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Experimental Salinity Alleviation at Malaga Bend of the Pecos River Eddy County, New Mexico

(U.S.) Geological Survey
Albuquerque, NM

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From July 22, 1963 through December 1968, approximately 3,878 acre-feet of brine had been pumped. Total brine storage in July 1968 was 540 acre-feet, including about 200 acre-feet of salt precipitate. From 1963 to 1968, water downgradient of the storage depression increased in chloride concentration by amounts ranging from 1,500 to 99,400 milligrams per liter, and water levels near the depression increased over 3 feet.

For water years 1952-63, the Pecos River gained about 240 tons per day of chloride in the reach from Malaga gaging station to Pierce Canyon Crossing. In the same reach, the average chloride gain to the Pecos River from July 1963 to August 1966 was 167 tons per day; in 1967-68 the gain increased to 256 tons per day following a major flood in August 1966.

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NOTICE

EXPERIMENTAL SALINITY ALLEVIATION AT MALAGA BEND OF THE PECOS RIVER, EDDY COUNTY, NEW MEXICO

BY JOHN S. HAVENS AND D.W. WILKINS

U.S. GEOLOGICAL SURVEY
WATER-RESOURCES INVESTIGATIONS 80-4

PREPARED IN COOPERATION WITH
THE PECOS RIVER COMMISSION

DECEMBER 1979

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

GEOLOGICAL SURVEY

H.William Menard, Director

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U.S. Geological Survey
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Albuquerque, New Mexico 87125

CONTENTS

CONTENTS - Concluded

ILLUSTRATIONS

TABLES

INCH-POUND UNIT TO METRIC-UNIT CONVERSION FACTORS

In this report figures for measurements, except water temperature, are given in inch-pound units only. The following table contains factors for converting to metric units.

Multiply inch-pound units	By	To obtain metric units
in (inch)	2.54	cm (centimeter)
ft (foot)	0.3048	m (meter)
ft^2/d (foot squared per day)	0.0929	m^2/d (meter squared per day)
ft^3/s (cubic foot per second)	0.02832	m^3/s (cubic meter per second)
acre	4047	m^2 (square meter)
acre-ft (acre-foot)	1.233×10^3	m^3 (cubic meter)
mi (mile)	1.609	km (kilometer)
gal/min (gallon per minute)	0.06309	L/s (liter per second)
ton/d (ton per day)	907.2	kg/d (kilogram per day)

Temperature °F(Fahrenheit) = 1.8 x temperature °C(Celsius) + 32

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EXPERIMENTAL SALINITY ALLEVIATION AT MALAGA BEND

OF THE PECOS RIVER, EDDY COUNTY, NEW MEXICO

By John S. Havens and D. W. Wilkins

ABSTRACT

Upward-leaking brine, from a confined aquifer at the base of the Rustler Formation, mixes with fresher water in a shallow aquifer, resulting in discharge to the Pecos River in southern Eddy County, New Mexico, of about 0.5 cubic feet per second of saturated brine. Pumping brine from the aquifer at a rate greater than 0.5 cubic feet per second lowered the potentiometric head in the confined aquifer.

From July 22, 1963 through December 1968, approximately 3,878 acre-feet of brine had been pumped. Total brine storage in July 1968 was 540 acre-feet, including about 200 acre-feet of salt precipitate. From 1963 to 1968, water downgradient of the storage depression increased in chloride concentration by amounts ranging from 1,500 to 99,400 milligrams per liter, and water levels near the depression increased over 3 feet.

For water years 1952-63, the Pecos River gained about 240 tons per day of chloride in the reach from Malaga gaging station to Pierce Canyon Crossing. In the same reach, the average chloride gain to the Pecos River from July 1963 to August 1966 was 167 tons per day; in 1967-68 the gain increased to 256 tons per day following a major flood in August 1966.

Seepage investigations made prior to pumping of the brine aquifer show that the main area contributing brine to the river was located between the Malaga gage and well USGS 11. In 1968 most of the brine inflow apparently entered the river downstream of the Malaga-USGS 11 reach. The head in the brine aquifer was lowered and discharge to the river was decreased above the Malaga gage. Leakage from the depression contributed salts to the river below the Malaga gage during brine pumpage.

INTRODUCTION

Location and background

The Malaga Bend of the Pecos River is located about 5 miles east of Malaga, New Mexico. The principal study area includes parts of Townships 24 and 25 south and Ranges 28 and 29 east (fig. 1). The area is traversed by the Pecos River, and most drainage is toward the river; however, several depressions and sinkholes have closed drainage patterns, and surface water flowing into these areas does not enter the river directly.

Historically, the lower reaches of the Pecos River have been notoriously saline. As early as 1582, Spanish explorers noted salt springs and seeps along the banks of the river (Lingle and Linford, 1961, p. 18-19). In the 1930's irrigators complained that excessive salinity of the river was harmful to their cotton crop.

Purpose of the investigation

The salinity alleviation project at Malaga Bend was conducted in cooperation with the Pecos River Commission. Its purpose was to evaluate the effectiveness of pumping brine from a well at Malaga Bend to reduce brine discharge into the Pecos River. This report outlines the details of the project, the type of data collected, and the conclusions reached.

Previous investigations

Chemical-quality investigations by Howard and White (1938, p. 62-75) showed that large quantities of chloride were discharging into the Pecos River in the Malaga Bend area. Further investigation has shown that a sodium chloride brine from an artesian aquifer discharges in a 3-mile reach of the Malaga Bend, in secs. 16 and 17, T. 24 S., R. 29 E. (fig. 1).

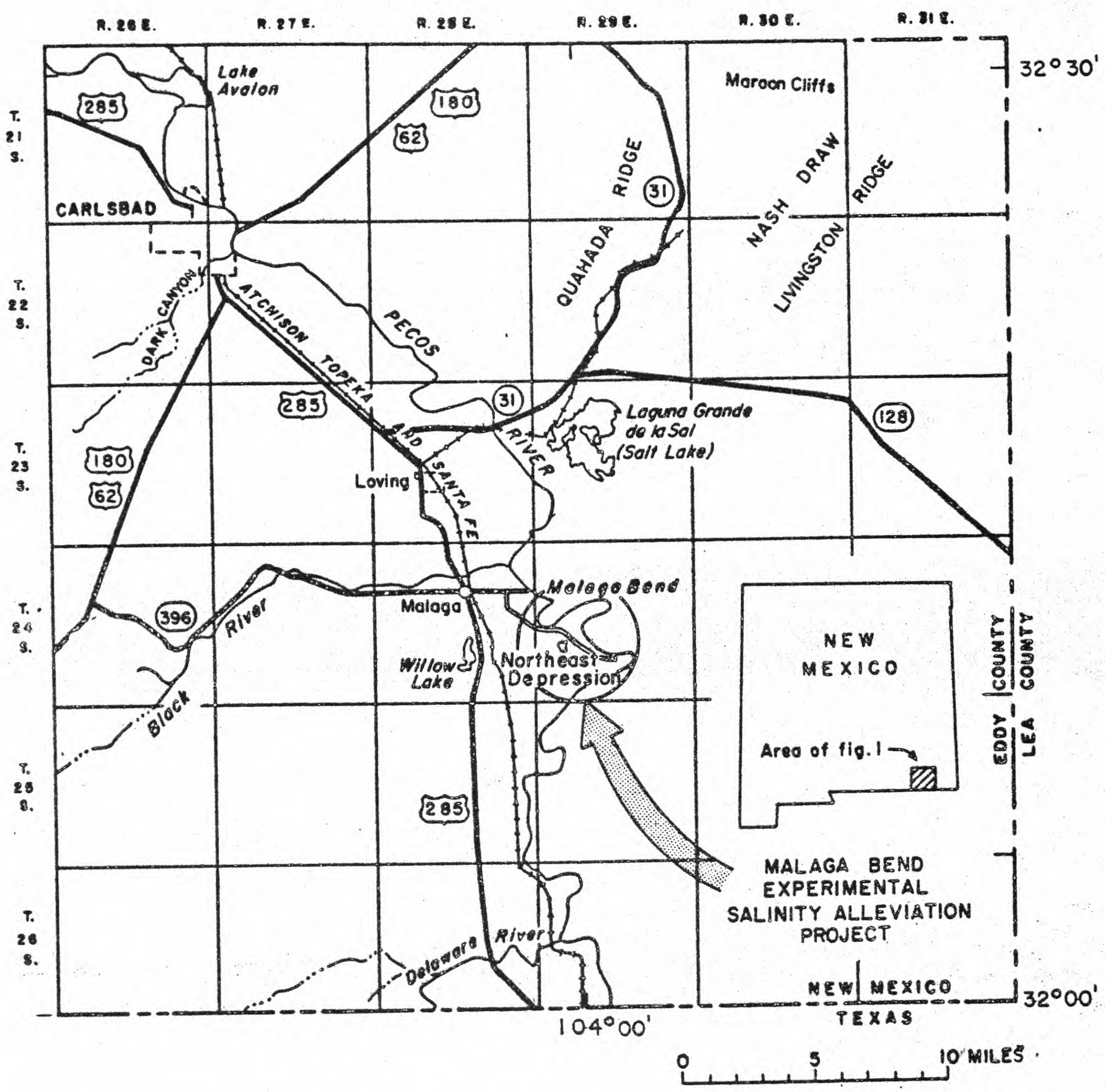


Figure 1.--Index map.

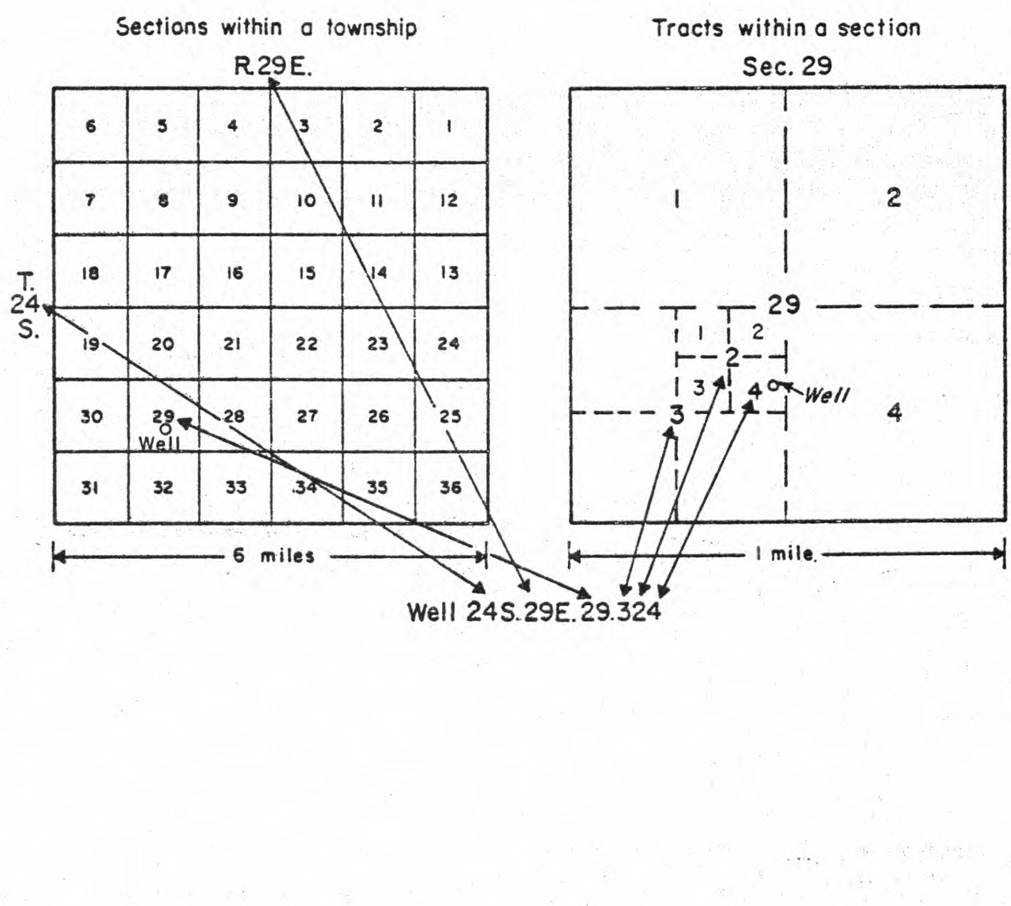
Laguna Grande de la Sal, a natural salt lake about 6 miles east-northeast of Loving, N. Mex., was thought to be a possible source of saline-water leakage to the river. Laguna Grande served as a disposal pond for saline wastes from a nearby refinery. A study of ground-water conditions (Robinson and Lang, 1938) showed that less-concentrated saline water was present beneath the lakebed than was present in the lake. The potentiometric (pressure-head-indicating) surface of water in the alluvial aquifer sloped toward the lake, indicating that there was little possibility of leakage from the lake into the topographically lower Pecos River.

Robinson and Lang (1938, p. 100) concluded that an aquifer containing highly concentrated brine "occurs at the base of the Rustler Formation and overlies the extensive deposit of salt known as the Salado halite," and that "the available evidence points to the conclusion that the lake brine does not reach the Malaga Bend through the brine horizon or by any other route."

Theis and others (1942, p. 38-75) concluded that if most of the salt entering the river discharged from the brine aquifer at the base of the Rustler Formation, the total brine inflow was about 0.44 ft^3/s, and that diversion of this comparatively small quantity of water would, therefore, eliminate much of the salt load added to the river at Malaga Bend. Hale and others (1954, p. 2) discussed two general methods of accomplishing this: (1) Cutting off the Malaga Bend and damming the ends of the loop; and (2) pumping the brine aquifer at Malaga Bend to intercept the brine before it enters the river. Other reports dealing with the Malaga Bend area include: Cox and Havens (1961); Cox and Havens (1965); Cox and Kunkler (1962); and Howard and White (1938).

System of numbering wells in New Mexico

All wells referred to in this report are identified by a location number assigned by the U.S. Geological Survey and the State Engineer of New Mexico. The location number is based on the system of public land surveys. The number indicates the location of the well to the nearest 10-acre tract, if the well can be located that accurately. The location number consists of a series of numbers corresponding to the township, range, section, and tract within a section, in that order, as illustrated below. If a well has not been located closely enough to be placed within a particular section or tract, a zero is used for that part of the number. Letters a, b, c, and so forth are added to the last segment to designate the second, third, fourth, and succeeding wells in the same 10-acre tract.



GEOHYDROLOGY

Geologic formations and their water-bearing characteristics

Malaga Bend and the surrounding area are in the structural feature known as the Delaware basin. A massive subsurface reef limestone (the Capitan Limestone) forms the northwest, north, and east borders of the basin. The west part of the study area is bordered by a steep slope of the Capitan Limestone that extends northeastward from Guadalupe Peak in Texas to Carlsbad, N. Mex. East of Carlsbad the reef is overlain by rocks laid down in the Delaware basin. A generalized geologic map of part of this region is shown in figure 2.

The Capitan Limestone is part of the Guadalupian Series of Permian age, which are the oldest rocks exposed in the area. The Capitan is equivalent in age to the upper part of the Delaware Mountain Group of the Delaware basin and to the upper part of the Artesia Group north of the basin.

The top of the Delaware Mountain Group is approximately 2,800 feet below land surface in the Malaga Bend area and underlies the Ochoan Series in the Delaware basin. The group averages about 3,600 feet in thickness. Using drill-stem tests, less than 10 gal/min of salt or sulfur water were recovered from the upper part of the Delaware Mountain Group in southeastern Eddy County.

The Ochoan Series of Late Permian age is composed predominantly of evaporites and red beds, which are, from oldest to youngest, the Castile, Salado, and Rustler Formations, and the Dewey Lake Red Beds.

The Salado Formation, the oldest unit penetrated in test drilling during this investigation, includes thick beds of halite and anhydrite with lesser amounts of siltstone, sandstone, claystone, and potassium minerals. According to Lang (1938, p. 81), the Salado has a maximum thickness of 1,000 to 1,500 feet in the eastern part of the Delaware basin. As determined from oil-test wells, the Salado is about 600 feet thick in the Malaga Bend area. Small amounts of connate brine have been reported in the upper part of the formation in potash mines. Porosity and permeability of the remainder of the Salado are so low that the unit is generally considered dry. In places, solution at the top of the formation and the hydration of anhydrite to gypsum have resulted in formation of a residuum just above the top of the salt. In this report the residuum is placed in the basal Rustler Formation.

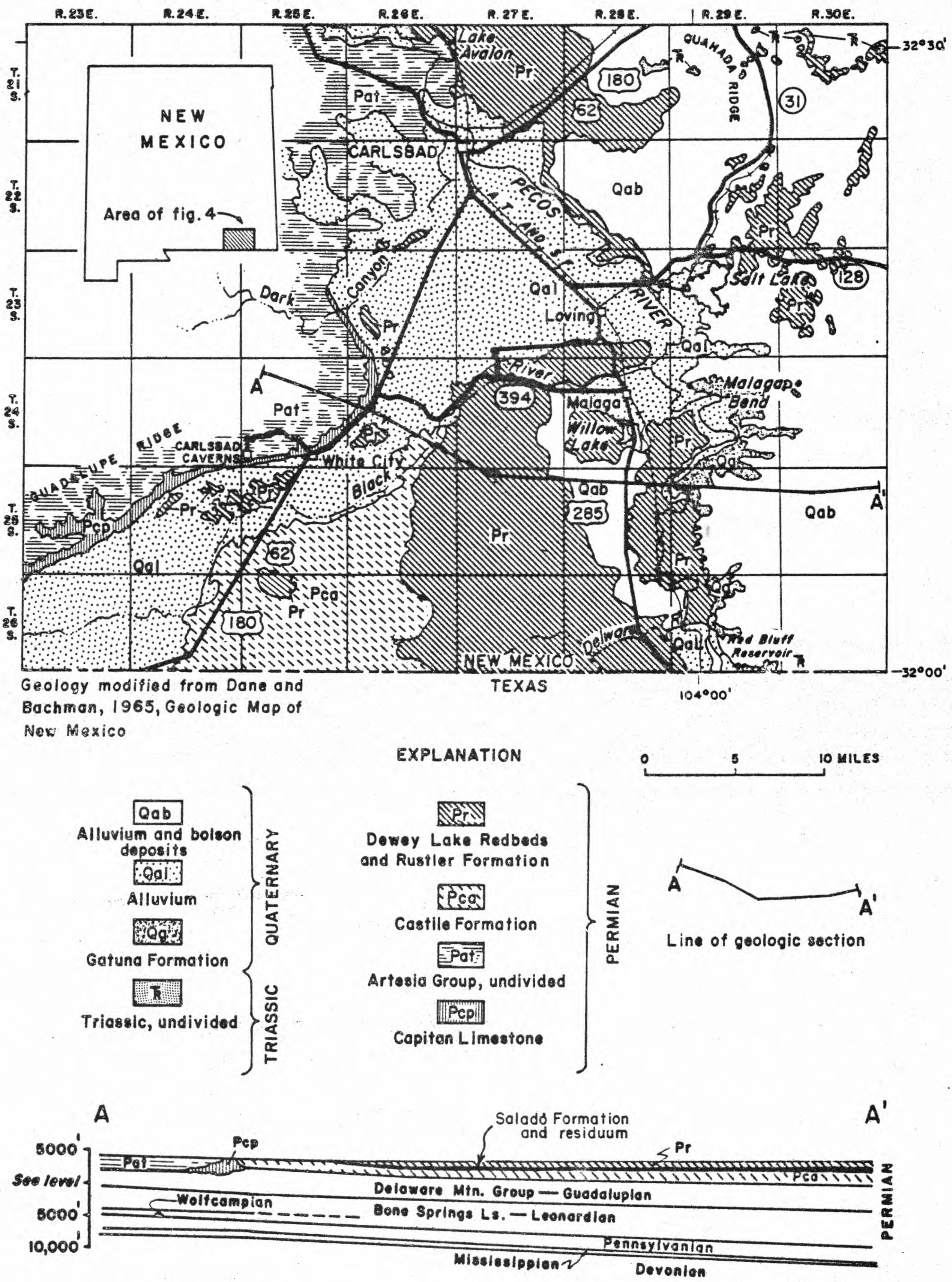


Figure 2 --Generalized geologic map of southeastern Eddy County, and generalized geologic section A-A'.

In New Mexico the Rustler Formation is composed principally of gypsum, anhydrite, salt, siltstone, sandstone, and minor amounts of clay and dolomite. A persistent dolomite (the Culebra Dolomite Member) is exposed in the Malaga Bend area where it is about 40 feet thick. In the Pecos River Valley and the area to the west, most of the Rustler above the Culebra Dolomite Member has been removed by erosion.

In general, the Rustler Formation yields small quantities of water to wells in the Malaga Bend area. Although a large part of the formation consists of soluble gypsum, the relatively impermeable clay and siltstone restrict the circulation of water through the soluble rocks. The residuum in the basal part of the Rustler Formation is a result of solution in beds near the salt contact in the Nash Draw and Malaga Bend areas. Ground water which moves from the northern part of Nash Draw in this highly permeable zone becomes saturated with sodium chloride. Water in this brine aquifer has sufficient head to enter the alluvial fill at Malaga Bend and discharge into the Pecos River. Small to moderate quantities of poor-quality water are available locally to wells from solution channels in the dolomite members, notably the Culebra.

The alluvium consists of sand, gravel, silt, and clay in the Malaga Bend area; it generally ranges from 50 to 100 feet in thickness, but is about 170 feet thick at well USGS 8 (Hale, and others, 1954, fig. 3). Quaternary alluvium and windblown sand are at the surface of most of the Pecos River Valley in the Malaga Bend.

Hydrology

Two principal aquifer systems are present in the Malaga Bend area: (1) the brine aquifer in the basal part of the Rustler Formation, and (2) shallow aquifers in the Culebra Dolomite Member of the Rustler Formation and alluvium.

The chemical quality of ground water in the Malaga Bend area ranges from brine in the aquifer of the basal Rustler Formation to saline water in the shallow aquifers. For the purposes of this report, water containing more than 35,000 mg/L (milligrams per liter) dissolved solids is considered "brine"; water with less than 1,000 mg/L is "fresh"; and water from 1,000 to 35,000 mg/L is "saline."

Brine aquifer

The source of brine discharged to the Pecos River in the Malaga Bend area is the artesian brine aquifer in the basal part of the Rustler Formation. This aquifer discharges about 0.4 ft^3/s (or about 200 gal/min) of brine into the river in the Malaga Bend area (Hale and others, 1954, p. 15). The brine aquifer underlies Nash Draw and the Malaga Bend, Queen Lake, and Willow Lake areas (fig. 3).

Saline water was encountered in test wells drilled in support of Project Gnome about 8 miles east-northeast of Malaga Bend. In USGS test hole 2, located in sec. 4, T. 24 S., R. 30 E., saline water containing 10,800 mg/L of chloride was found at a depth of 453 to 583 feet between the Culebra Dolomite Member of the Rustler Formation and the top of the halite in the Salado Formation (Cooper, 1962a, p. 117). USGS test hole 5, located in sec. 33, T. 23 S., R. 30 E., encountered water "in the rocks directly above the top of the Salado salt at a depth of about 685 feet" (Cooper, 1962a, p. 121).

Wells in the project area which have penetrated halite of the Salado Formation are wells USGS 1 (24S.29E.16.311), USGS 2 (24S.28E.24.211), USGS 3 (24S.29E.8.111), USGS 7 (24S.29E.16.314), USGS 8 (24S.29E.16.133), and USGS 11 (24S.29E.17.444). Because these wells are in the brine aquifer, the water is nearly saturated with sodium chloride. To compare altitudes of the potentiometric surface in wells in the brine aquifer, water-level measurements in this report are corrected to a specific gravity of 1.2. Robinson and Lang (1938, fig. 2) corrected their water-level data to the same specific gravity and concluded that the hydraulic gradient in the brine aquifer was southward from the upper end of Nash Draw, and the heads were lowest at discharge points in Malaga Bend. Hale and others, (1954, p. 23) stated that Malaga Bend was the only known discharge area of the brine aquifer.

Water in the brine aquifer ranges in quality from nearly saturated brine at well USGS 8 with chloride and sulfate concentrations of 187,000 mg/L and 13,100 mg/L respectively and a density of 1.209 g/mL (grams per milliliter), to brine containing 125,000 mg/L chloride and 10,000 mg/L sulfate with a density of 1.142 g/mL at well USGS 12 (24S.29E.30.421).

Transmissivity (the volume of water, in cubic feet per day, that will flow through an aquifer section 1 foot wide and the full thickness of the aquifer under a hydraulic gradient of 100 percent) was estimated as about 8,000 ft^2/d using drawdown in well USGS 11 and about 12,000 ft^2/d using drawdown in well USGS 2 for the first 120 days of pumping well USGS 8. The storage coefficient (the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head) appears to be about 1×10^{-4}.

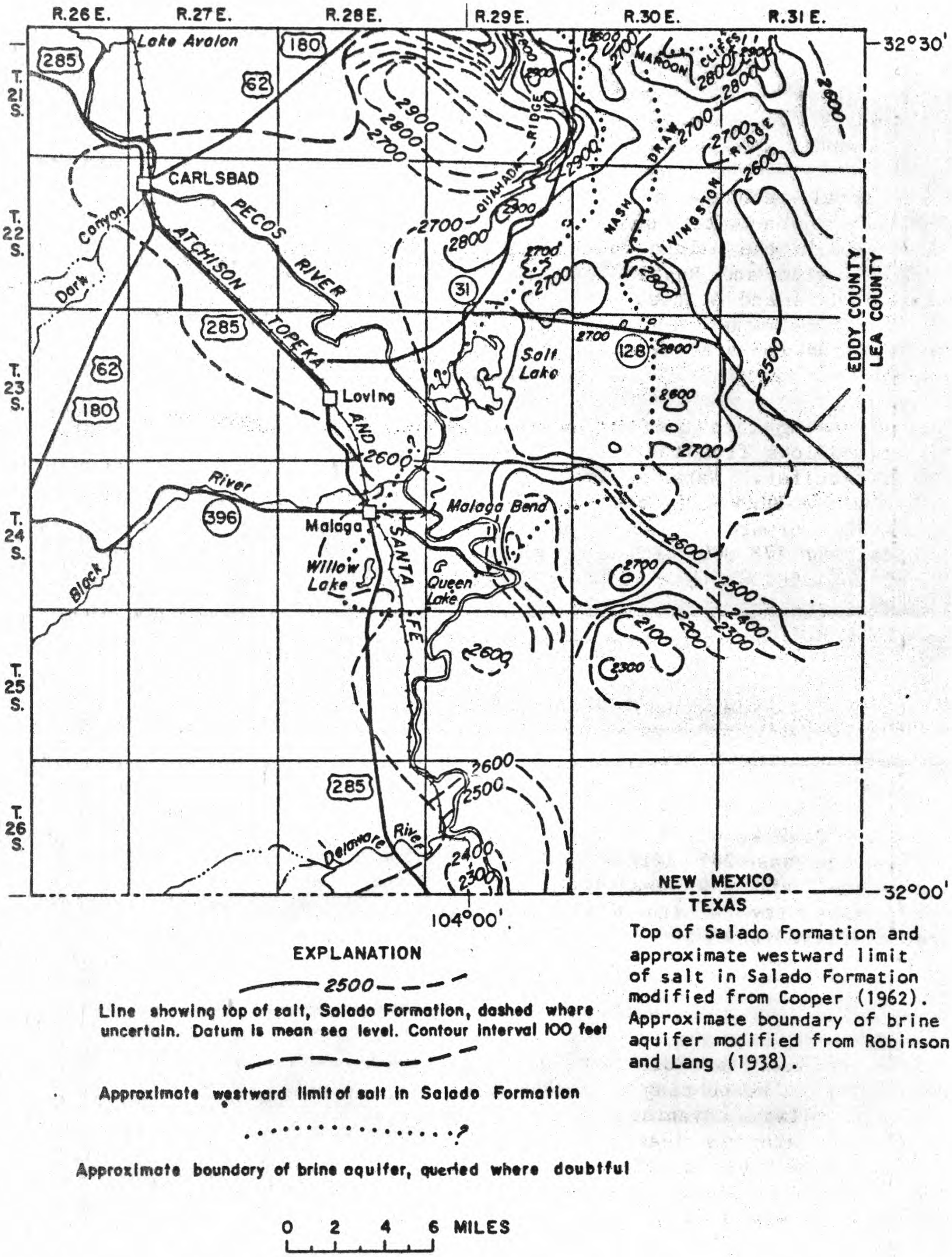


Figure 3.--Top of the salt in the Salado and Castile Formations and known extent of the brine aquifer.

Shallow aquifers

Local recharge and geologic conditions seem to be the major influences on water quality in the shallow aquifers. Water-table contours in the Malaga Bend area indicate that, in general, water in the alluvium and Rustler Formation moves eastward toward the Pecos River (Hale and others, 1954, plate 2) with some minor modifications by local recharge. Shallow ground water in the Malaga Bend area is a mixture of recharge from precipitation, return irrigation water from applied river water, and ground water moving into the area from outside the bend. This last classification includes shallow ground water moving into the area from the west or southwest, infiltration of floodflows from the Pecos River, and brine moving upward from the brine aquifer. Water in some wells tapping the shallow aquifers in the Malaga Bend area contains large amounts of chloride, indicating possible upward brine leakage. Well 24S.29E.20.134 has water containing 178,000 mg/L chloride with a density of 1.201 g/mL, and well 24S.29E.20.141 contains 183,000 mg/L chloride with a density of 1.201 g/mL.

Well USGS 14 (24S.29E.30.421a), which taps the collapsed breccia of the Rustler Formation in the Queen Lake area, was pumped for 24 hours on December 9-10, 1958, at about 90 gal/min. The transmissivity of this aquifer, based on calculations from recovery data in the pumped well, was about 2,800 ft^2/d.

An aquifer test was made January 15, 1959, using well 24S.28E.36.224, which was finished in the alluvium. The average pump discharge was 265 gal/min during the 13.5-hour test. Other wells were not affected measurably by the pumping of this well. The transmissivity of the alluvium at this site was calculated to be about 21,400 ft^2/d.

CONSTRUCTION AND INSTRUMENTATION

The most feasible method of reducing brine inflow to the river appeared to be pumping from the basal brine aquifer (Hale and others, 1954). Two advantages of pumping from this aquifer are: (1) Freshwater is less likely to be drawn into the system from the alluvium and (2) as the aquifer has a high transmissivity and small storage coefficient, pumping one well should lower the head in the basal brine aquifer below the elevation of the riverbed in the Malaga Bend area.

The Northeast Depression (fig. 1) was chosen by the Pecos River Commission for disposal of brine pumped from well USGS 8. The brine pumped from the well was stored in the depression forming a small lake.

Well construction and brine-disposal system

Well USGS 8, drilled in 1939, was the only existing well finished in the brine aquifer which was capable of producing sufficient brine to reduce the head in the aquifer. The first contract let for the construction of brine pumpage and disposal works at Malaga Bend involved reworking the well. The casing was pulled and the hole reamed to a diameter of 16 inches to the top of the brine aquifer at a depth of 195 feet. Twelve-inch diameter plastic casing was cemented in the hole and the hole was drilled 11 inches in diameter below the casing to a depth of 223 feet. An 8-inch diameter steel pipe about 43 feet long with the bottom 20 feet slotted with 1/4-inch by 4-inch slots was placed in the bottom as a liner. Gravel was placed between the liner and the walls of the hole. During a 24-hour test, the well yielded 600 gal/min of brine with a drawdown of about 42 feet.

The second contract involved well protection and the brine-disposal system. This included: (1) an embankment to raise the land surface at the production well even with the nearby terrace to protect the well from large floods in the Pecos River, (2) furnishing and installing a pump, pumphouse, and brine meter, (3) installing an 8-inch asbestos-cement pipeline from the well to the brine-disposal area (the Northeast Depression), and (4) drilling and casing ten observation wells around the depression.

The pipeline extends 10,456 feet from the pumphouse to the venting structure at the edge of the Northeast Depression. The venting structure is an open, concrete box at the highest point of the pipeline where gases associated with the brine escape, thus preventing airlock. The pipeline rises about 33 feet throughout its length and is buried at least 2 feet deep. The 8-inch diameter, asbestos-cement pipe has an epoxy coating on the inside, provided at no cost by the manufacturer for experimental purposes. The lower end of the pipeline has a drainage valve. A 6-inch diameter, plastic pipe extends from the venting structure to the Northeast Depression. This pipe lies on or just below ground surface, and lengths can be removed as the depression fills.

Observation wells were drilled near the Northeast Depression to obtain water-level and quality-of-water data used in evaluating the effectiveness of the depression as a brine-disposal area. Some wells drilled in the Queen Lake area prior to 1962 are included in the observation network. The new wells were drilled to a depth 20 feet below the top of the water-bearing zone. They were cased with 2-inch diameter, plastic casing slotted opposite the water-bearing zone and gravel packed. That part of the casing above land surface is steel pipe. Two additional wells (24S.29E.20.141 and 24S.29E.20.122) and one replacement well (24S.29E.20.432a) were drilled in April 1967 to provide added control points. The locations of observation wells used in this study are shown in figure 4. Table 1 gives information on selected wells in the Malaga Bend area.

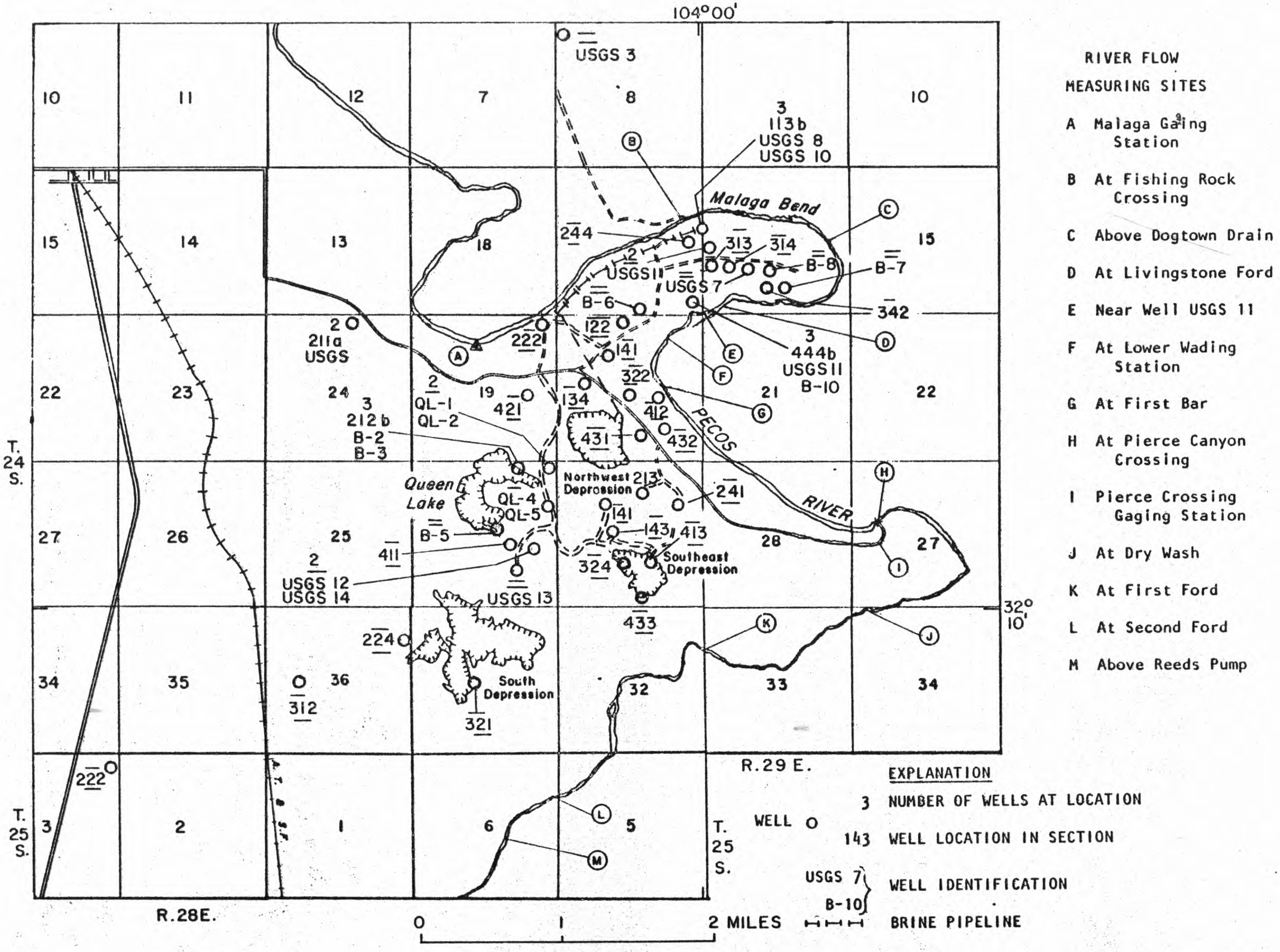


Figure 4.--Well locations and surface-water measuring stations on the Pecos River near Malaga Bend.

Table 1.--Well data for the Malaga Bend area

[Well number: See explanation of well numbering system in text; Well identification: USGS 8, U.S. Geological Survey well No. 8; B-8, Borehole No. 8; QL-1, Queen Lake test well No 1.]

Well number	Well identification	Well depth (feet below land surface)	Perforated interval (feet below land surface)	Remarks
24S.28E.24.211	USGS 2	286	-	Cased to 275 ft
24.211a	-	50	-	-
36.224	-	53	-	Finished in alluvium
36.312	-	70	-	-
24S.29E.08.111	USGS 3	376	-	-
16.133	USGS 8	223	203-223	Finished in brine aquifer
16.133a	USGS 10	160	-	Finished in alluvium
16.133b	-	12	12	-
16.311	USGS 1	240	-	-
16.311b	B-6a	22	22	Finished in alluvium
16.313	-	22	-	-
16.314	USGS 7	230	-	-
16.323a	-	218	-	-
16.324	B-8	-	-	Finished in alluvium
16.342	-	9	-	-
16.431	B-7	8	8	-
16.431a	-	5	-	-
17.244	-	-	-	Finished in alluvium
17.444	USGS 11	246	-	-
17.444a	B-10	14	14	-
17.444b	-	5	-	-
19.222	-	58	-	-
19.421	-	-	16-72	-
20.122	-	-	77-97	-
20.134	-	-	46-92	-
20.141	-	-	150-165	-
20.322	-	-	62-80	-
20.412	-	-	72-102	-
20.431	-	-	54-84	-
20.432	-	-	27-61	-
20.432a	-	-	109-143	Replaced 20.432

Table 1.--Well data for the Malaga Bend area - Concluded

Well number	Well identification	Well depth (feet below land surface)	Perforated interval (feet below land surface)	Remarks
24S.29E.29.141	-	-	54-90	-
29.143	-	-	33-62	-
29.213	-	-	62-101	-
29.241	-	-	56-115	-
29.314	-	-	-	Yates test hole
29.324	-	15	-	Reported depth
29.413	-	24	8-18	Finished in alluvium
29.433	-	24	9-19	Finished in alluvium
30.212a	B-3	17	-	-
30.212b	-	10	-	-
30.213	B-2	10	-	-
30.222	QL-1	33	24-29	-
30.222a	QL-2	28	22-27	-
30.233	B-5	11	-	-
30.242	QL-3	33	20-26	-
30.242a	QL-4	26	20-26	-
30.411	QL-9	15	10-15	Finished in alluvium
30.421	USGS 12	380	271-302	-
30.421a	USGS 14	156	127-148	-
30.414	USGS 13	65	43-65	Finished in Culebra Dolomite Member of Rustler Formation
31.321	-	13	-	-
25S.28E.13.111	USGS 9	173	-	-

The third contract involved clearing and compacting the floor and lower slopes of the Northeast Depression plus fencing the area. Lack of funds would not permit clearing or compacting more than the bottom 52.5 acres of the depression (to altitude 2,938 feet). After the bottom area was cleared and plowed to a depth of 18 inches, brine was used to bring the soil to optimum moisture content. The upper 18 inches of soil was compacted to at least 98 percent of maximum density using a vibrating roller. The Bureau of Reclamation established a grid system in the depression and determined the locations and altitudes of the observation wells.

Instrumentation

Climatological observations

To evaluate climatological parameters in the Malaga Bend area, a weather station was set up near well 24S.29E.19.421. Other climatological data were collected for inflow-outflow determinations for the Northeast Depression. The station is in a slight depression comparable with the Northeast Depression in altitude and exposure to prevailing winds. Instrumentation included a recording rain gage, a wedge-type rain gage, an anemometer, a hydrothermograph, a maximum-minimum thermometer (installed in a standard Weather Bureau instrument shelter), and a recording evaporation pan. A wedge-type rain gage was installed on a staff gage in the Northeast Depression about 4 1/2 feet above land surface, and an additional wedge gage was attached to the recorder shelter at well USGS 10 about 100 yards east of well USGS 8.

Average climatological readings

At Malaga Bend the following were average readings from July 1963 to August or September 1968:

Air temperature, in °C ----------------------------------	17
Relative humidity, in percent ----------------------------	52
Wind speed, in miles per hour ---------------------------	2.6
Temperature, water surface in evaporation pan, °C, from December 1965 to September 1968 ------------------	21

Monthly and yearly average temperature, relative humidity, and wind speed are given in table 2.

Table 2.--Monthly and yearly average air temperature, relative humidity, and wind speed at Malaga Bend weather station

Year	1963			1964			1965			1966			1967			1968			Monthly average (period of record)		
Month	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)	Temperature (°C)	Relative humidity (percent)	Wind (average miles per hour)
January	–	–	–	5	39	2.6	8	51	2.4	2	64	2.0	6	43	2.1	7	74	2.0	6	54	2.2
February	–	–	–	4	49	2.9	6	58	2.9	4	56	3.0	7	37	2.4	8	76	2.1	6	55	2.7
March	–	–	–	12	30	3.9	9	48	3.1	12	43	2.4	16	37	2.6	11	69	2.5	12	45	2.9
April	–	–	–	17	24	3.8	19	34	3.4	17	47	3.2	20	34	3.4	16	53	3.2	18	38	3.4
May	–	–	–	23	36	4.1	22	50	3.8	21	57	3.2	21	32	3.2	21	52	2.5	22	45	3.4
June	–	–	–	26	42	3.5	27	53	4.1	25	60	3.4	27	56	3.0	27	42	2.6	26	51	3.3
July	–	–	–	29	40	3.5	28	46	3.1	29	41	2.9	27	62	2.6	27	60	2.5	28	50	2.9
August	27	49	2.7	29	46	2.9	25	60	2.4	24	62	2.4	24	62	2.5	26	65	2.2	26	57	2.5
September	23	57	2.3	24	64	2.7	23	54	2.8	23	67	1.7	22	68	2.2	22	62	–	23	62	2.3
October	19	51	2.0	17	55	1.8	17	49	1.9	16	52	1.9	16	61	1.9	–	–	–	17	54	1.9
November	11	49	2.4	10	53	2.5	13	56	1.7	12	52	1.6	12	62	2.2	–	–	–	12	54	2.1
December	4	64	2.0	7	56	2.4	11	69	1.9	5	52	2.0	4	65	2.4	–	–	–	6	51	2.1
Yearly average	–	–	–	17	44	3.0	17	52	2.8	16	54	2.5	17	52	2.5	–	–	–	17	52	2.6

Evaporation

The evaporation pan at the weather station was a standard-size class "A" land pan connected by a 1-inch, galvanized pipe to a covered reservoir tank (the closed pan). The open pan was exposed in the center of the weather station according to Weather Bureau instructions. Both pans were set on platforms to allow free air circulation. No dense shadows fell on the open pan.

The closed pan was filled with water taken from well 24S.29E.19.421 (a few feet from the pan), or with brine being pumped to the Northeast Depression, or with freshwater brought from Carlsbad. Evaporation was from a saturated brine and during times of greatest evaporation, a substantial accumulation of salt built up in the bottom of the open pan. As the reservoir tank had twice the capacity of the open pan, all readings were multiplied by three to obtain net evaporation.

A recorder set above the closed pan recorded water levels to the nearest 0.01 foot. Water-level readings in the open pan seldom agreed with the recorder; the difference in readings was proportioned throughout the week. Density differences between water in the open and closed pans may account for some of the error.

Water temperatures in the evaporation pan and at the lake surface were read weekly with a mercury thermometer held parallel to and as near the water surface as possible and shaded from direct sunlight.

Lake stage

A lake-stage recorder installed in February 1966 at the Northeast Depression gave a daily record of gage height. The recorder was checked using the nearby east staff gage. The recorder was mounted on a 55-gallon barrel which was bolted to stakes driven into the floor of the depression. Runoff from storms could be determined from this gage.

Two sets of staff gages were used in the Northeast Depression. Each 3 1/3-foot section of gage was mounted on iron pipe set in concrete. Zero on the series was at altitude 2,920.68 feet msl (mean sea level) which was very near the low point of the depression. Successive pairs of gages were set east and west up the slopes from the center of the depression.

BRINE-AQUIFER PUMPING

Pumping operations

A 40-horsepower, 5-inch, submersible pump, capable of pumping 450 gal/min of water against a head of 160 feet and constructed of corrosion-resistant alloys, was installed in the well initially. The pump was set at a depth of 175 feet below land surface. The submersible pump failed in April 1964, apparently due to failure of the packing around the power supply to the motor. A standard irrigation pump was installed as a replacement.

After 1 year of operation, the standard irrigation pump showed no signs of corrosion or electrolysis on any part of the impellers or pump column. Most surfaces were still protected by their original paint. The exposed metal surfaces of the bowls and impellers were covered by a thin, reddish-black coating that resembled copper oxide.

The meter on the pump discharge line was a 6-inch Sparling salt-water type. The original discharge indicator and a replacement meter head oscillated, and therefore were not dependable. In August 1964 the meter failed completely and was returned to the factory for repair. A new meter was installed in January 1965. Checks of the metered discharge by measurement at the end of the pipeline indicate agreement within ± 5 percent.

Changes in water levels

Change in brine-aquifer water levels as a result of pumping well USGS 8 on an almost continuous basis from July 1963 through December 1968 are shown for wells USGS 11 and 2 in figures 5 and 6, respectively. Total pumpage from well USGS 8 from July 1963 through July 1968 was about 3,575 acre-feet. Water-table contours at the end of five years of pumping (fig. 7) show a cone of depression in the brine aquifer around well USGS 8.

In November 1962, a year before pumping began from well USGS 8, the water level in well USGS 11 was at an elevation of 2,900.8 feet. At that time, the approximate elevation of the riverbed near well USGS 11 sampling site was 2,889.7 feet, which was more than 11 feet below the static head of the brine aquifer. Before the August 1966 flood the elevation of the brine surface in well USGS 11 was 2,889.9 feet, only 0.2 feet above the riverbed.

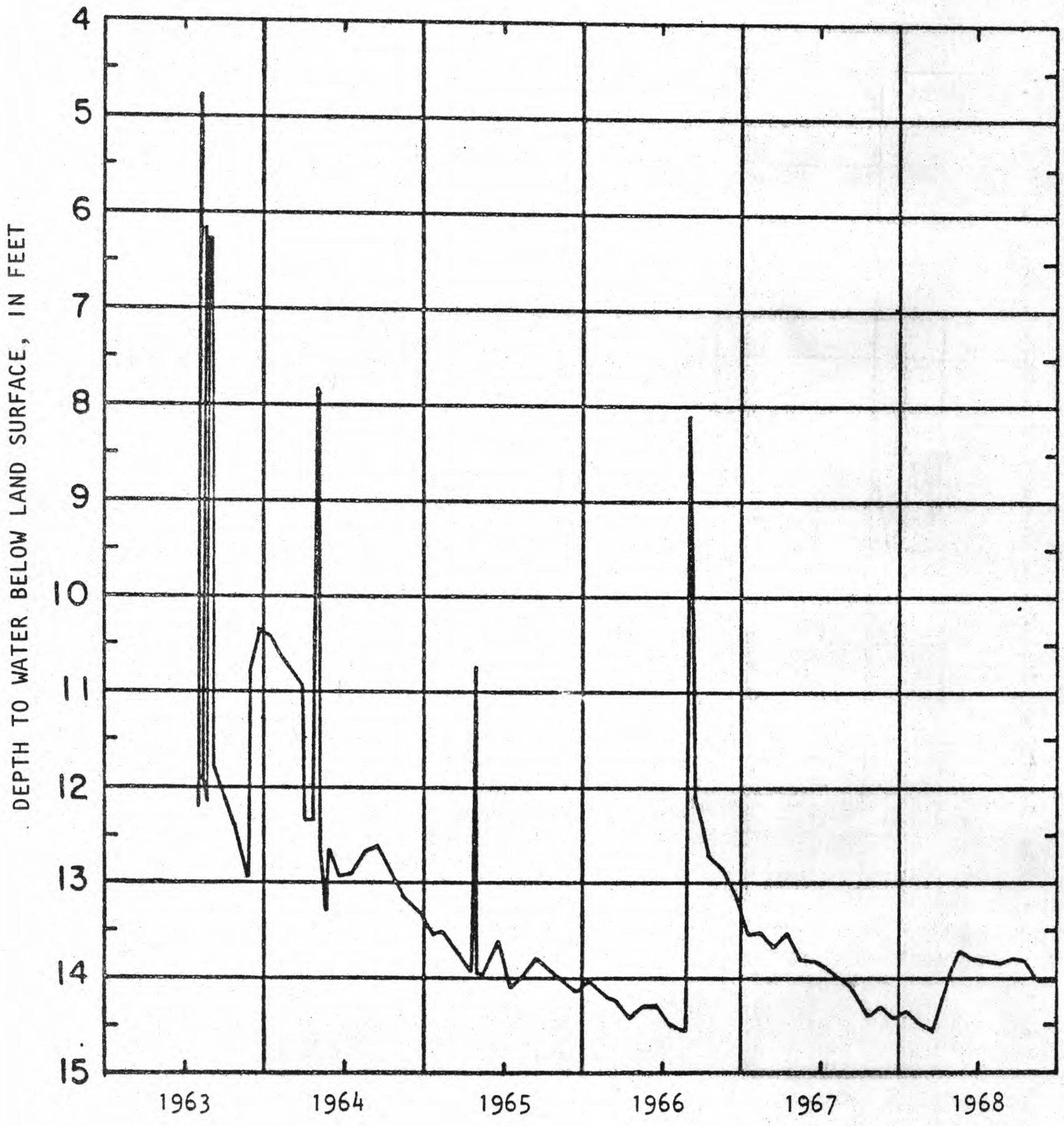


Figure 5.--Hydrograph of water levels in well USGS 11 (24S.29E.17.444) from July 1963 - December 1968.

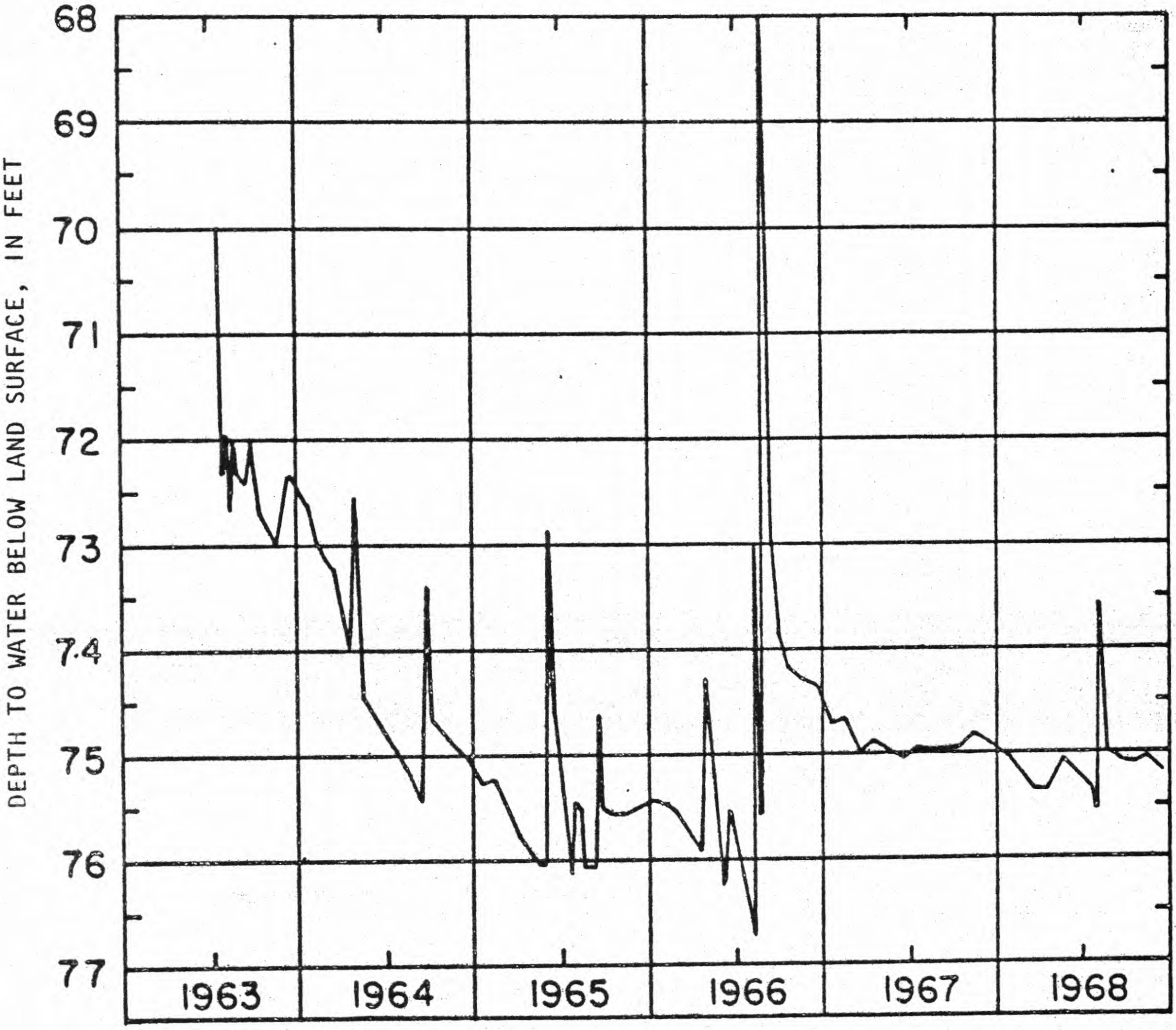


Figure 6.--Hydrograph of water levels in well USGS 2 (deep)(24S.28E.24.211) from July 1963 - December 1968.

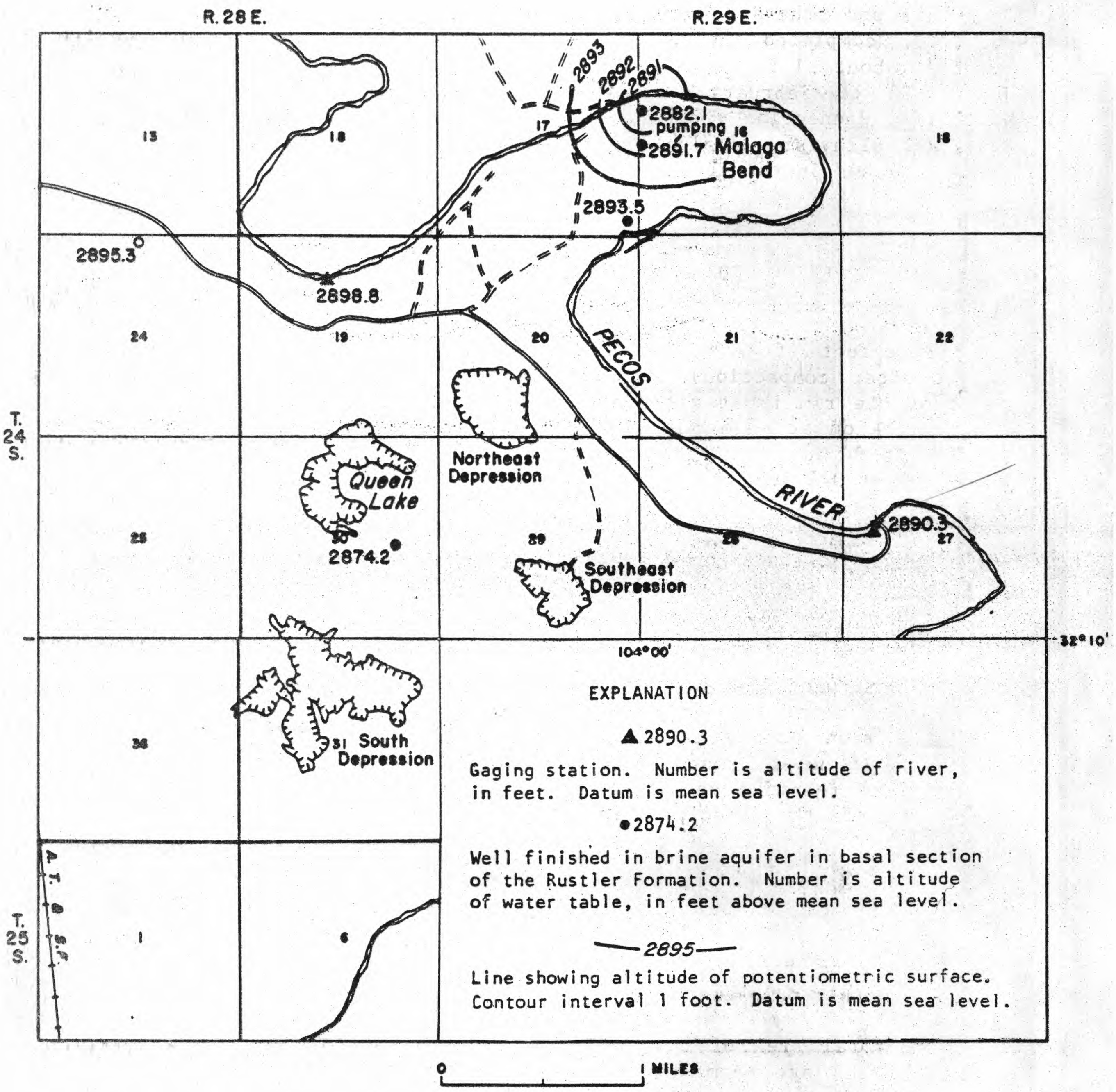


Figure 7.--Computed altitude of the potentiometric surface of the brine aquifer in the Malaga Bend area, July 1968, corrected to 1.2 density.

Hale and others (1954, p. 31) reported that the water level in USGS 10, completed in alluvium about 200 feet from USGS 8, was lowered about 1 foot while pumping USGS 8 at 310 gal/min from January 28 to February 25, 1954. This shows there is very poor hydraulic connection between the basal brine aquifer and the overlying alluvium. Insignificant water-level declines were noted in wells finished in the alluvium as a result of pumping USGS 8.

BRINE STORAGE IN THE NORTHEAST DEPRESSION

The Northeast Depression has a storage capacity of 1,300 acre-feet (fig. 8). The bottom of the depression ("0" gage height after compaction) is at altitude 2,928.7 feet, and the low point on the rim is at altitude 2,952.0 feet. Brine will spill from the depression at gage height 23.3 feet. The maximum area for brine storage is 94 acres. The bottom 52.5 acres, to altitude 2,938.0 feet (gage height 9.3 feet), has been cleared and compacted.

Precipitation of salt in the depression

Crystalline halite precipitated rapidly from brine pumped into the Northeast Depression. Thin rafts of salt formed on the surface of the lake when the water was calm; through wave action the salt accumulated along the lake shore forming a "salt sand." The salt sand was soon partly cemented together by precipitation of other salt, but it never created a seal on the depression floor. As long as the lake remained saturated, salt continued to precipitate. The thickness of the precipitated salt in March 1968 is shown in figure 9.

Inflow

Inflow to the Northeast Depression is dominantly from pumped brine. Monthly pumpage to the depression is given in table 6.

The total area of the depression watershed is about 170 acres. Of this, the lake normally occupies about 65 acres leaving slightly more than 100 acres which may contribute runoff to the depression. Inflow from runoff is influenced by amount, intensity, and duration of rainfall; soil moisture; and slope and roughness of the depression sides; runoff from any particular storm could only be estimated. Precipitation data are given in table 3.

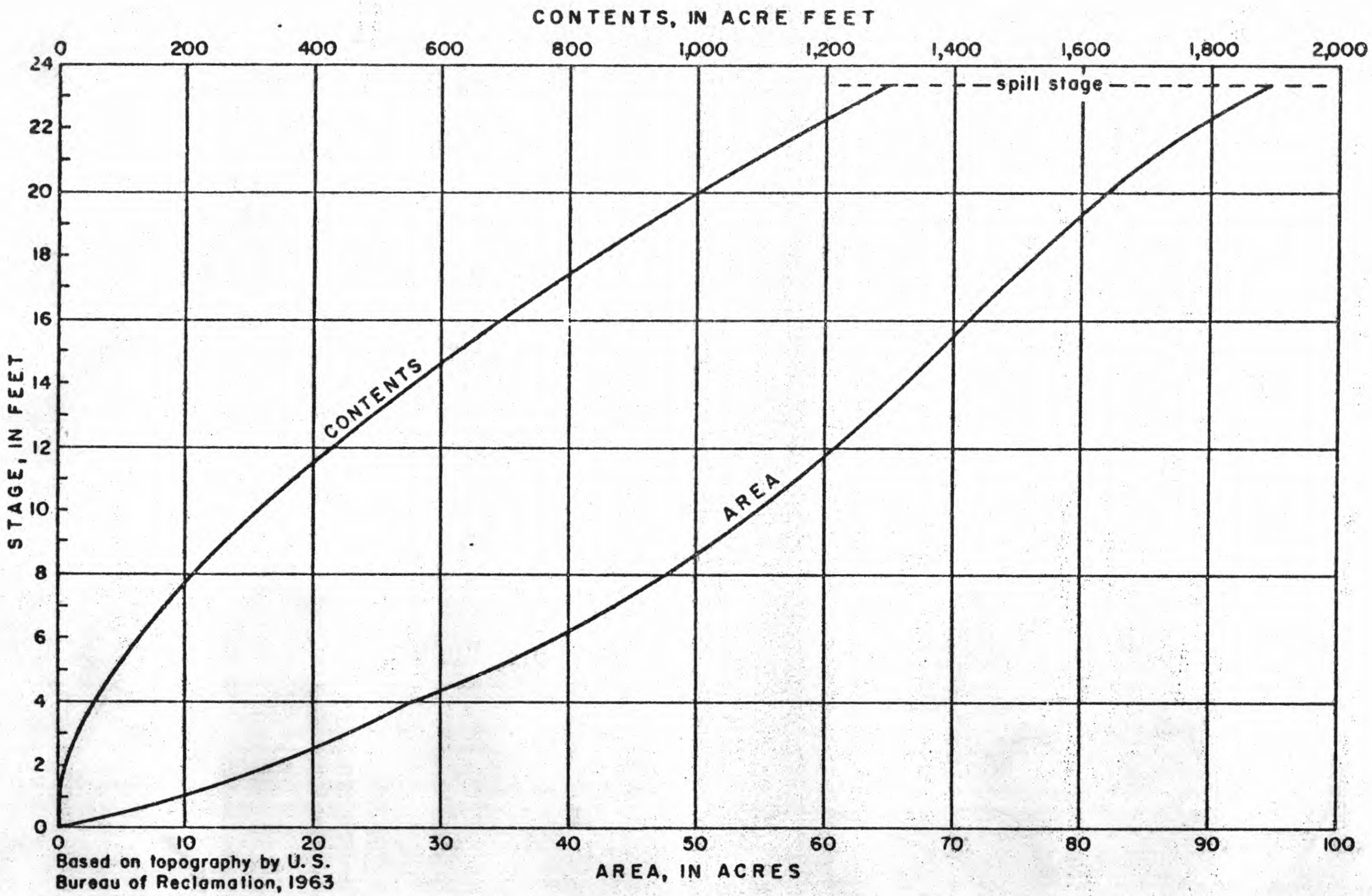
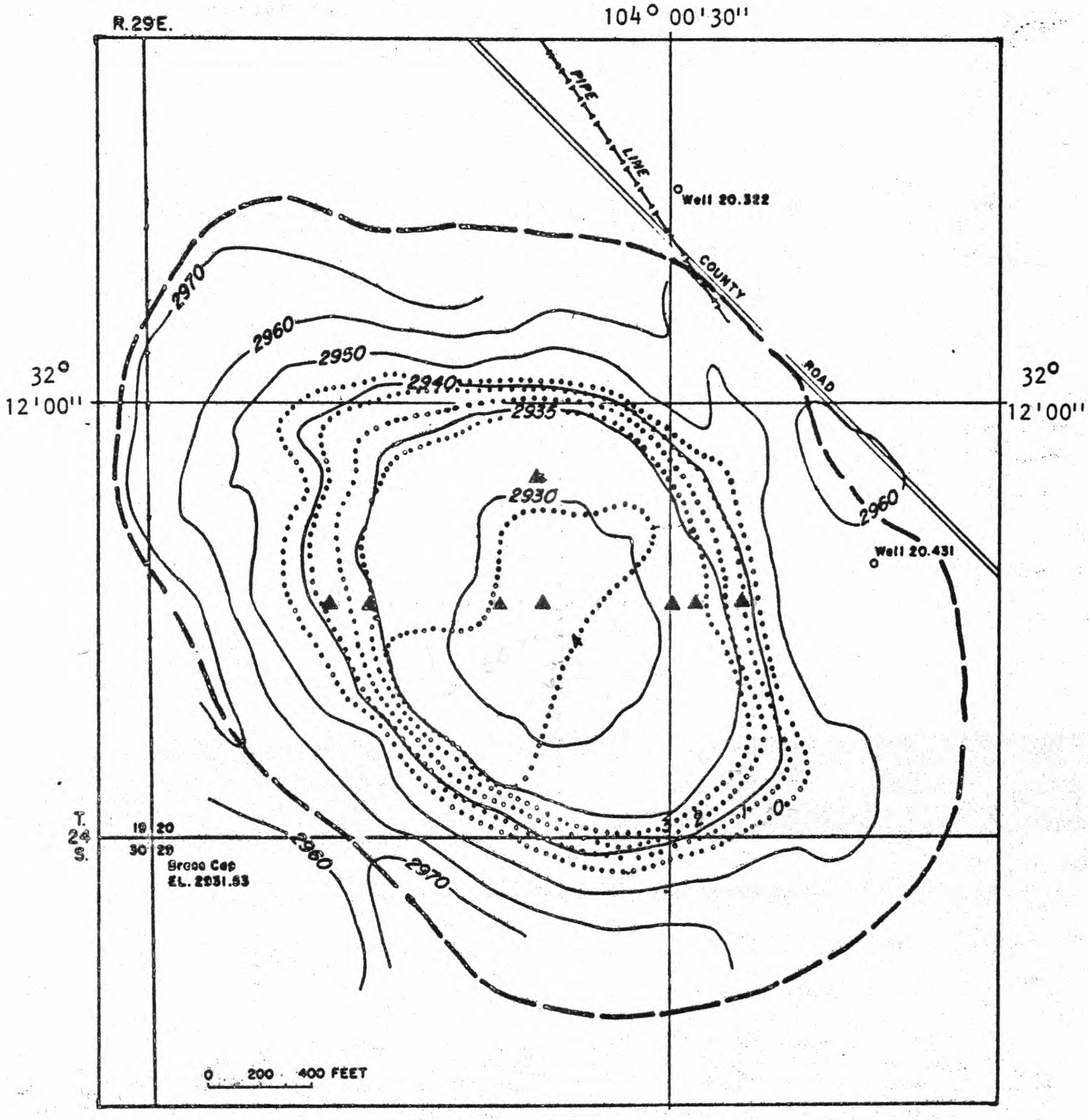


Figure 8.--Area-contents curves, Northeast Depression.



EXPLANATION

Staff gage

2930

Line showing altitude of the surface of depression. Datum is mean sea level. Interval 10 and 5 feet.

2

Line showing thickness of salt. Interval 1 foot.

Approximate drainage boundary of depression

Figure 9.--Thickness of salt in the Northeast Depression, March 26, 1968.

Lining at elev. 2938
20.68
Bottom of Anderson 2928.7

Table 3.--Monthly precipitation in the Malaga Bend area

[All values reported in feet; Tr means trace]

Year	1963			1964			1965			1966			1967			1968		
Month	Weather station	Northeast Depression	Well USGS 8	Weather station	Northeast Depression	Well USGS 8	Weather station	Northeast Depression	Well USGS 8	Weather station	Northeast Depression	Wells USGS 8 and 10	Weather station	Northeast Depression	Well USGS 10	Weather station	Northeast Depression	Well USGS 10
January	-	-	-	Tr	Tr	0	Tr	0	0	0.034	0.027	0.029	0	0	0	0.099	0.076	0.078
February	-	-	-	0.002	0	0.001	0.021	0.012	0.024	0	0	0	0.009	0.005	0.001	.062	.053	.060
March	-	-	-	.053	0.053	.046	.002	.002	.002	.026	.024	.054*	.003	.005	.012	.123	.119	.115
April	-	-	-	0	0	0	.008	.011	0	.162	.114	.128	.004	.006	.006	.006	.006	.005
May	-	-	-	.056	.016	.029	.172	.128	.114	.027	.028	.012	.023	.028	.031	.148	.104	.102
June	-	-	-	.048	.079	-	.077	.078	.103	.263	.301	.271	.324	.230**	.248**	.007	0	0
July	-	-	-	.021	0	-	.186	.163	.205	.006	0	0	.068	.048	.048	.276	.235	.265
August	0.141	0.092	0.100	.039	.041	.039	.045	.055	.048	.544	.433	.439	.079	-	.072	.141	-	.208
September	.083	.053	.039	.234	.170	.155	.093	.078	.092	.062	.055	.084	.046	-	.031	-	-	-
October	.009	.003	.018	.010	.008	Tr	0	0	0	.007	.004	.002	0	0	0	-	-	-
November	.002	.002	.004	.002	0	.004	.023	.025	.015	0	0	0	.026	.027	.025	-	-	-
December	.022	.024	.022	.008	.008	.008	.031	.030	.032	0	0	0	.054	.019	.017**	-	-	-
Yearly total	-	-	-	0.473	0.375		0.658	0.582	0.635	1.131	0.986	1.019	0.636	-	-	-	-	-

Tr - Trace
* - Moved gage 100 yards northeast to Well USGS 10; exposure similar
** - Partial record

The brine may have absorbed some water from the atmosphere. During a survey of the salinity and of the thickness of salt crust in January 1965, specific conductances as low as 173,000 micromhos were measured at the lake surface; specific conductance of the incoming brine was about 229,000 micromhos. There had been no significant precipitation for a month prior to the specific-conductance measurement. It seems reasonable to assume that the lake surface had received moisture from the atmosphere. Analyses of the incoming brine and of the brine in the Northeast Depression in 1964 are given in table 4.

Outflow

Outflow from the Northeast Depression is a result of evaporation, leakage, wetting of the shore by wind and wave action, and capillarity. Wetting of the lakeside sediments probably does not consume any significant percentage of brine; total wetted area would be from two to four additional acres. During the early stages of filling the depression, a greater percentage of water was probably absorbed by the dry lakebed sediments.

Evaporation

Evaporation from a Class A pan can be used to estimate the evaporation from a lake by means of a suitable factor or coefficient. Essentially, the coefficient compensates for the difference in size between the small sample represented by the pan and the relatively large lake. Among the factors influencing the choice of a coefficient are: salinity, temperature of the solutions to be evaporated, air temperature, wind speed, and relative humidity. The factors that appear to have the greatest influence on evaporation in the Malaga Bend area are air and water temperatures, which influence the difference in vapor pressure between air and water. Evaporation is proportional to the difference in vapor pressure of the air contacting the water surface and the air at a greater height above the water (Harbeck, 1955, p. 1).

According to Weather Bureau evaporation maps, the average annual Class A pan evaporation for 1946-55 was about 110 inches, and the coefficient used for correcting this figure to a lake evaporation is about 67 percent (Kohler and others, 1959, pl. 1, 3). This coefficient is for correcting from freshwater pan evaporation to freshwater lake evaporation.

Table 4.--Chemical analyses of water from well USGS 8 and the Northeast Depression

[All concentrations given in mg/L unless otherwise noted]

Location:	Well USGS 8	Northeast Depression, west gage
Date:	1-17-64	5-1-64
Gage height (ft):	-	8.86
Discharge (gal/min):	325	-
Water temp. (°C):	21	19
Constituent		
SiO_2	5.7	15
Al	0.05	-
Fe	0.01	0.01
Mn	0.02	-
Ca	550	436
Mg	2,700	3,540
Na	120,000	119,000
K	4,500	6,300
Li	23	-
HCO_3	102	146
CO_3	0	0
SO_4	13,100	15,300
Cl	187,000	187,000
F	4.4	2.8
Br	58	-
I	1.2	-
NO_3	1.0	41
B	15	19

Table 4.--Chemical analyses of water from well USGS 8 and the Northeast Depression - Concluded

Location:	Well USGS 8	Northeast Depression, west gage
Constituent		
Calculated (dissolved solids)	330,000	331,000
Hardness as $CaCO_3$	12,400	15,500
Noncarbonate hardness	12,300	15,400
Percent sodium	93	92
Sodium adsorption ratio	425	374
Specific conductance (micromhos per centimeter at 25°C)	229,000	228,000
pH	6.7	7.4
Density (g/mL at 20°C)	1.209	1.214

The nearest Class A land pan, other than that set up for this project, is at Lake Avalon about 3 miles north of Carlsbad (fig. 1). A comparison of evaporation from this freshwater pan and the pan at Malaga is shown in table 5. The ratio of evaporation at Malaga to that at Avalon is given as a percentage; an average of each month for a 4- to 6-year period (1963-68) is shown as well as an overall average. For the entire period of record, the average ratio of Malaga evaporation divided by Avalon evaporation is 0.622.

The ratio of Malaga Bend brine-pan evaporation to Lake Avalon freshwater pan evaporation is less than the ratios found by other experimenters. Moore and Runkles (1966, p. 61) arrived at a factor of 0.91 from brine to freshwater evaporation. Differences in exposure, local climatic conditions, elevation, or undiscovered influences may account for this variation.

Kohler and others (1959, pl. 3) give the average annual Class A pan coefficient as 67 percent for the Carlsbad area. Kohler (1954, p. 146), in the Lake Hefner studies, indicated a coefficient of 0.69 for that freshwater lake. The Pecos River Commission uses a coefficient of 0.77. A factor of 0.70 was chosen for this report.

The majority of evaporation from the Northeast Depression is from the lake surface, an area of about 65 acres. However, some evaporation occurs in the 10-15 foot wetted periphery of the lake. The amount of water lost in this zone is unknown.

The pan and the lake (the Northeast Depression) contained saturated solutions of sodium chloride brine. When water is evaporated completely from a unit volume of saturated brine, the volume of the salt residue that remains is about 15 percent. The volume of water evaporated, as water alone, is 88 percent of the unit volume of the brine. The volumes of the salt and water are not additive because the dissolved salt ions occupy space between the water molecules. Thus, for each 88 parts of water evaporated, 15 parts of solids will precipitate; for each 100 parts of water, 17 parts of salt will be deposited. Therefore, the amount of brine evaporation will be 1.17 times the estimated amount of water evaporated. Hence, the following relationships may be used to compute brine evaporation:

1. Freshwater evaporation = 0.70 x pan evaporation x average monthly area of the lake;

2. brine evaporation = 1.17 x freshwater evaporation.

Combining these equations and multiplying the coefficients, we obtain:

3. Brine evaporation = 0.82 x pan evaporation x average monthly area of the lake.

Table 5.--Monthly pan evaporation totals at Malaga Bend and Lake Avalon and ratio of Malaga Bend brine evaporation to Lake Avalon freshwater evaporation

[Evaporation reported in feet]

Year	1963			1964			1965			1966			1967			1968			Average monthly ratio
	EVAPORATION		Ratio	EVAPORATION		Ratio	EVAPORATION		Ratio	EVAPORATION		Ratio	EVAPORATION		Ratio	EVAPORATION		Ratio	
Month	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga	Lake Avalon	Malaga-Lake Avalon	Malaga-Lake Avalon
January	-	-	-	0.297	0.457	0.649	0.369	0.472	0.782	0.148	0.282	0.524	0.300	0.542	0.554	0.078	0.310	0.252	0.552
February	-	-	-	.290	.371	.782	.270	.478	.565	.177	.425	.416	.330	.603	.547	.149	.437	.341	.530
March	-	-	-	.614	.864	.711	.491	.732	.671	.416	.761	.547	.741	.959	.773	.270	.564	.479	.636
April	-	-	-	.978	1.219	.802	.749	1.108	.676	.399	1.052	.379	.721	1.318	.547	.508	1.071	.474	.576
May	-	-	-	.983	1.376	.714	.757	1.193	.635	.495	1.136	.436	.858	1.414	.607	.718	1.182	.607	.600
June	-	-	-	.930	1.431	.650	.779	1.286	.606	.599	1.064	.563	.915	1.278	.716	.877	1.439	.609	.629
July	-	-	-	.966	1.452	.665	.726	1.332	.545	1.146	1.403	.817	.638	1.162	.549	1.029	1.021	1.008	.717
August	0.705	1.146	0.615	.897	1.211	.741	.576	1.048	.550	.832	.895	.930	.610	1.093	.558	.629	.962	.654	.675
September	.533	.772	.690	.678	.808	.839	.441	.878	.502	.524	.620	.845	.457	.751	.609	-	-	-	.697
October	.432	.658	.657	.616	.748	.823	.294	.711	.414	.427	.681	.627	.468	.827	.566	-	-	-	.617
November	.404	.490	.824	.440	.524	.840	.284	.492	.577	.237	-	-	.269	.516	.521	-	-	-	.690
December	.178	.259	.687	.290	.471	.616	.121	.293	.413	.213	.438	.486	.174	-	-	-	-	-	.550
Yearly total	-	-	-	7.979	10.932	-	5.857	10.023	-	5.613	-	-	6.481	-	-	-	-	-	0.622

Table 6 presents the inflow, storage, and outflow relationships in the Northeast Depression from July 1963 through most of 1968. Acre-feet of inflow is the total of pumpage plus rainfall and runoff. Storage is the difference in first-of-the-month capacities in acre-feet. Brine evaporation is determined as described above.

Leakage

Table 6 shows the "other losses," which are probably mostly leakage, from the depression. These values are computed by:

Inflow - change in storage - evaporation = other losses.

For water year 1963-64, approximately the first year of pumping, the estimated loss from the depression was about 24 percent of the total inflow. The loss increased to 47 percent in water year 1965, 53 percent in 1966, 55 percent in 1967, and about 60 percent in 1968. At an average rate of pumping of nearly 2 acre-feet per day (about 1 ft^3/s) this represents a 0.65 ft^3/s loss from the depression in 1968, most of which was brine of the same or slightly higher salinity than brine from USGS 8.

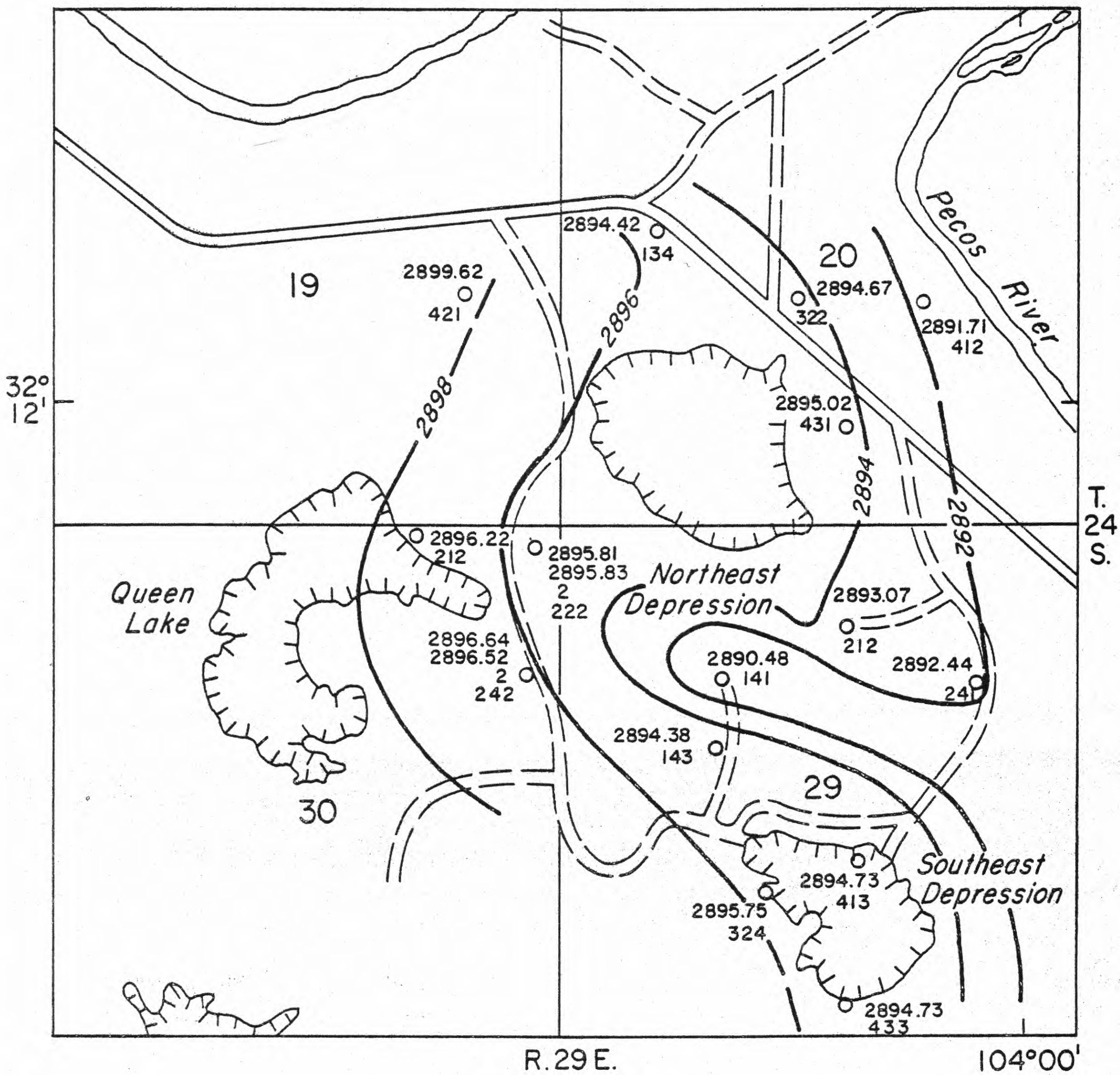
Brine leaking from the Northeast Depression can be detected in observation wells that ring the depression. A rise in the water level or an increase in chloride concentration of water in the wells, or both, may result from leakage from the depression. Figure 10 shows the ground-water level, in 1962, in the shallow aquifer surrounding the Northeast Depression. These contours are based on water-level data that has been corrected for density variations according to Bond (1973, p. 363). In general, the ground-water flow in 1962 was eastward under the Northeast Depression. Figure 11 shows the ground-water contours in 1968. These contours are based on water-level data corrected in the same manner as the 1962 data. The ground-water flow is eastward beneath the depression but the 1968 contours are farther apart west of the depression, and closer together east of the depression. The contour spacing indicates increased eastward ground-water flow east of the depression and a reduced eastward flow west of the depression. The mound of brine beneath and surrounding the area (fig. 12) is responsible for the change in flow from 1962 to 1968. Figure 12 shows a rise in water levels of more than 3 feet south of the depression and at least 1 foot surrounding the depression.

Table 6.--Inflow, storage, evaporation, and other losses, Northeast Depression

Date	INFLOW			STORAGE				
	Pumpage (acre-ft)	Rainfall and runoff (acre-ft)	Total (acre-ft)	Increase (+) or decrease (-) (acre ft)	Pan evaporation (ft)	Average monthly area (acres)	Brine evaporation (acre-ft)	Other losses (acre-ft)
1963								
July	22	0	22	+ 16	0.225	7.8	1	5
Aug.	58	7	65	+ 50	.705	22.1	13	2
Sept.	73	3	76	+ 52	.533	32.8	14	10
Oct.	77	0	77	+ 52	.432	40.0	14	11
Nov.	64	0	64	+ 37	.404	44.6	15	12
Dec.	44	1	45	+ 24	.178	47.4	7	14
1964								
Jan.	44	0	44	+ 19	0.297	49.2	12	13
Feb.	42	0	42	+ 14	.290	50.3	12	16
Mar.	50	4	54	+ 5	.614	51.1	26	23
Apr.	45	0	45	- 7	.978	51.1	41	11
May	67	3	70	+ 16	.983	51.4	41	13
June	61	4	65	+ 5	.930	52.3	40	20
July	63	0	63	+ 4	.966	52.8	42	17
Aug.	62	2	64	+ 14	.897	53.3	39	11
Sept.	61	14	75	+ 33	.678	54.6	30	12
Oct.	63	0	63	+ 13	.616	56.0	28	22
Nov.	61	0	61	+ 17	.440	56.8	20	24
Dec.	63	0	63	+ 23	.290	58.0	14	26
1965								
Jan.	64	0	64	+ 16	0.369	59.1	18	30
Feb.	54	1	55	+ 14	.270	59.9	13	28
Mar.	61	0	61	+ 11	.491	60.5	24	26
Apr.	56	1	57	- 7	.749	60.7	37	27
May	59	12	71	+ 6	.757	60.3	37	28
June	56	6	62	- 11	.779	60.5	39	34
July	61	16	77	+ 4	.726	60.3	36	37
Aug.	60	5	65	- 1	.576	60.2	28	38
Sept.	58	7	65	+ 3	.441	60.4	22	40
Oct.	60	0	60	+ 6	.294	60.7	15	39
Nov.	57	2	59	+ 15	.284	61.2	14	30
Dec.	58	3	61	+ 18	.121	61.9	6	37

Table 6.--Inflow, storage, evaporation, and other losses, Northeast Depression - Concluded

Date	INFLOW: Pumpage (acre-ft)	INFLOW: Rainfall and runoff (acre-ft)	INFLOW: Total (acre-ft)	STORAGE: Increase (+) or decrease (-) (acre ft)	Pan evaporation (ft)	Average monthly area (acres)	Brine evaporation (acre-ft)	Other losses (acre-ft)
Jan.	59	2	61	+ 16	.148	62.6	8	37
Feb.	52	0	52	+ 9	.177	63.1	9	34
Mar.	57	2	59	+ 3	.416	63.4	22	34
Apr.	56	15	71	+ 8	.399	63.5	21	42
May	57	2	59	- 11	.495	63.4	26	44
June	56	31	87	+ 14	.599	63.6	31	42
July	58	0	58	- 23	1.146	63.5	60	21
Aug.	42	54	96	+ 31	.832	63.6	43	22
Sept.	56	6	62	+ 1	.524	64.2	28	33
Oct.	64	0	64	- 1	.427	64.1	22	43
Nov.	62	0	62	+ 15	.237	64.4	13	34
Dec.	64	0	64	+ 13	.213	65.0	11	40
1967								
Jan.	64	0	64	+ 18	.300	65.6	16	30
Feb.	58	0	58	+ 8	.330	66.0	18	32
Mar.	64	0	64	+ 2	.741	66.2	40	22
Apr.	62	0	62	- 15	.721	65.9	39	38
May	63	2	65	- 16	.858	65.4	46	35
June	61	36	97	+ 20	.915	65.4	49	28
July	59	3	62	- 20	.638	65.5	34	48
Aug.	63	6	69	- 9	.610	64.9	32	46
Sept.	60	5	65	0	.457	64.7	24	41
Oct.	63	0	63	- 3	.468	64.7	25	41
Nov.	60	2	62	+ 12	.269	64.8	14	36
Dec.	62	1	63	+ 17	.174	65.4	9	37
1968								
Jan.	62	8	70	+ 25	.078	66.2	4	41
Feb.	58	4	62	+ 11	.149	66.8	8	43
Mar.	62	6	68	+ 11	.270	67.2	15	42
Apr.	60	0	60	- 18	.508	67.0	28	50
May	62	15	77	- 3	.718	66.6	39	41
June	60	0	60	- 32	.877	66.0	47	45
July	62	18	80	- 8	1.029	65.3	55	33
Aug.	62	11	73	+ 5	.629	65.2	34	34
Sept.	60			- 9	.525	65.2	28	-
Oct.	62	0	62	0	.416	65.0	22	40
Nov.	55			+ 16	.201	65.3	11	-
Dec.	62			+ 14	.146	65.8	8	-



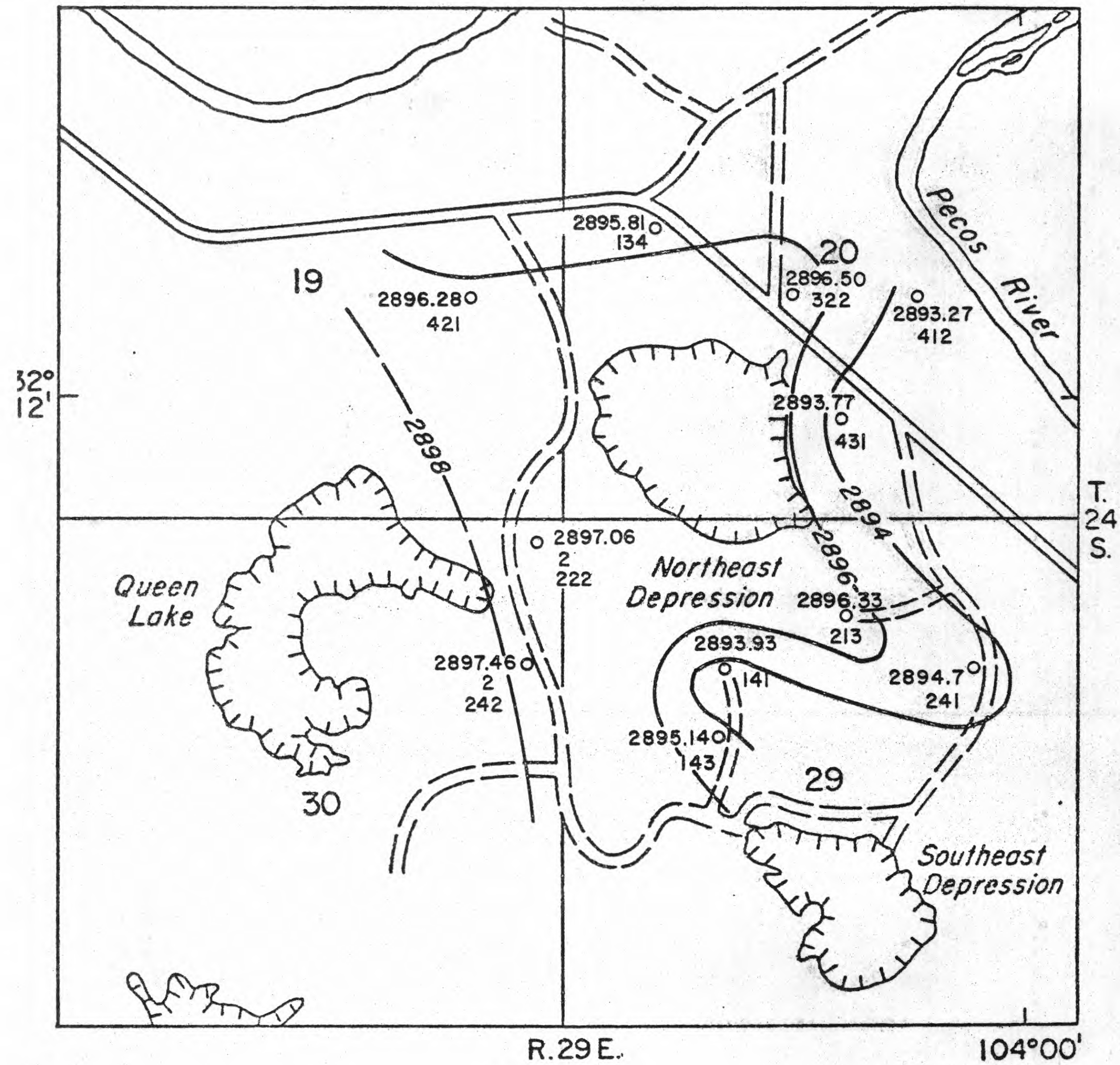
EXPLANATION

2899.62 O
2
421

Observation well - Top number is altitude of water surface corrected for water density variations (Bond, 1973). 2 shows number of wells at the location. Bottom number is last three numbers in well location designation.

2898 Water-table contour - shows altitude of water table corrected for water density variations (Bond, 1973), 1962. Dashed where approximately located. Contour interval 2 feet. Datum is mean sea level

Figure 10.--Altitude of water surface and water-level contours in shallow aquifers around the Northeast Depression, 1962.

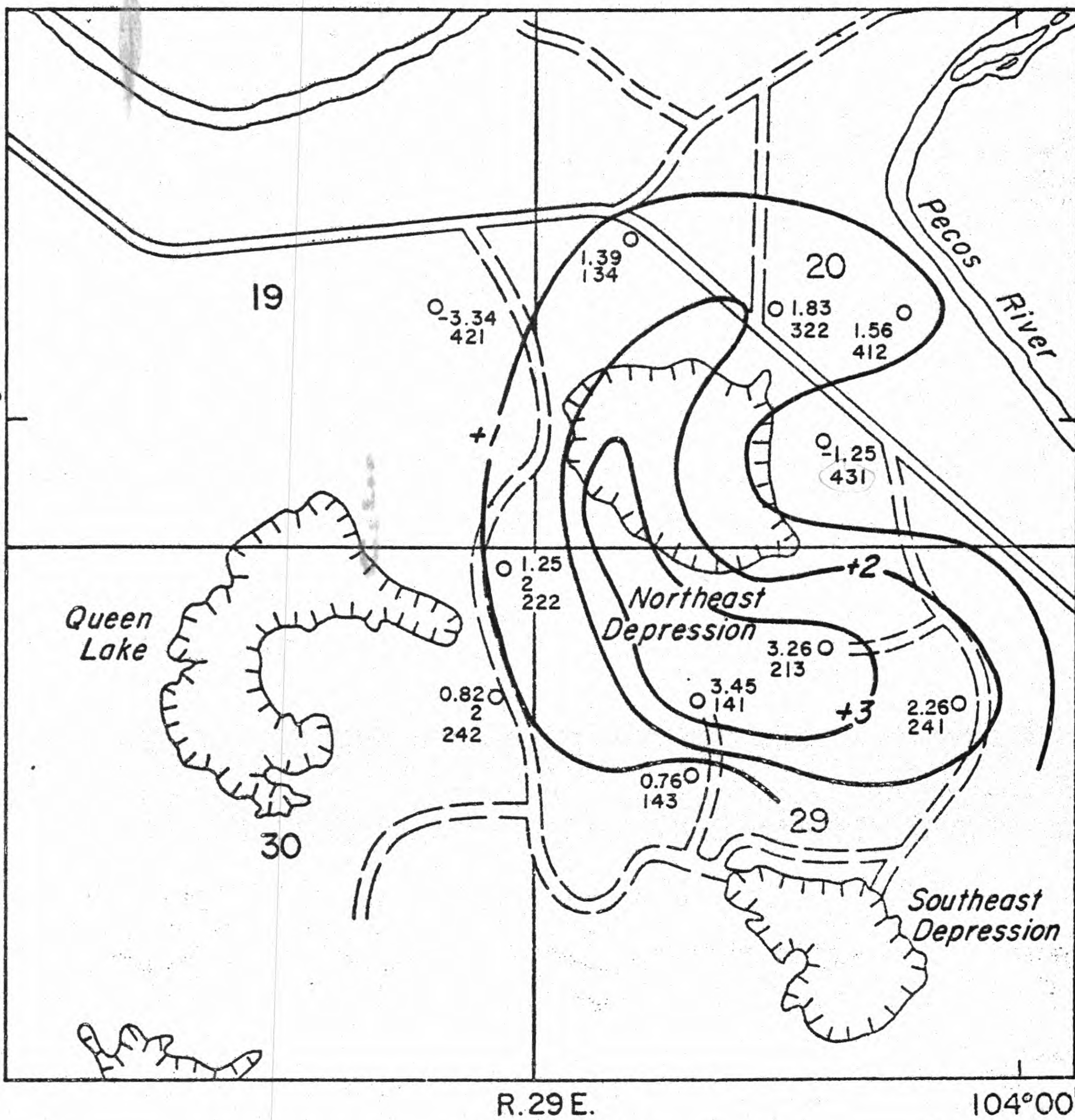


EXPLANATION

2897.46
2
242 o — Observation well - Top number is altitude of water surface corrected for water density variations (Bond, 1973). 2 shows number of wells at the location. Bottom number is last three numbers in well location designation.

—2898— Water-table contour - shows altitude of water table corrected for water density variations (Bond, 1973), 1968. Dashed where approximately located. Contour interval 2 feet. Datum is mean sea level

Figure 11.--Altitude of water surface and water-level contours in shallow aquifers around the Northeast Depression, 1968.



EXPLANATION

0.82 ○ 2 242 Observation well - Top number is change in water level 1962-68, in feet. 2 shows number of wells at the location. Bottom number is last three numbers in well location designation.

—+2— line of equal water-level change 1962-68

Figure 12.--Contours of change in water level in shallow aquifers around the Northeast Depression, 1962-68.

Upward leakage from the brine aquifer was probably responsible for the high chloride concentration in water from many shallow wells surrounding the Northeast Depression prior to 1963. In July 1963, the chloride concentration of water in the shallow aquifers ranged from 14,600 to 181,000 mg/L. Most analyses ranged from 50,000 to nearly 100,000 mg/L. Chloride concentrations in 1968 are shown in figure 13. Changes in chloride concentration in shallow observation wells, for the period 1963-68, surrounding the Northeast Depression are shown in figure 14. Figure 14 shows that chloride concentration of ground water in the shallow aquifers northeast, east, and southeast of the depression increased for the period 1963-68. Water samples from wells finished in shallow aquifers in other directions from the depression indicate a decrease in chloride concentration. Figures 15, 16, 17, and 18 show water-levels in and chloride concentrations from water in observations wells 20.322, 20.412, 20.431, and 29.213 respectively. The chloride concentration increased in the above four wells by amounts ranging from 99,400 mg/L for well 20.431, directly east of the depression, to only 1,500 mg/L for well 20.412 north and east of the depression. Well 20.412 is near the river and ground-water quality may be influenced by river water.

Water levels declined in well 20.431 during the 1963-68 period even though the chloride content of the water increased almost 100,000 mg/L. This well may be in a very transmissive area, perhaps near or in a collapse structure. The increased head surrounding the depression, caused by the brine leaking from the depression and large transmissivity values, could result in an increase in chloride concentration in the well water and a slight lowering of the water level. If the well is in or near a collapse structure, there could be good hydraulic connection between the brine and alluvial aquifers. A decrease in head in the brine aquifer could result in a decline in water level in well 20.431.

Water levels in wells 24S.29E.20.134 and 24S.29E.29.241 (figs. 19 and 20) rose while chloride concentrations decreased. The higher water levels are a result of the brine mound forming beneath the depression (fig. 12). The decrease in chloride concentrations could be attributed to decreased upward flow from the brine aquifer, dilution of the brine in the mound by eastward flowing freshwater (fig. 11), or a combination of both.

Wells 24S.29E.29.413 and 24S.29E.29.433 are finished in alluvium in the South Depression floor (fig. 4) and are influenced by recharge from water which occasionally stands in the depression. Chloride concentrations ranged from 5,000 to 8,000 mg/L in well 24S.29E.29.413 and from 10,000 to 15,000 mg/L in well 24S.29E.29.433. Changes in chloride concentration and water level for wells 24S.29E.20.122, 24S.29E.20.141, and 24S.29E.20.432a are shown in figure 21. As these wells were drilled in 1967, long-term change data are not available. These data show the influence of leakage on the shallow aquifer. The effect of leakage on the deeper aquifer and the influence of the river on the shallow or the deep aquifer are not defined.

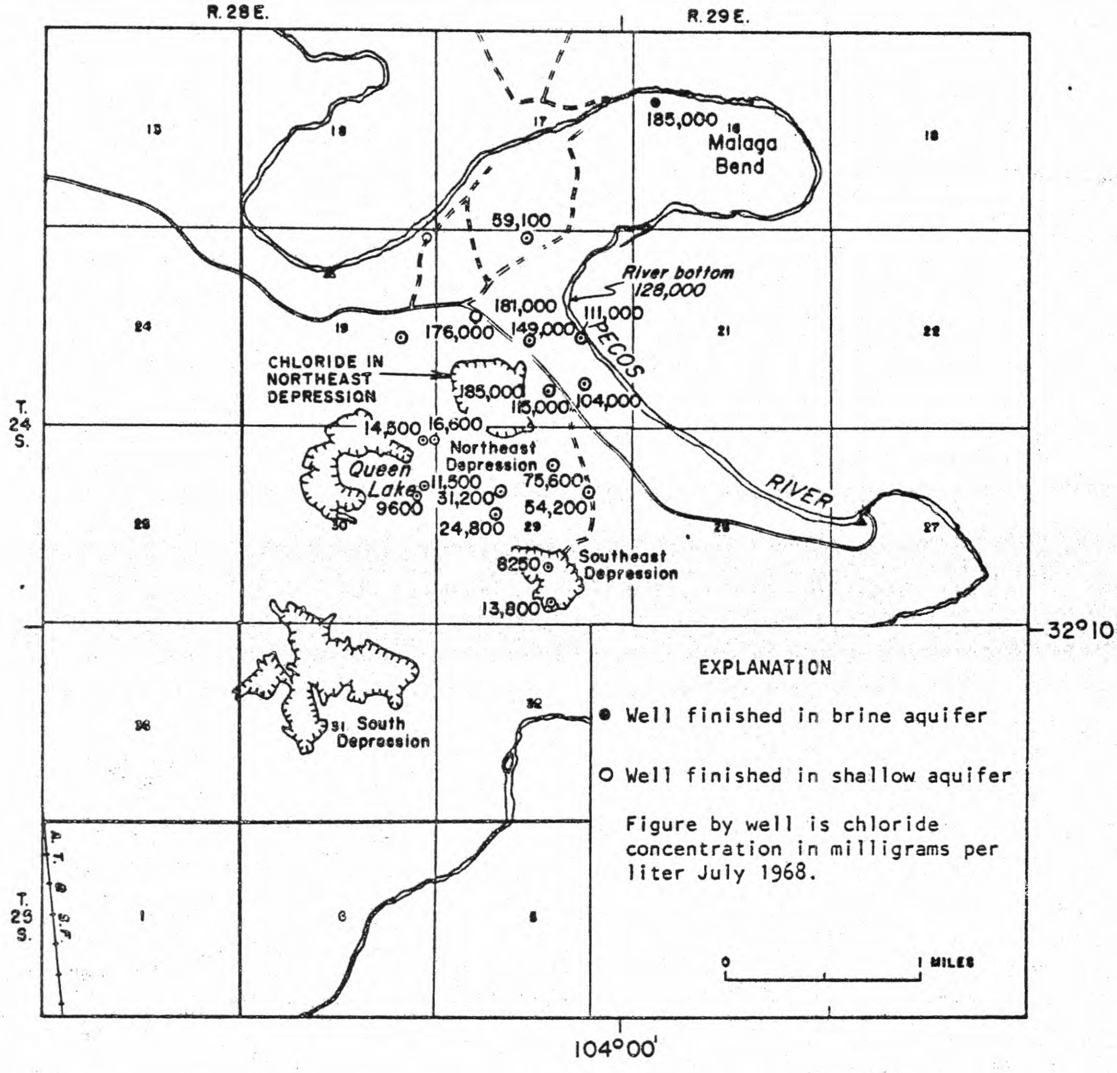


Figure 13.--Chloride concentration in wells near the Northeast Depression, in the Northeast Depression, and in river pools in the Malaga Bend area, July 1968.

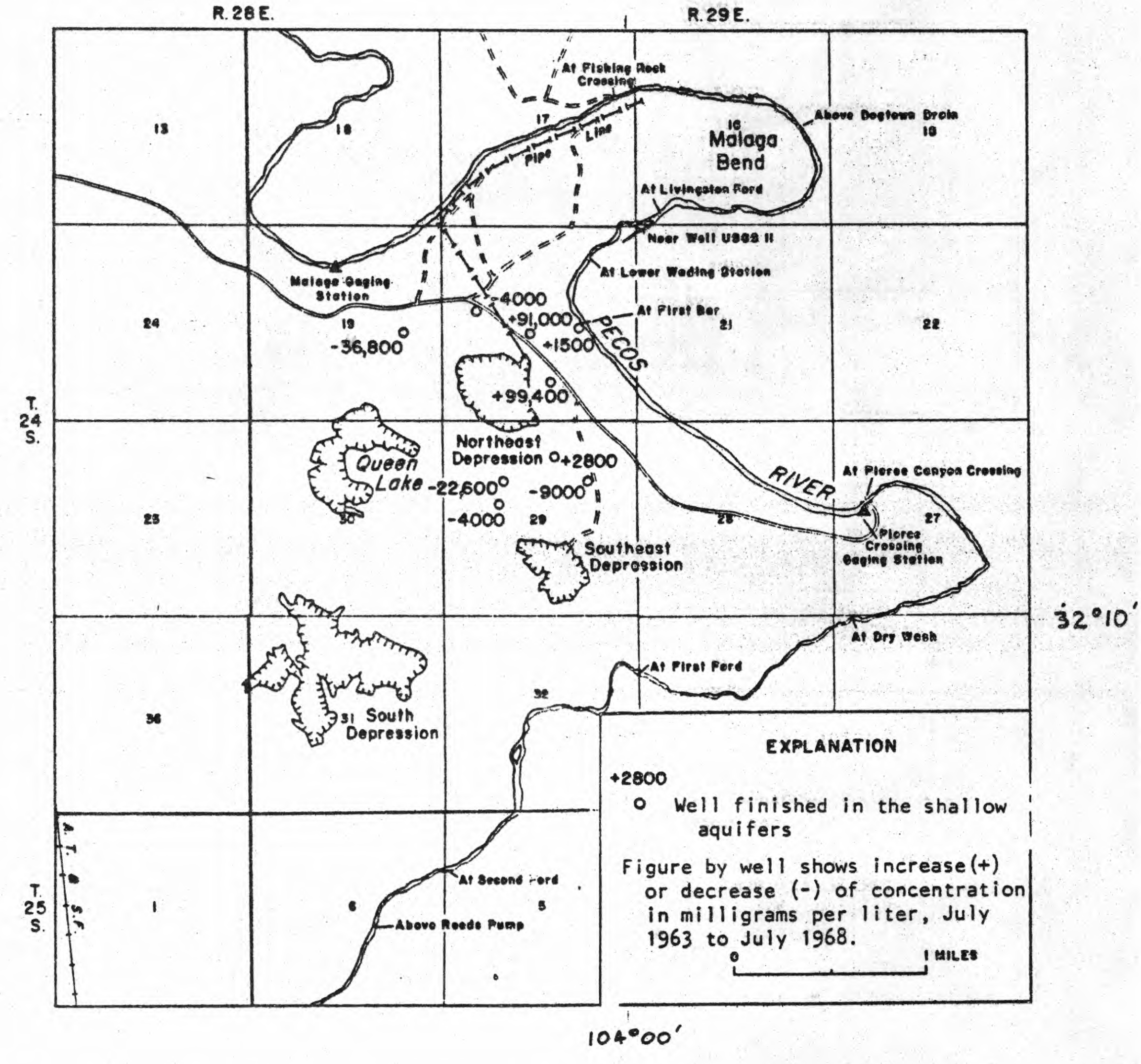


Figure 14.--Change in chloride concentration from June or July, 1963 to July 1968 in wells finished in shallow aquifers near the Northeast Depression.

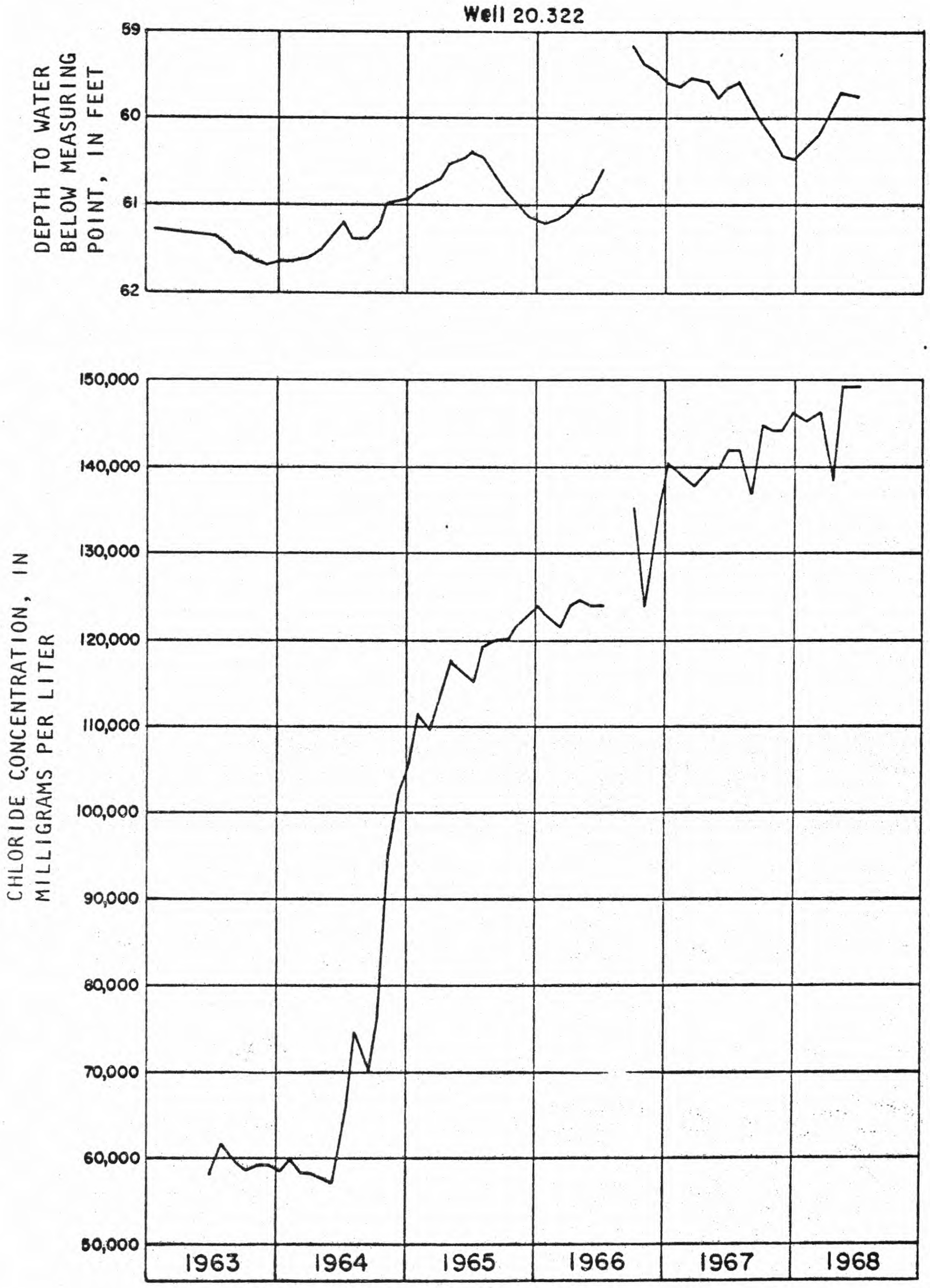


Figure 15.--Changes in water level and chloride concentration in observation well 24S.29E.20.322.

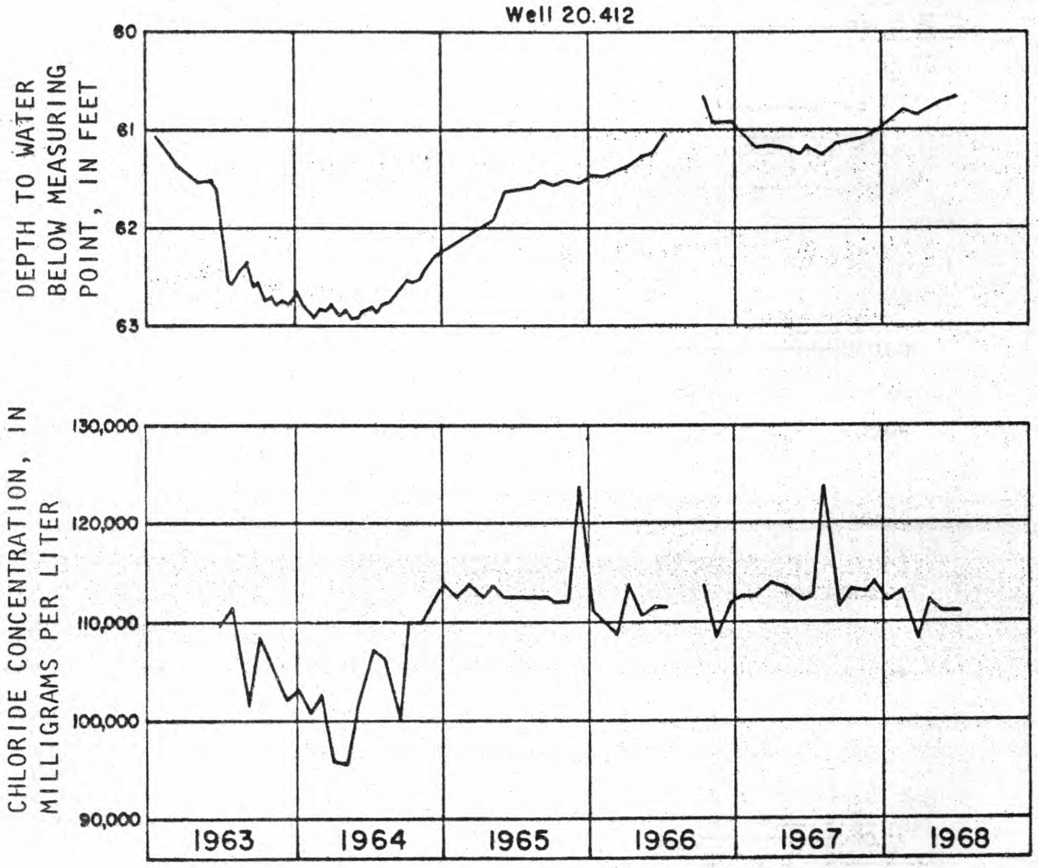


Figure 16.--Changes in water level and chloride concentration in observation well 24S.29E.20.412.

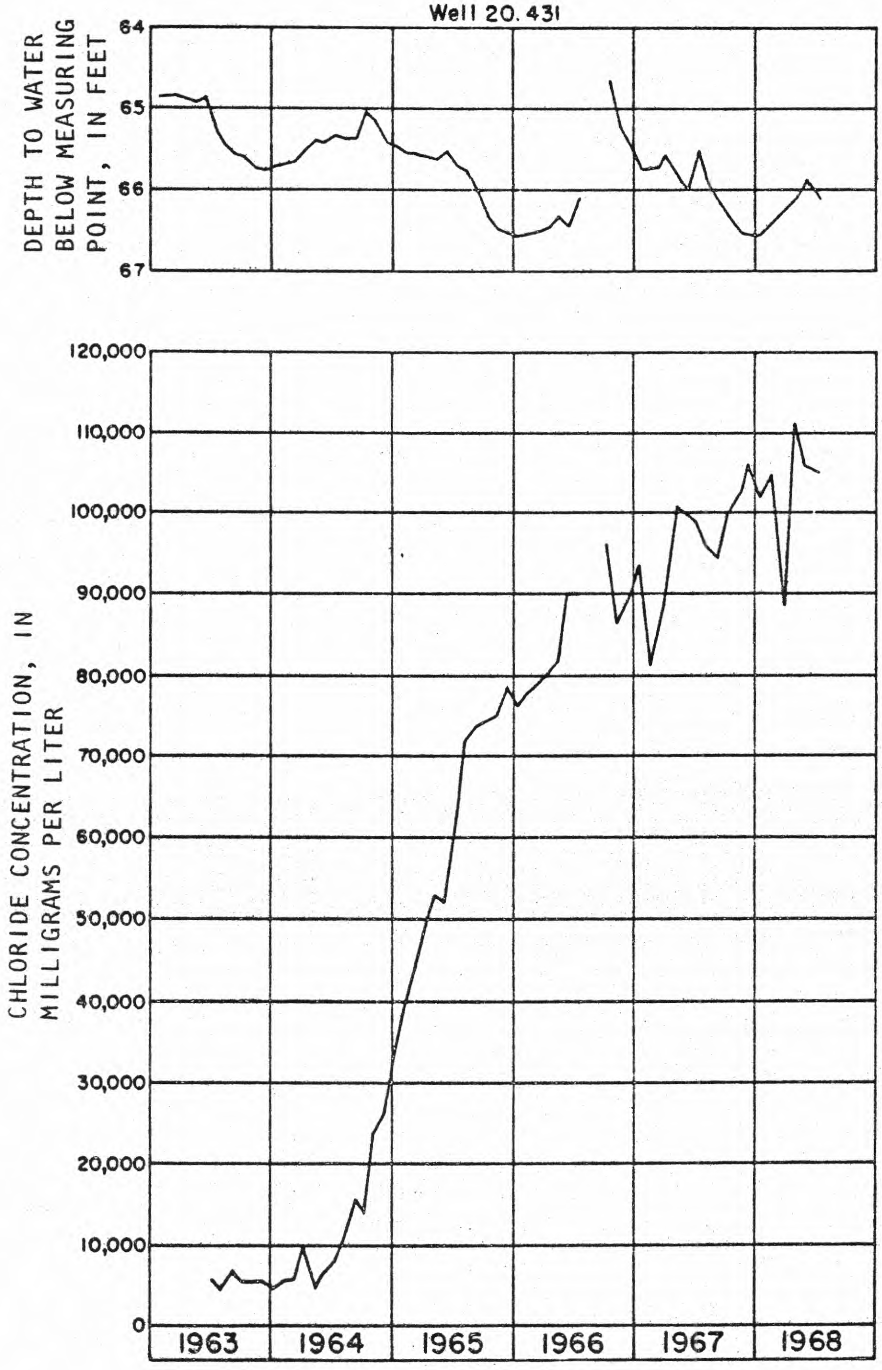


Figure 17.--Changes in water level and chloride concentration in observation well 24S.29E.20.431.

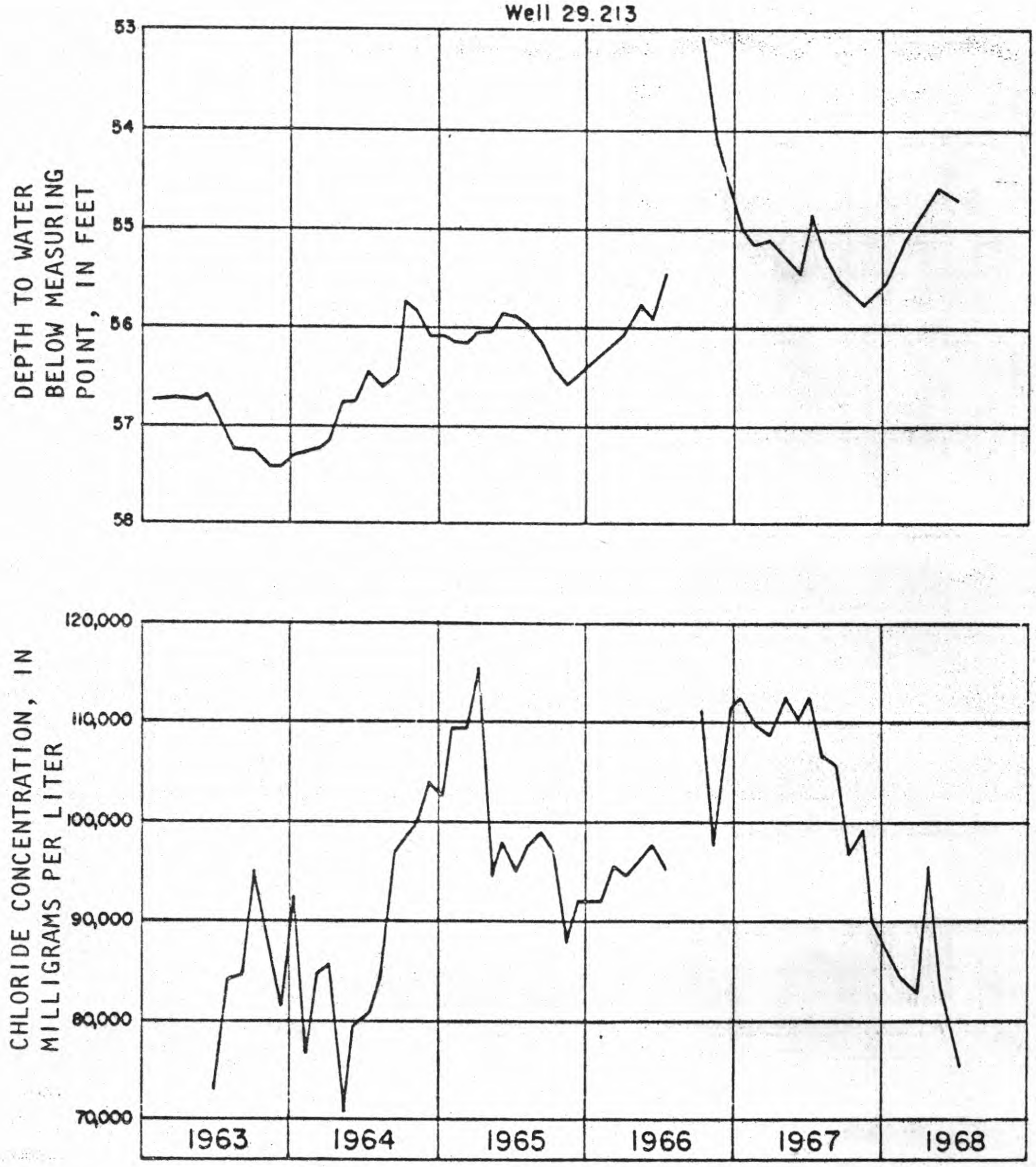


Figure 18.--Changes in water level and chloride concentration in observation well 24S.29E.29.213.

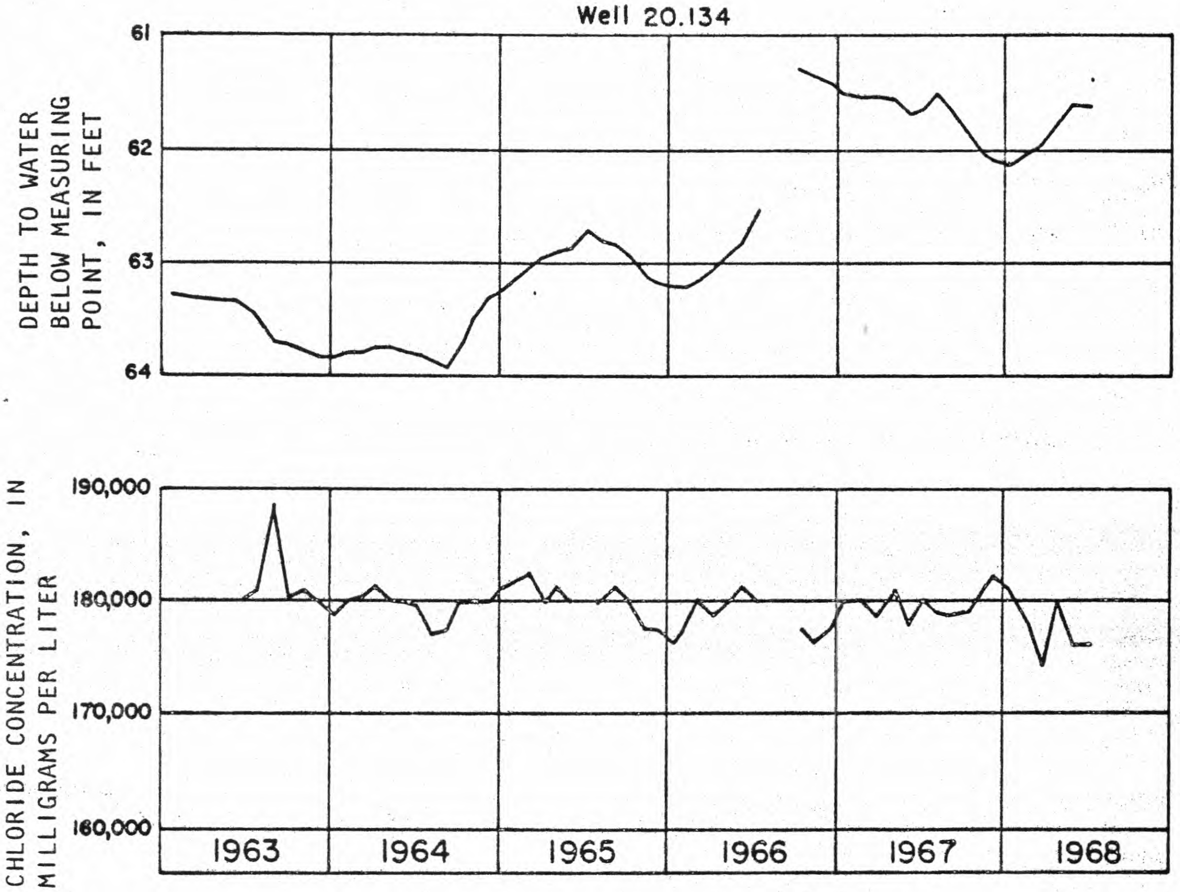


Figure 19.--Changes in water level and chloride concentration in observation well 24S.29E.20.134.

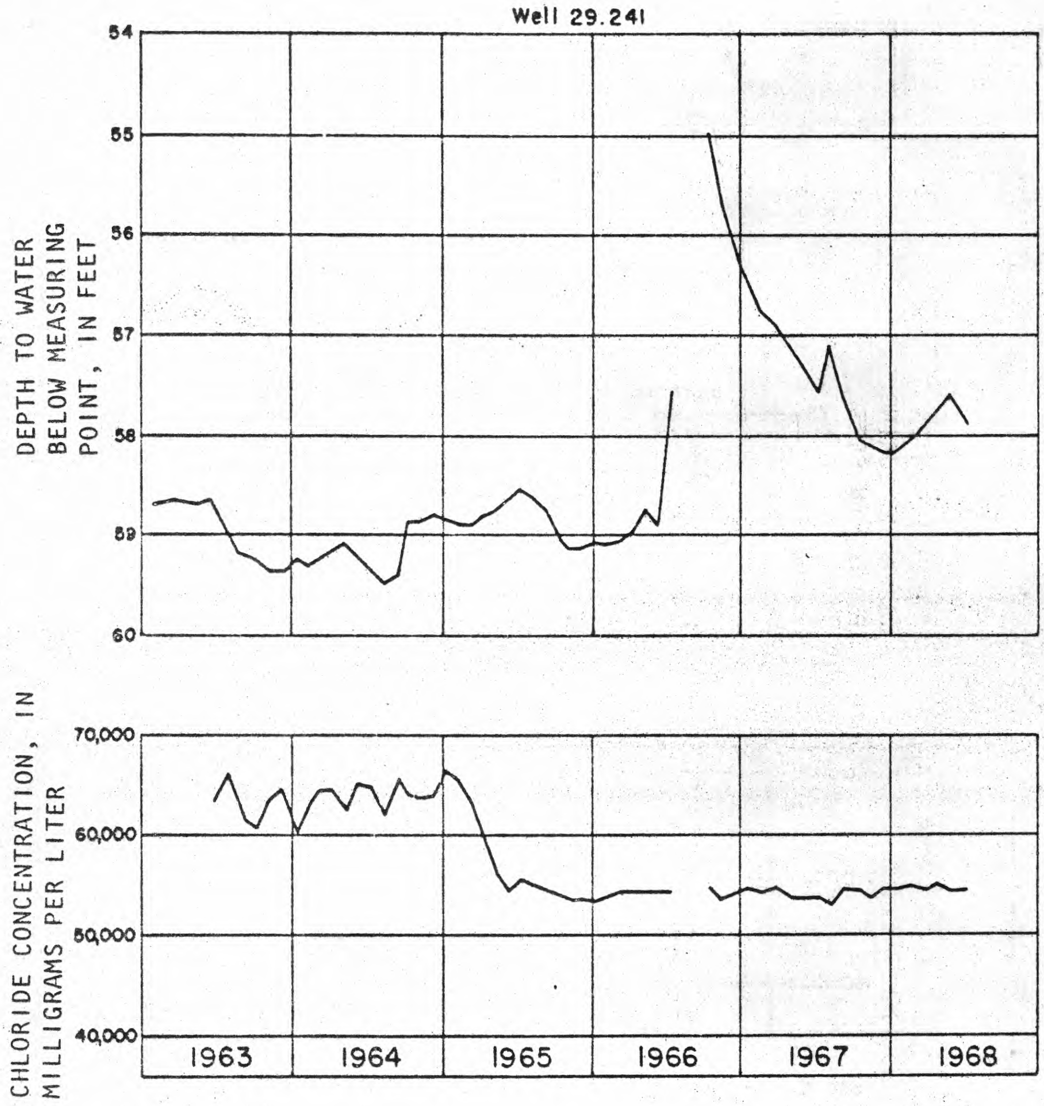


Figure 20.--Changes in water level and chloride concentration in observation well 24S.29E.29.241.

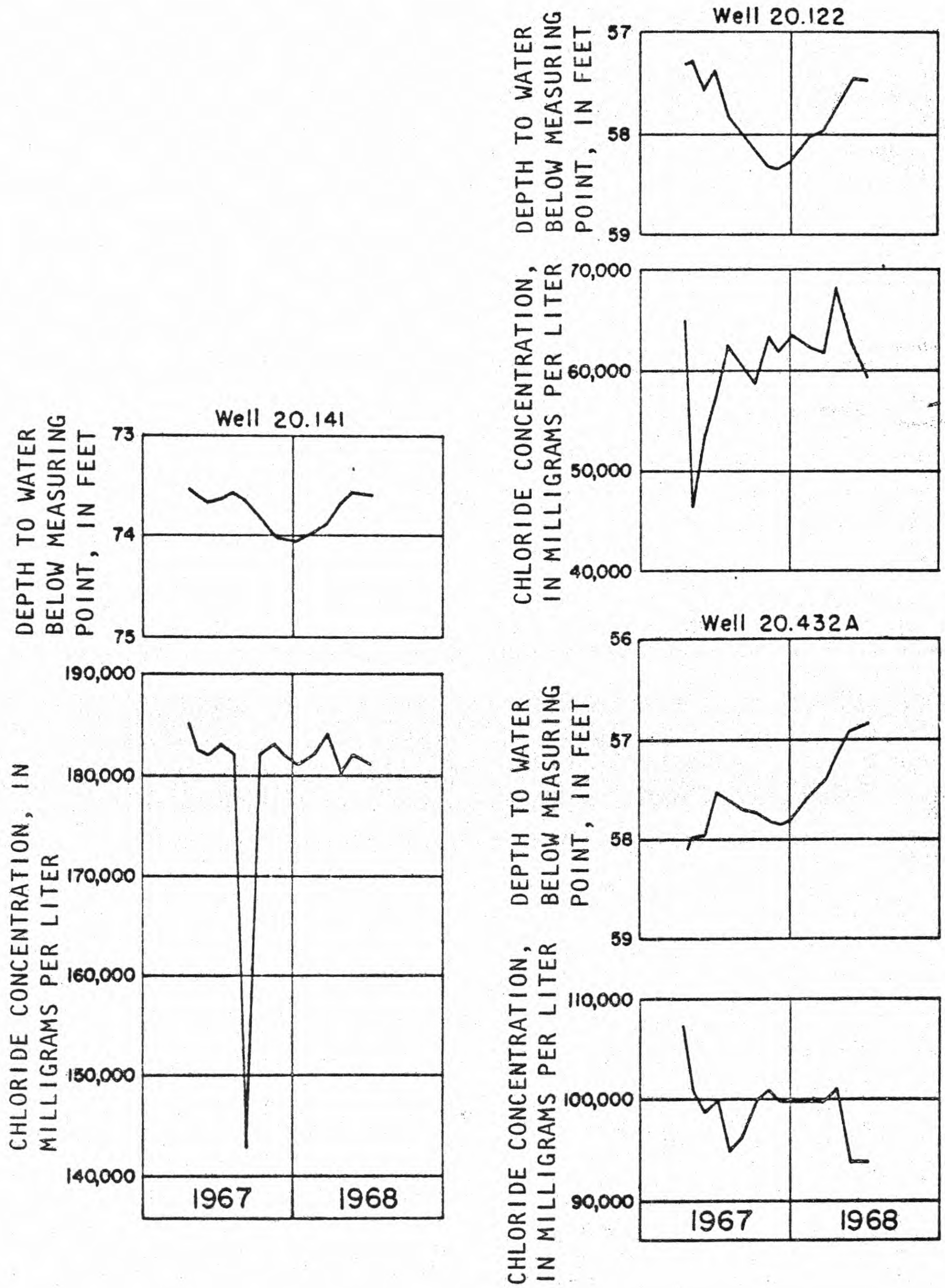


Figure 21.--Changes in water level and chloride concentration in observation wells 24S.29E.20.122, 24S.29E.20.141, and 24S.29E.20.432a.

CHANGES IN CHEMICAL QUALITY OF THE RIVER

The dissolved-solid load in the Pecos River for fiscal year 1938 (July 1937-June 1938) was about 40 percent greater at Red Bluff than at Carlsbad. From March 1 to June 30, 1938, the increase from Malaga to Pierce Canyon was about 450 tons/d of dissolved solids and about 370 tons/d of sodium chloride (Howard and White, 1938, p. 67 and 70).

Continuous records of chemical quality have been collected at Malaga, Pierce Canyon Crossing, and Red Bluff stations beginning in October 1951. The yearly gain in tons per day of chloride between Malaga and Pierce Canyon is shown in figure 22 for 1952-68 water years. The total chloride load and gain at the Malaga and Pierce Canyon gaging stations are given in table 7.

To determine variations in chemical quality of the river induced by pumping from the brine aquifer, additional samples were taken weekly at sites around Malaga Bend. The two regular sites were Fishing Rock Crossing at the upstream end of the reach and Pierce Canyon Crossing at the downstream end (fig. 4). Pecos River at First Ford was substituted for Pierce Canyon in February 1969. The samples were analyzed for specific conductance and chloride ion concentration. Several other sites were sampled for varying lengths of time after pumping began. In addition, daily water samples were collected by a paid observer at Pecos River near Malaga and Pecos River at Pierce Canyon Crossing. Complete results of chemical analyses are published in Geological Survey Water-Supply Papers giving quality of surface waters (see SELECTED REFERENCES).

Seepage investigations

In general, seepage investigations were made during periods of low river flow. From March 1959 to February 1968, average gains in chloride load in tons per day between adjacent sampling sites for the reach from Malaga gage to Red Bluff are shown in table 8. Locations of the seepage-run stations are shown in figure 4. Table 9 gives gain or loss in flow in the Malaga to Red Bluff reach.

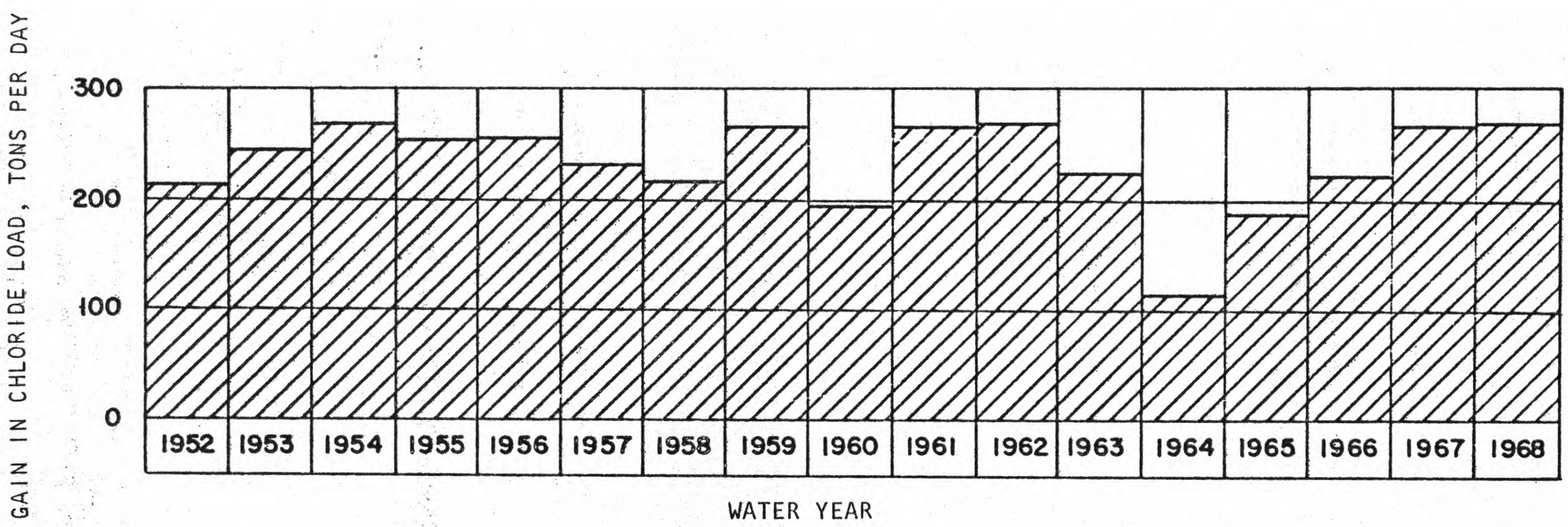


Figure 22.--Gain in chloride load from Malaga to Pierce Canyon Crossing from October 1951 to September 1968.

Table 7.--Chloride load and gain between Malaga and Pierce Canyon gaging stations, 1952-1968

Water year	Chloride load at Malaga gaging station (tons/d)	Chloride load at Pierce Canyon gaging station (tons/d)	Chloride gain (tons/d)
1952	147	360	213
1953	121	365	244
1954	110	378	268
1955	313	566	253
1956	274	528	255
1957	189	419	230
1958	304	519	215
1959	321	585	264
1960	372	564	192
1961	374	632	285
1962	224	485	261
1963	198	439	241
1964	136	238	102
1965	93	275	182
1966	168	387	219
1967	170	424	254
1968	159	417	258

Average gain, tons/d	
1952-63	239
1964-66	167
1964-68	203
1952-68	231

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Table 8.--Average gain or loss in chloride load between adjacent sampling sites for the reach Malaga gage to Red Bluff, March 1959 - February 1968

[Average load and gain or loss reported in tons/d]

Date:	3-12,13,14,15-59		10-10-61		10-12-61		3-13,14-62		7-16,17-63	
Sampling site	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride
Malaga gaging station	-	-	198	-	220	-	-	-	123	-
At Fishing Rock Crossing	-	-	242	+44	248	+28	-	-	140	+17
Above Dogtown Drain	-	-	-	-	-	-	-	-	183	+43
Moutray pump	-	-	-	-	-	-	-	-	*50	-
Near well USGS 11	-	-	-	-	-	-	291	-	257	+124
At First Bar	-	-	-	-	-	-	-	-	-	-
At Pierce Canyon Crossing	340	-	447	+205	480	+232	340	+49	273	+16
At Dry Wash	-	-	457	+10	488	+8	314	-26	274	+ 1
At First Ford	339	-1	423	-34	465	-23	342	+28	272	-2
At Second Ford	-	-	434	+11	498	+33	358	+16	272	0
Above Reed's pump	340	+1	406	-28	450	-48	342	-16	257	-15
At Red Bluff	306	-34	531	+125	411	-39	-	-	188	-69

*Moutray pump diversion added to difference between prior and following station, but not to any others.

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Table 8.--Average gain or loss in chloride load between adjacent sampling sites for the reach Malaga gage to Red Bluff, March 1959 - February 1968 - Concluded

2-7-64		7-28-64		8-12,13-64		5-18-66		7-25-66		8-5-66		2-6,7-68	
Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride	Average load	Gain chloride
179	-	103	-	-	-	92	-	-	-	93	-	235	-
199	+20	106	+3	102	-	83	-9	-	-	110	+17	241	+6
226	+27	144	+38	135	+33	99	+16	-	-	130	+20	247	+6
-	-	*64	-	*73	-	*74	-	-	-	*67	-	-	-
250	+24	133	+53	82	+20	60	+35	14	-	79	+16	-	-
-	-	-	-	-	-	-	-	-	-	-	-	451	+204
344	+94	235	+102	151	+69	119	+59	161	+147	639	+560	585	+34
322	-22	297	+62	-	-	114	-5	137	-24	-	-	-	-
333	+11	288	-9	-	-	103	-11	134	-3	-	-	530	-55
342	+9	-	-	-	-	122	+19	109	-25	-	-	-	-
332	-10	241	-47	-	-	116	-6	99	-10	-	-	548	+18
293	-39	141	-100	-	-	84	-32	17	-82	-	-	-	-

Table 9.--Gain or loss in streamflow between adjacent sampling sites for the reach Malaga gage to Red Bluff, October 1961 - February 1968

[Flow and gain or loss reported in ft^3/s]

Date:		10-10-61		10-12-61		3-13,14-62		7-16,17-63		2-7-64	
Site name	Site No.	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss
Malaga gaging station	333.5	39.2	-	37.6	-	-	-	17.8	-	25.6	-
At Fishing Rock Crossing	334	42.5	+3.3	40.9	+3.3	-	-	18.9	+1.1	27.4	+1.8
Above Dogtown Drain	335	-	-	-	-	-	-	19.5	+0.6	27.3	-0.1
Moutray pump	337	-	-	-	-	-	-	4.34*	-	-	-
Near well USGS 11	337.2	-	-	-	-	26.9	-	14.7	+0.2	26.1	-1.2
At First Bar	338.1	-	-	-	-	-	-	-	-	-	-
At Pierce Canyon Crossing	338.2	45.9	+2.5	42.5	-1.1	29.4	+2.5	17.0	+2.3	28.4	+2.3
At Dry Wash	338.3	47.4	+1.5	42.4	-0.1	26.6	-2.8	16.8	-0.2	25.7	-2.7
At First Ford	338.5	44.9	+1.4	40.4	-2.0	28.6	-2.0	16.6	-0.2	26.8	+1.1
At Second Ford	339.5	46.1	+1.2	43.1	+2.7	29.5	+0.9	17.2	+0.6	27.6	+0.8
Above Reed's pump	340	43.6	-2.5	39.7	-3.4	28.0	-1.5	16.4	-0.8	26.8	-0.8
At Red Bluff	342	52.6	+3.7	43.9	+1.5	-	-	13.7	-2.7	24.3	-1.7

*Moutray pump diversion added to difference between prior and following station.

Table 9.--Gain or loss in streamflow between adjacent sampling sites for the reach Malaga gage to Red Bluff, October 1961 - February 1968 - Concluded

7-28-64		8-12,13-64		5-18-66		7-25-66		8-5-66		2-2,7-68	
Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss	Flow	Gain or loss
10.7	-	8.2	-	11.2	-	-	-	13.6	-	53.6	-
10.3	-0.4	10.1	+1.9	10.3	-0.9	-	-	14.6	+1.0	52.6	-1.0
12.0	+1.7	10.5	+0.4	10.6	+0.3	-	-	15.2	+0.6	50.8	-1.8
4.5*	-	5.0*	-	6.8*	-	-	-	7.4*	-	-	-
8.6	+1.1	4.5	-1.0	3.5	-0.3	1.1	-	8.3	+0.5	-	-
-	-	-	-	-	-	-	-	-	-	53.0	+2.2
9.4	+0.8	6.3	+1.8	4.2	+0.7	2.7	+1.6	10.0	+1.7	55.9	+2.9
11.7	+2.3	-	-	3.9	-0.3	2.6	-0.1	-	-	-	-
11.3	-0.4	-	-	3.6	-0.3	2.5	-0.1	-	-	49.9	-6.0
-	-	-	-	4.3	+0.7	2.1	-0.4	-	-	-	-
9.3	-2.0	-	-	4.0	-0.3	1.9	-0.2	-	-	51.9	+2.0
5.8	-0.6	-	-	4.4	-0.1	0.5	-0.2	-	-	-	-

Amount of brine inflow

Chloride increase in the river near Malaga Bend is assumed to be caused by inflow of brine similar to the brine pumped from well USGS 8 containing 186,000 mg/L chloride. Table 10 gives the average increase in chloride in tons per day for gaged reaches of the Pecos River from Malaga to Reed's Pump.

Average chloride gain in the reach from Malaga gage to Pierce Canyon gage was 223 tons/d for water years 1939, 1940, 1952, and 1953 (Hale and others, 1954, table 4). For water years 1952-62, the average chloride gain from Malaga to Pierce Canyon was 240 tons/d (fig. 22), equivalent to a brine inflow of about 0.5 ft^3/s. The majority of the inflow entered the river between Malaga gage and well USGS 11. This inflow probably came from springs and seeps along the southern edge of the Malaga Bend with minor contributions along the northern edge upstream from the Dogtown Drain site. Chloride gains, after pumping started July 1963 but before the August 1966 flood, averaged about 170 tons/d in the Malaga-Pierce Canyon reach, equivalent to about 0.3 ft^3/s of brine inflow.

Possible causes of changes in chemical quality

Chemical-quality changes prior to July 1963

Before the beginning of sustained pumping from the brine aquifer, brine entered the river through springs and seeps along the banks and in the riverbed. In general, these spring areas were concentrated along the upper and lower edges of the Malaga Bend on the right bank. Flow from these spring areas represented a mixture of return irrigation water and brine. Flow from the observable spring areas accounted for only part of the chloride increase in the river; test borings in the banks and test borings and shallow holes in the river bottom disclosed water of concentration similar to springs and seeps along the banks (Howard and White, 1938, p. 71-73). Therefore, part of the increased chloride concentration around Malaga Bend almost certainly entered the river through the riverbed. Howard and White (1938, p. 70) noted that there were "unusually large increases in the load * * * when river stages were higher than normal * * *. It seems probable that deposits of salt along the river channel may be the source of at least some of this additional salt."

Table 10.--Average increase in chloride load of gaged reaches of the Pecos River from Malaga Bend to Reed's Pump

Reach	Before pumping (to 7-22-63)		Before flood of August 23-26, 1966		After flood (1 measurement)	
	Chloride gain (tons/d)	Equivalent brine inflow (ft^3/s)*	Chloride gain (tons/d)	Equivalent brine inflow (ft^3/s)*	Chloride gain (tons/d)	Equivalent brine inflow (ft^3/s)*
Malaga to Fishing Rock	30	.06	-	.01	6	.01
Fishing Rock to Dogtown Drain	43	.08	23	.05	6	.01
Dogtown Drain to USGS 11	173	.34	30	.06	-	-
Dogtown Drain to First Bar	-	-	-	-	204	.41
USGS 11 to Pierce Canyon Crossing	26	.05	59 (5-18-66)	.12	-	-
Do.	-	-	147	.24	-	-
do.	-	-	560 (8-5-66)	1.12	-	-
First Bar to Pierce Canyon Crossing	-	-	-	-	34	.07
Pierce Canyon Crossing to Dry Wash	11	.02	9	.02	-	-
Dry Wash to First Ford	-8	-.02	-3	-.01	-	-
Pierce Canyon to First Ford	-	-	-	-	-55	-.11
First Ford to Reed's Pump	-9	-.02	-	-.02	-	-

*Equivalent brine inflow if brine contains 186,000 mg/L Chloride (154,000 pounds per minute).

Some salt was brought into the Malaga Bend by irrigation water. The total inflow of return irrigation water in the Malaga Bend in 1952-63 could be taken as the average difference in flow between Malaga and Pierce Canyon Crossing sites, less 0.5 ft^3/s allowance for brine inflow in the reach. Average gain of flow in the Malaga-Pierce Canyon reach for 1952-63 was 2.8 ft^3/s. Therefore, pickup in the reach from return irrigation flow and normal ground-water contribution was about 2.3 ft^3/s, most of which can probably be attributed to return irrigation water. Salt cedar and other phreatophytes along the riverbanks and evaporation from the water surface consumed an undetermined quantity of water, but no allowance was made for this usage.

Chemical-quality changes after July 1963

Gain in chloride load from Fishing Rock Crossing to Pierce Canyon Crossing between 1963 and 1968 is shown in figure 23. These gains are based on weekly samples taken at these stations.

The tons of chloride pickup between Fishing Rock and Pierce Canyon (fig. 23) show a definite decline throughout the first year of pumping through June 1964. The pickup, with some fluctuations due partly to high flow, rises gradually in 1965 and the first half of 1966.

The largest flood of record, August 23-26, 1966, had a maximum discharge at Malaga of 120,000 ft^3/s. As a result of the flood there appears to have been an increased chloride load in the river. From late 1966 to June 1967, release of bank storage and other ground-water contributions in the reach and salts leached by increased flows probably account for much of the chloride increase.

When pumping began in July 1963, much of the total chloride load appears to have been entering the river in the reach between Malaga gage and well USGS 11. The pickup in this reach declined until the total contribution from May to December 1965 was less than 60 tons/d of chloride. Chloride contributions have, therefore, diminished upstream from the site near well USGS 11 since pumping began. Sampling was discontinued at well USGS 11 because the well was filled with silt when it was submerged during the August 1966 flood.

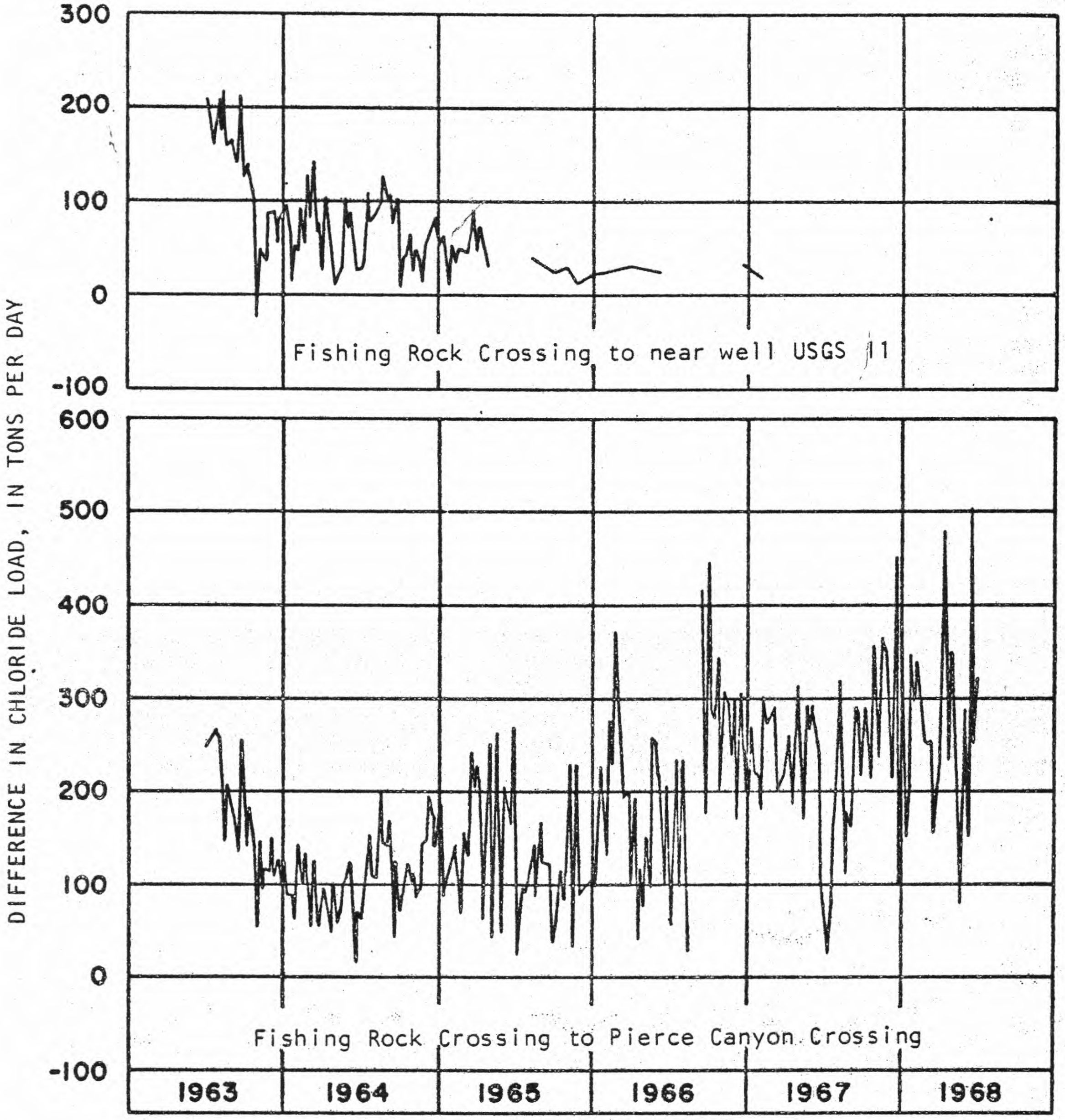

Figure 23.--Difference in chloride load from Fishing Rock Crossing to near well USGS 11 and from Fishing Rock Crossing to Pierce Canyon Crossing.

The diminished chloride contribution above USGS 11 site would support the conclusion that pumping from the brine aquifer has at least reduced contributions from brine springs and seeps in the reach from Fishing Rock Crossing to well USGS 11. The lowering of the water surface in USGS 11 from 2,900.8 feet in November 1962 to 2,889.9 feet in August 1966 also supports the above conclusion.

The average chloride gain in tons per day between sampling sites at Fishing Rock Crossing, USGS 11, and Pierce Canyon Crossing is shown in figure 23. It indicates that from 1965 to 1968 brine was entering the river downstream from well USGS 11.

On December 1, 1966, an abrupt temperature-salinity stratification was found in a pool at the measuring and sampling section, Pecos River at First Bar (1,000 feet below Lower Wading station) (fig. 4). About 2 feet of less-saline water flowed over nearly saturated brine. On December 13, 1967, a second specific-conductance survey was made of the same pool and the interface was about 1.2 feet below the water surface. Water of higher salinity is apparently ponded behind a sand and gravel bar extending across the river. Aerial photographs taken in 1946 show that the sandbar was present in the river even then.

In December 1967, the density separation of the brine and less-saline water was readily seen from a boat. Only the upper foot of water appeared to be moving rapidly, but water crossing the bar had a higher specific conductance on the bed of the channel than at the water surface. Some stratification was detected as far downstream as a second bar, but the water had a lower specific conductance than that behind the first bar. Beyond the second bar, the water was more or less homogeneous.

The increased brine contribution below USGS 11 site may be responsible for the observed brine pool above the first sandbar. Erratic "slugs" of brine were probably released from behind the sandbar and contributed to the increase in chloride load between Fishing Rock and Pierce Canyon. After the August 1966 flood, at least part of the increased chloride load resulted from channel scouring and realignment. Lowering the channel bed associated with a ground-water mound around the Northeast depression could cause increased inflow to the river between Fishing Rock and Pierce Canyon. Based on the daily samples, the average chloride gain for 1967-68 from Malaga to Pierce Canyon was 266 tons/d. Chloride increase in the Pierce Canyon-First Ford reach does not indicate any great contribution to the river.

Figure 12 shows that a mound of brine did form around the Northeast Depression. Figures 10 and 11 show a steeper ground-water gradient east of the depression in 1968 than in 1962. The steeper gradient indicates that there was flow from the depression to the river.

SUMMARY AND CONCLUSIONS

In 1938, Howard and White (p. 62-75) showed that large quantities of chloride were discharging into the Pecos River primarily at Malaga Bend. Simultaneous investigations by Robinson and Lang (1938, p. 100) showed that the source of the brine was a confined aquifer that extends northeastward along Nash Draw (fig. 1) from Malaga Bend.

Brine leaking upward from the confined aquifer mixes with less-saline water in the shallow aquifer in the Malaga Bend area and discharges into the river. Water in the brine aquifer contains about 187,000 mg/L chloride. Water in the shallow aquifer at Malaga Bend varies from about 2,000 mg/L chloride near the upper surface of the water table to nearly saturated brine containing about 180,000 mg/L chloride at the base of the shallow aquifer. The quality of the uppermost water is influenced by surface recharge while water near the base of the shallow aquifer is influenced by leakage from the brine aquifer.

Hale and others (1954) demonstrated by actual pumping tests that the head of the brine aquifer could be lowered by pumping, and it was decided to use this method in an effort to reduce brine inflow to the river. The Northeast Depression was chosen by the Pecos River Commission as a disposal area for the brine. The bottom 52.5 acres of the depression was cleared of brush, silt, and debris and then dampened and compacted by vibrating rollers. A brine-production well, USGS 8, was renovated, and about 2 miles of 8-inch asbestos-cement pipe with epoxy lining was laid to the Northeast Depression.

Ten observation wells were drilled around the depression to obtain quality-of-water and water-level data. Two additional wells and one replacement well were drilled in 1967 for additional control. Some wells from previous investigations in the area were utilized in the network. A weather station was installed and equipped for observations of evaporation, air temperature, humidity, and precipitation.

Installation of equipment was completed and continuous pumping from the brine aquifer began July 22, 1963. Pumping rates averaged about 450 gal/min; pumping was almost continuous through 1968. From July 1963 to July 1968, approximately 3,575 acre-ft of brine was pumped at an average of a little less than 2 acre-ft/d. Total brine pumped to December 31, 1968, was 3,878 acre-ft. Total storage in the Northeast Depression in July 1968 was 540 acre-ft including about 200 acre-ft of salt precipitate.

The natural hydraulic gradient in the Malaga Bend area was from the Northeast Depression toward the Pecos River. Water-level contours, using 1962 density-adjusted water-level data, show that ground-water flow was eastward toward the river. By 1968, a mound of brine had formed beneath and south of the depression. From 1962 to 1968 the flow rate increased from the depression to the river.

For water years 1952 through 1963 the average chloride gain from the Malaga sampling site to Pierce Canyon Crossing was about 240 tons/d. After pumping from the brine aquifer had begun, weekly water samples taken at sites on the Pecos River from Fishing Rock Crossing to Pierce Canyon Crossing showed a decline in chloride pickup from about 250 tons/d in July 1963 to less than 75 tons/d in June 1964 (fig. 23). The load then gradually increased to about 200 tons/d in 1965 and early 1966. The increase in load resulted from brine leakage from the Northeast Depression.

After the August 1966 flood, chloride loads increased and fluctuated rapidly. Some of the increase can be traced to release of bank storage, increased ground-water contributions, and leaching of salts by higher-than-normal flows in the reach. The increased river flow volume accounts for some of the chloride increase. The chloride pickup, after August 1966 through June 1967 from Malaga to Pierce Canyon, was as much as 440 tons/d but ranged generally from 200 to 300. Periods of high flow in June-August 1967 contributed to large fluctuations in the chloride load through June 1968.

Chloride pickup from Malaga gage to near well USGS 11 declined steadily until total contribution was less than 40 tons/d in December 1965, based on weekly samples (fig. 23). Apparently brine flow has not reappeared in this reach even after the August 1966 flood. As total chloride contribution upstream from Pierce Canyon increases, brine is, therefore, entering the river downstream from well USGS 11 site.

Pumping the brine aquifer appears to be an effective method of reducing brine inflow to the river. Leakage from the Northeast Depression is the primary reason for continued chloride loads of about 200-300 tons/d. If brine inflow to the river is to be reduced on a long-term basis, USGS 8 must be pumped continually and a suitable disposal site must be found. The Northeast Depression, if sealed, is not large enough to contain the brine when pumping USGS 8 continually. Laguna Grande de la Sal, located 6 to 7 miles north of Malaga Bend, is a possible storage site for the brine. Additional studies would be needed to determine its suitability.

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1953	1282	1953	1292
1954	1342	1954	1352
1955	1392	1955	1402
1956	1442	1956	1452
1957	1512	1957	1522
1958	1562	1958	1573
1959	1632	1959	1644
1960	1712	1960	1744
1950-60	1732	1961	1884
		1962	1944
		1963	1950
		1964-65	1961

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