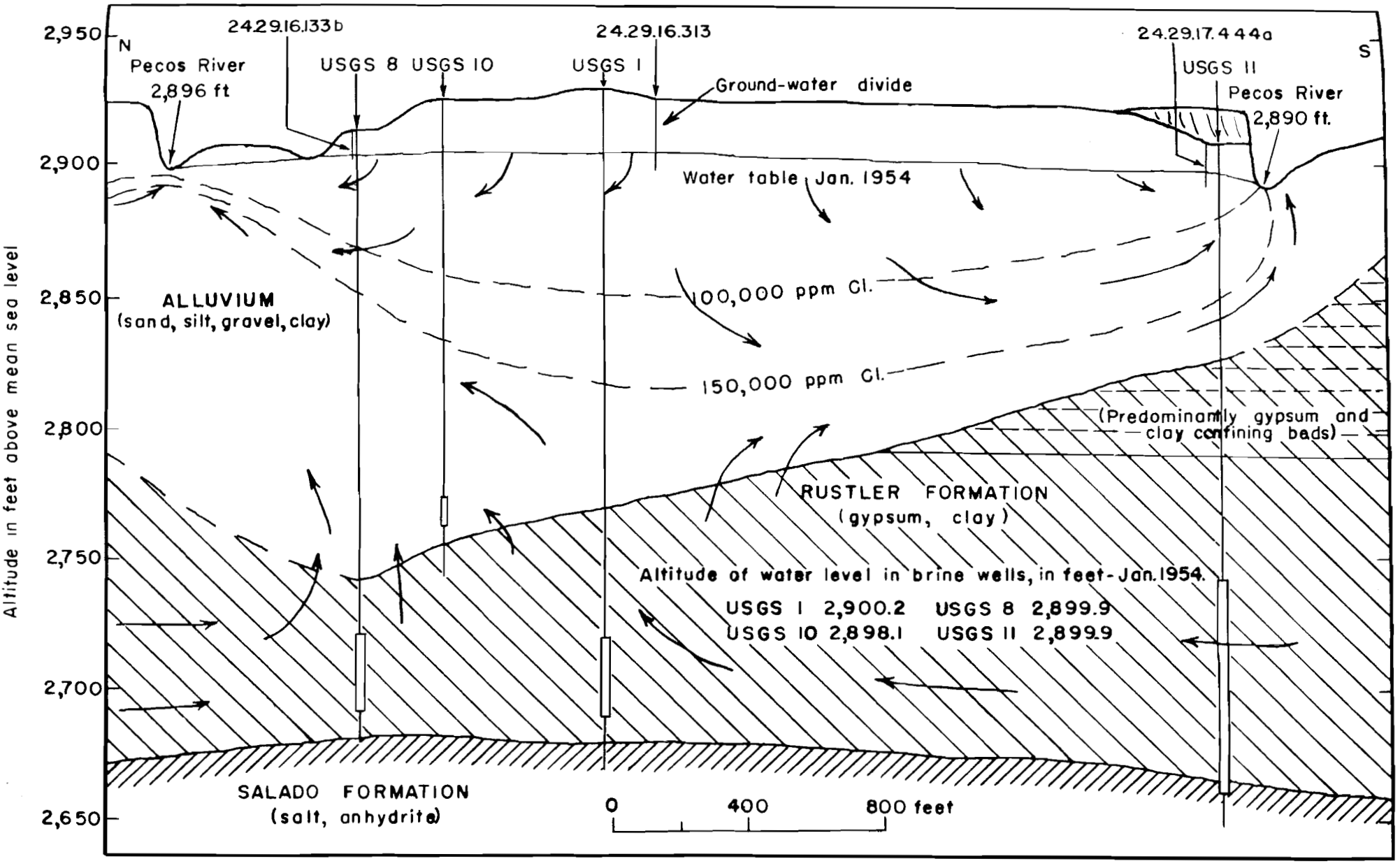


FIGURE 3. SECTION ALONG LINE BETWEEN SEC. 16 & 17, T. 24 S., R. 29 E., EDDY COUNTY, N. MEX., SHOWING SCHEMATICALLY THE GENERALIZED PATTERN OF GROUND-WATER MOVEMENT

may migrate south and east into Nash Draw, gradually dissolving the salt from the underlying Salado formation.

Some recharge to the brine aquifer occurs at times in the vicinity of brine test well 24.28.24.211 (USGS 2), about 2 miles west of the Malaga Bend. On October 22, 1953, the water level in USGS 2 rose about 2 feet in a period of less than 2 hours as a result of very heavy rain in the area. During the next 2 days the water level rose an additional 1 foot. The water level declined about 2 feet in the following 11 days and continued to decline more slowly thereafter. A rise of about 0.3 foot occurred in well 24.29.16.311 (USGS 1) in the Malaga Bend as a result of this recharge in the vicinity of USGS 2. Precipitation at other times in the vicinity of well USGS 2 has caused the water level to rise and recede sharply, but these fluctuations have not been reflected in well USGS 1. It is inferred that the recharge occurs through some solution passage in the Rustler formation that extends from near the surface to the basal brine aquifer in the vicinity of USGS 2. The level of the brine in well USGS 2 is about 2,905 feet. The brine has a specific gravity of about 1.18, and the water level would be at an elevation of about 2,944 feet if the head were converted to feet of fresh water. As the water table stands about 2,923 feet above sea level in this locality, fresh water normally would not enter the brine aquifer. If, however, during heavy rains a sink hole were to be filled to a point where the elevation of the water was more than 2,944 feet above sea level, then recharge could occur. It appears that only during heavy rains does any recharge occur in this locality, and only under exceptional conditions does any appreciable volume of recharge occur.

The amount of recharge to the brine-aquifer system should be on the average equal to the discharge of the brine at Malaga Bend. Inasmuch as there is no evidence of rejected recharge in the inferred recharge area, the removal of brine by artificial means, such as through wells, in excess of the decrease in natural discharge resulting from the artificial removal, should not be expected to increase the recharge to the system appreciably.

AQUIFER TESTS

Two aquifer tests were made during the investigation. The first test was made in May 1953 primarily to determine the characteristics of the basal brine aquifer. Measurements associated with the test were begun on May 11 and concluded on May 28. Periodic analyses were also made of the river water to learn if the natural inflow to the river decreased as a result of pumping. The second test was conducted in January, February, and March 1954, primarily to obtain, if possible, direct evidence of the effect of pumping of the basal brine aquifer upon the inflow of brine to the river.

Procedure

Three test wells finished in the basal brine aquifer were in existence in the Malaga Bend area in May 1953 - namely, USGS 1, 7, and 8. (See pl. 5.) Of these wells, only USGS 8 would yield more than a few gallons a minute. In wells USGS 1 and 7, the local permeability of the basal brine aquifer is very small. Initial tests on USGS 8 indicated that the well would yield more than 300 gallons a minute with a moderate drawdown. Well USGS 8 was selected therefore as the well for pumping in conducting the aquifer test of May 1953. It was not desirable to discharge the brine from the pumped well onto the sandy flats nearby because of the unknown effects it might have on the quantity and quality of the shallow ground water discharging into the river. It was decided therefore to discharge the brine into the Pecos River. As this additional brine load in the river would result in complications involving mixing of the brine with the river water and possibly mask any changes in the quantity of brine that enters the river under natural conditions, an attempt was made to secure pipe to conduct the pumped brine to the river below the bend area. This was not feasible financially, however, and the pipeline was laid to the river about 670 feet to the north of well USGS 8. A pumping rate of about 135 gallons a minute was selected to obtain as much discharge from the well as possible without contributing an excessive additional brine load to the river.

Recording gages were maintained on the other 2 wells penetrating the basal brine aquifer in the bend area and also on brine test well 24.28.24.211 (USGS 2) about 2 miles west of well USGS 8, and on brine test well 24.29.8.111 (USGS 3) about 1.7 miles north of well USGS 8. Several shallow wells inside the bend were measured periodically during the test. A microbarograph was set up in the area to provide data for correcting for barometric effects on the basal brine aquifer. The discharge rate of the brine from well USGS 8 was measured periodically during the pumping period by means of a barrel placed at the end of the discharge line.

In conjunction with the aquifer test, periodic samples of the river water at the Malaga and Pierce Canyon Crossing gaging stations and the 5 temporary stations around the bend (Fishing Rock, Corral, Head of Grandson Spring, Livingston Ford, and Lower Wading stations) were collected for 5 days prior to, during, and 3 days after the pumping period. The control for the flow of the river through the stretch was the gaging stations at Malaga and Pierce Canyon Crossing.

The time selected for pumping was a period when water was not being applied to the lands in the Malaga Bend area and when water would not be diverted from the river below the bend area. Pumping began at noon on May 16 and stopped at noon on May 25, a period of 9 days. The pumping rate was nearly constant and averaged 135 gpm.

The second aquifer test was made after two additional test holes had been drilled. One well 24.29.16.133a (USGS 10) about 200 feet from well USGS 8 was completed in the basal part of the fill for use as an observation well. Another well 24.29.17.444 (USGS 11) was drilled in the southwest part of the Malaga Bend area for possible use as a pumping well, but the yield was not sufficient for this purpose and the well was finished as an observation well in the basal brine aquifer. Well USGS 8 was again utilized as the pumping well. Results of the earlier test made in May 1953 confirmed the desirability of conducting the pumped brine away from the Malaga Bend area (see p.30), but the necessary pipe could not be obtained for the second test. Aside from increasing the pumping rate to somewhat more than 300 gallons a minute and pumping for a longer period, the pumping setup and observation wells involved, except for the addition of wells USGS 10 and 11, were essentially the same as for the test conducted in May 1953. The river sampling program involved the same stations as in May 1953. Additional discharge control on the river was obtained at the temporary sampling stations by establishing gages and making discharge measurements at various stages of the river to establish a rating curve. Again sampling of the river was begun before the pumping test, and it was continued for 8 days after pumping stopped. The pumping period began on January 28, 1954 and was concluded on February 25, 1954.

Water levels in wells in the basal alluvium in the Malaga Bend and in the basal brine aquifer fluctuate in response to a number of causes; from the return of irrigation water on the Malaga Bend, changes of stage in the Pecos River around the Malaga Bend, direct and indirect barometric effects, and earth tides. These effects must be considered in working with the water level fluctuations caused by pumping.(See fig.4.)

The fluctuations of water level caused by return of irrigation water to the fill are gradual and of small magnitude over a week's period. This type of fluctuation causes little error in determining the effects of pumping if only a few days or a week are considered. Over a period of a month, however, some correction needs to be applied. For example, the drawdown of well USGS 11, illustrated in figure 5, is too great in the final weeks of pumping because the seasonal decline in water levels in the brine aquifer is superimposed on the drawdown. It is estimated that the drawdown due to pumping of well USGS 8 should be about 0.6 foot less in well USGS 11 at the end of pumping period than was observed.

During the period of the aquifer test no important changes in the stage of the river occurred and hence no fluctuations of water level are attributable to this cause.

Barometric effects have an immediate effect on the water level in these deeper wells. A direct effect results in a decline in the water level when the barometric pressure rises. The apparent direct barometric efficiency of the wells in the basal brine aquifer in the Malaga Bend is

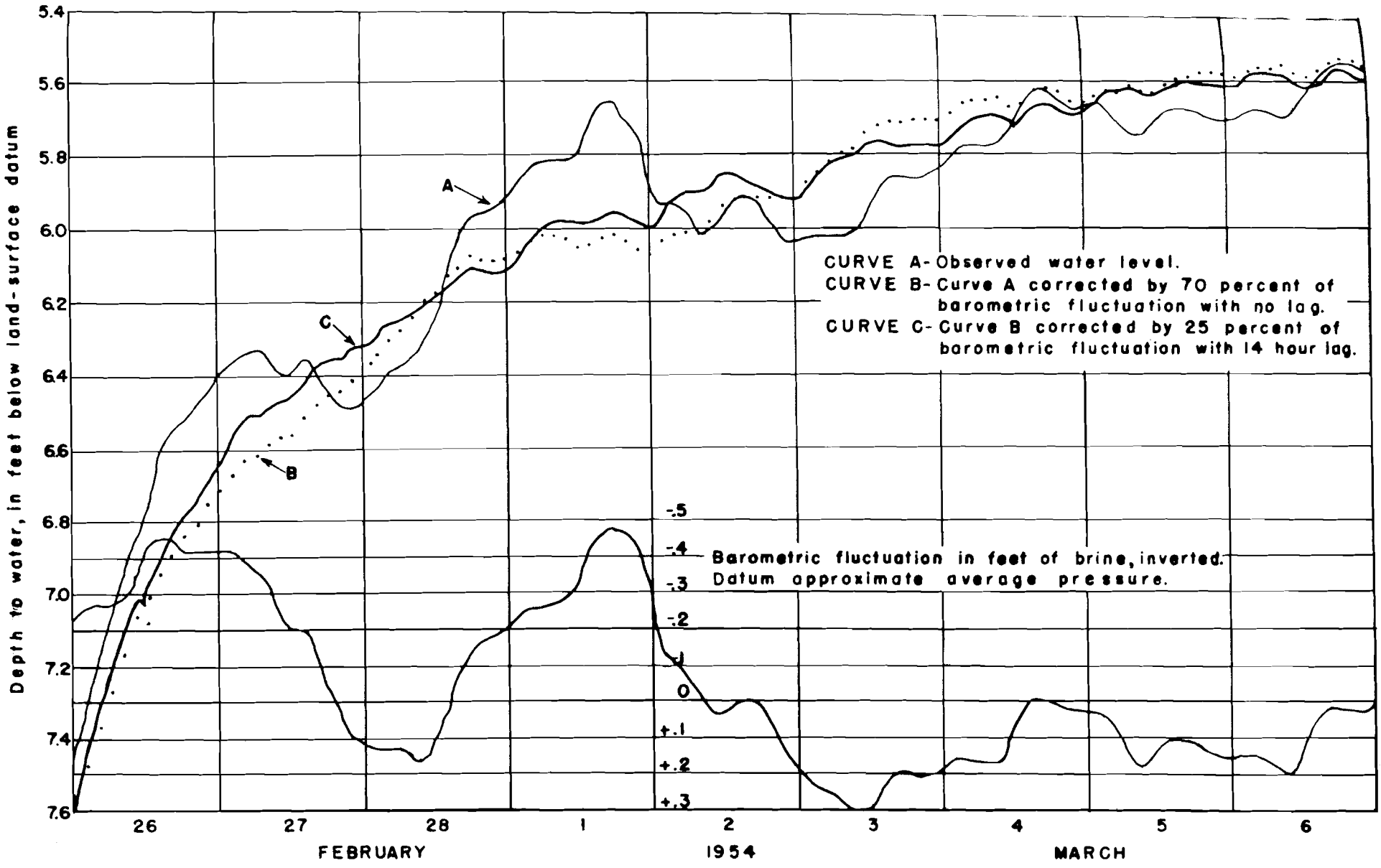


FIGURE 4. HYDROGRAPH OF WELL USGS 11, MALAGA BEND AREA, NEW MEXICO SHOWING CORRECTIONS FOR BAROMETRIC EFFECTS (FEB. 26 TO MAR. 6, 1954)

about 70 percent. Curve B on figure 4 shows the water level in well USGS 11 corrected for direct barometric effects. The resulting curve, however, shows peaks and sags which lag the direct barometric effects in a reverse order. This lag effect is probably caused by changes in the load acting on the aquifer through the aquifer in the fill. By trial, a lag of 14 hours and an efficiency of 25 percent produced the fairly smooth curve C shown in figure 4. Curve C still shows considerable minor fluctuations, presumably caused mostly by earth tides, but to some extent by the errors in correcting for direct and lag barometric effects. The direct barometric efficiency of well USGS 10, the well finished in the basal part of the alluvium, is about 50 percent and the lag correction is about 10 hours with an efficiency of about 25 percent.

Corrections for direct barometric and lag barometric effects were applied to the observed water levels in the observation wells in calculating the drawdown and recovery of water levels during the aquifer test.

Results

Test of May 1953

During the test of May 1953, water levels began to decline in the basal brine aquifer observation wells USGS 1 and 7 within a few minutes after pumping started in well USGS 8. Within an hour water levels began to decline also in basal brine wells USGS 2 and 3, west and north, respectively, of well USGS 8. At the end of 9 days of pumping at the rate of 135 gallons a minute, the pumping level in well USGS 8 was about 16.5 feet below land-surface datum, representing a drawdown of approximately 5.2 feet. Water levels declined during the period 2.4 feet in well USGS 1, 2.3 feet in well USGS 7, 0.9 foot in well USGS 2, and 1.1 feet in well USGS 3. Based on the rate of pumping and rate of decline in water levels in the observation wells, the basal brine aquifer has a transmissibility of about 60,000 gpd per foot. The coefficient of storage of the basal brine aquifer appears to be on the order of 1×10^{-4}. (The coefficient of storage is expressed as the fraction of a cubic foot of water that would be released from storage in a column of the aquifer having a cross sectional area of 1 square foot as a result of lowering the head in the aquifer 1 foot.)

The water levels declined also in shallow well 24.29.16.311a near the center of the area inside the Malaga Bend, but the decline was due almost entirely to natural drainage, as the rate of decline was essentially the same before and after the period of pumping as it was during the period of pumping. Shallow wells near the river showed fluctuations related to the stage of the river and very minor fluctuations related to changes in barometric pressure.

With regard to the effects of pumping on the natural inflow of brine to the river, the fluctuations in the river discharge and the attendant lag in adjustment of the mixing of the river water with the brine discharged from the pumping well were such that no satisfactory comparison of loads at various stations could be made with the required degree of refinement. It is of interest, however, that a cyclic change in the chloride concentration of the river water at the Lower Wading station was noticed and appeared to correlate with changes in barometric pressure.

Test of January-March 1954

The initial altitude of the brine level in wells finished in the basal brine aquifer prior to pumping well USGS 8 on January 28, 1954, was as follows:

Well		Altitude of water level in feet
USGS	1	2,900.2
	7	2,900.5
	8	2,899.9
	11	2,899.9

At the same time the brine level in well USGS 10, finished in the basal part of the alluvium and containing saturated brine, was 2,898.1 feet above sea level or approximately 1.8 feet lower than the head of the brine in well USGS 8 nearby and well USGS 11 across the bend, indicating a loss in head as the brine moves upward into the fill.

Some brine test holes outside the bend area have casing leaks. As a result, the altitude of the level of the mixture of brine and fresh water in the wells cannot be corrected precisely to the equivalent altitude based on concentrated brine. The data on fluctuations caused by pumping, however, can be utilized in calculating the transmissibility of the aquifer.

The approximate altitude of the water level in the river at most of the river stations around the bend was as follows:

Station	Altitude of water level in feet
Fishing Rock Ford	2,896.9
Head of Grandson Spring	2,893.9
Livingston's Ford	2,893.5
Lower Wading	2,890.3

Thus at the start of the test the head on the lower brine aquifer in the Malaga Bend was 3 to 10 feet above the river level around the bend.

When pumping began on January 28, water levels lowered equally in the three wells USGS 1, 7, and 11. A pumping rate of 310 gallons a minute was maintained with only 1 major shutdown, of less than 1 day, from

January 28 to February 25, 1954. By the end of the first day of pumping the water level in wells USGS 1, 7, and 11 had lowered 3 feet, and by the end of the second day the lowering totaled 3.8 feet. Thereafter, the declines were much more gradual and by the end of the pumping period the levels in the 3 wells were approximately 5.0 feet lower than at the start of the test, (see pl. 7) but were still about 5 feet above the river level at the lower end of the Malaga Bend. During the pumping period, the water level declined 2.7 feet in well USGS 3, 1.7 miles to the north of well USGS 8, and 2.3 feet in well USGS 2, about 2.0 miles west of well USGS 8.

Well USGS 10, finished in the basal alluvium, began to decline within 2 hours after pumping started and at the end of the pumping period the water level had declined approximately 1.0 foot below the prepumping level. If it is assumed that all the brine from the basal brine aquifer enters the fill along the bottom of the fill and, in so doing, loses approximately 1.8 feet of head (the difference between the prepumping heads in the basal alluvium and basal brine aquifer), then near the end of the test the flow of brine from the basal brine aquifer to the basal alluvium was reversed, as the differential head was reversed by about 2.2 feet. This reversal of differential head suggests that the amount moving back into the basal brine aquifer from the alluvium was roughly equal to that which was moving out of the brine aquifer prior to pumping. The trend in the decline of the water levels in wells in the basal brine aquifer after the first few days of pumping, compared to the initial trend, indicates also that the discharge of the brine into the alluvium had diminished or been stopped (fig. 5).

The water level in the shallow well 24.29.16.311a, in the center of the area inside the Malaga Bend, declined, as in the previous test of May 1953, before, during, and after the pumping period. However, the rate of lowering increased somewhat during the pumping period. About 0.1 foot of the total decline of 0.66 foot during the pumping period was apparently caused by the effects of pumping.

In connection with the aquifer test of January 28 to February 25, 1954, approximately 1,600 water samples were collected from the Pecos River in the Malaga Bend area. Determinations of specific conductance and chloride concentration were made in a field laboratory set up in Malaga Bend. The sampling program was begun on January 25, 3 days before pumping was started and continued until March 5, 8 days after pumping stopped. Samples were collected at 4-hour intervals at Fishing Rock Ford, at the Corral below Granddaddy Spring area, at the head of Grandson Spring area, from two channels at Livingston's Ford, and at the Lower Wading station. Samples were collected twice daily just below the Malaga gage at the Upper Wading station and at Pierce Canyon Crossing. At all these stations integrated samples were obtained by wading the river.

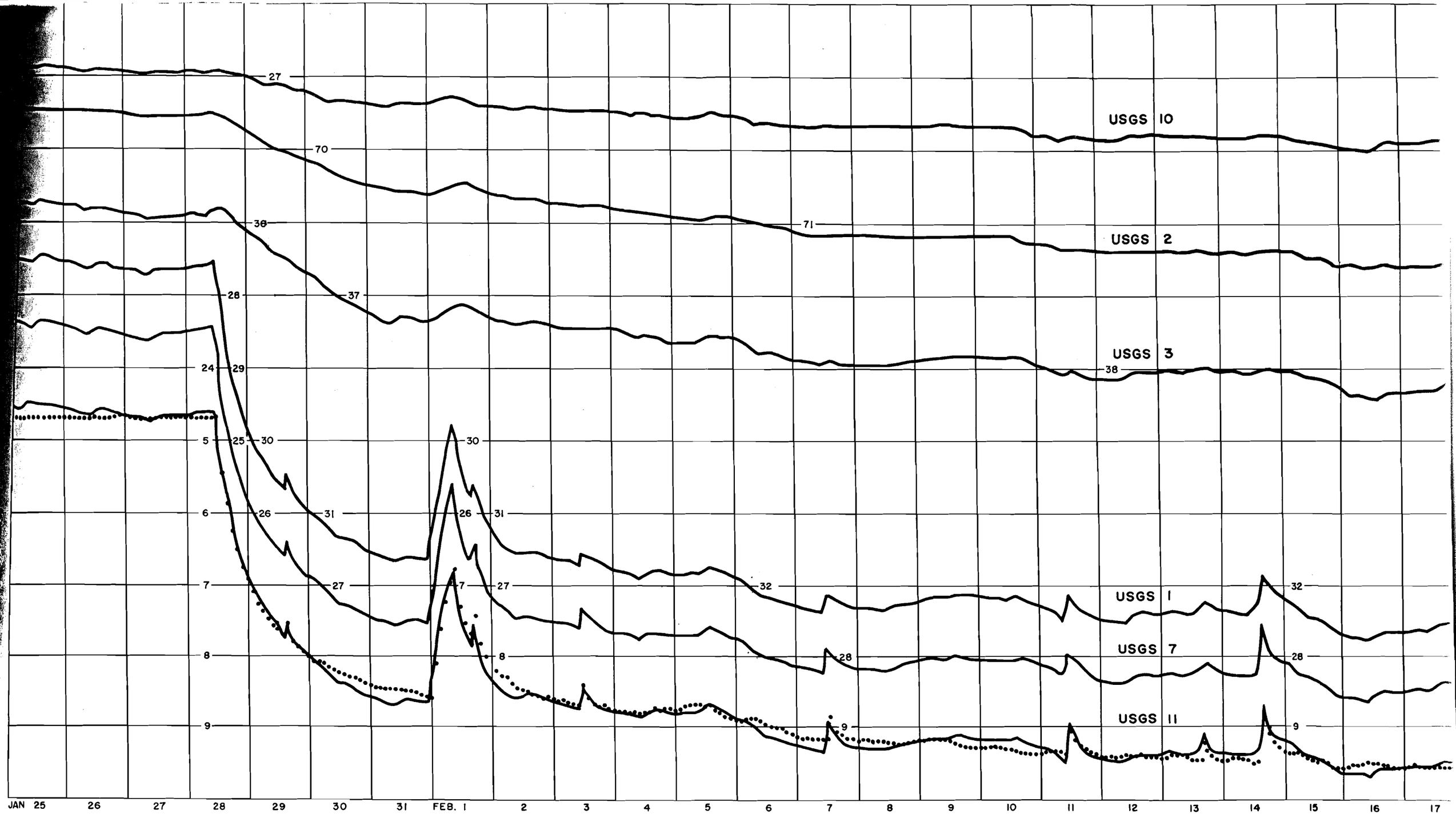
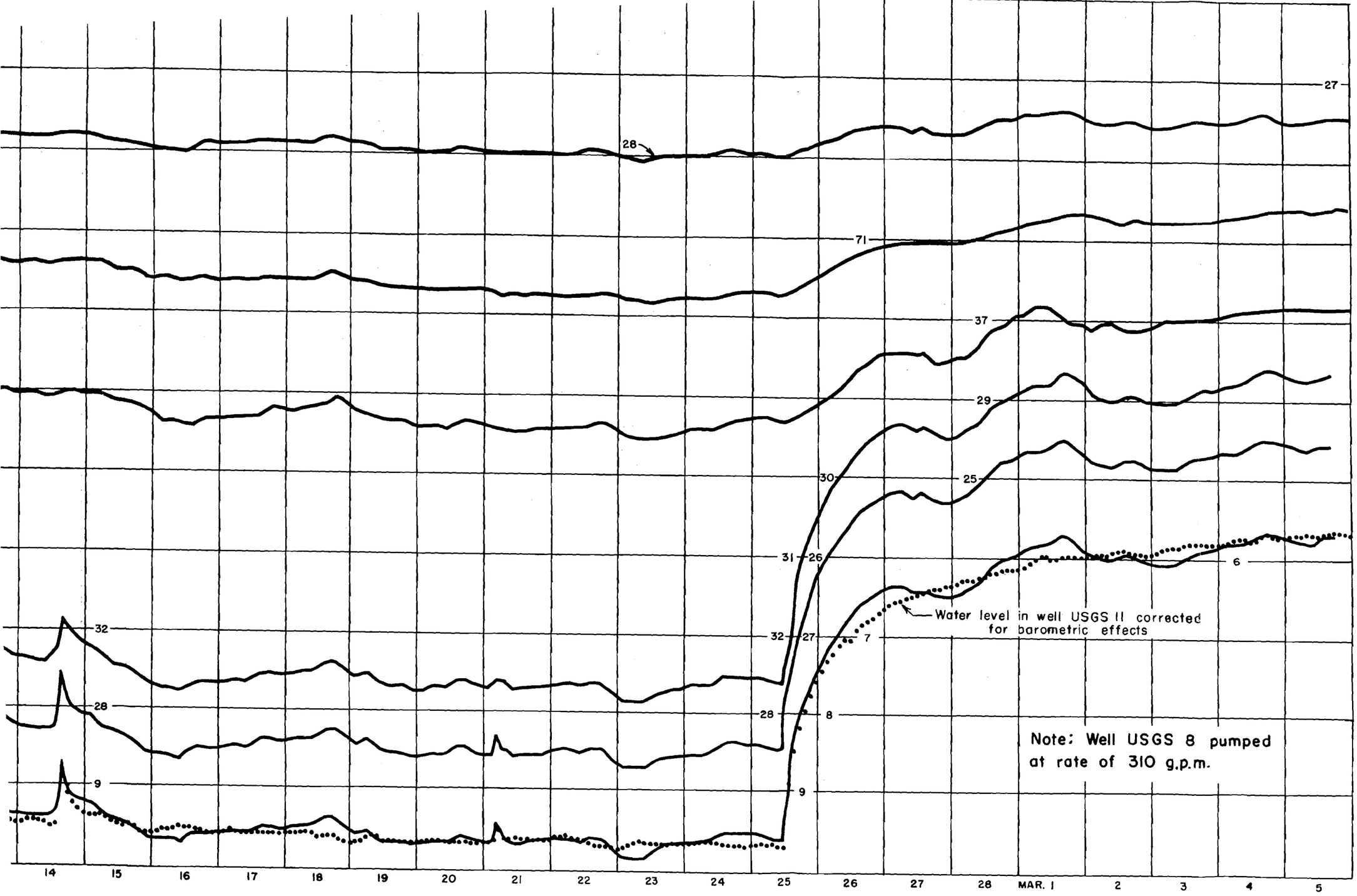


PLATE 7. HYDROGRAPHS OF SELECTED WELLS IN THE MALAGA BE
SHOWING EFFECTS FROM PUMPING WELL USGS 8, JANUAR



HE MALAGA BEND AREA, EDDY COUNTY, NEW MEXICO,
GS 8, JANUARY 28 TO FEBRUARY 25, 1954

PLATE 7.

Staff gages were installed at the sampling points from Fishing Rock Ford to the Lower Wading station and gage heights were measured each time samples were collected. During the study a series of six discharge measurements were made at each of the sampling points and rating tables were prepared.

Adverse effects produced by pumping the brine into the river at the upper side of the bend rather than below the bend are:

1. The additional load of chloride to be accounted for in the river made natural changes in concentration more difficult to detect.

2. The pumped brine flowed into the river with comparatively little mixing and was stored in a layer in the bottom of a pool near the point of pump discharge. Three days pumping was required to fill the pool before brine discharged from it at the average rate of pumping. After pumping was stopped, several days were required for the brine to be flushed out of the pool. The data obtained by sampling the river during these periods of adjustment is of doubtful value in computing chloride loads.

3. Agitation of the waters of the pool by strong winds caused large quantities of brine to pass out of the pool in slugs, and caused sharp increases in chloride concentrations at points below. Following movement of the slugs, time was required for the brine in the pool to be restored to overflow level and lower chloride concentrations appeared in the river below. Variations as great as 4,000 parts per million occurred within 2 hours during windy periods. Toward the end of the test, sampling at Corral and Lower Wading station was scheduled at 2-hour intervals during and immediately after windy periods. It is apparent that extreme variations in chloride concentrations could have been missed during the 4-hour sampling schedule. Although the brine mixed poorly with the water in the river pool at the pump discharge, cross-section sampling showed the brine and river water to be thoroughly mixed at the Corral station.

Precise computation of loads of dissolved matter carried by a stream depends in part on precise values for the rate of flow of the stream. When water has a concentration of 5,000 ppm of chloride, a change of 2 cfs in computed discharge will produce a change of 1 ton per hour in computed load of chloride. Discharge measurements made in the Malaga Bend area during the test period were rated "good," meaning that the error in measurement was believed to be less than 10 percent. As flow in the river ranged from 30 to 75 cfs, it is apparent that a 5-percent error in discharge could give errors in chloride load greater than 1 ton per hour. Intensive analysis of the discharge data obtained during the test indicated a gain in flow of 2 cfs between the Malaga and Pierce Canyon gaging stations, which was fairly uniform throughout the test period. It appeared that most of this increase in flow occurred in the lower part of the bend, between the sampling point at the head of the Grandson Spring area and the Lower Wading station.

Chloride loads at the Corral and Lower Wading stations are shown graphically on plate 8. Also shown is the gain in chloride load between the two stations. On this graph data for the Corral station are plotted 6 hours later than actual time because approximately 6 hours was required for actual movement of water between the two stations. This time was determined by placing dye in the river and observing its movement around the bend, and was confirmed by noting lags in chloride peaks.

Study of the chloride load data presented on plate 8 indicates that the gain in chloride load during the greater part of the test period averaged just under 7 tons per hour. During the last few days of sampling the gain appears to have been less than 6 tons per hour.

Most of the fluctuations in the curve showing gain of chloride appear to be associated with wind effects or to be the result of discharging the pumped brine into the river at the upper side of the bend. The low points on January 29 and 30 are caused by the time required for the brine to become mixed with all the water in the river between the Corral and Lower Wading stations. Part of the brine that passed the Corral station during those days did not reach the Lower Wading station but remained mixed with the river water around the bend. February 6 was a windy day, and it seems likely that a peak concentration of chloride was not sampled at the Lower Wading station. February 10 was a very windy day, but it appears that sampling was equally representative at both stations. However, on February 11, while the brine level was being restored in the pool at the pump discharge site, apparently a low in chloride concentration was missed at the Lower Wading station. Similar effects were produced by high winds February 15, 18, 19, and 22, and by moderate winds on the 23rd, 24th, and 25th. The increase in the gain in chloride on February 25 and 26 is the result of draining of the high chloride water stored in the river, in contrast to the conditions at the start of the pumping, on January 29 and 30.

It would appear, on the basis of these data, that the natural inflow of chloride in the reach between the Corral and Lower Wading stations decreased by about 1 ton per hour by the end of the period of pumping from the brine aquifer. It was stated previously that, with water having a chloride concentration of 5,000 ppm, an error in discharge of the river of 2 cfs would make a difference of 1 ton chloride per hour. However, during the last few days of the sampling of the river, concentrations of less than 2,500 ppm of chloride are involved and thus errors of 4 cfs would be required to account for 1 ton of chloride per hour. It seems unlikely that the values of discharge of the river as used could be in error that much.

The apparent decrease of 1 ton per hour in the chloride load of the river during the pumping period was accompanied by a decline in the water table of 0.66 foot in the center of the area on the inside of

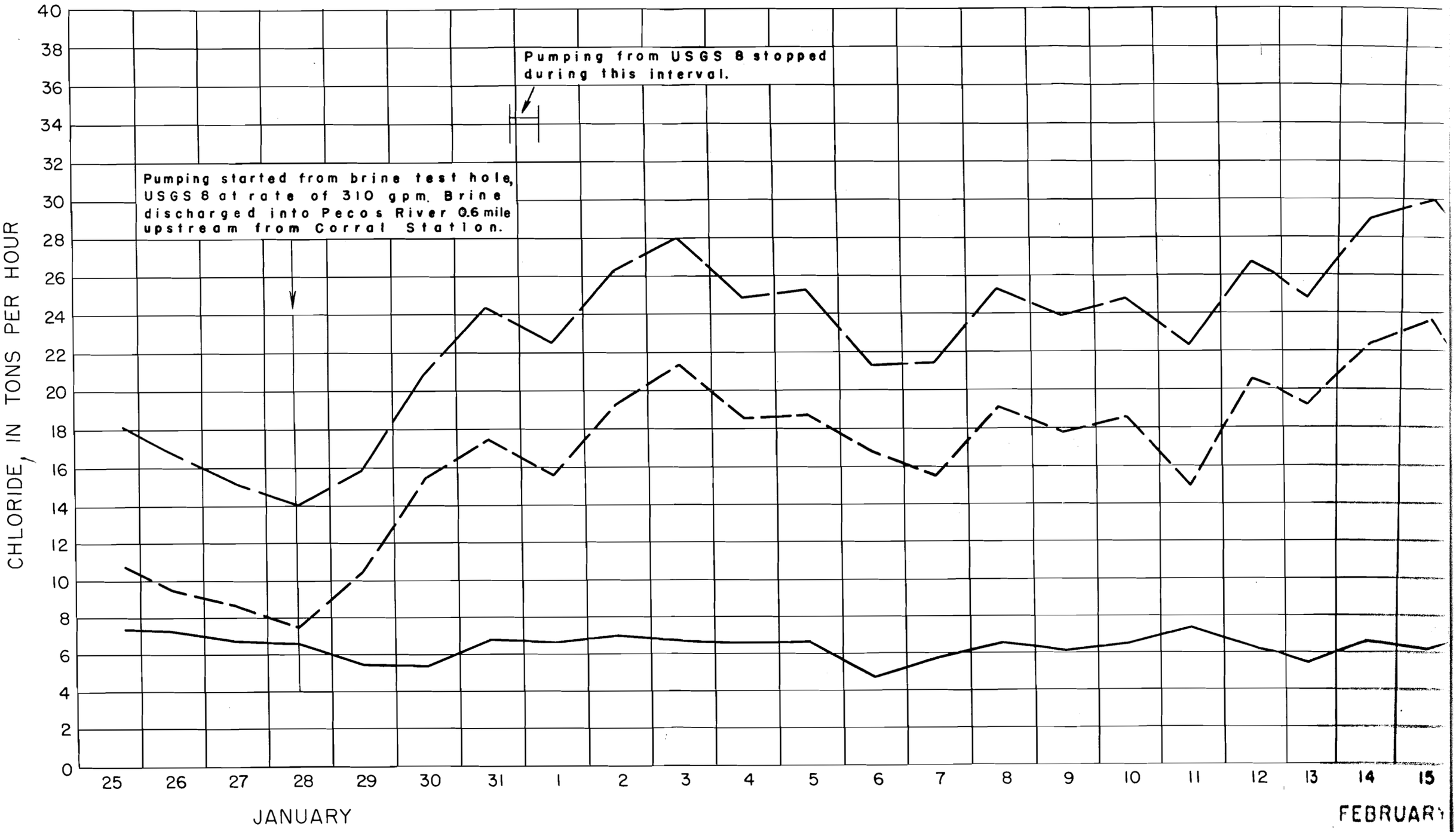
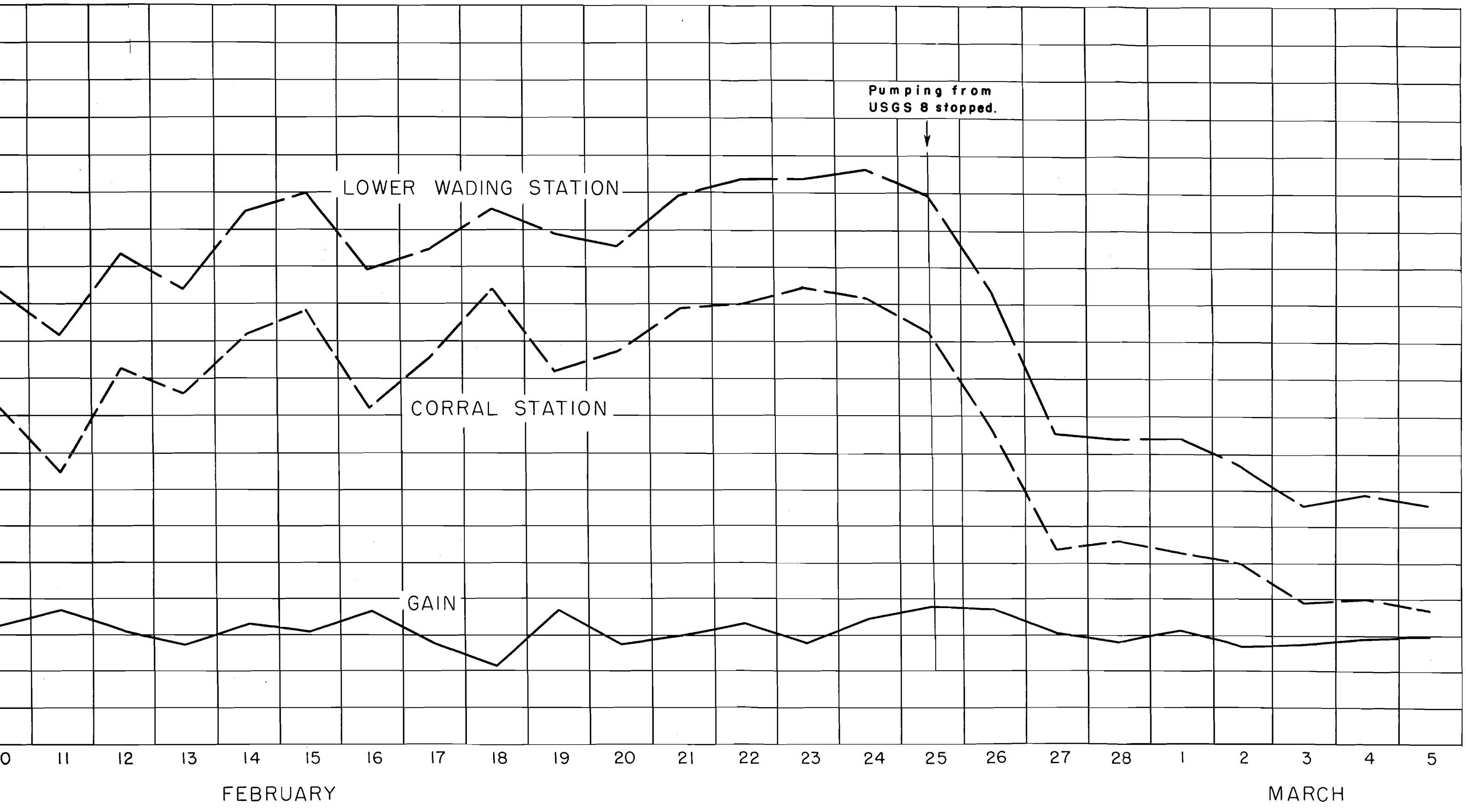


PLATE 8. DAILY AVERAGE CHLORIDE LOAD, PECOS RIVER AT CORRAL AND LOWER



AT CORRAL AND LOWER WADING STATIONS, MALAGA BEND AREA, N. MEX., 1954

PLATE 8.

the bend. As mentioned, about one-sixth (0.1 foot) of the decline in the water table appeared to be caused by pumping. It, therefore, seems that about one-sixth (0.15 ton per hour) of the decrease in the chloride load may have been caused by the pumping of well USGS 8 at the rate of 310 gallons a minute for approximately 1 month.

DECREASE OF BRINE INFLOW BY PUMPING METHODS

Any system of pumping the brine in the Malaga Bend area to divert the brine now discharging into the river must operate continually. An initial pumping rate in excess of the natural discharge rate should hasten the elimination of brine inflow to the river. Eventually, the pumping system should operate at a rate approaching 200 gallons a minute, the calculated natural discharge rate of the brine, although pumping may induce some additional water to enter the brine-aquifer system.

Pumping from the Alluvium

Pumping of wells constructed in the alluvium of the Malaga bend area and finished at depths of only a few feet into the saturated brine would have a more immediate effect in eliminating the brine inflow to the river than pumping of wells finished in the basal part of the alluvium or basal brine aquifer, in that a shallow-well system would remove the brine at points nearer the places of natural discharge. Further, this shallow-well system would have the least effect on the basal brine aquifer, in that the head on the basal brine aquifer would not be reduced appreciably. This system of pumping then would be less likely to induce entrance of additional water into the basal brine aquifer than would a well system developed in the basal alluvium or the basal brine aquifer.

One of the disadvantages of pumping brine from shallow wells is that the fill material in a large part of the bend area is not very permeable, and the yield and effects of pumping a single well finished at a shallow depth would not be appreciable. Thus a battery of wells would be needed to remove the brine and to maintain the head of the brine below river level. The overlying fresh water likely would be drawn into the well unless very careful regulation of the discharge were maintained. Frequent sampling of the water pumped would be required in order to regulate the discharge. This method, then, would involve considerable test drilling and expensive upkeep and observation procedures, and hence, at least at this time is considered impractical in view of alternate methods of pumping.

Wells finished and open only in the lower part of the alluvium, at the maximum distance below the upper boundary of the saturated brine, would be less likely to draw in the overlying fresh water than would shallow wells. As considerably more drawdown could be tolerated than in shallower wells without drawing in fresh water, the wells probably could

be pumped at a greater rate than the shallower wells. In addition, the lenticular clay beds in the alluvium would cause the effects of pumping to spread more rapidly than at shallower depths. Because of these conditions, fewer wells probably would be needed and pumping from the basal part of the alluvium would have only a moderate effect in reducing the head of the lower brine aquifer. Ideally, a total of approximately 200 gallons a minute would need to be pumped continuously from the system to divert the brine from the river. Because water-table conditions exist areally in spite of local confinement of the lower part of the fill by clay beds, there is a problem of ideal spacing of wells to pump only 200 gpm. Initially, however, the rate would have to be somewhat greater. Considerable test drilling would probably have to be done to locate satisfactory sites for the several wells that would be required.

Pumping from the Basal Brine Aquifer

On the basis of the pumping tests and other information gained during the investigation, the most feasible method of diverting the brine from the river appears to be by pumping from the basal brine aquifer.

Two of the advantages of pumping from the basal brine aquifer are: (1) No fresh water is likely to be drawn into the system from the alluvium in the Malaga Bend area; and (2) as the aquifer has a high transmissibility and small coefficient of storage, one or two properly located wells may suffice. One disadvantage of pumping from this aquifer is that the head must be reduced from its present elevation of 2,900 feet above sea level to 2,890 feet, a difference of 10 feet, to prevent the brine from discharging into the river. This lowering of head may induce some additional recharge into the brine-aquifer system from higher water-bearing beds in the Rustler formation.

At the sites of wells USGS 1, 7, and 11, the basal brine aquifer will not yield large quantities of the brine to wells. At well USGS 8, however, the aquifer probably will yield the initially required amount of brine. Although well USGS 8 was drilled and finished for use as an observation well, the well has a relatively high specific capacity. As mentioned, during the test of May, 1953, the well was pumped at the rate of 135 gallons a minute with a resulting drawdown of 5.2 feet, a specific capacity of 25 gpm per foot of drawdown. During the test of January-March 1954, the drawdown was about 18 feet at the end of about 1 month after pumping the well at the rate of 310 gallons a minute, a specific capacity of 17 gpm per foot of drawdown. The yield from a properly constructed well at or very near the site of well USGS 8 may be expected to yield the required quantity of brine from the basal brine aquifer. The effects of pumping the brine in the basal brine aquifer at well USGS 8 were so uniformly distributed over the bend area that one well here would serve to lower the head sufficiently over the bend area to stop the upward flow of brine into the alluvium. On the basis of the

results of the aquifer test, it is believed that the head in the brine aquifer could be reduced 10 feet, to the level of the water in the river near the lower end of the Malaga Bend, in a matter of a few days if the pumping were maintained at the site of well USGS 8 at a rate of 600 to 700 gpm. This rate could be reduced gradually over a period of a few years so as to maintain the brine head at the same altitude. Eventually the pumping rate would approach the present natural discharge rate of the brine, about 200 gpm. By maintaining the level of the brine in the basal brine aquifer at or near river level at the beginning, a considerable volume of brine should be induced to move from the basal alluvium into the brine aquifer, and thereby hasten the effect of reducing the natural discharge of brine into the river. As the head of the brine in the alluvium decreases with continued pumping the rate of movement of brine from the alluvium to the pumped aquifer will diminish.

Inasmuch as pumping from a single well in the basal brine aquifer causes the head of the aquifer to lower appreciably and fairly uniformly at an appreciable distance from the pumped well, consideration has been given to locating the pumped well or wells outside the bend area and nearer to the disposal (Queen Lake) area. Constructing a well near the center NW1/4 sec. 20, T. 24 S., R. 29 E., would require a pumping rate about one-third greater than a well at the site of well USGS 8 to obtain the same initial effects of lowering the brine levels in the basal brine aquifer in the amount of 10 feet at the south side of the bend area. It may not be possible to develop a well with this capacity at the site desired. Two or more wells might be required. Though a high-capacity well might not be obtained at this site, a somewhat smaller initial rate of pumping would mean only that lowering of the brine head would not take place as fast.

Though the brine level in the basal brine aquifer must eventually be lowered to the level of the river in the lower end of the Malaga Bend if pumping from the basal aquifer is to eliminate the inflow of brine, pumping could be maintained at such a rate as to keep the head in the basal brine aquifer only 1 to 2 feet below the brine level in the basal part of the alluvium at the Malaga Bend. This presumably would prevent movement of brine from the basal aquifer into the alluvium and the brine in the alluvium would drain slowly by natural means into the river. This would result in a slower rate of decline in the natural discharge of the brine into the river but would mean that pumping from the basal brine aquifer could be started at a rate of approximately 300 gpm if a well near well USGS 8 were used or about 400 gpm if a well were developed in the center NW1/4 sec. 20, T. 24 S., R. 29 E. This method of pumping as compared with pumping at a greater rate to reduce the brine head to river level almost immediately would, of ourse, result in permitting more brine to enter the river over a longer period of time. The advantages of the smaller pumping rate would be that facilities for pumping brine would not have to be as great and, of course, the brine storage facilities would last somewhat longer.

The volume of brine in the fill which will have to be flushed out to prevent further discharge of concentrated brine or a mixture of brine and the fresher water is not known. It may be of the order of 2,000 to 4,000 acre-feet. The flushing by natural discharge, if the brine were prevented from entering the fill, would take a great many years to accomplish, although appreciable diminution in the salt inflow should occur during the first year, followed by a somewhat lesser decrease the following year and so on. Pumping at the rate of 300 gallons a minute from the basal brine aquifer, would induce some brine to move from the fill to the basal brine aquifer, hastening the elimination of the brine from the river. Pumping at a greater rate from the basal brine aquifer will have a greater effect on the brine in the fill, but brine will continue to drain from the fill into the river for a number of years. A marked decrease in the brine inflow to the river should occur within a 3-year period at the greater rate of pumping but the reduction of brine inflow to the river might not reach 100 percent for a long time; 75 or 80 percent in the next decade or two is more likely. As mentioned, if pumping is maintained at a high rate, the storage facilities will be filled in a correspondingly shorter time.

CONSIDERATION OF THE QUEEN LAKE DEPRESSION FOR THE STORAGE OF BRINE

Queen Lake and the associated tributary drainage encompass an area of approximately 4 square miles in parts of secs. 23 to 26, T. 24 S., R. 28 E., and secs. 19, 29, and 30, T. 24 S., R. 27 E. The Queen Lake playa occupies an area of about 60 acres in parts of secs. 19 and 30, T. 24 S., R. 29 E. (pls. 2 and 6). Heavy rains in the drainage area result in the accumulation of considerable water in the playa, coming mostly from the tributary drainage to the west. Water is lost from the lake largely by evaporation, the evaporation rate and surface inflow being such that the playa is dry a good part of the time.

The general nature of the alluvial material partially filling the depression and of the exposed and underlying Rustler formation are discussed in previous sections of the report. A detailed geologic map of the Queen Lake depression is shown on plate 6.

Shallow ground water in the alluvium and upper part of the Rustler formation in the vicinity of Queen Lake is moving in a generally eastward direction toward the Pecos River (pl. 2). The water table surrounding the Queen Lake playa is at about the same elevation as the playa floor. During periods when the playa is dry, the movement of ground water into the playa is not sufficient to keep pace with evaporation from the clay and silt surface, with the result that water levels decline 2 feet or more below the playa floor. The water table around the lake rises slightly when the lake contains water, and the lake level at times is above the surrounding water table. Observations indicate that the rate of loss of water from the lake compares closely with that which should be lost by evaporation, indicating little movement of ground water

into the lake, or movement of lake water into the ground.

Evidence that the playa is not absolutely watertight is the fact that no deposits of salts are present on the playa floor. The water beneath the playa has a chloride content ranging between 12,000 and 45,000 ppm, suggesting a concentration of salts as a result of evaporation. These high-chloride waters mix with the fresher waters surrounding the lake at times when water is contained in the lake and move slowly to the east to discharge in the Pecos River.

R. S. Jones made several permeability tests of the playa sediments and adjacent alluvial material, using a saturated sodium chloride solution. The average initial permeability of several samples collected from the playa sediment was 1.0 gallon per day per square foot and the permeability of the samples decreased with each succeeding test run. The end result of some of the tests indicated that the samples had become essentially impermeable. The cause of the decrease in the permeability is not known. Sodium solutions commonly cause clays to become deflocculated and impermeable (Lee, 1941, p. 577-607), but there is some question whether concentrated brines will produce this effect (Eaton, 1950, p. 123-133). At any rate, the only available information on this area indicates that the passage of brine makes the sediments less permeable. Additional data are needed, and arrangements are being made to test additional samples.

One approach might be to seek a material that could be added to the brine, as bentonite is often added to fresh water, to seal the pores in the bottom of the lake, if some remedial measures are needed to retard leakage.

Assuming that the results of the permeability tests prove to be applicable to field conditions, the sediments of the lake floor may become somewhat tighter if a saturated brine is stored in the lake, and after a time the floor may become tighter also because of precipitation of salts and deposition of clay washed from the shore. The alluvial deposits along the margin of the playa are more permeable than the playa sediments but do contain clays that may react with the brine to make the sediments somewhat tighter.

Less leakage from the lake would occur initially if the playa and adjacent sediments were compacted. A good time to compact any given strip of the surface would be when the brine begins to encroach upon that strip, moistening the sediments. Salt may plug the cracks in the outcrops of gypsum and limestone, but the openings may have to be sealed by some other means if appreciable leakage develops and continues after a time.

As the brine to be pumped from the Malaga Bend is saturated with common salt, precipitation of the salt would begin immediately, assuming that the brine is discharged into a pool of saturated brine. If the lake

brine is maintained at the saturation point, the deposition of salt will proceed continuously to form a deposit over the floor of the lake and in so doing should reduce the leakage. To maintain this condition as nearly as possible, a dike could be constructed in the draw on the west side of Queen Lake along the west side of sec. 30, T. 24 S., R. 29 E., to keep out most of the storm runoff. The storm runoff thus would be impounded to the west of the lake and at times would inundate the land presently farmed in the draw west of Queen Lake (fig. 6).

If such a dike were constructed, brine stored in the lake would overflow into a depression to the southeast when a stage 25 feet above the playa floor is reached. The total capacity of the Queen Lake depression at this stage is approximately 5,500 acre-feet.

The average annual evaporation from a standard land pan in southeastern Eddy County amounts to about 118 inches per year. The ratio of evaporation of brine in Queen Lake to that of the standard land pan would be approximately 0.6. The average annual rainfall in the area is about 13 inches. On this basis about 5 feet of brine would be evaporated annually from the lake.

If brine were pumped to Queen Lake at the rate of 500 gallons a minute for 3 years, 300 gallons a minute for the next 7 years, and 200 gallons a minute thereafter for the life of the reservoir, the Queen Lake depression would provide storage for the precipitated salts and brine for approximately 100 years. The stage of the lake would rise appreciably during the first 3-year period, possibly to a level approaching 9 feet above the playa floor, and approximately 300 acre-feet of salts should have accumulated. The stage of the lake would rise more slowly during the next several years and the evaporation rate of the brines would approach or exceed the discharge rate of the brine into the lake.

A pipeline from well USGS 8 to the playa of Queen Lake would be about 2.0 miles long, and from a proposed well site in the NW1/4 sec. 20, T. 24 S., R. 29 E., about 1.0 mile long. The pipeline from well USGS 8 to the river used in test pumping of well USGS 8 showed no sign of salt incrustation on the inner walls and it is anticipated that no difficulty with incrustation will occur. From a point about 0.5 mile north of Queen Lake the land surface slopes toward the lake. The brine could flow by gravity in an open ditch to the lake. However, incrustation of the ditch would occur and the brine would gradually spread out over the slope area. This in turn would result in the leakage of brine into the fill along the slope. For this reason it may be desirable to conduct the brine to the lake entirely through a closed conduit. The altitude of the land surface at well USGS 8 is about 2,915 feet. The highest point along a pipeline to Queen Lake from well USGS 8 would be about 2,970 feet above sea level in the NW1/4 sec. 20, T. 24 S., R. 29 E.

A noticeable amount of almost pure nitrogen gas was pumped with the brine from well USGS 8 but this gas may not occur with the brine at

other sites. A gas would accumulate at the high point in a pipeline but whether this would cause difficulty is not known. Consideration might be given to means of bleeding gas from the pipeline.

CONCLUSIONS

An average of about 370 tons of common salt is added daily to the Pecos River through seeps and springs entering the river along the Malaga Bend. In this stretch the river gains on the average about 2 1/2 cfs, a mixture of water of which about 2 cfs is return from irrigation water applied to nearby lands and about 0.4 cfs is a concentrated brine.

Brine, almost saturated with sodium chloride, occurs at shallow depth in the Grandson Spring area on the inside of the bend and between Livingston's Ford and the Lower Wading station on the outside and lower end of the Malaga Bend. Elsewhere at shallow depth in the Malaga Bend area, the water is a mixture of the brine and water derived from application of water to the farm lands. The chloride content of the water in the alluvium increases with depth and, in the lower part of the fill, a saturated brine occurs.

The source of the concentrated brine in the alluvium at Malaga Bend is a brine aquifer that underlies the area at a depth of about 200 feet. The aquifer is developed mostly in gypsum near the base of the Rustler formation and in places directly overlies the Salado formation which here contains salt and anhydrite. The brine is under sufficient head in the Malaga Bend area to percolate upward through thin and incompetent beds of gypsum and clay into the alluvial sands, clay, and silt and thence into the river. The Malaga Bend area is the only known discharge area for the brine.

The basal brine aquifer extends northward from the Malaga Bend area to Laguna Grande de la Sal and Nash Draw in a strip 3 to 5 miles wide. The principal area of recharge is inferred to be in Bear Grass Draw in northern Eddy County where the truncated beds of the Rustler formation either crop out or immediately underlie the alluvium. Some recharge to the brine aquifer occurs at times in the area about 2 miles west of Malaga Bend. The salt in the underlying Salado formation is undoubtedly the source of the dissolved salt in the basal brine aquifer.

The transmissibility of the basal brine aquifer is about 60,000 gpd and, on the basis of the width of 5 miles and a gradient of 1.4 feet per mile, is estimated to be transmitting about 0.6 cfs through a given cross section. This value is of the same order of magnitude as the rate of discharge (0.4 cfs) calculated on the basis of the observed gain in the salt load in the Malaga Bend area; the value of 0.4 cfs is considered the more precise.

Pumping the brine to divert it from the Pecos River apparently can be best accomplished by pumping from the basal brine aquifer. One or two wells properly located in the Malaga Bend and finished in the basal brine aquifer and pumped at an initial rate of 600 to 700 gpm would lower the head to river level throughout the bend area within a short time. Eventually the rate could be reduced to about 200 gpm, the present natural discharge rate of the brine, but some additional water might be induced into the basal brine aquifer when the head is lowered. In this event, the pumping rate would have to be maintained at a rate slightly greater than 200 gpm to keep brine from entering the river. At the higher pumping rate some brine should be induced to move out of the basal alluvium into the underlying brine aquifer, thus hastening the diminution of brine inflow to the Pecos River.

The Queen Lake depression is not watertight but the sediments in the playa appear to be only slightly permeable. The clays and silts bordering the playa area and the playa sediments may become tighter when they come in contact with the brine, although additional study of this point is needed. Compaction of the clays and silt bordering the lake as they become moist would decrease their permeability and make the depression more nearly watertight. Construction of a dike across a draw to the west of Queen Lake would prevent much of the storm runoff from reaching the lake and would permit maintaining the lake brines in a more concentrated condition. Precipitation of the salt, together with the influx of clays washed in from the sides should aid in sealing the floor of the depression. Brine stored in the lake would over-flow into a depression to the southeast when a stage 25 feet above the playa floor is reached. The total capacity of the Queen Lake depression at this stage is approximately 5,500 acre-feet.

If brine were pumped to Queen Lake at the rate of 500 gpm for 3 years, 300 gpm for the next 7 years, and 200 gpm thereafter for the life of the reservoir, the Queen Lake depression would provide storage for the precipitated salts and brine for approximately 100 years.

If a pumping project is begun in the Malaga Bend area and brine is stored in Queen Lake, the project should be considered as an experiment, and should be evaluated. Detailed observations should be made of the fluctuation of the head of the brine in the basal brine aquifer and the basal part of the alluvium and of the water levels at shallow depths in the Malaga Bend area. Observations on the fluctuation and altitude of water levels in the basal brine aquifer northward from the bend area should be made also. This would require sealing the leaks in the casings of wells USGS 2, 3, and 4. Data on the discharge and mineral content of the Pecos River at the Pierce Canyon Crossing and Malaga stations and occasional measurements of discharge and mineral load in the Malaga Bend area should be obtained to observe the trend in the influx of salts. These various data will show the effectiveness of the pumping system and will aid in making necessary alterations to the pumping system.

Observation wells in pairs should be constructed and maintained around Queen Lake for the periodical collection of water samples and the observation of water-level fluctuations. Data obtained on the quality of the water and water-level fluctuations in these wells will provide a basis for any remedial measures, if necessary, to retard leakage. A gage should be installed to record the stage of the lake. Periodic checks of the volume of salt deposited also should be made.

Consideration should be given to plugging any active sinkholes located in the area about 2 miles west of the Malaga Bend. If after a few years the decrease in the inflow of brine to the river is not appreciable, or if it is desirable to hasten the diminution in the flow of brine to the river, consideration might be given to the construction of wells in the basal part of the alluvium to be pumped, or possibly drilled and opened into the basal brine aquifer to drain the brine in the alluvium.

LITERATURE CITED

Adams, J. E., 1944, Upper Permian Ochoa series of Delaware basin of west Texas and southeastern New Mexico: Am. Assoc. Petroleum Geologists Bull., v. 28, p. 1596-1625, figs. 1-4.

Eaton, F. M., 1950, Significance of carbonate in irrigation waters: Soil Science, v. 69, no. 2, p. 123-133.

Howard, C. S., and White, W. F. (revised by J. H. Bliss) 1938, Chemical character of Pecos River in New Mexico: New Mexico State Engineer 12th and 13th Bienn. Repts., p. 62-75, figs. 2-5.

Howard, C. S., White, W. F., and Hastings, W. W., 1942, Quality of Water: Nat. Resources Plan. Board, Pecos River Joint Inv., p. 102-132, figs. 18-22.

Lang, W. B., 1935, Upper Permian formations of Delaware basin of Texas and New Mexico: Am. Assoc. Petroleum Geologists Bull. v. 19, p. 962-970.

Lee, C. H., 1941, Sealing the lagoon lining at Treasure Island with salt: Am. Soc. Civ. Engineers Trans., 66-106, no. 2110. p. 577-607, figs. 1-6.

Richardson, G. E., 1904, Report of a reconnaissance in trans-Pecos Texas north of the Texas and Pacific Railway: Texas Univ. Bull. 23, p. 1-119.

Robinson, T. W., and Lang, W. B., 1938, Geology and ground-water conditions of the Pecos River valley in the vicinity of Laguna Grande de la Sal, with special reference to the salt content of the river water: New Mexico State Engineer 12th and 13th Bienn. Repts. p. 79-100, pls. 1-5, figs. 1-3.

Theis, C. V., Morgan, A. M., Hale, W. E., and Loeltz, O. J., 1942, Ground-water hydrology of areas in the Pecos Valley, N. Mex.: Nat. Resources Plan. Board, Pecos River Joint Inv., p. 38-75, figs. 5-15.

TABLES

Table 1.—Weighted averages of analyses of water from Pecos River near Malaga, N. Mex., for water years 1938 to 1953

(Results in parts per million except percent sodium and conductance)

Year ended September 30	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids Sum: Parts per million	Dissolved solids Sum: Tons per acre-foot	Dissolved solids Sum: Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Percent sodium	Specific conductance (micromhos at 25°C)
1938	164	17	448	146	494	11	143	1,490	801	2.2	3,470	4.72	1,540	1,720	1,600	38	4,680
1939	130	18	509	175	576	13	152	1,710	944	3.4	4,020	5.47	1,410	1,990	1,870	38	5,420
1940	124	19	488	179	597	13	141	1,690	976	3.7	4,030	5.48	1,350	1,950	1,840	40	5,500
1941	1,652	15	285	64	191	7.5	111	856	291	2.8	1,770	2.40	7,880	974	884	30	2,420
1942	1,098	18	425	105	332		144	1,330	504	2.3	2,790	3.79	8,270	1,490	1,370	33	3,700
1943	326	19	469	141	410		150	1,540	649	3.0	3,300	4.49	2,900	1,750	1,630	34	4,380
1944	174	15	485	161	511		160	1,650	804	5.9	3,710	5.05	1,740	1,870	1,740	37	4,960
1945	145	18	474	157	492		174	1,590	777	4.2	3,600	4.90	1,410	1,830	1,690	37	4,780
1946	99.0	20	454	166	525		181	1,550	884	4.5	3,650	4.96	976	1,820	1,670	39	4,920
1947	128	20	494	158	501		173	1,620	810	4.5	3,690	5.02	1,280	1,880	1,740	37	4,840
1948	118	17	320	111	380		153	1,040	614	5.5	2,560	3.48	816	1,260	1,130	40	3,600
1949	139	19	417	139	411		163	1,340	689	5.3	3,100	4.22	1,160	1,610	1,480	36	4,240
1950	208	16	471	141	425		168	1,490	696	4.1	3,330	4.53	1,870	1,760	1,620	34	4,470
1951	159	16	505	158	470		171	1,630	772	4.4	3,640	4.95	1,560	1,910	1,770	35	4,880
1952	50.1	19	515	188	659		187	1,730	1,090	6.2	4,300	5.85	582	2,060	1,900	41	5,860
1953	37.4	18	510	189	727		195	1,730	1,200	5.8	4,480	6.09	452	2,050	1,890	44	6,230

Table 2.--Weighted averages of analyses of water from Pecos River at Pierce Canyon Crossing, near Malaga, N. Mex., for water years 1939 to 1941, 1952 to 1953

(Results in parts per million except percent sodium and conductance)

Year ended September 30	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids Sum: Parts per million	Dissolved solids Sum: Tons per acre-foot	Dissolved solids Sum: Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Percent sodium	Specific conductance (micromhos at 25°C)
1939	143	--	510	184	880	20	149	1,760	1,430	3.1	4,860	6.61	1,880	2,030	1,910	48	6,890
1940	130	19	497	192	944	21	138	1,760	1,530	3.3	5,030	6.84	1,770	2,030	1,920	50	7,200
1941	1,694	13	290	68	239	9.0	110	879	367	2.2	1,920	2.61	8,780	1,000	914	34	2,660
1952	54.6	17	524	219	1,570		180	1,870	2,510	--	6,800	9.25	960	2,210	2,060	61	9,880
1953	42.4	17	533	231	2,010		177	1,920	3,190	--	7,990	10.9	915	2,280	2,140	66	11,800

Table 3.--Weighted averages of analyses of water from Pecos River at Red Bluff, N. Mex., for water years 1938 to 1953

(Results in parts per million except percent sodium and conductance)

Year ended September 30	Mean discharge (cfs)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Dissolved solids Sum: Parts per million	Dissolved solids Sum: Tons per acre-foot	Dissolved solids Sum: Tons per day	Hardness as $CaCO_3$: Calcium, magnesium	Hardness as $CaCO_3$: Non-carbonate	Percent sodium	Specific conductance (micromhos at 25°C)
1938	182	17	457	160	907	21	138	1,570	1,450	2.1	4,650	6.32	2,280	1,800	1,690	52	6,680
1939	148	17	509	186	940	24	134	1,780	1,510	2.7	5,030	6.84	2,020	2,030	1,930	50	7,140
1940	135	18	496	190	982	22	131	1,770	1,580	2.8	5,120	6.96	1,880	2,020	1,910	51	7,340
1941	1,655	17	297	68	267		103	911	397	1.9	2,010	2.73	8,970	1,020	936	36	2,700
1942	1,102	18	424	109	443	11	140	1,360	681	1.8	3,110	4.23	9,250	1,510	1,390	39	4,230
1943	327	18	463	143	631	19	131	1,580	980	2.1	3,900	5.30	3,440	1,740	1,640	44	5,160
1944	168	19	481	174	828	22	140	1,710	1,290	5.5	4,600	6.26	2,090	1,920	1,800	48	6,450
1945	143	19	487	173	908		153	1,670	1,440	3.2	4,780	6.50	1,850	1,930	1,800	51	6,740
1946	104	20	459	185	1,110		163	1,650	1,750	4.6	5,260	7.15	1,480	1,910	1,770	56	7,560
1947	137	19	490	167	913		161	1,650	1,440	4.2	4,760	6.47	1,760	1,910	1,780	51	6,680
1948	128	14	303	125	873		135	1,050	1,380	2.7	3,810	5.18	1,320	1,270	1,160	60	5,660
1949	156	15	417	160	823		153	1,410	1,330	4.4	4,230	5.75	1,780	1,700	1,570	51	6,090
1950	218	15	475	157	695		161	1,520	1,130	5.0	4,080	5.55	2,400	1,830	1,700	45	5,720
1951	146	15	525	170	891		169	1,740	1,420	3.6	4,850	6.60	1,910	2,010	1,870	49	6,810
1952	56.5	16	530	223	1,600		173	1,900	2,550	---	6,900	9.38	1,050	2,240	2,100	61	10,000
1953	41.6	11	539	236	2,110		146	1,980	3,350	---	8,300	11.3	932	2,320	2,200	66	12,300

Table 4.--Summary of average gains in mineral load in various reaches of the Pecos River below Malaga, Eddy County, N. Mex.

Reach of the river	Period a/	Chloride			Sodium chloride			Dissolved solids		
		Tons per hour	Tons per day	Tons per year	Tons per hour	Tons per day	Tons per year	Tons per hour	Tons per day	Tons per year
Malaga to Red Bluff	Water years 1938-40 1943-53	11.1	267	97,500	18.4	441	161,000	21.2	510	186,000
Do.	Water years 1939, 1940, 1952, 1953	10.6	254	92,700	17.5	420	153,000	21.7	520	190,000
Malaga to Pierce Canyon Crossing	Water years 1939, 1940, 1952, 1953	9.3	223	81,400	15.3	368	134,000	17.9	430	157,000
Upper Wading station to Fishing Rock	June 12-13, 1952	.5	12	4,380	.8	20	7,230	--	--	---
Do.	Sept.13-15, 1954	.5	12	4,380	.8	20	7,230	--	--	---
Fishing Rock to Corral	June 12-13, 1952	.5	12	4,380	.8	20	7,230	--	--	---
Do.	Sept. 13-15, 1954	.5	12	4,380	.8	20	7,230	--	--	---
Corral to Head of Grandson Spring area	June 12-13, 1952	.8	19	7,010	1.3	31	11,600	--	--	---
Do.	Sept. 13-15, 1954	.8	43	15,800	3.0	71	26,100	--	--	---
Head of Grandson Spring area to Lower Wading station	June 12-13, 1952	4.7	113	41,200	7.8	186	68,000	--	--	---
Do.	Sept. 13-15, 1954	6.0	144	52,600	9.9	238	86,800	--	--	---
Fishing Rock to Lower Wading	June 12-13, 1952	7.0	168	61,300	11.6	277	101,000	--	--	---
Do.	Sept. 13-15, 1954	9.3	223	81,500	15.3	368	134,000	--	--	---
Return flow from 4,500 acre-feet of irrigation water per year (estimated Malaga to Pierce Canyon Crossing	Water years 1938-40, 1943-53	.5	12	4,380	.8	20	7,230	--	--	---
Average inflow of brine (total gain less irrigation return) Malaga to Pierce Canyon Crossing	Water years 1938-40 1943-53	8.8	211	77,000	14.5	348	127,000	15.8	379	138,000

a/ The Geological Survey water year is the 12-month period ending September 30 of the indicated year.

Table 5.--Analyses of water from seeps and springs in the Malaga Bend area of the Pecos River, Near Malaga, N. Mex.

(Results in parts per million except conductance and specific gravity)

No.	Description	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (sum)	Specific conductance (micromhos at 25°C)	Specific gravity at 20°C
1	Spring at Fishing Rock Ford, 6 gpm	June 10, 1952				---		4,220		14,900	1.007
2	Seep in area 350 yards below Fishing Rock Ford	June 10, 1952				---		40,000		---	1.053
3	Granddaddy Spring area pool at USGS well 8	Feb. 11, 1953				---		27,100		---	1.038
4	Stream flowing into river on left bank below Granddaddy Spring area, about 20 gpm	June 10, 1952				---		16,000		45,100	1.044
5	Pool in Grandson Spring area, flow 4-5 gpm	May 16, 1953				---		98,200		---	1.125
6	Inflow in Grandson Spring ravine, flow 3-4 gpm	Oct. 17, 1951				244		17,200		47,900	1.023
7	Hole dug in river bank near USGS well 11, slight flow	May 16, 1953						26,600		---	1.035
8	Stream from pools in gravel bar in river below Livingston Ford, flow 3-4 gpm	Oct. 17, 1951	475	1,980	95,600	114	9,400	147,000	255,000	---	1.189
9	Small boil on right bank at Lower Wading Station, flow 1 gpm	May 15, 1953				---		22,400		---	1.025

Table 6.—Analyses of water from well and test holes in the Malaga Bend area of the Pecos River, near Malaga, N. Mex.

(Results in parts per million except conductance and specific gravity)

No.	Description	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Dissolved solids (sum)	Hardness (as $CaCO_3$)	Specific conductance (micro mhos at 25°C)	Specific gravity at 20°C
1	Well 24.28.25.122	June 3, 1954	-		-	764	207	2,420	1,150	-	2,650	6,800	-
2	Well 24.28.25.123	do.	-		-	673	233	2,330	955	-	2,500	6,200	-
3	Well 24.28.25.123a	Feb.10, 1948	1,140	461	-	8,270	- 36	3,780	13,300	27,000	4,740	36,500	1.019
4	Well 24.28.26.211	June 2, 1954	-	-	-	817	- 318	2,780	965	-	2,740	7,070	-
5	Well 24.28.36.144	Oct.21, 1947	729	135	-	520	- 233	1,960	900	4,360	2,370	5,410	-
6	Do.	June 2, 1954	-	-	-	626	- 224	1,870	1,100	-	2,320	6,070	-
7	Well 24.28.36.222	Oct.21, 1947	52	16	-	206	- 168	157	240	756	196	1,380	-
8	USGS well 8 (24.29.16.133)	Feb. 25, 1954	411	2,020	101,000	3,310	78	10,200	158,000	275,000	9,330	-	1.207
9	USGS well 10 (24.29.16.133a) (depth 160 ft.)	Sept.18,1953	-	-	- -	-	-	-	155,000	-	-	-	1.205
10	Well 24.29.16.133b	Feb. 11, 1953	-	-	-	360	-	-	12,900	-	-	37,800	1.017
11	USGS well 1 (24.29.16.311); depth, 33 ft	Oct. 27, 1937	196	124	-	-	-	1,820	3,180	-	-	-	-
12	USGS well 1 (24.29.16.311); depth, 54 ft	do.	697	1,340	45,300	-	165	6,970	69,700	124,000	-	-	1.091
13	USGS well 1 (24.29.16.311); depth, 84 ft	Nov. 1, 1937	982	1,610	63,400		137	8,460	97,800	172,300	-	-	1.171
14	USGS well 1 (24.29.16.311); depth, 113 ft	do.	656	2,160	99,900		103	10,100	154,000	267,000	-	-	1.204
15	USGS well 1 (24.29.16.311)	Jan. 18, 1952	-	-		-	-	-	155,000	-	-	-	1.207
16	USGS well 7 (24.29.16.314)	do.	-	-		-	-		150,000	-	-	-	1.203

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

ocation umber	Owner or name	Date completed	Topo-graphic situation	Altitude of land-surface datum (feet above sea level)	Type of well	Depth of well (ft)	Diam-eter of well (in)	Principal water-bearing bed				Depth to which well is cased (ft)
								Depth to top of bed (ft)	Thick-ness (ft)	Char-acter of material	Geo-logic horizon	
.30.17.313	USGS 5	May 1938	Flat	3,076.57	D	342	7	335	10	Gypsum	Rustler forma-tion	331
.29.17.232	USGS 4	Mar. 1938	do.	2,955.58	D	265	7	242	32	do.	do.	226
.29.22.122	U.S.Potash Co. 1	Sept. 1937	do.	2,967.66	D	31	7	24	16	Dolomitic limestone	do.	21.5
.29.28.123	U.S.Potash Co. 2	Dec. 1937	do.	2,967.48	D	316	3 1/2	272	61	Gypsum	do.	269
.28.24.211	USGS 2	Feb. 1938	Flat	2,975.0	D	286	7	285	44	do.	do.	275
.28.25.122*	Mr.Pulley	-	Slope	2,912.4	D	65R	10	-	-	-	-	-
.28.25.122a	do.	-	do.	2,912.1	D	10	6	-	-	-	-	-
.28.25.123*	do.	-	Knoll	2,925.2	D	32R	6	-	-	-	-	-
.28.26.211*	Guy Reed	-	Flat	2,937.4	D	60R	5	-	-	-	-	-
.28.36.144*	Reed South-well	-	do.	2,947.8	D	62	6	-	-	-	-	-
.28.36.222*	Guy Reed	-	do.	2,909.5	D	53	8	-	-	-	-	-
.28.36.312	do.	-	do.	2,948.1	D	70	8	-	-	-	-	-

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Water level		Method of lift	Yield		Drawdown (ft)	Duration of test (min)	Use of water	Remarks
	Feet below land-surface datum	Date of measurement		Rate (gpm)	Date of measurement				
22.30.17.313	149.67	May 19,1938	N	18	May 1938	3.65	13	N	Brine test
23.29.17.232	45.93	Mar. 6, 1938	N	42	Feb. 1938	No appreciable drawdown	26	N	Brine test
23.29.22.122	23.33	Sept.25,1937	N	-	-	-	-	N	-
23.29.28.123	54.96	Dec. 20,1937	N	-	-	-	-	N	Brine test
24.28.24.211	73.15	Feb. 2, 1938	N	24	Dec. 1937	76.2	22	N	Brine test
24.28.25.122	5.37	June 2, 1954	-	-	-	-	-	I	-
24.28.25.122a	5.25	do.	N	-	-	-	-	N	-
24.28.25.123	17.55	do.	-	300-325R	-	-	-	D	-
24.28.26.211	20R	May 10, 1954	J	-	-	-	-	D	-
24.28.36.144	40.70	June 2, 1954	W	-	-	-	-	S	-
24.28.36.222	11.93	do.	N	-	-	-	-	N	-
24.28.36.312	20.27	do.	N	-	-	-	-	N	-

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Owner or name	Date completed	Topo-graphic situation	Altitude of land-surface datum (feet above sea level)	Type of well	Depth of well (ft)	Diam-eter of well (in)	Principal water-bearing bed				Depth to which well is cased (ft)
								Depth to top of bed (ft)	Thick-ness (ft)	Char-acter of material	Geo-logic horizon	
.29.5.244	USGS 6	Apr. 1939	Flat	3,045.1	D	153	7	110	41	Dolomite	Rustler forma-tion	116
.29.8.111	USGS 3	Jan. 1938	do.	2,957.9	D	293	7	235	108	Gypsum	do.	239
.29.16.133*	USGS 8	May 1939	Terrace	2,911.5	D	221.5	7	199	31	do.	do.	221.5
.29.16.133a*	USGS 10	Sept.1953	Flat	2,925.1	D	160	7	124	40	Sand, clay, gravel	Alluv-ium	160
.29.16.133b	USGS	June 1952	do.	2,911.8	A	12	4	11	-	Silt, sand, clay	do.	12
.29.16.311*	USGS 1	Nov. 1937	do.	2,927.8	D	240	7	212	36	Gypsum	Rustler forma-tion	240
29.16.313	USGS	Mar. 1953	do.	2,920.5	A	22	2	17	-	Silt, sand	Alluv-ium	22
.29.16.314*	USGS 7	May 1939	do.	2,923.9	D	230	7	205	38	Gypsum	Rustler forma-tion	230
.29.16.342*	USGS	Mar. 1953	do.	2,902.1	A	9	2	6	-	Fine sand	Alluv-ium	9

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Water level		Method of lift	Yield		Drawdown (ft)	Duration of test (min)	Use of water	Remarks
	Feet below land-surface datum	Date of measurement		Rate (gpm)	Date of measurement				
24.29.5.244	105.13	Jan. 8, 1953	N	25	Apr. 1939	7.62	12	N	-
24.29.8.111	54.67	Feb. 1, 1938	N	23	Jan. 1938	7.2	23	N	Brine test
24.29.16.133	11.30	Sept.30, 1954	N	310	Jan. 28,1954	27.0	Jan.28,1954 to Feb.25,1954		
24.29.16.133a	26.17	do.	N	13	Sept.18,1953	113.8	17	N	Brine test Lower 10 feet of casing slotted
24.29.16.133b	9.62	do.	N	-	-	-	-	N	-
24.29.16.311	27.28	do.	N	7	Apr.10, 1953	42.7	15	N	Brine test Lower 30 feet of casing slotted
24.29.16.313	17.25	do.	N	-	-	-	-	N	-
24.29.16.314	23.17	do.	N	10	Apr. 13,1953	25	27	N	Brine test Lower 30 feet of casing slotted
24.29.16.342	3.99	do.	N	-	-	-	-	N	-

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Owner or name	Date completed	Topo-graphic situation	Altitude of land-surface datum (feet above sea level)	Type of well	Depth of well (ft)	Diam-eter of well (in)	Principal water-bearing bed				Depth to which well is cased (ft)
								Depth to top of bed (ft)	Thick-ness (ft)	Char-acter of material	Geo-logic horizon	
24.29.16.431*	USGS	Mar. 1953	Flat	2,897.1	A	8	2	1	-	Fine sand	Alluv-ium	8
24.29.16.431a	USGS	Feb. 1953	do.	2,896.8	A	5	4	1	-	do.	do.	5
24.29.17.444*	USGS 11	Nov. 1953	do.	2,904.5	D	246	7	235	11	Gypsum, clay	Rustler forma-tion	246
24.29.17.444a	USGS	Mar. 1953	do.	2,905.0	A	14	2	10	-	Sand, clay, gravel	Alluv-ium	14
24.29.17.444b*	USGS	do.	Draw	2,896.4	A	5	2	3	-	Sand	do.	5
24.29.29.324*	Mr. Pulley	-	Flat	2,902.3	D	15R	4	8	-	Dolomite	Rustler forma-tion	-
24.29.30.212*	USGS	Apr. 1952	Lake bottom	2,897.3	A	10	4	2	-	Clay, silt, sand, gypsum	Alluv-ium	10

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Water level		Method of lift	Yield		Drawdown (ft)	Duration of test (min)	Use of water	Remarks
	Feet below land-surface datum	Date of measurement		Rate (gpm)	Date of measurement				
24.29.16.431	1.05	Sept.30,1954	N	-	-	-	-	N	-
24.29.16.431a	.81	do.	N	-	-	-	-	N	-
24.29.17.444	3.88	do.	N	19	Nov.5,1953	141.6	151	N	Brine test Lower 80 feet of casing slotted
24.29.17.444a	10.33	do.	N	-	-	-	-	N	-
24.29.17.444b	2.77	do.	N	-	-	-	-	N	-
24.29.29.324	7.93	June 2,1954	W	-	-	-	-	S	-
24.29.30.212	1.53	Sept.30,1954	N	-	-	-	-	N	-

Table 7.-- Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.-- Continued

Location number	Owner or name	Date completed	Topo-graphic situation	Altitude of land-surface datum (feet above sea level)	Type of well	Depth of well (ft)	Diam-eter of well (in)	Principal water-bearing bed				Depth to which well is cased (ft)
								Depth to top of bed (ft)	Thick-ness (ft)	Char-acter of material	Geo-logic horizon	
4.29.30.212a*	USGS	Feb. 1953	Terrace above lake	2,907.1	A	17	4	12	-	Silt, sand	Alluv-ium	17
4.29.30.212b	USGS	Apr. 1952	Lake bottom	2,897.2	A	10	4	2	-	Clay silt sand gypsum	do.	10
4.29.30.233*	USGS	do.	do.	2,897.5	A	11	4	4	-	do.	do.	11
4.29.31.321	Guy Reed	-	Small knoll in de-pression	2,905.1	D	13	5	-	-	-	-	-
5.28.3.222*	Chinaberry well	-	Flat	2,990.8	D	-	5	-	-	-	-	-
5.28.13.111	USGS 9	July 1939	do.	2,886.8	D	173	7	167	2	Clay	Rustler forma-tion	173

Table 7.--Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.--Continued

Location number	Water level		Method of lift	Yield		Drawdown (ft)	Duration of test (min)	Use of water	Remarks
	Feet below land-surface datum	Date of Measurement		Rate (gpm)	Date of measurement				
4.29.30.212a	11.90	Sept. 30, 1954	N	-	-	-	-	N	-
4.29.30.212b	.95	do.	N	-	-	-	-	N	-
4.29.30.233	3.81	Aug. 5, 1954	N	-	-	-	-	N	-
4.29.31.321	10.74	June 2, 1954	N	-	-	-	-	N	-
5.28.3.222	35.12	do.	W	-	-	-	-	S	-
5.28.13.111	17.61	Feb. 10, 1940	N	-	-	-	-	N	Brine test

Table 7.-- Records of selected wells in the vicinity of Malaga Bend, Queen Lake, and Nash Draw, Eddy County, N. Mex.

Location No.: See figure 1; * indicates chemical analysis in table 6.

Type of well: A, auger hole; D, drilled.

Water level: Measured depth to water given to nearest 0.01 foot, reported depth given to nearest foot. Generally recent water levels given except when not representative because of casing leaks.

Method of lift: J, jet; N, none; W, wind.

Yield: R indicates reported yield; other yields determined by pumping or bailing.

Use of water: D, domestic; I, irrigation; N, none; S, stock.