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LAKE MEREDITH
SALINITY STUDY

Appraisal-Level
Investigation
Canadian River

Texas - New Mexico

March 3, 1849

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

OCT 1979

LAKE MEREDITH SALINITY STUDY
CANADIAN RIVER
TEXAS - NEW MEXICO

APPRAISAL-LEVEL INVESTIGATION
OCTOBER 1979

THIS REPORT WAS PREPARED PURSUANT TO ACT OF JUNE 17, 1902, AND ACTS AMENDATORY THEREOF OR SUPPLEMENTAL THERETO. PUBLICATION OF THE FINDINGS AND CONCLUSIONS HEREIN SHOULD NOT BE CONSTRUED AS REPRESENTING EITHER THE APPROVAL OR DISAPPROVAL OF THE SECRETARY OF THE INTERIOR. THE PURPOSE OF THIS REPORT IS TO PROVIDE INFORMATION AND ALTERNATIVES FOR FURTHER CONSIDERATION BY THE BUREAU OF RECLAMATION, THE SECRETARY OF THE INTERIOR, AND OTHERS.

Prepared by

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SOUTHWEST REGION
AMARILLO, TEXAS

SUMMARY SHEETS

Lake Meredith Salinity Study

Location

The area of investigation includes Lake Meredith near Fritch, Texas, and the reach of the Canadian River approximately 150 river miles upstream to Ute Reservoir near Logan, New Mexico. This reach of the river lies within Hutchinson, Moore, Potter, and Oldham Counties of the Texas Panhandle and Quay County in eastern New Mexico.

Scope

The scope of the investigation is to identify the sources contributing water highly concentrated with sulfates and chlorides to the Canadian River reach between Lake Meredith and Ute Reservoir. The investigation is also to study methods of alleviating the contamination of water in this reach of the river.

Background

Lake Meredith is the storage facility for the Canadian River Project which supplies municipal and industrial water to 11 member cities on the Texas High Plains. The project was constructed by the Bureau of Reclamation in the mid-1960's and is operated by the Canadian River Municipal Water Authority (CRMWA). The project facilities consist of Sanford Dam located on the Canadian River in Hutchinson County, Lake Meredith, some 322 miles of pipeline, 10 pumping stations, 3 regulating reservoirs, and chlorination facilities.

Gradually increasing salinity of the water in Lake Meredith has created problems for the users of the project water. Recent news media coverage has focused on drinking water quality concerns raised by the Environmental Protection Agency (EPA). Amarillo, Texas, which is one of the largest member cities, has been listd by the EPA as having a drinking water quality problem. Local concern has been expressed through area U.S. Congressional representatives to alleviate the salinity problem in Lake Meredith. The CRMWA also supports corrective action and has provided assistance to the Bureau of Reclamation in seeking solutions to the problem.

Problem and need

The Canadian River is the principal surface water source for the project area but is generally poor in quality. Recent sampling and chemical analyses of reservoir water indicate that the concentrations of sodium, chloride, sulfate, and total dissolved solids (TDS) exceed the maximum limits recommended by the Public Health Service and others. The following tabulation shows the quality of the reservoir water for selected constituents in January 1968 and January 1978 and the recommended limits of concentration for drinking water supplies.

Selected constituents	Recommended limits for drinking water - mg/l	Lake water conditions - mg/l Jan. 1968 - Jan. 1978	
Sodium	200	213	301
Sulfate	250	210	282
Chloride	250	220	324
Total dissolved solids (TDS)	500	980	1,210

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mg/l = milligrams per liter

Corrective action should be taken to maintain the concentration of salts in Lake Meredith within desirable limits and preclude the need for additional expensive water treatment requirements or development of new sources of water.

Study results

A thorough testing of the riverbed sands and subsurface water conditions of the Canadian River accompanied by exploratory drilling resulted in the identification of a brine artesian aquifer contributing saline pollution to the natural flow of the river. The leaky aquifer is located in the general area of Logan, New Mexico, downstream from Ute Reservoir.

Analyses of water samples from wells indicate that the brine aquifer has a TDS concentration in excess of 30,000 mg/l. Flow from the aquifer aggregates about 0.6 cubic feet per second (ft^3/s) of brine pollution to the river system. The postulated relationship between the annual salt contribution of the aquifer and the annual inflow values to Lake Meredith is shown in the following tabulation.

Constituent	Contribution of brine aquifer tons/yr 1/	Inflow to Lake Meredith-tons/yr 2/	Percentages contribution to inflow
Sodium (as Na)	8,500	27,660	31
Chlorides (as Cl)	13,000	29,525	44
Sulfate (as SO_4)	5,400	26,910	20
Total of the above constituents	26,900	84,095	32

1/ Assumes a constant discharge of 0.6 ft^3/s

2/ Based on inflow and water quality records 1965-77

A potential plan to control the brine flow from the aquifer has been formulated, based on field test data. The plan as presently envisioned would continuously pump the aquifer at a sufficient rate (thought to be about 1 ft^3/s) to lower the piezometric surface or head pressure thereby reducing the upward flow of brine from the aquifer to the Canadian River. The brine discharge from the well(s) would be transported by pipeline to a nearby playa for evaporation-disposal.

The estimated construction costs for operating a well discharge-surface evaporation plan to control the aquifer at its source are:

Production well	$ 209,000
Observation wells (6)	100,000
Pumping plants (2)	147,000
Pipeline (7 miles)	1,324,000
Brine disposal area	5,600,000
Powerline	269,000
Seepage monitor system	221,000
Field cost	$7,870,000
Other costs (35%) 1/	$2,750,000
Construction cost (July 1979)	$10,620,000
Total annual operation, maintenance, and energy cost 2/	$20,500

1/ Includes 10 percent for preconstruction planning

2/ A separate cost for replacements was not identified since the pumping plants are small; a minor cost is included in the maintenance cost figure.

Should isolation of the brine pollution at its source result in improved water quality at Lake Meredith, direct benefits would be realized from lower water treatment costs, lower maintenance cost of municipal distribution systems and domestic plumbing, as well as health aspects. Indirect benefits may include improved recreation aspects on Lake Meredith, environmental enhancement for wildlife, and improved livestock watering along the affected reach of the river.

Conclusions

Appraisal-level data gathered from the current investigation indicate that an improvement in Lake Meredith water quality might be achieved through isolation of the brine artesian aquifer. Isolation could probably be achieved by pumping brine from the aquifer to a surface evaporation pond.

Based on an aggregate flow of about 0.6 ft^3/s, it is estimated that the contribution of sodium, chloride, and sulfate from the brine aquifer averages about 26,900 tons per year or about 32 percent of these constituents entering Lake Meredith. If the effects of the brine aquifer are eliminated, the average concentration of sodium, chloride, and sulfate flowing into Lake Meredith should be reduced from about 500 to about 350 mg/l. Under present reservoir conditions, this should result in an average TDS concentration in the reservoir of about 800-900 mg/l. Present TDS concentration in Lake Meredith is about 1,250 mg/l.

Recommendations

A major source of saline water in the Canadian River has been identified; this is the leaky, artesian, brine aquifer near Logan, New Mexico. Further testing and studies would be required to validate the long-term effects of lowering the aquifer's piezometric surface on and of isolating the brine from the Canadian River-Lake Meredith system.

Economic and financial analyses of the potential plans would be provided if further studies are made on the salinity problem. The economic analysis, along with additional hydrological and engineering studies, would assist the local authorities in determining the best future course of action. The financial analysis would assist the local entity in determining its potential repayment commitment.

Therefore, recommendations are that this study be continued at a feasbility level to permit a thorough investigation of methods of reducing the salinity of Canadian River water flowing into Lake Meredith, and thus the salinity of municipal and industrial water supplied by the lake to Canadian River Project member cities on the High Plains. If plans to reduce the salinity in the Canadian River cannot be shown to be engineeringly and economically feasible, alternative means would be explored to provide better quality water for municipal and industrial use.

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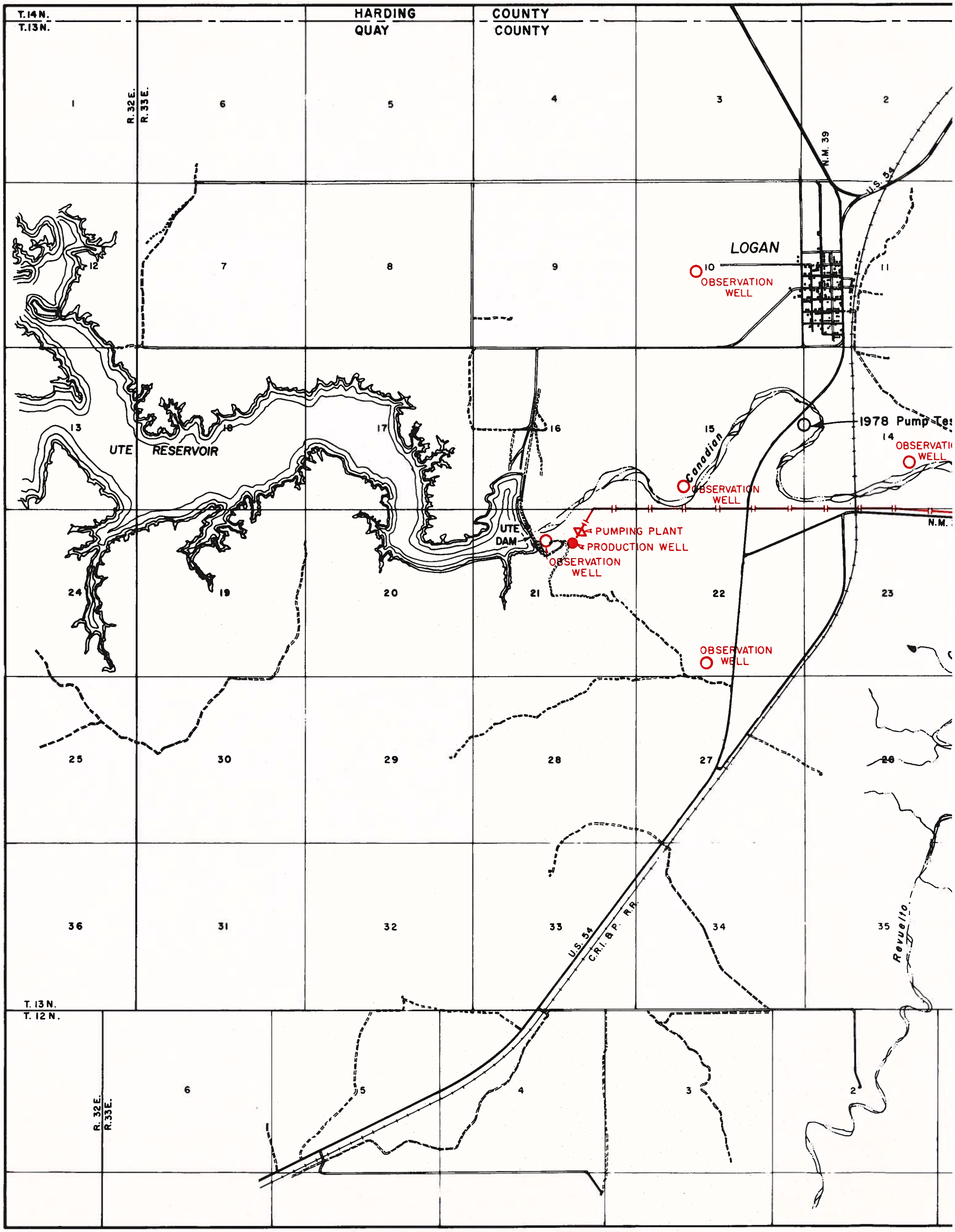
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QUAY COUNTY
R.32E.
R.33E.
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N.M. 39
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LOGAN
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OBSERVATION WELL
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Revuelto
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T. 12 N.
R. 32 E.
R. 33 E.
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Federal

Environmental Protection Agency, Dallas, Texas
Fish and Wildlife Service, Tulsa, Oklahoma, and Albuquerque, New Mexico
Department of Commerce, Galveston, Texas
Geological Survey, Albuquerque, New Mexico

Problem and Need

The concentration of salts in Lake Meredith has reached levels considered undesirable by the United States Public Health Service and the Environmental Protection Agency (EPA). The results of periodic sampling and chemical analyses of reservoir water indicate that the amounts of sodium, chlorides, sulfates, and total dissolved solids (TDS) are in a general upward trend. Analyses conducted in January 1978 show the concentrations of these constituents exceed the recommended maximum limits for drinking water supplies. Table 1 provides a water quality analysis of Lake Meredith and the city of Amarillo's tap water for selected constituents.

There is an urgent need to take feasible corrective measures to at least maintain and possibly reduce salt concentrations of the water flowing into Lake Meredith. Recent news media coverage (including national television) has focused on drinking water quality concerns raised by the EPA. Amarillo, Texas, has been listed with other cities by the EPA as having a drinking water problem. Action is needed to maintain the concentration of salts in Lake Meredith within desirable limits and preclude additional expensive water treatment requirements or development of new sources of water.

Local Interest

The overall public acceptance of Lake Meredith water for domestic uses has, in most cases, been good. Most people recognize that area ground water resources are rapidly being depleted, and the availability of a supplemental surface water supply is extremely important to the economy of the area.

However, complaints have been voiced with respect to Lake Meredith water having a poor taste, strong odor, and contributing to excessive maintenance costs of domestic plumbing. The public attitude therefore favors any reasonable action that could be taken to improve the quality of Lake Meredith water. Local interest and support in the Bureau's current appraisal investigation has been expressed through area U.S. Congressional representatives.

The CRMWA has also provided support and assistance to the Bureau during the current study and will continue to assist if future studies are warranted.

A letter indicating support of the Bureau's investigation is presented in appendix B.

Table 1
Lake Meredith Water Quality

Selected Constituent	Recommended limits for drinking water supply (mg/l)	Lake water conditions (intake structure) Jan. 1968 (mg/l)	Lake water conditions (intake structure) Jan. 1978 (mg/l)	Lake water conditions as predicted by Reclamation in November 1960 Report 1/ average (mg/l)	maximum (mg/l)	minimum (mg/l)
Sodium	200 (AWWA)	213	301	216	417	135
Bicarbonate	-	229	212	309	597	194
Sulfate	250 (PHS)	210	282	210	406	132
Chloride	250 (PHS)	220	324	200	386	125
Fluoride	0.8-1.7 (PHS) 2/	1.0	0.8	1.9	3.7	1.2
Total Dissolved Solids	500 (PHS)	980	1,210	950	1,838	596
Hardness (As $CaCO_3$)	-	269	266	301	583	189
Calcium	-	69	59	-	-	-

1/ Based on 1941-59 reservoir operation period (Condition 3) in which 1951-57 was the critical period representing maximum concentrations of constituents

2/ Values change with the daily air temperature

AWWA - American Water Works Association

PHS - Public Health Service (1962) Drinking Water Standards - 42 CFR, Part 72, Interstate Quarantine Drinking Water Standards

Representative Amarillo tap water, after 70/30 blend with well water, February 1978:

Sodium	210 mg/l
Bicarbonate	220 mg/l
Sulfate	193 mg/l
Chloride	214 mg/l
TDS	921 mg/l
Hardness	234 mg/l

PREVIOUS INVESTIGATIONS

Prior to and following construction of the Canadian River Project several reports have been prepared which deal with the water quality of the Canadian River and Lake Meredith. Presented below is a synopsis of each report and its findings.

Definite Plan Report--Canadian River Project 1960

The Definite Plan Report was the Bureau's final report prior to construction and development of the Canadian River Project. In this report existing and future water quality conditions were analyzed based on data available at that time. Reservoir operation studies indicated that during critical reservoir drawdown periods the maximum concentrations of chlorides and TDS of water stored in the reservoir could reach levels of about 400 mg/l and 1,800 mg/l, respectively (projected concentrations are shown in table 1). It was recognized that the quality of water in the Canadian River was marginal and that during critical periods of low reservoir inflow combined with reservoir evaporation the level of salinity in the reservoir could be expected to increase. The report further noted that mixing of surface water with available ground water supplies would normally result in an acceptable quality of water.

Texas Water Quality Board Study

In 1969 the Texas Water Quality Board conducted a streamflow-water quality study between Ute Dam in New Mexico and Boys Ranch, Oldham County, Texas. The results of the study suggest that most salts were entering the river between Ute Dam and the New Mexico-Texas State line, with the most significant amounts appearing near Ute Dam. The Board recommended that a complete study be made of the river from Logan, New Mexico (Ute Dam), to Lake Meredith during periods of base flow and for periods of runoff from the watershed.

Mason-Johnston and Associates, Inc., 1972

The CRMWA commissioned the firm Mason-Johnston and Associates, Inc., to conduct a study of data reduction and interpretation relative to water quality of base flow of the Canadian River between Conchas Dam, New Mexico, and Lake Meredith. Conchas Dam is located on the Canadian River about 50 miles upstream from Ute Dam. In 1972 findings of the study were presented in report form to the CRMWA. The results and recommendations of the report are summarized as follows:

1. Primary contribution of chlorides, sulfates, and TDS to Canadian River base flow is of natural origin.

2. Industrial, commercial, and agricultural sources of pollution are only minor contributors of contaminants to the overall base flow water quality of the river.

3. A detailed surface reconnaissance and a water sampling survey should be made of main stem base flow between Ute Dam and Boys Ranch, Texas. Particular attention should be given to the reach from Ute Dam to immediately downstream from the confluence of Revuelto Creek and the Canadian River; to areas immediately downstream from the confluence of the major tributaries; and to any other ground water sources including springs, seeps, and municipal and private wells.

4. A detailed study should be made of geologic and ground water conditions in the Ute Dam-Revuelto Creek area.

GENERAL GEOLOGIC AND GROUND WATER CONDITIONS

General Geology

Northeastern New Mexico is underlain by sedimentary rocks ranging in age from Permian to Tertiary (see the Generalized Geologic Column, figure 1). The formations shown on the column may not all be present at any one location in northeastern New Mexico.

The Canadian River valley between Ute Dam and Lake Meredith is eroded in fluvial sediments and detrital and chemical sedimentary rocks. From oldest to youngest, the rock units are: (1) shale, siltstone, sandstone, dolomite, gypsum, anhydrite, and halite constituting formations of Permian age; (2) shale, siltstone, and sandstone of the Triassic Dockum Group; and (3) sands, gravels, caliche, silts, and clays of the Tertiary Ogallala Formation. In addition, the river in eastern New Mexico is downcutting through gravels, sands, silts, and clays of earlier flood plains and eolian sands and silts of Quaternary age. The broad outer valley, along the north and south margins of the "breaks" of the High Plains is cut through the Ogallala Formation. The inner valley between the river and the "breaks" is cut in rocks of Triassic and Permian ages. These sedimentary rocks extend to depths of 1,500 to more than 4,000 feet and rest on igneous basement rocks. More specifically, from Lake Meredith upstream to the vicinity of U.S. Highway 87 and for a short distance immediately downstream from the New Mexico-Texas State line, the inner valley is cut into Permian age rocks. Elsewhere, the inner valley is cut in Triassic age rocks.

Near Logan, New Mexico, the Canadian River valley is cut into the Triassic Dockum Group sandstones, shales, and siltstones. Nearly everywhere the river channel proper is cut into the massive sandstone locally known as the Logan sandstone, which forms precipitous bluffs up to 100 feet high. Downstream from the confluence with Revuelto Creek, however, the river channel has cut through the Triassic age sandstone and into the underlying Permian age siltstones and shales of the Bernal Formation.

Considerable ambiguity and confusion are to be found in the geologic literature of the region concerning subsurface conditions and formational nomenclature. F. D. Trauger (Ground Water in East-Central New Mexico - New Mexico Geological Society - 23rd Field Conference, 1972, page 203) noted the similarity between the Santa Rosa and Chinle sandstone members. He explicitly refers the "thick sandstone near Logan" to the middle sandstone member of the Chinle Formation. Tracing with certainty the lensing middle sandstone member of the Chinle and the rapidly thinning or discontinuous Santa Rosa sandstone is difficult. The sandstone in the Logan area is more commonly assigned to the Santa Rosa sandstone. The thickness attributed to the Santa Rosa sandstone at any one location can be due either to irregularities of the Permian depositional surface or to

GENERALIZED GEOLOGIC COLUMN
QUAY COUNTY, NEW MEXICO
LAKE MEREDITH SALINITY STUDY, TEXAS-NEW MEXICO

ERA PERIOD GROUP	FORMATION THICKNESS (FT)	CHARACTER
CENOZOIC QUATERNARY	ALLUVIUM 0-100 0-50	Sand, silt, and gravel in present Canadian River channel. Silty sand, gravel, and clay of high terrace deposits with some aeolian sand and silt.
TERTIARY	OGALLALA 0-200	Sand, gravel, and caliche, with some silt and clay.
MESOZOIC TRIASSIC DOCKUM	CHINLE 0-865	Shale, siltstone, and silty sandstone with local thin beds of conglomerate and limestone. Three well-defined members may occur; upper and lower members of predominantly shale and siltstone, and a middle member similar to the Santa Rosa sandstone. Greenish-gray to bluish-gray but weathering to brown, red, or purplish red. In Texas, known as Trujillo formation.
	SANTA ROSA 200-450	Silty to clean, fine to coarse-grained, massive to crossbedded gray to bluish-gray sandstone, locally conglomeritic, with thin to thick beds of red and bluish-gray shale and siltstone. Thin beds of carbonaceous shale or soft coal in upper member. In Texas, upper members known as Trujillo formation and lower fine-grained sandstone known as Tecovas formation.
PALEOZOIC PERMIAN ARTESIA	BERNAL 200-500	Salmon, pink to orange-red to gray shale, siltstone, sandstone, limestone, dolomite, halite, and gypsum.
	SAN ANDRES 500±	Gray limestone, dolomite, halite, gypsum, and anhydrite.
	GLORIETA 0-80	Fine to medium grained well sorted, gray, tan, or white sandstone, usually cross-bedded with minor shale and siltstone.

Figure 1

where the contact with the overlying Chinle is picked. In addition, the sandstone constituting the river bluffs at Logan has a strong lithologic resemblance to the Trujillo and Tecovas Formations of the Dockum Group in Texas. Zane Spiegel (Cenozoic Geology of the Canadian River Valley, New Mexico, 23rd Field Conference New Mexico Geological Society, 1972, pages 118-119) refers to the "resistant sandstone of the Trujillo Formation" in the Logan, New Mexico, area. Notwithstanding the various stratigraphic assignments for the sandstone outcrops at Logan, for this report these outcrops are considered to be correlative to the Triassic Dockum Group.

The rock formations in the general area of Logan are essentially flat-lying. However, in the area of aquifer investigations south and southwest of Logan there appears to be a westward or northwestward (upstream) component of dip. The attitude of the formations is related to the Logan anticline, a broad north-northeast trending flexure, the axis of which crosses the Canadian River about a mile downstream from the Canadian River-Revuelto Creek confluence. This flexure is believed to be a depositional feature developed over a topographic high in the Precambrian basement, rather than a compressional or tectonic feature. Local rapid thinning of beds and pronounced lithologic or facies changes in short distances result in variable local dips. No faulting or surface evidence of solution-collapse structures was observed within the immediate area and none are reported in the literature. Jointing is particularly prominent in the hard sandstones of the Triassic Dockum Group.

The floor of the river channel is blanketed by fine sand, silty sand, and silt. The uplands above the channel, particularly on the north side of the river, are blanketed by gravelly and sandy terrace and windblown deposits. Such deposits are similarly noted in the Logan area.

Ground Water

By far, the major portion of ground water in the Canadian River valley is highly mineralized, probably by association with chemical sediments of salt and anhydrite of Permian age. Some of these ground waters are probably connate in origin, i.e., trapped sea water.

Highly mineralized brine aquifers of Permian age occur at shallow depths beneath the entire study area between Lake Meredith and Ute Reservoir and also occur in overlying rocks of Triassic age. Total thickness of these aquifers range from about 1,500 to 4,000 feet. Records from a number of oil test wells indicate these salty aquifers are under sufficient artesian pressure to flow to ground surface.

Flow in Canadian River, except from direct storm runoff, is primarily base flow. Most of the streams tributary to the Canadian River originate as fresh ground water flow from the Ogallala Formation along the "breaks" of the outer valley. In the inner valley and along the river, such flows are from either or both the Triassic and Permian Formations. As a rule, water from the Triassic rocks is of fair to poor quality, while water derived from the Permian rocks is highly mineralized.

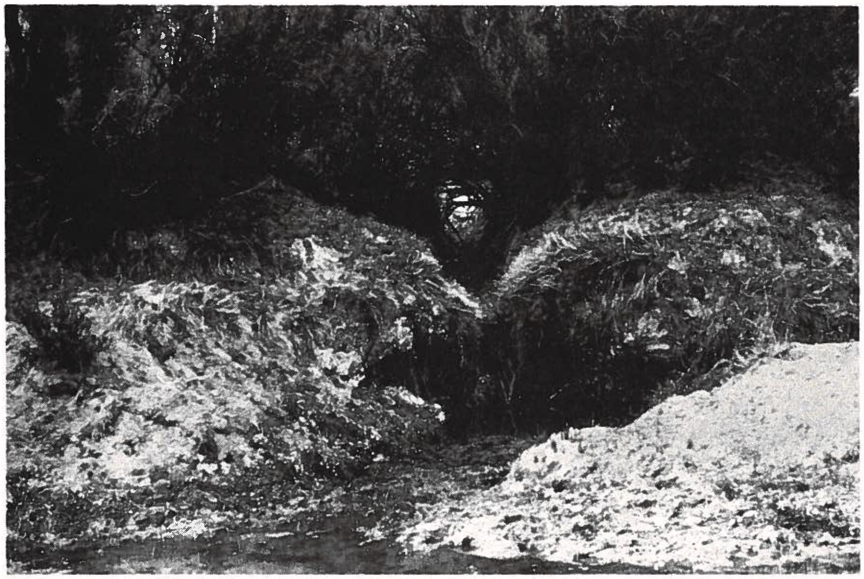
Ground water of poor quality in the Triassic rocks in the Canadian River valley appears as salt pollution in the stream below Ute Dam and is most probably derived from natural upward leakage along rock discontinuities from underlying Permian evaporites. Thick accumulations of salt deposited with sand, silt, and clay within Early Triassic collapse structures or juxtapo-sition of Triassic sands with Permian salt beds may have occurred during deposition of Triassic sedimentary rocks over an older topography of sinkholes and subsidence features. Old and numerous rock joints and fractures may be strongly developed over these local features. Saline waters may migrate upward from these features through the subsurface joints, fractures, and other discontinuities and may then occur as shallow brine or saline aquifers. When rock discontinuities reach the surface, the upward leakage occurs as surface springs or seeps.

Investigators, using electrical conductivity meters in the field, correlated small visibly colored areas, probably representing proliferation of saline water algae, as being adjacent to the numerous small brine seeps and springs scattered along the Canadian River reach between Ute Dam and Revuelto Creek. By their dimensions the colored areas indicate no major structural conduit is involved in the leakage.

Since construction of Ute Dam in 1962, ground water discharge immediately downstream from the dam has increased due to reservoir leakage and possibly to hydraulic loading on the Triassic aquifers.

There are no significant occurrences of potable water in the Logan area except for local occurrences at shallow depths of "fair to poor quality" water in Triassic sandstones and Pleistocene terrace material in and beneath the inner valley.

View of highly saline seep areas along the Canadian River channel below Ute Dam



PRELIMINARY INVESTIGATIONS
(1972-74)

Riverbed Sand Test

In January 1972, the Bureau of Reclamation began special investigations aimed at locating a point source or sources contributing to the salinity problem. Initially, it was felt that a significant amount of saline pollution existed in the riverbed sands above Lake Meredith. The salts were thought to be accumulating as a result of evaporation during low-flow periods then flushed out and transported downstream during high flows. Hydrologic field investigations, using an all-terrain vehicle, were initiated along the Canadian River between Lake Meredith and Ute Dam.

A sampling and testing program of the riverbed sands combined with an evapotranspiration study was conducted at various points along the river channel. The results of these investigations generally indicated that the evaporation and flushing process was not a primary source of saline pollution. Thus, it was concluded that an upward migration or inflow of poor quality water from beneath the riverbed was a more likely source of pollution.

Subsurface Water Test

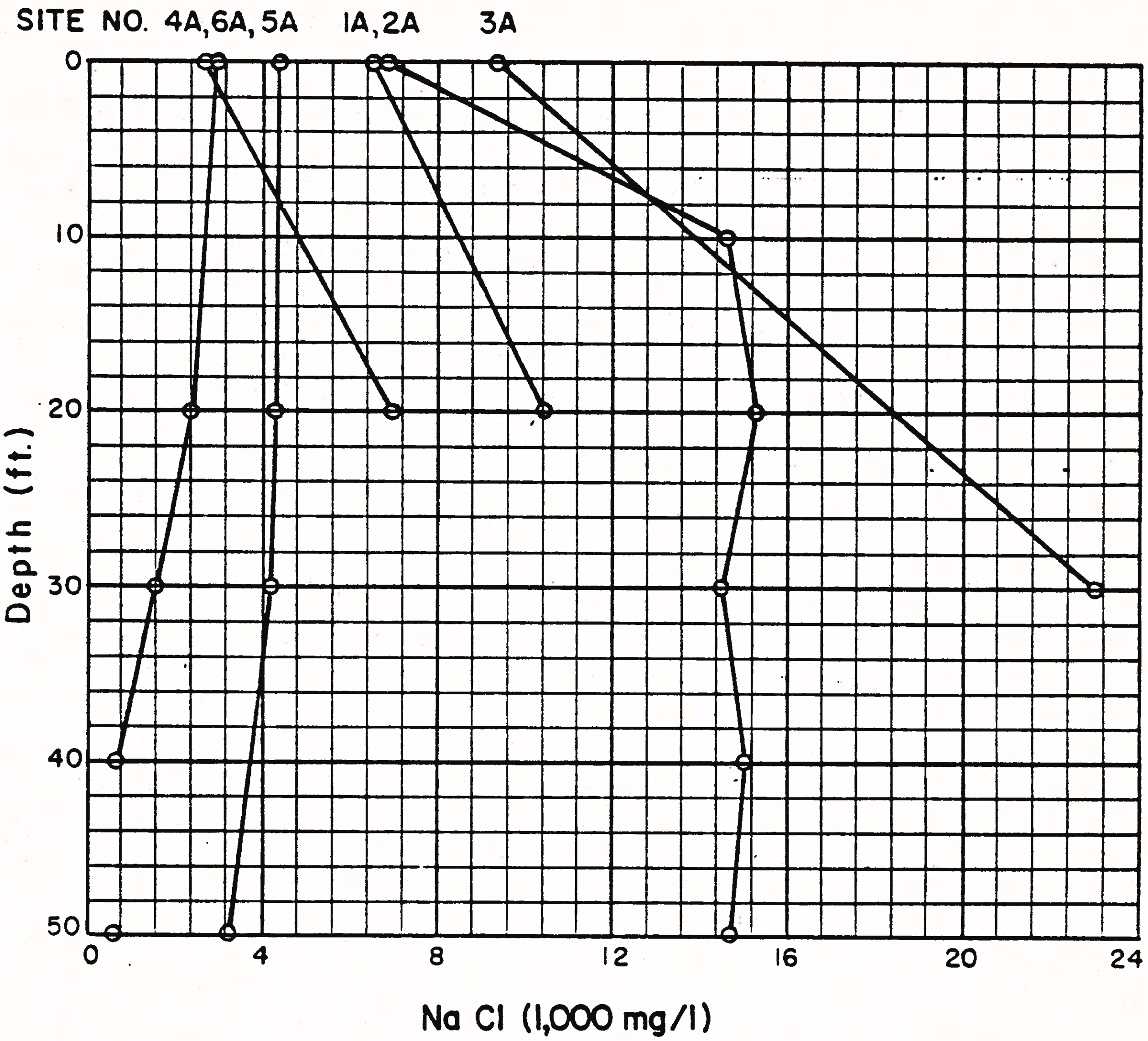
In the spring of 1974, the Bureau initiated the first of two subsurface water sampling programs in the river channel. Groups of five sand points (test holes) were drilled at four sites between the U.S. Highway 54 bridge near Logan, New Mexico, and the U.S. Highway 87 bridge just above Lake Meredith, a reach covering about 120 miles of the Canadian River.

Water samples were taken at 10-foot intervals up to depths of 50 feet at each site. The results of the chemical analyses indicated that high concentrations of sodium chloride occur in the riverbed between Ute Dam and the New Mexico-Texas State line. These data prompted a second series of test holes and water sampling to be conducted in an effort to further isolate the sources of contaminant inflow.

Additional groups of sand points were drilled and sampled at six sites in the river channel between Ute Dam and the State line. Chemical analyses of the water sampled were made, and the results indicating concentrations of sodium chloride are shown in figure 2. These data strongly suggested an area of subsurface pollution inflow along the channel 2 to 5 miles downstream from Ute Dam.

Contractor personnel drilling shallow wells in the Canadian River channel

Shallow well being surged during water sampling along Canadian River



Na Cl (mg/l) vs. Depth for water samples from drill holes in channel alluvium. Sampled 3/6/75

Site 1A - 1 Mi. D/S from Ute Dam
Site 2A - 2 Mi. D/S from Ute Dam
Site 3A - 5 Mi D/S from Ute Dam
Site 4A - 6 Mi D/S from Ute Dam
Site 5A - 11 Mi D/S from Ute Dam
Site 6A - 29 Mi D/S from Ute Dam

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Na Cl vs. Depth

FIGURE 2

EXPLORATORY DRILLING
(1975)

General

In April 1975, a decision was made to drill and water sample two fairly deep test holes adjacent to the river channel near Logan, New Mexico. It was felt that data gathered from these holes would confirm the suspected presence of a highly saline aquifer located beneath the Canadian River in the general area of Logan.

One hole, drilled to a depth of 356 feet, designated DH-1, was located at the U.S. Highway 54 bridge and the Canadian River near Logan. The second hole, drilled to a depth of 536 feet and designated DH-2, was located about 2,000 feet downstream from the Canadian River-Revuelto Creek confluence, about 2 miles northeast of DH-1.

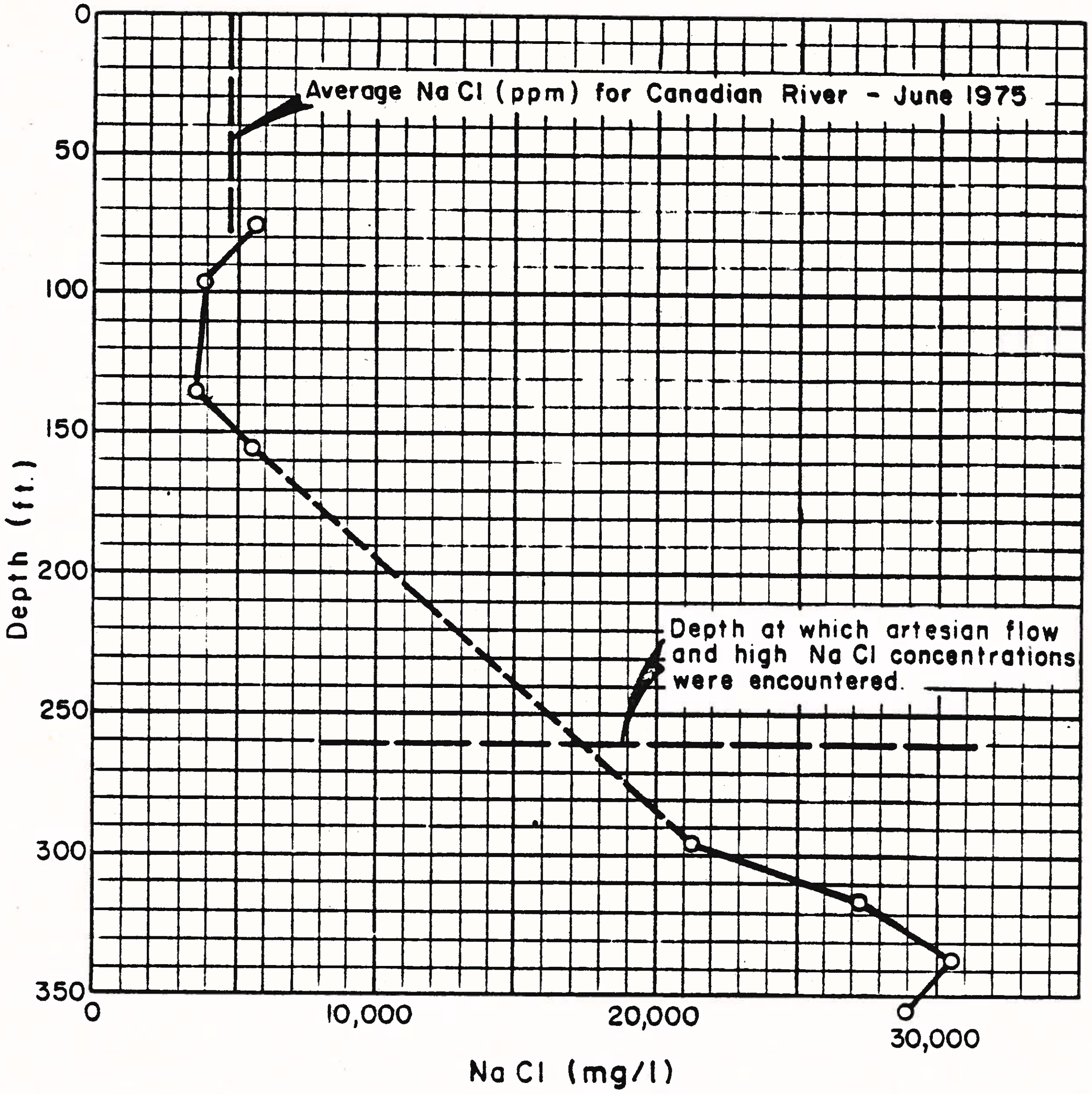
The holes were drilled and sampled in June-July 1975 by a Bureau crew and equipment. In August 1975, the geologic conditions in the 7-mile river reach downstream from Ute Dam, as well as major tributaries, were surveyed by Bureau personnel. There was no surface evidence of either fault or subsidence-collapse structures in the area surveyed. Electrical conductivity meters were also used to map saline concentrations and extents along the river.

Summary of Exploration

Drilling and sampling through the sandy channel alluvium was accomplished by using a 7-7/8-inch rock bit. Six-inch surface casing was set through the alluvium and tightly seated into formation rock. Formation rock was drilled using 4-3/4-inch drag bits. Cuttings samples were obtained at 10-foot intervals, bagged, and marked for future logging. Thin bentonitic drilling mud was used throughout the operations.

Water samples were taken by air lift pumping to a depth of 156 feet in DH-1. Samples of artesian flow were taken as the hole was drilled between depths of 261 and 356 feet; the flow rate was about 30 gallons per minute (gal/min). The concentration of sodium chloride for various depths in DH-1 and an average concentration for riverflow during the time of drilling are given in figure 3. Water sampling at periodic intervals was not done in DH-2; however, drilling fluid return at DH-2 was monitored by electrical conductivity readings in order to detect significant changes in water quality. At depths of 516 and 536 feet in DH-2, chemical analyses of water samples of minor artesian flow indicated sodium chloride concentrations of 7,920 and 8,168 mg/l, respectively.

Cutting samples from the holes were analyzed under a binocular microscope, and geologic logs were prepared. Based on the geologic



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Na Cl vs. Depth

DH-1

JUNE 1975

FIGURE 3

literature, a general knowledge of the geology of the region and area, interpretations made from cutting samples, and results of chemical analyses of water samples, it appears that DH-1 penetrated material which can be divided into four separate layers. The sequence is as follows:

Depth, feet	General Character
0 - 30	Sand, gravel, cobbles
30 - 196	Sandstone
196 - 261	Shale and sandstone
261 - 356	Sandstone - contains brine under sufficient pressure to flow at surface

By deduction from similar data, DH-2 penetrated three differing layers. The sequence is as follows:

Depth, feet	General Character
0 - 33.7	Sand, gravel, cobbles
33.7 - 56	Sandstone and shale
56 - 536	Shale

Geologic logs prepared on these two drill holes are appended to this report (appendix D).

Based on meager geologic literature pertaining to northeastern New Mexico, it appeared at that time that a brine aquifer of "Glorieta-like" sandstone was encountered at the relatively shallow depth of 261 feet in DH-1. Neither the brine aquifer nor any "Glorieta-like" sandstone was encountered in DH-2. The Glorieta Formation is described in figure 1.

No salt beds were encountered in the Bureau's drilling operations.

Findings

The initial findings of the exploratory drilling program confirm the presence of a major area of salt pollution occurring in the river reach extending from Ute Dam downstream to the vicinity of the Canadian River-Revuelto Creek confluence (approximately 6 miles). The saline pollution, which is suspected to originate as water flowing through Permian evaporites, is considered to be a direct result of upward migration of brine from a relatively shallow artesian aquifer. The aquifer exhibited sufficient pressure to flow at the ground surface. A three-dimensional configuration of the brine artesian aquifer in "Glorieta-like" sandstone encountered at DH-1 could not be determined on the basis of available data.

Determination of the upstream-downstream extent, thickness, and hydrologic characteristics of the aquifer would be useful in determining the feasibility of alleviating brine migration into the river channel.

GEOPHYSICAL INVESTIGATIONS
(1975)

General

In December 1975 the geologic and hydrologic situation of the brine aquifer located in the vicinity of Logan, New Mexico, was reviewed. The analysis of existing information led to the conclusion that electrical resistivity and seismic refraction geophysical investigations could be used advantageously in determining the depth, thickness, and extent of the aquifer.

At this point in the study, Bureau personnel began considering various alternatives that might reduce and possibly eliminate the upward migration of brine from the identified aquifer. One solution which appears to have merit would be to lower the piezometric surface */ of the aquifer by pumping. A lowering of the piezometric surface or head pressure of the aquifer might reduce or eliminate the upward flow of brine and prevent brine from entering the Canadian River. Two factors affecting the success of such a scheme would be (1) the rate of pumping required to lower the piezometric surface and (2) an acceptable means to dispose of the brine.

With a potential plan in mind, the Bureau proceeded with the geophysical investigations to determine to the extent possible the gross physical characteristics of the brine aquifer. In May 1976 personnel proceeded to conduct seismic refraction and electrical resistivity sounding surveys.

Field Procedures

One seismic refraction line 2,400 feet long was located near Logan. Seven shot-points and 24 geophones were used for the line. Surface layer velocity control was obtained by exploding blasting caps at a depth of one-half foot utilizing 12 geophones spaced at 5-foot intervals. In addition, six Wenner array resistivity soundings up to a maximum spacing of 1,200 feet were obtained.

Results

The seismic refraction field data were plotted on time-distance graphs and analyzed to determine the number of seismic boundaries. The respective boundary velocities were used in a computer analysis to obtain a layer-thickness profile. The seismic profile developed shows four layers. In

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*/ The piezometric surface of an aquifer is the imaginary surface representing the static head of ground water and is defined by the level to which water will rise in a well. Synonyms are potentiometric surface, isopotential level, and pressure surface. (Gary, McAfee, and Wolf, Glossary of Geology, American Geological Institute, 1974.) The piezometric surface of this particular brine aquifer near Logan, New Mexico, is above the bed of the Canadian River and also above the adjacent ground surface.

assuming that seismic boundaries correspond to lithologic boundaries, the following correlation is the most probable:

Layer	Seismic Velocities (feet/sec)	Lithology
1	2,156	Alluvium and weathering
2	7,467	Sandstone
3	8,100	Shale
4	9,600	Sandstone

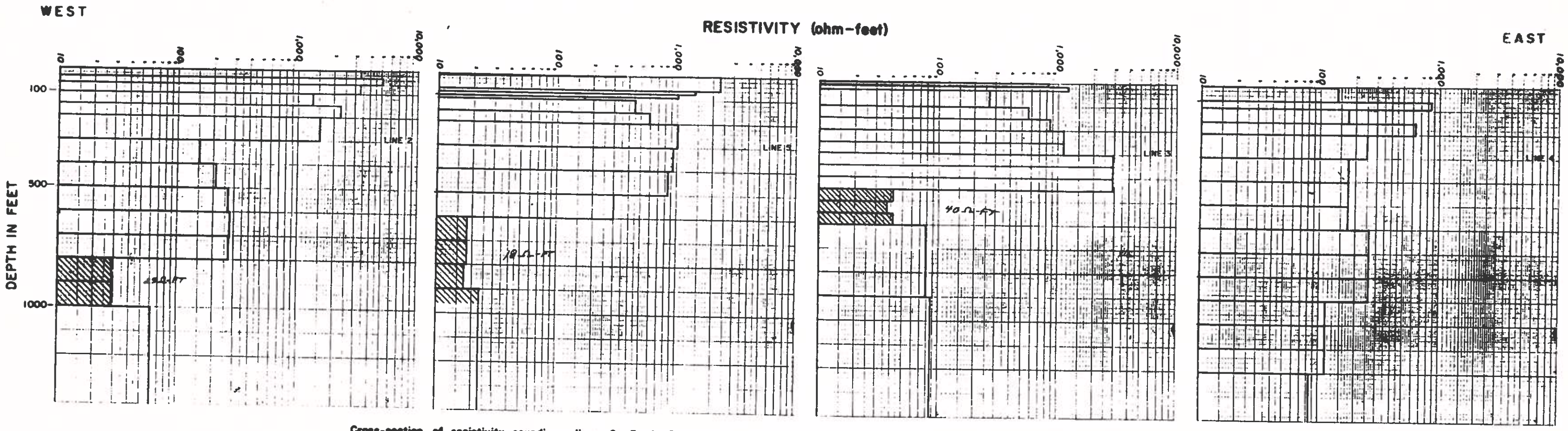
An estimate of aquifer fluids was not an objective nor was such an estimate achieved by this seismic survey. However, the seismic survey demonstrated that:

1. Layering is present in the subsurface materials.

2. Layering could probably be mapped in the Logan area using simple seismic refraction methods.

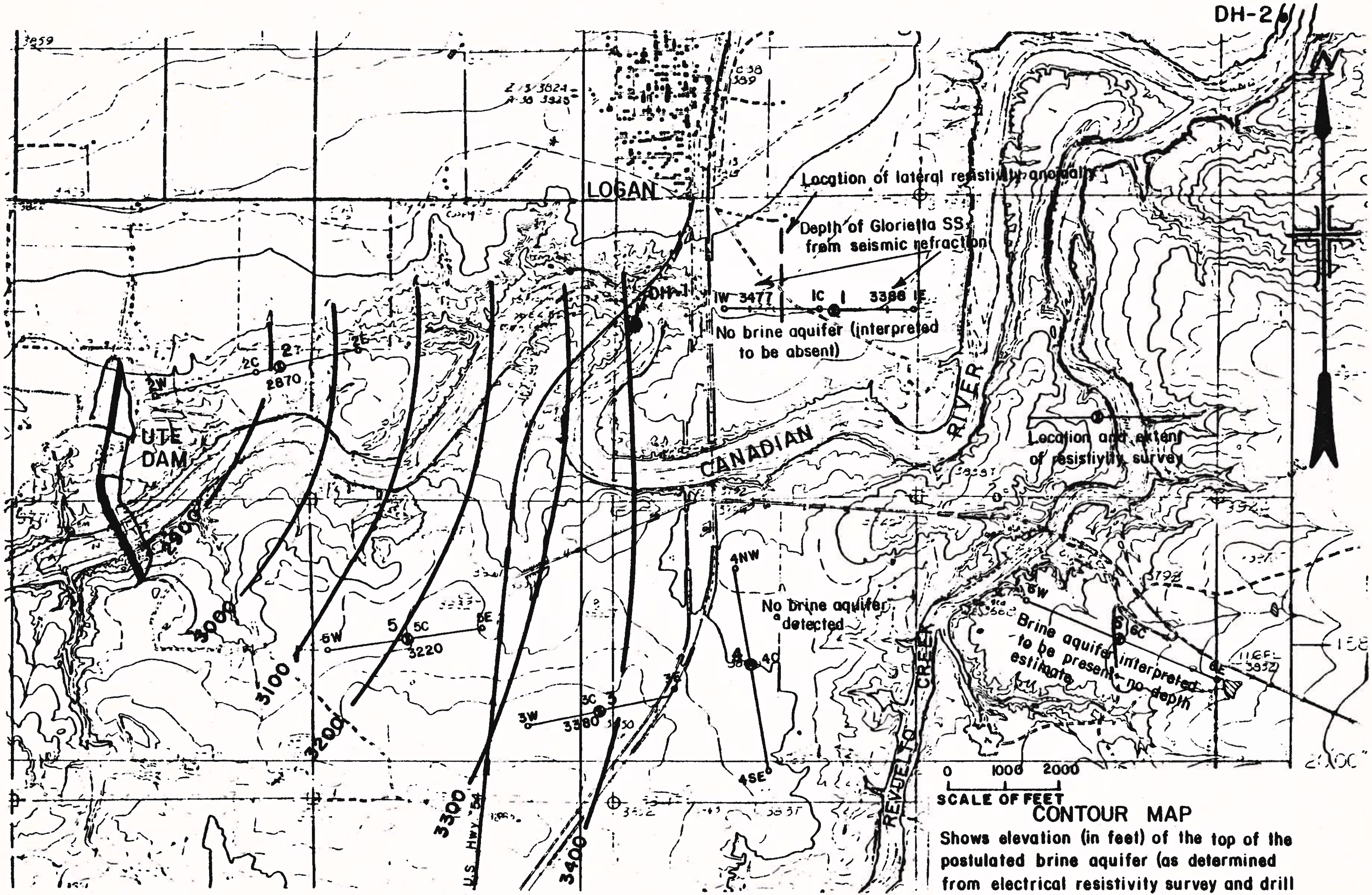
The electrical resistivity sounding field data were submitted to a computer curve matching program to obtain estimates of layer depth and resistivities. Four of the six resistivity soundings were curve matched and are displayed in a general west to east sectional view on figure 4 (the interpreted major low resistivity layers have been hatched). For the deeper portion of the sounding curve, each profile model was arbitrarily divided into even depth increments. It should be pointed out that the computer program does not account for lateral resistivity changes within each horizontal layer, but assumes a constant lateral resistivity for each layer. If present, severely dipping beds, faults, joints, and extremely rugged topography could further violate the assumed horizontal layer distribution and, therefore, curve matching techniques would not be valid.

Soundings 2, 3, 4, and 5 indicate some reasonably reliable results. The brine aquifer is interpreted to be present in soundings 2, 5, 3, and 6. This interpretation is made on the basis of an abrupt lower resistivity of the materials. The brine aquifer is interpreted to be absent in both soundings 1 and 4. A sharp resistivity low recorded at sounding 1 is attributed to an abrupt lateral change in resistivity. A change of this nature may be attributed to a subsurface fault, a joint system, or cultural phenomena (powerlines, etc.). The approximate location of this lateral change is shown on figure 5. The interpreted elevations of the top of the brine aquifer have been contoured on figure 5 to help envision the areal configuration of the top of the aquifer. The brine aquifer appears to be dipping to the west at approximately 4°. The thickness of the brine aquifer was interpreted to be about 300 feet for sounding 2, greater than 300 feet for sounding 5, and about 150 feet for sounding 3. These soundings are located east and southeast of Ute Dam (shown on figure 5).



Cross-section of resistivity soundings, lines 2, 3, 4, 5, the brine aquifer has been cross-hatched.

FIGURE 4



Drill Hole - DH

FIGURE 5

CONTOUR MAP

Shows elevation (in feet) of the top of the postulated brine aquifer (as determined from electrical resistivity survey and drill hole information).

Lake Meredith Salinity Study

Geophysical investigations, such as those previously described, do not determine the direction or magnitude of flows within aquifers; lateral flow in the brine aquifer is unknown. In the Logan area, saline waters enter the Canadian River from below the riverbed.

The results of the electrical resistivity survey also tend to indicate a possible channelization (localized occurrence) of low-resistivity material in the area about one-fourth mile southeast of Logan. Brine seepage along joints or fault zone may relate to this possible channelization. Recommendations are that if additional geophysical surveys are performed, the anomalous event occurring at sounding 1 should be tracked by electrical resistivity profiling in a direction toward the river. In addition, three more resistivity soundings could be useful: one located between sounding 1 and DH-1; a second to the south of 4; and a third to the north of sounding 6. The electrical resistivity survey mainly demonstrated that:

1. The brine aquifer can be detected by this method.

2. Resolution of the lateral variation, depth, and thickness of the brine aquifer is questionable when compared to more expensive drill hole results.

3. The brine aquifer extends for at least several miles south and west of DH-1 (soundings were not performed north of DH-1).

4. A discontinuity or boundary of the brine aquifer may exist east of DH-1.

AQUIFER PUMP TEST
(1978)

Investigations to this point confirmed the presence of a brine artesian aquifer located in the vicinity of Logan, New Mexico. The aquifer is considered to be a point source of pollution contributing to the salinity problem at Lake Meredith. Exploratory drilling, supplemented by electrical resistivity and seismic refraction geophysical surveys, has established the vertical configuration of the aquifer within the limits of data interpretation. DH-1 encountered the top of the aquifer at elevation 3,414 feet or a depth of 261 feet. Resistivity surveys further located and determined the relative thickness of the aquifer. The data suggested a dip of 4-5° to the west from DH-1.

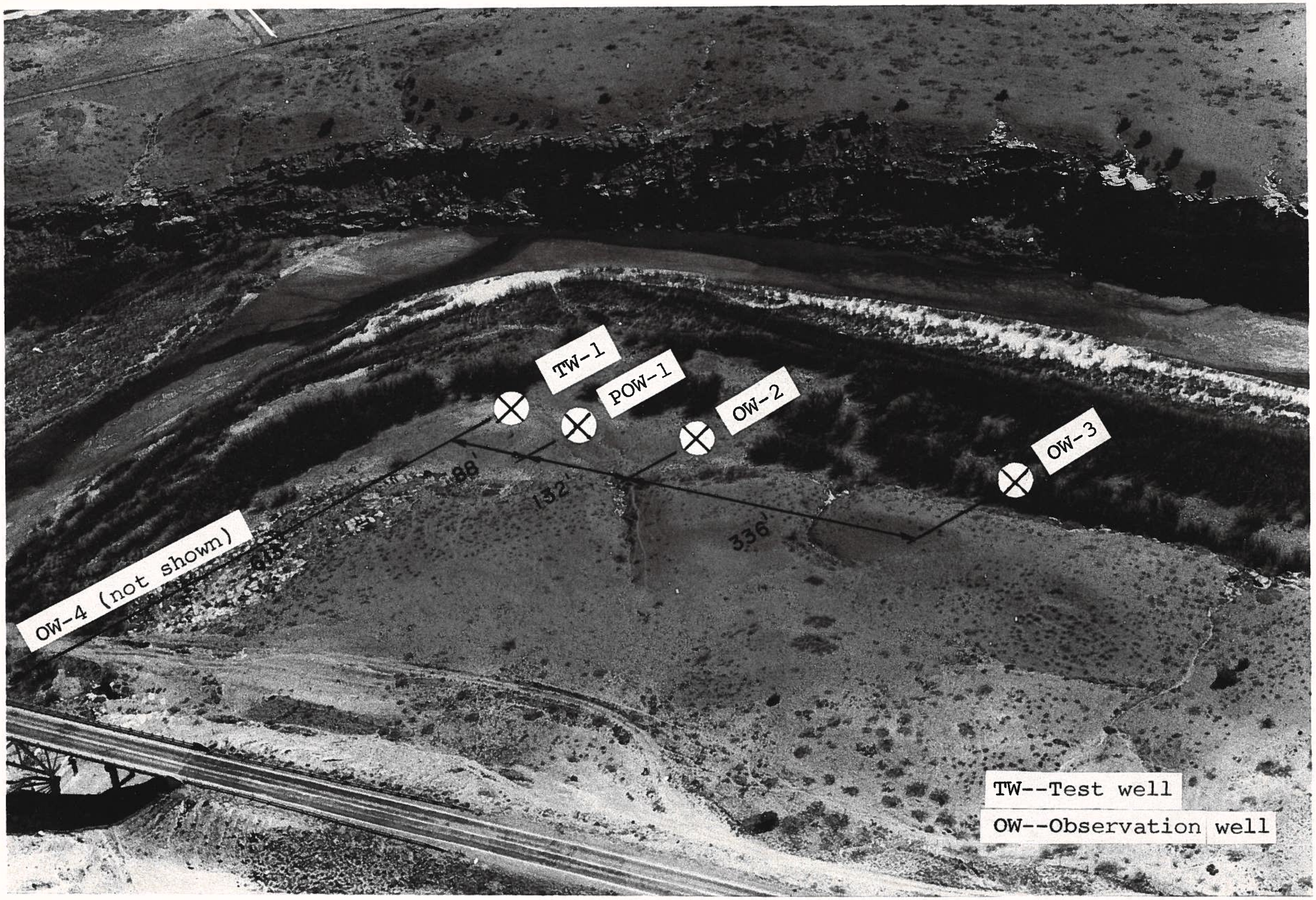
DH-2 located about 2 miles to the east-northeast of DH-1 did not encounter a brine aquifer but did encounter artesian conditions. Several interpretations possibly explain the lack of brine in DH-2. These are: (1) the brine aquifer dips to the east and DH-2 was not drilled sufficiently deep to penetrate it; (2) the brine aquifer wedges or pinches out within the 2-mile interval between the two holes; or (3) the aquifer is continuous to the east, but a salinity change occurs in the aquifer between the two holes.

An examination of the above findings led to the conclusion that further delineation of the aquifer at this point in the investigation was not essential in developing a plan to control the pollution. It was felt, however, that additional data were needed concerning the hydraulic characteristics of the aquifer. With this type of information, the feasibility of isolating the brine by lowering the piezometric surface of the aquifer could be determined. In order to obtain the necessary hydraulic data, an aquifer pump test was required.

Location and Design

The pump test site was chosen for ease of access and for its location about midway between Ute Dam and Revuelto Creek, the known limits of saline water inflow to the river. The specific location is adjacent to DH-1 in the west half of sec. 21, T. 13 N., R. 33 E., about three-fourths mile south of Logan, New Mexico. The test site and well configuration are shown in the following photograph.

A test well (TW-1) and four observation wells (OW-1 thru -4) were drilled by a private contractor. The location, design, spacing, and number of wells were determined from inspection of the logs of DH-1 and chosen to allow data interpretation by several methods.



Lake Meredith Salinity Study -- View of pump-test site located at U.S. Highway 54 and Canadian River near Logan, N.M. Flow in the river is left to right. North is to the viewer's left.

The contractor experienced difficulties with both drilling and well completion. Observation well No. 2 became plugged and did not experience a water level change during the pump test. The failure of this well to function properly, however, did not seriously affect the overall results of the pump test. A complete description of each well is contained in the Aquifer Pump Test Report which is appended to this report (appendix C).

Geologic Results

Cuttings and core samples from the four observation wells were examined, and the geologic logs prepared are appended in this report (appendix D). Drilling and sampling methods for each well are described on the logs. In addition, electric logging was done in the holes, and a probable correlation is shown on drawing No. 1253-500-14 located in appendix D. The top of the brine aquifer in each well was selected taking into consideration data from drilling and sampling.

It appears that the five wells were drilled entirely within sandstone and shales of the Triassic Dockum Group. The Santa Rosa sandstone is reported to be as much as 450 feet thick near the Canadian River south of Logan (Berkstresser and Mourant 1966). The Olean No. 1 Woods well in sec. 9, T. 13 N., R. 34 W., lying 5 to 6 miles east of the Logan site, was drilled from an elevation of 3,915 feet and reportedly penetrated 375 feet of Santa Rosa sandstone. The Triassic age sandstones appear to be higher and somewhat thicker at the test site. Up to 800 feet of Permian age rocks younger than the Glorieta-like sandstone may be expected beneath the Triassic age sandstones and shales (Foster et al. 1972). Many brine aquifers occur in east-central New Mexico within Permian age rocks. Brine aquifers, such as the one located in these investigations, are also present in Triassic age rocks in Quay County due to natural upward leakage through Permian evaporites.

Aquifer Test

A 3.7-hour step drawdown test was completed March 7, 1978. No attempt was made to analyze the preliminary test results in detail. The test was used to assure that the test well was completely developed and to assist in setting the pump discharge for the constant yield test. The test demonstrated that significant drawdowns could be developed at a pumping rate of about 475 gal/min and that the pump and engine could readily handle such a discharge.

The constant yield test was started at 2 p.m., March 8, 1978, and continued until 3 p.m., March 12, 1978 (elapsed time, 97 hours). Recovery was recorded until about 11 a.m., March 15, 1978 (elapsed time, 68 hours). The early portion of the test went quite smoothly with a constant pumping rate of 475 gal/min. After 930 minutes, a mechanical problem developed at the well head, and the pump was shut down 5 minutes for repairs. At 3,974 minutes, the pump was found to be discharging only 400 gal/min. After engine adjusting and refueling of the propane fuel tank, the discharge was returned to the 475 gal/min rate. These two variations in pump discharge do not appear to have significantly affected the long-term average discharge and are reflected in only a few of the many water level observations in the observation wells.

The brine pumped from TW-1 was routed through an aluminum irrigation pipe to the river channel and diffused into the riverflow through numerous small pipe outlets. Water was purchased from Ute Reservoir and released downstream during the test period as a means to further dilute the discharge entering the river. Numerous water samples and monitoring of the riverflows were taken to assure adequate dilution of the brine discharge and to provide base data for flow versus quality studies.

Barometric readings taken before and after the tests were limited, but there appeared to be no significant change in the regional water level during the test period. There appeared to be some indication of a low barometric efficiency but not enough to warrant correction of water level observations.

Pump Test Results

Feasibility of pumping

The results of the pump test conducted in March 1978 indicate that the piezometric surface of the identified brine aquifer intersects the bed of the Canadian River in the vicinity of Logan, New Mexico. The artesian flow from the aquifer, in the form of seeps and springs, aggregates about 0.6 cubic foot per second (ft^3/s) and is a major source of salt pollution to the river and presumably to Lake Meredith. The identification of a localized source of pollution near Logan does not preclude that there may be additional contributions of saline water to the river channel farther downstream which are unaccounted for in this study.

At the pump test site, the piezometric surface of the brine aquifer was determined to be about 10 feet above riverbed level. Test results indicate that significant head pressure could be relieved throughout the Ute Dam-Revuelto Creek reach of the Canadian River by pumping one or more wells completed in the aquifer. In this manner the piezometric surface of the brine aquifer could be lowered and maintained below the riverbed, and saline pollution of the Canadian River in the Logan area would be correspondingly reduced.

A sustained pumping rate of about 1 ft^3/s over the first year would be required to lower the piezometric surface to required levels. After 1 year, a reduced pumping rate could probably maintain the level within the desired limits. A constant discharge of 1 ft^3/s would result in about 730 acre-feet per year of brine being brought to the surface which would require an acceptable means of disposal.

Contractor's drilling rig and equipment at Test Well No. 1, south of Logan, New Mexico. Canadian River channel is about 100 yards beyond the equipment.

In order to select the optimum well site(s) for continuous pumping from the aquifer, an array of observation wells completed as piezometers should be first installed in the Logan area. The piezometric surface and local extent of the brine aquifer could then be more accurately determined before final drilling and pumping of brine from the aquifer. These observation wells could also serve as monitors during a sustained pumping program. It is also recommended that an additional aquifer pump test be conducted after completion of the piezometer network and prior to a final pumping program. Such a test well would be designed for sustained pumping use.

Effects of isolating the aquifer

The effects of isolating the brine aquifer can be determined through an analysis of salt concentration entering the channel at Logan and comparing these amounts with the total inflow amounts entering Lake Meredith. Numerous brine samples were taken directly from the pump discharge line during the test and analyzed. The results of two representative analyses (partial) are shown in the followng tabulation.

Sample No. 1 taken 7 March 1978 1/

pH	7.10
Sodium (as Na)	14,300 mg/l
Chloride (as Cl)	22,000 mg/l
Sulfate (as SO_4)	9,700 mg/l
Total of above constituents	46,000 mg/l

Sample No. 2 taken 12 March 1978 1/

pH	7.56
Sodium (as Na)	14,300 mg/l
Chloride (as Cl)	22,000 mg/l
Sulfate (as SO_4)	8,600 mg/l
Total of above constituents	44,900 mg/l

1/ Complete analysis unavailable

The above values were analyzed with other quality and flow data to determine the annual rate of salt contribution from the aquifer. The annual inflow values to Lake Meredith were determined by monthly studies based on water quality records covering the period 1965 through 1977. The relationship between the estimated annual salt contribution of the aquifer and the annual inflow values to Lake Meredith is shown in the following tabulation.

Constituent	Contribution of brine aquifer tons/yr 1/	Inflow to Lake Meredith-tons/yr 2/	Percentages contribution to inflow
Sodium (as Na)	8,500	27,660	31
Chlorides (as Cl)	13,000	29,525	44
Sulfate (as SO_4)	5,400	26,910	20
Total of above constituents	26,900	84,095	32

1/ Assumes a constant discharge of 0.6 ft^3/s

2/ Based on inflow and water quality records 1965-77

From the above values it can be seen that a significant improvement in the water quality of the riverflows near Logan could be obtained by isolating the brine seepage from the aquifer. It must be determined, however, whether the isolation of salinity from the brine aquifer in the area of intersection with the river channel will in fact reduce the salinity of water flowing into Lake Meredith, since lateral movement of the brine may be occurring. The length of time for an improvement to occur in Lake Meredith water must also be determined.

It is obvious that the predicted improvement in Meredith water quality would not be immediate after isolating the brine aquifer at Logan. It is postulated that improvement of the lake's water quality would be a gradual process directly related to the ability of the Canadian River flows to flush accumulated evaporites from the upper portions of the channel alluvium. Future studies would attempt to verify this.

In addition to the surface saturation, there is undoubtedly a large amount of water contained in the river channel alluvium that continually moves slowly downstream toward Lake Meredith. Preliminary estimates indicate the total volume could be as much as 80,000 acre-feet. Some of this water is poor quality attributed to the brine seepage occurring at Logan. The amount of poor quality water and the length of time it would take to become depleted following isolation of the brine aquifer are not known at this point. Estimating the time period would depend on determining such values as the cross-sectional area of the alluvium, the hydraulic gradient or slope of the system, and the coefficient of permeability of the alluvial riverbed material. It should be pointed out that even if all of these factors could be determined at one or more points, homogeneity of the alluvium would have to be assumed. Such homogeneity is not likely. Nevertheless, future studies should consider this condition in evaluating the effects of isolating the brine aquifer at Logan.

Future studies would attempt to establish proof that salt from the brine aquifer actually reaches Lake Meredith. If confirmed, these studies would also evaluate the possibility of removing poor quality water from the channel alluvium by pumping from the bottom portion of the alluvium at a point just above Lake Meredith. This concept is based on the assumption that the more dense poor quality water is still stratified at that location. If so, the brine could be isolated at Logan with a simultaneous withdrawal occurring at the lower end of the river reach near Lake Meredith. Pumping from the alluvium near Meredith would require additional disposal facilities.

If the effects of the brine aquifer at Logan are eliminated, the average concentration of sodium, chloride, and sulfate inflow into Lake Meredith should be reduced from about 500 to about 350 mg/l. This reduction is expected to result in a reservoir average concentration for TDS of about 800-900 mg/l under present lake water conditions. Thus it appears that isolation of the brine aquifer at Logan would result in a water quality improvement of the Canadian River-Lake Meredith system that otherwise would probably not occur.

ALTERNATIVE PLANS - BRINE AQUIFER ISOLATION

This section of the report provides a narrative description of three alternative plans which were given consideration in isolating the brine aquifer located near Logan, New Mexico. All data presented are considered to be appraisal grade and would require further refinement at the feasibility level. Design data and cost estimates are provided for only the plan that appears to be the most viable at this time.

The three isolation alternatives include: (1) surface containment by constructing a holding reservoir across the river channel, (2) lowering the piezometric surface by pumping from wells and injecting the brine in deeper wells, and (3) lowering the piezometric surface of the aquifer by pumping from wells and disposal of the brine by surface evaporation.

Surface Containment (Channel Dam)

This plan considers the possibility of constructing a diversion dam or low-flow storage dam on the Canadian River immediately downstream from the aquifer seep area. Low flows, which generally contain the highest concentration of salts, could be impounded in the channel and allowed to evaporate or collected and pumped to an off-stream surface evaporation pond. This plan would allow the upward migration of brine from the aquifer to continue but would intercept the brine flow at a point downstream and provide for some means of disposal through evaporation.

The preliminary findings for implementing such a plan indicate that excessive development and maintenance costs would be incurred. The rugged terrain and steep canyon walls would reduce the possible diversion aspect, and large flows originating upstream would periodically flush out a holding reservoir and permit salts to proceed downstream. Therefore, it appears that a surface containment plan as envisioned above would not be practical. Additional study and evaluation of such a plan would be required to determine its viability.

Well Pumping and Deep Hole Injection

This plan is based on the reasoning that the upward migration of brine into the river channel could be reduced by lowering the piezometric surface of the artesian aquifer by pumping from a well(s). For this alternative, the method of disposal would be injection of the brine into wells in a suitable deep permeable layer. This method is often used for disposal of oilfield brines. It would consist of drilling a well(s) to some formational layer and injecting the brine into that layer either by gravity flow or by forced pumping.

Problems associated with this method of disposal are: locating a reasonably close formation suitable for injection, excessive drilling costs if the formation is deep, and the capability of the formation to receive and retain the brine for the life of the project. If the amount of brine to be disposed is rather large, it could require development of a series of disposal wells rather than a single well.

A preliminary investigation of the available oil well exploration logs in the Logan, New Mexico, area indicates that a formation suitable for brine injection is not available.

Additional geologic studies of the entire regional area would be needed in order to completely evaluate the feasibility of brine disposal by injection. It could be expected that exploratory drilling would be required if a potential formation was located.

Well Pumping and Surface Evaporation

This plan would reduce brine seepage into the river by lowering the piezometric surface of the aquifer through pumping and discharging the brine to surface disposal. The method for brine disposal would be a surface evaporation pond. Based on hydraulic data obtained from the pump test, a production well with a pumping capacity of about 1 ft^3/s could lower the artesian head of the aquifer sufficiently to prevent the upward seepage of brine into the river channel. The discharge from the well could be transported by pipeline to a nearby playa for storage and evaporation.

Plan features

The production well would be located about one-quarter mile downstream from Ute Dam in sec. 14, T. 13 N., R. 33 E., NMPM, Quay County, New Mexico, on the south bank of the Canadian River. At this location the well would be about 100 feet above streambed elevation. The well would be drilled to depth of about 970 feet and cased with 12-inch-diameter casing including 100 feet of 12-inch-diameter well screen. For this report the well is assumed to have a capacity of 400 gal/min to equate with estimates presented in the Aquifer Pump Test Report (appendix A).

Six observation wells would be located and drilled at various points in the area of the production well for monitoring purposes. Each well would be completed as a piezometer into the artesian brine aquifer with a 1-1/4-inch-diameter casing and well screen. Well depths would range from about 600 to 1,400 feet. Proposed location of the production and observation wells is shown on drawing No. 1253-500-13.

A potential brine storage and evaporation site selected for this study is within a playa located southeast of the production well site in sec. 5, T. 12 N., R. 34 E., NMPM. The site is located on low-productive land and has a minimal drainage area of about 12.5 square miles. Protective measures including monitoring devices would be required to minimize brine seepage from occurring at the site. Two hundred and thirty acres, lined with 20-mil polyvinyl-chloride (pvc) membrane of liner and enclosed with a dike, are used for estimating purposes. A system of drainpipes with risers under the liner material and eight observation wells around the perimeter are provided to monitor any seepage. Rights-of-way required for the disposal site are estimated at 350 acres and would be purchased in fee title. Some 2.7 miles of fencing would also be required to enclose the area.

The annual amount of salts that would accumulate through evaporation is estimated to be 34,500 tons. It is assumed that the storage site has the capacity to contain 100 years of salt and sediment deposits in addition to the water.

Delivery of the brine from the production well to the surface disposal site would be accomplished by a pipeline and two pumping plants. The pipeline would have a 12-inch-diameter and a lenth of about 36,750 feet (7 miles). The pipeline route would head east across open rangeland to State Highway 39, southeast along Highway 39, and then south to the playa. Approximately 42 acres of easement right-of-way would be required using a width of 50 feet.

The first pumping plant would be located at the production well; the second plant would be about at the midpoint or mile station 3.4 on the pipeline. Each plant would have electrically-operated pumps rated at a capacity of 400 gal/1min.

Location of the pipeline route and pumping plants are shown on drawing No. 1253-500-13.

Construction costs

Based on July 1979 price levels, the constructin costs for a surface discharge-surface evaporation plan that would isolate and control the brine at its source are:

Production well	$ 209,000
Observation wells (6)	100,000
Pumping plants (2)	147,000
Pipeline	1,324,000
Brine disposal area	5,600,000
Powerline	269,000
Seepage monitor system	221,000
Field cost	$ 7,870,000
Other costs (35%) 1/	2,750,000
Construction cost	$10,620,000

1/ Includes 10 percent preconstruction planning

Annual operation, maintenance, and energy costs (OM&E)

It is assumed that operation and maintenance (O&M) of plan features would be provided by a non-Federal entity such as the CRMWA utilizing its present personnel and equipment. A separate cost for replacements was not identified since the pumping plants are small; a minor cost is included in the maintenance cost figure. Energy cost was computed using a power rate of 35 mils per kilowatt-hour (kWh) and a pump efficiency of 72 percent. The pipeline O&M was estimated at 2.5 mils per dollar of field cost.

For a pumping system as would be employed for this playa disposal plan, electric power could be provided by solar and/or wind energy production methods. The potential should be explored for this plan in the feasibility study phase.

The O&M cost for monitoring the observation wells and brine disposal area is estimated using a salary equivalent to a GS-9 for 36 man-days per year to travel, monitor, and formulate data. Estimated annual O&M and energy costs to operate the facilities after conclusion of successful tests are:

Operation and maintenance		$ 7,600
Pumping plants	($1,100)	
Pipeline	($3,200)	
Observation wells and disposal area	($3,300)	
Energy (368,000 kWh)		12,900
Total annual OM&E cost		$20,500

Investment and annual cost

The total construction cost was estimated to be $10,620,000. It was assumed that 2 years would be required for preconstruction planning, and 1 year would be required for construction. Based on a 1-year construction period at an interest rate of 6.875 percent, the interest during construction (IDC) was estimated to be $365,100. This gives a total investment of $10,985,100. When amortized for 100 years at 6.875 percent, the annual investment is $756,200, and with the $20,500 for OM&E, the total annual cost would be $776,700.

The repayment of the construction cost and IDC would be based on the interest rate of 6.595 percent. The IDC would be $350,200, and the total investment would be $10,970,200. Total annual cost (50 years at 6.595 percent) would be $774,900 which includes the $20,500 for OM&E.

Benefits

Obviously, the isolation of the brine aquifer at Logan would produce benefits to the Canadian River-Lake Meredith system. Benefits would be derived from the reduction of salt concentration in the riverflows and the riverbed alluvium. The reduction of salt would not be immediately noticeable but would occur after several years. Some benefits should be realized relatively early after brine isolation begins. These might be in the nature of livestock and wildlife watering. However, the short-term benefits would be difficult to identify and quantify.

Long-term benefits would most likely be realized from the reduction of the salt concentration in Lake Meredith. This reduction would be realized by those cities and communities that receive water from the CRMWA. An improvement would be realized in taste and health aspects due to the reduction in sodium chloride. Monetarily, the reduction in salt would lower the maintenance costs of domestic and industrial water facilities.

The quantification of these benefits would be difficult. The esthetic benefits might be determined in the form of attitudes of persons utilizing the water. An attitude survey could be derived and questions directed to the public involved. The estimation of replacement costs might be determined utilizing information obtained from plumbing companies.

ENVIRONMENTAL ASPECTS

General Description

Administration of fish and wildlife resources

Fish and wildlife resources within Lake Meredith and the Canadian River are managed in Texas by the Texas Parks and Wildlife Department and in New Mexico by the New Mexico Department of Game and Fish. The National Park Service administers 28,433 acres of Lake Meredith project lands which are above the top of the conservation pool.

There are approximately 150 river miles between Ute Dam and Lake Meredith. Thirty-five miles are in New Mexico and 115 miles in Texas.

Aquatic, riparian, and wetland habitats and resources

Aquatic habitats in the study area include the Canadian River and Lake Meredith. The Canadian River below Ute Dam is intermittent although streamflows fluctuate widely depending on rainfall.

The New Mexico Department of Game and Fish collected 659 fish specimens, representing 11 species, at five collecting sites along the Canadian River in 1975. These sites were located from just below Ute Dam to a point 18.5 miles east of Logan. The fish collected represented species of carp, killifish, mosquitofish, chub, catfish, shiner, and minnow.

The Texas Parks and Wildlife Department developed a list in 1976 of fish species occurring in Lake Meredith and the Canadian River. The species list does not differentiate between river and lake dwelling species and includes species not in the New Mexico list. The primary sport-fish species in the lake include channel catfish, white bass, largemouth and smallmouth bass, crappie, and walleye. Rough fish include carp, carp-sucker, and gizzard shad.

Information concerning aquatic invertebrates in the study area is not available.

Water quality values of Lake Meredith were studied by the Texas Parks and Wildlife Department in 1976, and none of the values were found to be detrimental to the fishery. Canadian River water quality has not been evaluated for its harmful or beneficial effects on the aquatic fauna. The Environmental Protection Agency reports that, "the most important consideration regarding the effect of salinity upon wildlife is the degree of fluctuation in salinity" (Environmental Protection Agency, undated, Proposed Criteria for Water Quality).

Fish habitat in Lake Meredith has been reduced in quantity and quality due to water level changes. The lake depth has decreased at a near-steady rate from 1973 to 1976, resulting in a loss of about 17 feet in water depth. Species needing littoral areas for spawning cover and rearing purposes, such as crappie, largemouth bass, and sunfishes, have been adversely affected. Fish food organisms have similarly been affected by the declining waters. Other fish species, such as smallmouth bass, and walleye, have benefited from declining waters, which have provided gravel beds, rock ledges, and rocky points suitable for spawning.

Streamside vegetation is dominated by saltcedar, with cottonwoods, willows, grasses, and forbs also being present. Sedges and rushes are found in shaded and cooler areas of the river. Within the 150-mile river system there are roughly 7,000 acres of riparian woodland, 6,100 acres in Texas and 900 acres in New Mexico. Wetland vegetation in Lake Meredith consists mainly of smartweed and wild millet. Riverine wetland vegetation is primarily submerged.

Terrestrial habitats

Major habitat types of the terrestrial area include mesquite shrub land with scattered pinon juniper and gramagrass understory, cropland between the river and playa basin, and desert shrub land around Lake Meredith.

The Ecoregions and land surface forms maps indicate three divisions within the area of this project study. These three areas are briefly described below.

Ecoregions: All three divisions are classified as dry domain, semiarid, steppe divisions */, with gramagrass and buffalograss as characteristic vegetation. Flood plain and canyon vegetation includes saltcedar, cottonwoods, black willow, one-seeded juniper, grasses, and forbs.

Physical subdivisions: (1) Lower Canadian River and Lake Meredith area, extending about 40 miles upstream on the Canadian River to Boys Ranch. Land Surface Form: interior, high plains, tablelands, moderate relief. (2) Canadian River canyon from Boys Ranch upstream to Antelope Creek. Land Surface Form: interior, high plains, irregular plains, with 20 to 50 percent of area gently sloping. (3) Canadian River canyon from Antelope Creek upstream to the Ute Reservoir. Land Surface Form: interior rocky mountain piedmont, tablelands, moderate relief.

Important wildlife resources inhabiting the study area include mule deer, white-tailed deer, pronghorn antelope, fox squirrels, beaver, scaled quail, mourning doves, cottontails, ducks, geese, bobcats, coyotes, and jackrabbits. The area likely supports a wide variety of amphibians, reptiles, songbirds, smaller mammals, and invertebrates.

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*/ Steppe Division: Variable winter, cold, dry in all seasons; short grasses and shrubs dominate vegetation; chestnut brown soils

Fish and Wildlife Oriented Recreation

Numbers of hunters and fishermen are not available; however, sport hunting is believed to be low because most of the land area is privately owned and public access is restricted. The limited hunting which does occur is primarily for antelope and deer. Some goose hunting occurs in adjacent croplands in New Mexico. The upland area is good quail habitat, but hunting is restricted because of limited access. A limited amount of trapping occurs for fox, bobcat, and coyote.

Fishing within the river system is negligible. Lake Meredith is an important recreation area with the National Park Service administering seven recreation sites in the area. Fishing is the primary recreational value on the lake, but no creel census data exist.

Nonconsumptive uses of wildlife resources occur in the project area. Wildlife observation, photography, and other esthetic values undoubtedly are associated with Lake Meredith and portions of the Canadian River valley that are accessible at bridges or other points. No attempt has been made to quantify or estimate specific values.

Endangered or Threatened Species

An indepth investigation by the U.S. Fish and Wildlife Service has not been conducted to determine the presence of endangered flora or fauna; however, no endangered plants are known to occur in the study area.

The following tabulation lists endangered species that possibly occur in the Canadian River area from Ute Dam to Lake Meredith (Texas, New Mexico, and Federal).

Species	Texas	New Mexico	Federal
Falco peregrinus anatum (Peregrine falcon)			X
Haliaeetus leucocephalus (Bald eagle)			X
Hybopsis aestivalis tetranemus (Speckled dace)		X	
Melanerpes erythrocephalus caurinus (Red-headed woodpecker)		X	
Notropis girardi (Arkansas river shiner)		X	
Sterna albifrons athalassos (Interior least tern)	X		
Trionyx muticus muticus (Smooth softshell turtle)		X	
Thamnophis proximus diabolicus (Western ribbon snake)		X	

Changes in the Natural Environment

Brine disposal area

The playa basin proposed for brine disposal and evaporation was examined during the spring and summer of 1978. The large, central flat was devoid of vegetation. The reason for its barren condition was not apparent. Sparse grass and broom weed indicated heavy grazing in a 50-yard perimeter beyond the bare area. Numerous active rabbit holes were found within this area, probably due to the low vegetation and long sight distances. Low mesquite, prickly pear, and cholla were common on the surrounding slopes and upland. There were no wet areas.

The use of this playa for brine disposal would inundate a large area that is of virtually no value to wildlife. Inundation of the peripheral zone would destroy jackrabbit habitat within the playa area, although it is by no means unique. No especially valuable wildlife food-producing zones would be lost.

If the playa is occasionally wet and provides resting habitat for waterfowl and shorebirds, its loss will not be significant since there are other permanent lakes nearby. Hudson Lake, a playa 7 miles to the west, had about 1 acre of shallow water during the April field inspection. There was an extensive mudflat (1-3/4 acres) and fairly good peripheral vegetation. A potential waterfowl feeding area (wheatfield) was within 200-300 yards of the lake. Ute Reservoir is within 5-1/2 miles of the proposed brine disposal area.

If brine disposal in this playa is infeasible, a basin could be constructed with essentially the same kind and magnitude of environmental impact.

Waterfowl are not expected to experience any ill effects from landing on the brine lagoon. Prolonged exposure of waterfowl to the brine would result in death. However, a recent study (Colorado State University, June 28, 1977, "Colorado River Desalinization Wild Duck Study") showed that waterfowl released on brine ponds move to freshwater within 1 to 2 hours.

Canadian River

The elimination of saltwater infiltration of the Canadian River alluvium at Logan will cause a long-term reduction in salinity downstream. The flood plain vegetation, comprised mostly of saltcedar, willow, and various annuals, will not be significantly affected by a salinity reduction of the magnitude anticipated. A lowering of the water table is not anticipated. Any change in species composition that might result will take place gradually over a period of many years. About 150 miles of river will be affected.

The fish in the Canadian River are mostly minnows, able to survive in small pools during periods of zero flow. These fish are adapted to a relatively wide range of salinities and should not be affected by water quality changes caused by the project.

Lake Meredith

A project resulting in isolation of the brine aquifer at Logan should reduce the concentration of salts in Lake Meredith.

Endangered species

No endangered species are expected to be affected by implementing any of the alternatives being considered for this project. Two species of fish found in the Logan area, the Arkansas River shiner (*Notropis girardi*) and the speckled chub (*Hybopsis aestivalis tetranemus*), are considered endangered in the State of New Mexico. However, changes in salinity are not expected to be severe enough to affect these species.

Aquaculture

It is possible that the brine discharge at Logan will be suitable for growing shrimp. If bioassays indicate that this is the case, the feasibility of an aquaculture enterprise will also be investigated.

FINDINGS AND CONCLUSIONS

A major source of saline contamination to the Canadian River and probably Lake Meredith has been identified. This source is a leaky, artesian, brine aquifer near Logan, New Mexico.

The artesian flow from the aquifer aggregates about 0.6 ft^3/s of brine pollution to the river system. At this rate it is estimated that the contribution of sodium, chloride, and sulfate from the aquifer averages about 26,900 tons per year or about 32 percent of the total of these constituents entering Lake Meredith. If the flows from the brine aquifer are eliminated from Canadian River waters reaching Lake Meredith, the average concentration of these constituents in the river's waters entering the lake should be reduced from about 500 to about 350 mg/l. Under present reservoir conditions, this should result in an average concentration of TDS in the reservoir of about 800-900 mg/l.

Alternative methods have been proposed to alleviate the impact of this saline inflow into the Canadian River. Presently, the most promising method of isolating this contamination is by pumping from the brine aquifer near Logan. Leakage from the aquifer can be effectively reduced by pumping and disposing brine from wells completed within the aquifer.

If the Lake Meredith Salinity Study is continued at feasibility level, the following elements could be included in future investigations:

1. Prepare a coordinated plan of study to extend over 4 years.

2. Investigate and model the effects on Lake Meredith of isolating the brine aquifer near Logan, New Mexico.

3. Investigate any other major sources of saline contamination between Ute Reservoir and Lake Meredith.

4. As required, ascertain the characteristics of saline sources. For example, install about six observation wells in and perform ancillary geophysical (resistivity) measurements of the brine aquifer near Logan to collect additional data for that source.

5. Evaluate the potential of using solar and wind energy for pumping at a feasible site(s) for the extraction and disposal of waters contaminating the Canadian River.

6. Determine the construction, operation, maintenance, energy costs, and benefits of alternative plans for isolating sources of saline contamination to the Canadian River-Lake Meredith system.

7. If alternative plans to reduce the salinity of waters flowing into Lake Meredith are not feasible, compare alternative means for providing better quality of water to users.

8. Report any beneficial or adverse effects various alternative plans might have on water users and on the environment in the study area.

9. Evaluate the study results, explore reimbursability of costs, and, if so warranted, recommend plan implementation.

10. Prepare an environmental statement to accompany the feasibility report if a plan is recommended to be implemented.

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REFERENCES

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APPENDIX A

Notice of Initiation of Investigation

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
NOTICE OF INITIATION OF INVESTIGATION

Name of Investigation: Lake Meredith Salinity Study

Location of Investigation: Canadian River drainage area from Ute Dam, New Mexico, to Lake Meredith, Texas

Date Investigation Initiated: January 1972 Probable date of completion June 30, 1974

1. Scope of proposed investigation:

Reconnaissance investigation to identify the sources contributing water highly concentrated with sulfates and chlorides. The investigation is also to study methods of alleviating the contamination of water in this area of the Canadian River.

2. Nature of problems involved:

Current sampling of water in Lake Meredith indicates a high concentration of sulfates and chlorides while the concentration of these salts in Ute Lake water is relatively low. The concentration of sulfates and chlorides in the Lake Meredith water is approaching the level considered undesirable by the U. S. Public Health Service. Lake Meredith is the storage facility for the Canadian River project which supplies water to eleven cities. Action needs to be taken to keep the concentration of sulfates and chlorides within the desirable limits.

3. Prospective solutions which should be explored:

Identify if possible the sources contributing water with high concentrations of sulfates and chlorides. Study different methods of alleviating the contaminated water from entering the Canadian River. The investigation should be performed as rapidly as possible to avoid more costly water treatment procedures or the development of new sources of water.

2-1-72
(Date)

Leon W Hill
Regional Director, Region 5

APPENDIX B

Letter of Support-Canadian River Municipal Water Authority

CANADIAN RIVER MUNICIPAL WATER AUTHORITY

TELEPHONE AC 806 865-3325
P. O. BOX 99
SANFORD, TEXAS
79078

EXECUTIVE COMMITTEE
RAY RENNER, PRESIDENT
JACK SKAGGS, VICE-PRESIDENT
JOHN C. WILLIAMS, GENERAL MANAGER AND SECRETARY TREASURER

MEMBER CITIES
DIRECTORS
AMARILLO, TEXAS
ROBERT PATTERSON
E. W. ROBINSON
BORGER, TEXAS
L. D. PATTON
JAMES H. GODFREY
PAMPA, TEXAS
FRED THOMPSON
JERRY CARLSON
PLAINVIEW, TEXAS
R. V. PAYNE
JACK SKAGGS
LUBBOCK, TEXAS
J. RAY DICKEY
WARLICK CARR
SLATON, TEXAS
W. HOWARD HOFFMAN
TAHOKA, TEXAS
V. F. JONES
O'DONNELL, TEXAS
E. R. MOORE
LAMESA, TEXAS
STANSELL CLEMENT
RAY RENNER
BROWNFIELD, TEXAS
T. A. HICKS
LEVELLAND, TEXAS
I. F. LEA
JOHN H. DAVIS

August 1, 1979

The Honorable Abraham Kazen, Jr.
Chairman, Water and Power Subcommittee
House Interior and Insular Affairs Committee
Room 2411, Rayburn House Office Building
Washington, D.C. 20515

Dear Congressman Kazen:

By letter dated July 11, 1979, addressed to Speaker O'Neill and Vice-President Mondale, the Department of the Interior has requested Congressional authorization for several studies of water and energy resource projects. I understand that this letter was forwarded to your subcommittee for evaluation and possible drafting of legislation. One of the studies for which authorization is requested is of much importance to the Canadian River Municipal Water Authority.

This Authority operates Lake Meredith on the Canadian River in the Texas Panhandle, furnishing a municipal and industrial water supply to our eleven member cities through a 322-mile aqueduct system. The entire Canadian River Project was constructed for us by the U. S. Bureau of Reclamation, and the Authority is repaying over $83,000,000 of the construction cost to the Federal Treasury with interest. Because of the declining underground water supply in this area, this source of surface water is extremely important to our member cities and their 450,000 citizens.

Gradually increasing salinity of the water in Lake Meredith has created problems for the users of Lake Meredith water. The chloride, sulfate, and total dissolved solids content of Lake Meredith water currently exceed the maximums recommended by the U. S. Public Health Service by significant margins. While this condition was foreseen in the planning studies completed before construction, improvement of the water quality would be highly beneficial if it can be accomplished at a reasonable cost.

The U. S. Bureau of Reclamation has studied this problem since 1972, in an appraisal-grade investigation known as the "Lake Meredith Salinity Study"[1/]. This study, which is now complete except for issuance of the final report, has located a major source of saline water contribution and has determined that control of that source could probably be accomplished.

In the letter referred to above, the Department is requesting authorization for continuation of the study on a feasibility level, to thoroughly investigate methods of controlling the salinity of Canadian River water flowing into Lake Meredith, and to address other aspects of the problem.

The Authority, through its Board of Directors, has continually expressed support for the feasibility study, and has urged the Congressional delegation from this area to work on behalf of this program. We believe that this effort is one in which the Federal Government can achieve the best and perhaps only solution, and would urge that your subcommittee act favorably regarding this request for authorization.

Please let us know if any additional information is needed. If testimony before your subcommittee or the full committee would be of assistance, I am sure that we can arrange for a representative of the Authority to appear.

With best regards,

Ray Renner
President, Board of Directors

cc The Honorable Jack Hightower
The Honorable Kent Hance
The Honorable Charles W. Stenholm
The Honorable Bob Eckhardt

Canadian River Municipal Water Authority Board of Directors

Mr. Robert H. Weimer, Regional Director, U. S. Bureau of Reclamation

APPENDIX C

Aquifer Pump Test Report

March 3, 1849

United States Department of the Interior
BUREAU OF RECLAMATION
ENGINEERING AND RESEARCH CENTER
P.O. BOX 25007
BUILDING 67, DENVER FEDERAL CENTER
DENVER, COLORADO 80225

IN REPLY
REFER TO: D-440
452.

JAN 9 1978

Memorandum

To: Regional Director, Amarillo, Texas
Attention: SW-700

From: Chief, Division of O&M Technical Services, E&R Center

Subject: Lake Meredith Salinity Study Project, Texas - Logan, New Mexico Brine Aquifer Test

INTRODUCTION

Purpose of Test

Studies of the increasing salinity in Lake Meredith identified a reach of the Canadian River immediately below Ute Dam, near Logan, New Mexico, as a source of saline inflow. Investigations suggested that the saline water originates from an artesian aquifer that lies at a depth of about 260 feet below the river flood plain. The present testing program was designed to determine the basic aquifer characteristics and to determine the feasibility of reducing seepage of saline water into the river. Seepage reduction would be accomplished by pumping to control the piezometric surface at an elevation below river level.

Location

The area of saline discharge extends along the Canadian River from the toe of Ute Dam to about the mouth of Revuelto Creek about 6.4 river miles downstream (figure 1). The dam is located about 2 miles west-southwest from Logan, Quay County, New Mexico. The aquifer test was conducted in the west half of Section 14, T.13N., R.33E., about 3/4 mile south of Logan, New Mexico. The test well and observation wells were drilled on the river flood plain in the bottom of the approximately 75-foot deep incised river canyon.

Previous Investigations

In 1969, the Texas Water Quality Board conducted stream flow water quality tests which suggested that most of the salinity was entering between Ute Dam and the New Mexico-Texas State line with the most significant amounts appearing near Ute Dam.

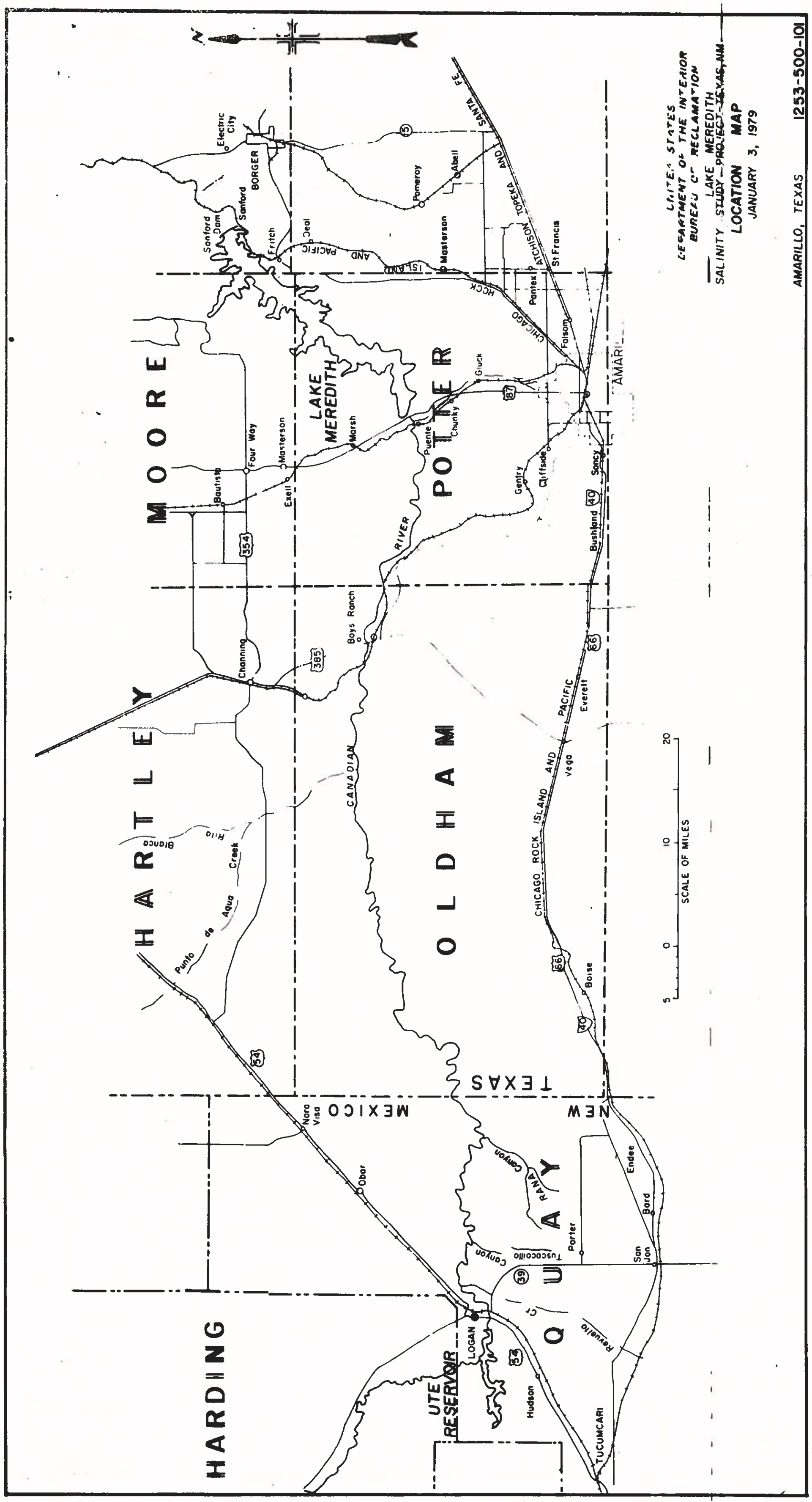

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LAKE MEREDITH
SALINITY STUDY - PROJECT - TEXAS-NM
LOCATION MAP
JANUARY 3, 1979
AMARILLO, TEXAS
1253-500-101
N
HARDING
HARTLEY
MOORE
OLDHAM
POTTER
QUAY
TEXAS
NEW MEXICO
LAKE MEREDITH
UTE RESERVOIR
CANADIAN RIVER
Electric City
BORGER
Sanford Dam
Sanford
Fritch
Deal
Pomeroy
Abell
Masterson
St Francis
Pantex
Folsom
AMARILLO
Gluck
Chunky
Puente
Marsh
Four Way
Bautista
Exell
Gentry
Cliffside
Soncy
Bushland
Channing
Boys Ranch
Vega
Everett
Boise
Nora Visa
Obar
Logan
Hudson
Tucumcari
Porter
San Jon
Bard
Endee
Revuelto
Tuscocollo Canyon
Rana Canyon
Punta de Agua Creek
Rita Blanca
CHICAGO ROCK ISLAND AND PACIFIC
ATCHISON TOPEKA AND SANTA FE
5
15
40
54
66
87
354
385
39
5 0 10 20
SCALE OF MILES

Figure 1

In 1971, the Canadian River Municipal Water Authority commissioned a study by private consultants that concluded that the salinity is primarily of natural origin with only minor contribution from industrial, commercial, or agricultural sources. The report recommended further studies along the main stream of the Canadian River, with emphasis below the major tributaries and on ground-water sources. The reach of the river between Ute Dam and Revuelto Creek was singled out for special study.

The USBR began appraisal grade investigations in 1972 which included sampling and testing of riverbed sands and evapotranspiration studies. During 1974 and 1975 test holes were drilled in the river channel to various depths at 10 sites to further isolate the areas of saline inflow. These tests strongly suggested the reach of the river for 6 miles downstream from Ute Dam near Logan, New Mexico, as a primary source of saline inflow.

A literature search suggested that the most logical source of saline water is artesian flow from aquifers associated with evaporites. These rocks occur at depth below the Triassic Dockum Group and Permian Artesia Group shales and sandstones. Two drill holes were completed in 1975, one about 3/4 mile south of Logan and the other about 2 miles east. The results of this drilling is included in Site and Ground-water Geology.

Regional Geology

Northeastern New Mexico is underlain by essentially flat lying sedimentary units. Units of interest to this particular problem include Permian and more recent clastic and chemical sedimentary rocks which show considerable variation in local occurrence and thickness because of depositional and erosional controls. Local stratigraphic strikes and dips may reflect depositional conditions as well as tectonic conditions.

The surface outcrops at river level are commonly the Triassic Dockum Group. The subsurface geology of northeastern New Mexico is rather poorly known and more than one stratigraphic correlation can be proposed for the units encountered in the USBR investigations to date.

One logical source of saline water is the Permian San Andres Formation which in this area consists of dolomite, anhydrite, and salt. The San Andres has been reported to extend northwest to the vicinity of Logan, New Mexico. Underlying the San Andres and commonly associated with it is the Glorieta sandstone. However, this sandstone has not been reported east of R.31E., a distance of about 10 miles west of

Logan. If the brine aquifer tested in the aquifer test is the Glorieta, it occurs at a very shallow depth. The San Andres apparently is absent and the confining thin shale represent the Permian Bernal Formation.

A second and more logical interpretation would be that the brine aquifer tested is a portion of the Triassic Santa Rosa Formation, possibly that portion equivalent to the Tacovas of the Texas Panhandle. Therefore, if the San Andres-Glorieta is present, it was not reached by the present drilling. The significance of the latter interpretation is that investigations to date might not have been carried sufficiently deep to determine the origin of saline water seeping into the Canadian River.

Site and Groundwater Geology

The aquifer performance test was completed adjacent to the site of Drill Hole No. 1 (DH-1). At this site the top of the artesian brine aquifer was encountered at elevation 3402 feet (depth of 271'). Several possible correlations of individual beds can be suggested resulting in differing strikes but the dip would appear to be less than 5° in any case. Electrical resistivity surveys completed in 1976 suggest a dip of 4-5° to the west for the top of a conductive layer postulated to be the brine aquifer. Figure 2 summarizes the local lithology as determined from electric and gamma logs and cored samples from the test well and observation wells. Depending on the interpretation correlation, the aquifer appears to be about a 70 feet thick sandstone layer with an overlying 4- to 20-feet thick confining shale layer. Above this is another sandstone aquifer with a number of thin shale interbeds.

Drill Hole No. 2 (DH-2), located about 2 miles to the east-northeast did not encounter a brine aquifer but did encounter artesian conditions. This hole also encountered considerably more shale than DH-1. Several interpretations possibly explain the lack of brine in DH-2: (1) The brine aquifer dips to the east and DH-2 was not sufficiently deep to penetrate it; (2) the saline aquifer wedges or pinches out within the 2-mile interval between the two holes; or (3) the aquifer is continuous but a water quality changes in the aquifer between the two holes. However, as will be noted later, there was no indication during the aquifer test that a significant boundary was encountered by the expanding cone of depression from the test well. This cone had a theoretical radius of more than 10,000 feet at the end of the test.

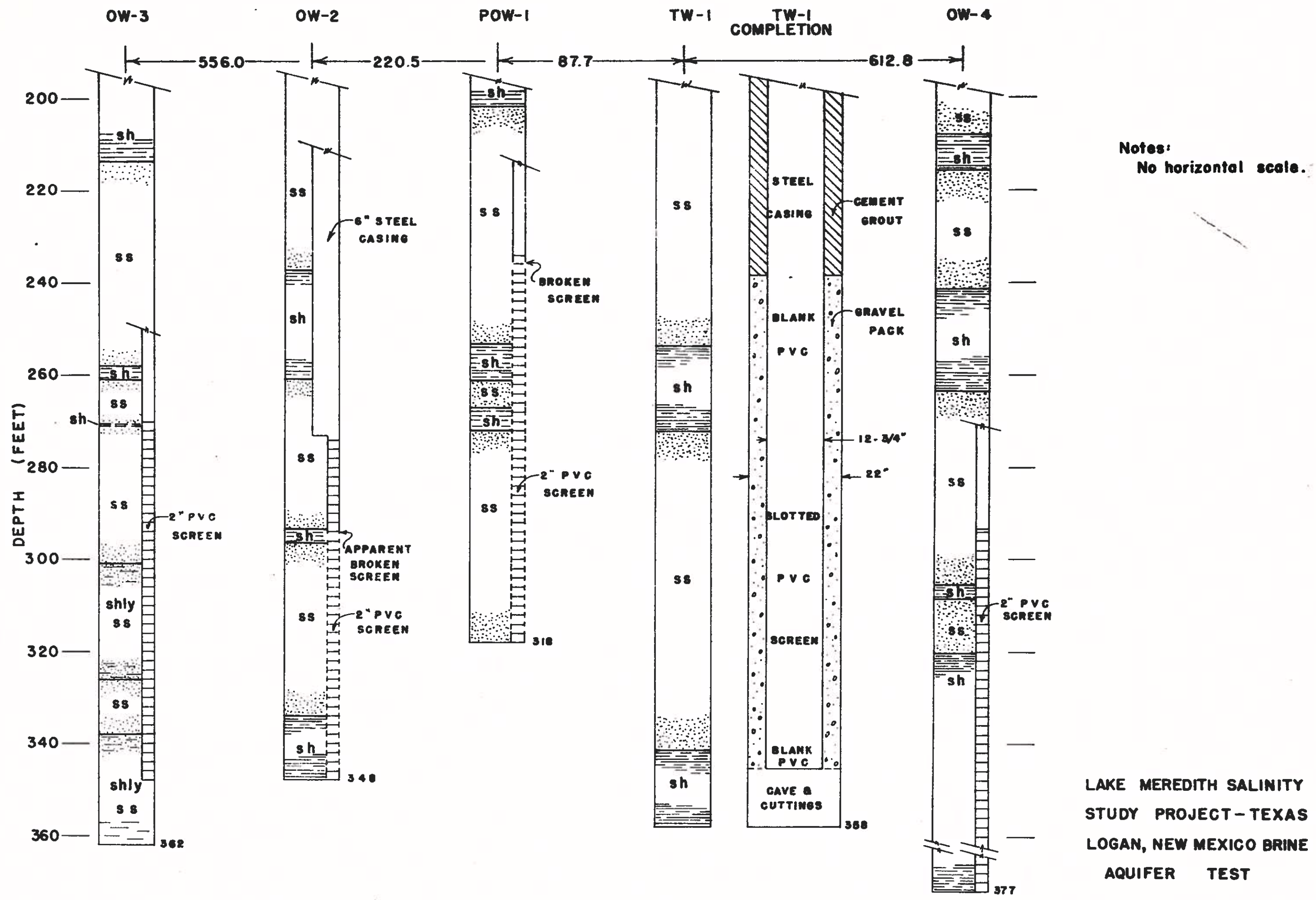


Figure 2. Brine aquifer lithology at aquifer test site.

WATER QUALITY STUDIES

Water quality studies in the Logan, New Mexico area have been directed at several aspects: (1) Changes in water quality along the river below Ute Dam; (2) changes in water quality with depth in DH-1; and (3) changes in water quality with time during the aquifer pumping test.

Seeps and springs of saline water all of similar quality, are found at many locations along the river downstream from Ute Dam to about the confluence of Revuelto Creek. The river water quality generally deteriorates easterly, downstream through this reach.

Water samples collected from DH-1 at a depth of 156 feet were generally about the same in quality as the river water. No water samples were collected between 156 feet and 296 feet where artesian flow of brine was encountered.

Water samples collected periodically from the test well discharge during the aquifer test remained essentially the same but were of better quality than samples collected from the flowing observation wells OW-3 and OW-4. The apparent reason for this is the inclusion in the test well discharge of an unknown amount of water from a higher, less saline aquifer. This will be discussed in a later section.

AQUIFER TEST

Location and Design

The test site was chosen for ease of access as well as for its location about midway between Ute Dam and Revuelto Creek, the assumed limits of saline water inflow to the river. The locations, design, spacing, and number of observation wells were determined from inspections of the log of DH-1 and chosen to allow interpretation of data by several methods. The final screen design for Test Well No. 1 (TW-1) was based on cuttings and core samples from the nearby observation wells.

Contract

The test well and 4 observation wells were drilled and completed by contract. The contractors experienced difficulties with both drilling and well completion. The following summarizes the condition of each well as determined from a review of the daily drill reports, soundings of wells, and aquifer test results.

TW-1 (Test Well No. 1)

The test well was drilled to required depth and casing and screen were installed. Gravel pack volume placed exceeds that calculated by

33.5 ft^3 indicating the presence of a void or an enlarged hole. The gravel pack was emplaced to the top of a 20 ft length of PVC (polyvinyl-chloride) blank casing at the top of the screen string which extends about 13 ft above the top of the brine aquifer and into a higher aquifer (figure 2). Consequences of this will be discussed under Results. The annular space between the top of the gravel pack and the ground surface was filled with cement grout.

POW-1 (Pilot Observation Well No. 1)

The contractor experienced numerous problems with this well and was allowed to drill it with bentonitic mud. Nevertheless, he did not complete the well as designed. The PVC screen was set too high and apparently is broken in several places. Sounding indicates that broken casing near the top of the screen assembly is open in an aquifer above the brine aquifer.

OW-2 (Observation Well No. 2)

This well was drilled and cored oversize to accommodate the float of a continuous recorder. However, because of downhole problems, the contractor was allowed to drill the well using bentonitic mud. The well is plugged apparently with the drilling mud, although flushing procedures were performed. Essentially no water level change occurred in this well during either the step or constant yield tests.

OW-3 (Observation Well No. 3)

This well was satisfactorily completed in the brine aquifer.

OW-4 (Observation Well No. 4)

This well was satisfactorily completed in the brine aquifer, after being redrilled.

Development

The test well was developed by pumping and surging with the test pump. The discharge water cleared almost immediately and no sand was detected during subsequent pumping.

Water Disposal

The well discharge flowed to the river through aluminum irrigation pipe. The discharge was diffused into the river through a gated pipe section having numerous small pipe outlets. Proper permits for this discharge were acquired, including releases of fresh water from Ute Lake into the Canadian River for dilution purposes.

Regional Water Level Trends and Barometric Efficiency

Readings taken before and after the tests were limited but there appeared to be no significant change in the regional water level during the test period. There appeared to be some indication of a low barometric efficiency but not enough to warrant correction of pump test well reading data.

Step Test

A 3.7 hour step test was completed March 7, 1978. No attempt was made to analyze the test results in detail. The test was used to ensure that the well was developed and to assist in setting the pump discharge for the constant yield test. The step test demonstrated that significant drawdowns could be developed at a pumping rate of about 475 gallons per minute (gpm) and that the pump and engine could readily handle such a discharge. During the step test, observers perfected reading and recording techniques. It became obvious that the brine gave very small needle deflection on the electric water level measuring devices. Accordingly, observers had to be cautious in taking measurements of the water levels in wells.

Procedures

Elapsed time was kept by stop watch at each observation well for about the first 120 minutes of the test and by local time on a common watch thereafter. Wooden staffs were mounted on each observation well and times and drawdowns of artesian heads were recorded directly on the staff. Periodically the data was transferred to standard recording forms. Log-log plots of time/radius^2 versus drawdown and distance-drawdown (r versus s) were prepared after about the first two hours and were maintained essentially current thereafter.

Aquifer Test

The constant yield test was started at 2:00 p.m. March 8, 1978, and continued until 3:00 p.m. March 12, 1978. Recovery was recorded until about 11:00 a.m. March 15, 1978. The early portion of the test went quite smoothly with an even pumping rate of 475 gpm. After 930 minutes a pump shaft adjusting nut on the right angle drivehead was observed to be working loose and the pump was shut down 5 minutes for repairs. At 3974 minutes after starting the constant yield test, the pump was found to be discharging only 400 gpm. After considerable adjusting and refueling of the propane tank, the discharge was returned to the 475 gpm rate. These two variations in pump discharge do not appear to have significantly affected the long average discharge and are reflected in only a few of the many water level observations in the observation wells. However, the variations are strongly reflected in the hydrograph of the pumped well.

Test Result

Test results were mixed. It was apparent from early data from the step test that OW-2 was plugged and not functioning. The time drawdown plot from POW-1 fits a Theis curve but did not fit with the pattern established by the test well (TW-1) and the outside observation wells (OW-3 and OW-4). This confirmed the earlier conclusion that POW-1 had been completed in a higher aquifer. It also indicated that some of the test well production was coming from the higher aquifer by radial flow, as revealed by the shape of the time drawdown curve.

Initial interpretations and calculations of the transmissivity (T) and coefficient of storage (S) were made from the time-drawdown plots of OW-3 and OW-4 assuming that the entire well discharge was produced from the saline aquifer. When theoretical distance drawdown plots were calculated from these values of T and S, the theoretical cone of depression at the well was found to be deeper than the measured pumping level in the well, an impossibility for a single aquifer well. A review of the completion details of TW-1 indicates that water from the upper aquifer probably flowed downward through the gravel pack to the well screen and pump. Considering the overrun on gravel pack, it is possible that the pack could have settled during development and early pumping and that flow from the upper aquifer could have occurred through an open annular space. The question becomes one of determining how much of the 475 gpm pumped came from each aquifer.

Several theoretical procedures for determining the contribution of each aquifer were considered:

1. If the gravel pack remained in place and an acceptable estimate of gravel pack permeability can be made, it is possible to compute a maximum contribution by vertical flow in the pack from the upper aquifer.

2. If the gravel pack settled significantly during development and preliminary pumping, an open annular space could extend from the upper aquifer to the upper portion of the screen. In this case the permeability of the upper aquifer and the amount of exposure to the open hole would control the contribution from the upper aquifer.

At the prevailing aquifer temperatures the brine would be 2-3 percent more dense and have a viscosity about 0.06 centipose greater than fresh water. Any correction for these factors would be minor relative to the other uncertainties so no corrections were attempted.

Neither 1 or 2 above can be accurately evaluated from the data available. The best estimate assumes that about 50 gpm was produced from the upper aquifer and 425 gpm came from the brine aquifer. This flow distribution appears more logical than full flow from the brine aquifer but the reliability of the approximation is not known. Considering the uncertainty of the flow distribution and the intended use of the results, the test has been evaluated assuming two different flow conditions (see Table 1).

Control of Piezometric Surface by Pumping

Pumping one or more wells completed in the brine aquifer has been proposed as a means of lowering the piezometric surface to a point below river level through the river reach containing saline springs and seeps. Preliminary economic analyses indicate that 400-500 gpm could be pumped to evaporation ponds at costs competitive with other alternative remedial methods. Theoretical distance-drawdown curves were calculated for a single well pumping 400 gpm from the saline aquifer after one year of operation assuming each of the two sets of aquifer characteristics given in Table 1. These drawdown curves are shown in Figure 3. Figure 4 shows the one-year effects of pumping 400 gpm from a single well located 1/4 mile downstream from Ute Dam. Figure 5 shows the drawdown effects along the meandering reach of the Canadian River from Ute Dam to Revuelto Creek.

At the site of the aquifer tests, the piezometric surface was determined to be about 10 feet above river level. A 400 gpm well located as proposed above would cause about 12 feet of drawdown at this site after one year of continuous pumping. Significant pressure head could be relieved throughout the Ute Dam-Revuelto Creek reach of the Canadian River by pumping such a well but whether the piezometric surface can be drawn below river level at all points cannot be determined with the data presently available.

Recommendations

Sufficient piezometers should be installed in the area of the Ute Dam-Revuelto Creek reach of the canadian River to establish the piezometric surface of the brine aquifer. This would allow estimation of the effects of pumping one or more wells at various locations at various rates. The drill holes should completely penetrate the aquifer and be carefully logged. Piezometers should be designed to allow water quality sampling.

An additional aquifer test should be planned but its location and design should be determined only after completion of the piezometer network.

Bd Prichard

Copy to: Regional Director, Amarillo, Texas, Attention: SW-200 and SW-400

Table 1.- Calculated Characteristics of Brine Aquifer

	Q = 475 gpm			Q = 425 gpm		
Transmissivity	2500 ft^2/d	18,800 gpd/ft	765 m^2/d	2250 ft^2/d	16,800 gpd/ft	684 m^2/d
Permeability	36 ft/d	270 gpd/ft^2	11 m/d	32 ft/d	240 gpd/ft^2	10 m/d
Coefficient of Storage	.00015	.00015	.00015	.00013	.00013	.00013

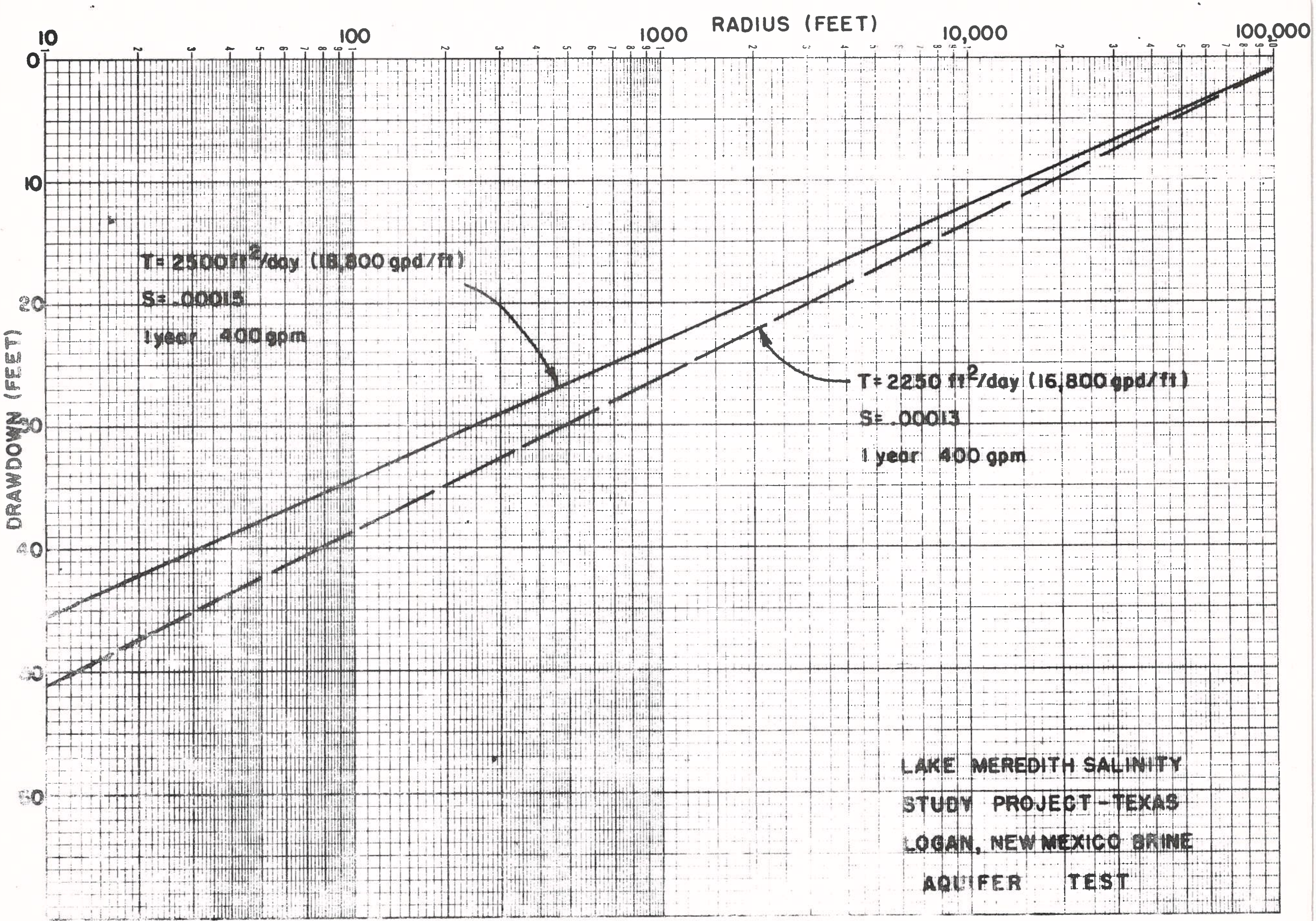


Figure 3 Theoretical distance-drawdown plots — One year 400 gpm

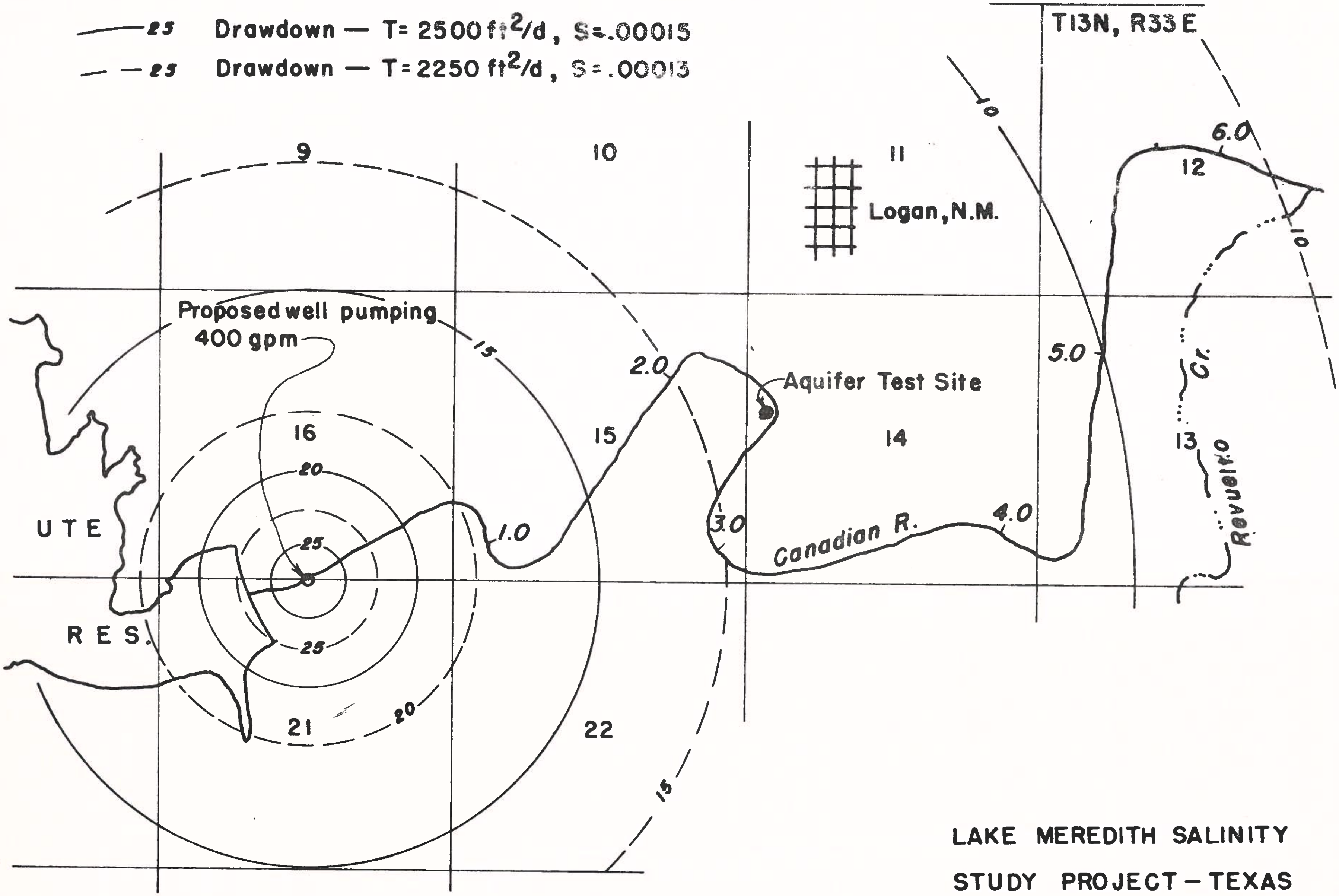


Figure 4. Theoretical drawdown after pumping 400 gpm for 1 year

LAKE MEREDITH SALINITY
STUDY PROJECT – TEXAS
LOGAN, NEW MEXICO BRINE
AQUIFER TEST

APPENDIX D

Geologic Section

Drawing No. 1253-500-14

Drill Logs

- DH-1
- DH-2
- POW-1
- OW-2
- OW-3
- OW-4

7-1337 (9-69)
Bureau of Reclamation

GPO 854-401

GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 5

FEATURE Canadian River Below Ute Dam PROJECT Canadian River Salinity Study STATE New Mexico
HOLE NO. DH-1 LOCATION COORDS. N. 35° 21' 13" E. 103° 24' 51" GROUND ELEV. 3680' A.M.S.L. DIP (ANGLE FROM HORIZ.) 90
BEGUN 6/24/75 FINISHED 6/30/75 DEPTH OF OVERBURDEN 30.0' TOTAL DEPTH 356' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian 30 GPM 6/28/75 LOGGED BY D. Smith and J. K. Morrison LOG REVIEWED BY S. E. Kluender

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS | TYPE AND SIZE OF HOLE | CORE RECOVERY (%) | PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm) TO; LOSS (G.P.M.); PRESSURE (P.S.I.); LENGTH OF TEST (MIN.) | ELEVATION (FEET) | DEPTH (FEET) | GRAPHIC LOG | SAMPLES FOR TESTING | CLASSIFICATION AND PHYSICAL CONDITION

Drill Rig:
Failing 1500

Casing:
Set 30.7" of 6" casing; upon hole completion 6" casing pulled, set 31.5' of 4" casing and cemented to ground level and welded cap on to seal.

Drill Fluid Loss:
0' - 106' 0%
106' - 116' 10%
116' - 256' 0%
256' - 356' Artesian-No loss

Sampling:
Sampled cuttings approximately at 10' intervals from drill fluid return ditch. Water samples taken at irregualr intervals from casing; river water samples also taken.

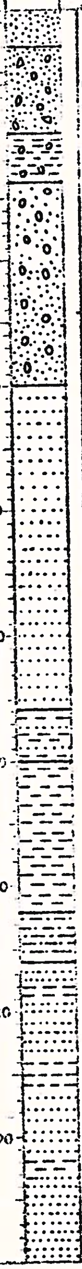
Water Samples:
1. Packered hole 51' - 76', blew hole.
Chloride 3,450 mg/l
NaCl 5,692 "
Sulfate 700 "
Total Fe 0.12 "
Conductance 11,000

2. Packered hole 51' - 76'; after blow-rest cycle sample cleared.
Chloride 3,060 mg/l
NaCl 5,049 "
Sulfate 700 "
Total Fe 0.12 "
Conductance 10,200

3. River water 6/25/75.
Chloride 3,150 mg/l
NaCl 5,198 "
Sulfate 500 "
Total Fe 0.08 "
Conductance 10,200

Type and size of hole:
7-7/8" Rock Bit
CS-
4-3/4" Drag Bit

Depth (feet):
3.0
10.0
14.0
30.0
56.0
60.0
72.0
76.0



0' - 30'
Quaternary Alluvium

0' - 3' Sand, poorly sorted. Contains some very fine gravel, some fine to very fine sand, mostly medium sand. Strong HCL reaction. Contains some quartzite, and feldspars, all less than 5% of total. Mottled reddish color.

3' - 10 Sand, coarse and poorly sorted. Contains some very fine gravel, some fine to very fine sand, mostly medium to coarse. Strong HCL reaction. Contains some quartzite, opal, mica, and chalcopyrite, all less than 5% of total. Mottled reddish color.

10' - 14' Gravelly Clay, coarse fragments to greater than 5 mm indicate gravel interbedded. Contains a few calcareous oolites, some opal, mica, and chalcopyrite, all less than 5% of total. Strong HCL reaction. Mottled reddish color.

14' - 30' Gravel, poorly sorted; very fine gravel and cobbles; coarse sand with minor amount of fine to very fine sand. Contains some calcareous oolites, mica flakes, small concretions and chalcopyrite, all less than 5% of total. Staining on some fragments, mottled buff color.

30' - 196'
Triassic Santa Rosa Sandstone

30' - 56' Sandstone, medium to coarse grained, small fraction of very coarse sand and some clay and silt. Good HCL reaction. Calcareous and argillaceous cement. Fair induration. Contains some opal, a few small concretions, and a few mica flakes (muscovite). Grades into shale. Buff to gray color.

56' - 60' Sandstone, medium to coarse grained, with shale layers interbedded. Weak HCL reaction; argillaceous and calcareous cement; fair induration. Dark buff to brown color.

60' - 72' Shale, silty with high argillaceous content. Contains a few coarser sand grains. Weak HCL reaction; fairly well indurated. Variegated dark buff to brown color.

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole . . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-27/32", Bx = 2-3/8", Nx = 3"

FEATURE Canadian River Below Ute Dam PROJECT Salinity Study STATE New Mexico SHEET 1 OF 5 HOLE NO. DH-1

7-1337 (4-69)
Bureau of Reclamation

GPO 864-401

GEOLOGIC LOG OF DRILL HOLE

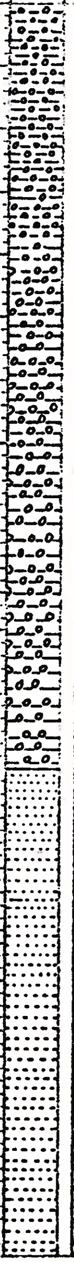
SHEET...3... OF ..5...

FEATURE .... PROJECT .... STATE ....

HOLE NO. ..DH-1... LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP *(ANGLE FROM HORIZ.)* ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
9. Same as 7, next day. Water level 3.75' in pipe; blew hole, took sample. Chloride 3,350 mg/l NaCl 5,528 " Sulfate 300 " Total Fe 0.06 " Conductance 10,100 10. River water 6/28/75. Hard rain during previous night. Chloride 1,150 mg/l NaCl 1,898 " Sulfate 300 " Total Fe 0.08 " Conductance 4,000 11. At 296' hole flowed est. Q=30 gal/min. Sampled while flowing. Chloride 11,800 mg/l NaCl 19,470 " Sulfate 1,650 " Total Fe 0.80 " Conductance 34,000 12. At 296' after flowing more than one hour. Chloride 11,800 mg/l NaCl 19,470 " Sulfate 1,450 " Total Fe 0.24 " Conductance 37,000 13. At 296' after flowing all night. Chloride 12,950 mg/l NaCl 21,368 " Sulfate 2,150 " Total Fe 0.42 " Conductance 36,000 14. At 296' after circulating to clear hole. Chloride 2,350 mg/l NaCl 3,878 " Sulfate 500 " Total Fe 0.08 " Conductance 8,600 15. At 316' flowing 32 gal/min. Chloride 16,450 mg/l	4-3/4" Drag Bit 10 20 30 40 50 60 70 80 90								10 20 30 40 50 60 261 70 80 90			326' - 336' Quartzose Sandstone. Sucrose textured fine to very fine, well sorted sand. No HCL reaction. Seams of shale with much mica. Grayish-white color. 336' - 346' Quartzose Sandstone. Sucrose textured fine to very fine, well sorted sand. Thickly interbedded shale. No HCL reaction. Argillaceous cement; poorly indurated. Grayish-white color. 346' - 356' Shale, with same sucorse sand and silt. No HCL reaction. Poorly indurated. Grayish-white color. Explanation of Graphic Log: INDURATED ROCK ▦ Sandstone ▤ Shale ▤ Sandy Shale CONSTITUENT PARTICLES ▨ Clay ▨ Pebbles, Gravel, Cobbles or Boulders ▦ Sand ▨ Silt MISCELLANEOUS SYMBOLS ▨ Mica

EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole .... D = Diamond, H = Heystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X series) . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE .... PROJECT .... STATE .... SHEET .3.. OF .5.. HOLE NO. DH-1 ....

7-1337 (9-69)
Bureau of Reclamation

GPO 854-401

GEOLOGIC LOG OF DRILL HOLE

SHEET 4 OF 5

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-1 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
NaCl 27,142 " Sulfate 2,000 " Total Fe 0.48 " Conductance 45,000	4-3/4" Drag Bit											

16. At 336' circulated 30 minutes, took sample.
Chloride 18,500 mg/l
NaCl 30,525 "
Sulfate 1,950 "
Total Fe 0.80 "
Conductance 52,000

17. At 356' after flowing 15 minutes.
Chloride 16,100 mg/l
NaCl 26,565 "
Sulfate 1,900 "
Total Fe 0.27 "
Conductance 51,000

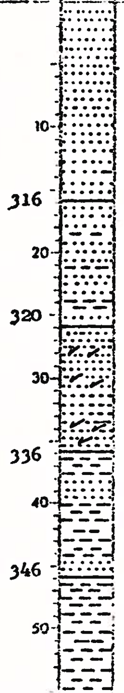
18. At 356' after flowing 30 minutes.
Chloride 15,950 mg/l
NaCl 26,318 "
Sulfate 500 "
Total Fe 0.10 "
Conductance 50,000

19. At 356' after flowing all night.'
Chloride 17,500
NaCl 28,875
Sulfate missing
Total Fe 0.48
Conductance 49,060

20. Sample of drinking water.
Chloride 245 mg/l
NaCl 404 "
Sulfate 60 "
Total Fe 0.03 "
Conductance 500-600

21. Mix of drinking water 50% and water from well 50%.
Chloride 8,850 mg/l
NaCl 14,602 "
Sulfate 900 "
Total Fe 0.10 "
Conductance 26,000

22. River water 6/30/75.
Chloride 2,900 mg/l
NaCl 4,785 "



60
70
80
90

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole .... D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) .. Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE .... PROJECT .... STATE .... SHEET 4 OF 5 HOLE NO. DH-1

GEOLOGIC LOG OF DRILL HOLE

SHEET..5....OF..5.

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-1..... LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGIN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Sulfate 500 mg/l Total Fe 0.03 " Conductance 11,000 23. At 356' after flowing 24 hours. Chloride 16,250 mg/l NaCl 26,812 " Sulfate 1,750 " Total Fe 0.29 " Conductance 49,000 24. River water 7/1/75. Chloride 3,000 mg/l NaCl 4,950 " Sulfate 500 " Total Fe 0.10 " Conductance 11,900 Note: Conductance in micromhos /cm @ 25° C	10 20 30 40 50 60 70 80 90								10 20 30 40 50 60 70 80 90			

EXPLANATION

☐ CORE LOSS

CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X series) .. Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (3-63)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE

FEATURE . . Canadian River Below Ute Dam . . . . PROJECT Canadian River Salinity Study . . . . SHEET . 1 . . . OF . 6
HOLE NO. . DU-2 . . . LOCATION 13N . - 34E . - 7BCD1 . . . STATE . New Mexico
COORDS. N . 35° . 22' . 10" . . E 103° 22' 35" GROUND ELEV. . 3665' A.M.S.1 DIP (ANGLE FROM HORIZ.) . . 90
BEGUN 7/01/75 . . FINISHED 7/06/75 . . . DEPTH OF OVERBURDEN . 33.7' . . . . TOTAL DEPTH . 556.0' . . BEARING . . . . . .
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED 3 GPM 7-6-75 Artesian . . . . LOGGED BY . D. Smith J. K. Morrison . . . . LOG REVIEWED BY . . S. E. Kluender . . . .

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS | TYPE AND SIZE OF HOLE | CORE RECOVERY (%) | PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm) TO; LOSS (G.P.M.); PRESSURE (P.S.I.); LENGTH OF TEST (MIN.) | ELEVATION (FEET) | DEPTH (FEET) | GRAPHIC LOG | SAMPLES FOR TESTING | CLASSIFICATION AND PHYSICAL CONDITION

Drill Rig:
Failing 1500.

Casing:
Set 40.5' of 6", upon completion of drilling; casing pulled, set 42' of 4" casing, cemented to ground level and welded cap on to seal. Cap has pet-cock.

Drill Fluid Loss:
0' - 466' 0%
466' - 554' artesian-no loss.

Sampling:
Sampled cuttings at approx. 10' intervals from drilling fluid return ditch.

Water samples taken at irregular intervals from casing. River water samples also taken.

Water Samples:

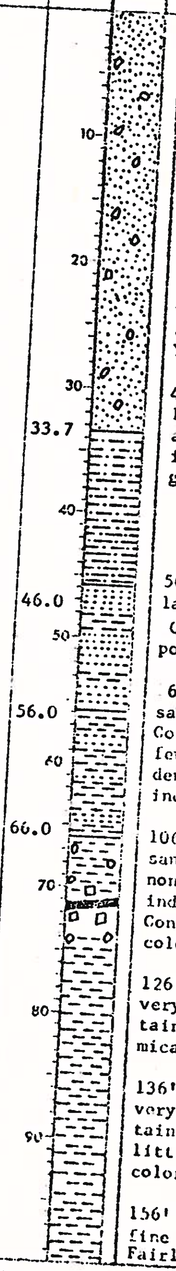
1. River water 7/2/75.
Chloride 6,100 mg/1
NaCl 10,065 "
Sulfate 540 "
Total Fe 0.06 "
Conductance 11,400

2. River water 7/3/75
Chloride 4,550 mg/1
NaCl 7,508 "
Sulfate 610 "
Total Fe 0.08 "
Conductance 13,900

3. River water 7/4/75.
Chloride 5,050 mg/1
NaCl 8,332 "
Sulfate 710 "
Total Fe 0.12 "
Conductance 15,200

4. River water 7/5/75.
Chloride 5,700 mg/1
NaCl 9.045 "

7-7/8" Rock Bit
10
20
30
4-3/4" Drag Bit
45
CS
50
60
70
80
90



0' - 33.7'
Quarternary Alluvium

0' - 33.7' Sand, fine to medium. Some gravel and cobbles. Fair HCL reaction. Contains a few mica flakes. Many particles limonite stained. Mottled reddish color.

33.7' - 56'
Triassic Santa Rosa Sandstone

33.7' - 46' Sandy Shale, some fine to very fine and medium sands. Many particles limonite stained. Poorly indurated. Yellowish-gray color.

46' - 56' Sandstone, fine to very fine. Fair HCL reaction, calcareous and argillaceous cement. Seams of shale interbedded; poorly indurated. Yellowish gray color.

56' - 536'
Permian Bernal Formation

56' - 66' Shale, fine to very fine sand layers interbedded. Poor HCL reaction. Contains some limonite and chalcopyrite poorly indurated. Grayish-yellow color.

66' - 105' Shale, some fine to very fine sand. Seams of chalcopyrite encountered; Contains small limonite particles and a few mica flakes. Limonite staining evident. Fair HCL reaction. Fair to poor induration. Whitish-gray color.

106' - 126' Shale, some fine to very fine sands. Seams of clay interbedded. Clay non-indurated. Fair HCL reaction, fair induration, limonite staining evident. Contains some chalocopyrite. Whitish-gray color.

126' - 136' Sandy Shale, a lot of fine to very fine sand. Fair HCL reaction. Contains some chalocopyrite and lots of mica flakes. Whitish-gray color.

136' - 156' Sandy Shale, some fine to very fine sand. Fair HCL reaction. Contains some mica and chalcopyrite, also a little smoky quartz. Light grahish-white color.

156' - 176' Shale, seams of fine to very fine sand interbedded. Fair HCL reaction. Fairly well indurated. Grayish-white color.

EXPLANATION

☐ CORE LOSS
▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-69)
Bureau of Reclamation

GPO 834-461

GEOLOGIC LOG OF DRILL HOLE

SHEET 2 OF 6

FEATURE .... PROJECT .... STATE ....

HOLE NO. DH-2 .... LOCATION .... COORDS. N .... E .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

Sulfate 790 mg/1
Total Fe 0.06 "
Conductance 17,600

5. From 516', artesian encountered at 466', 3gpm.
Chloride 4,800 mg/1
NaCl 7,920 "
Sulrate 1,015 "
Total Fe 0.24 "
Conductance 16,300

6. From 534', flowing from casing.
Chloride 4,950 mg/1
NaCl 8,168 "
Sulrate 1,013 "
Total Fe 1.08 "
Conductance 16,900
Artesian pressure = 0.5 lb/in^2

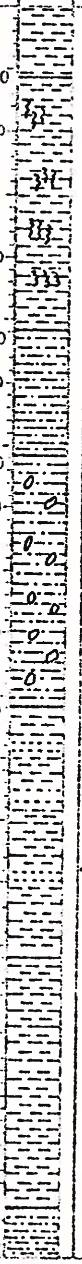
7. River water
7/7/75
Chloride 6,000 mg/1
NaCl 9,900 "
Sulfate 650 "
Total Fe 0.10 "
Conductance 17,600

Note: Conductance in micromhos /cm @ 25° C.

4-3/4"
Drag
Bit

10
20
30
40
50
60
70
80
90

106.0
10
20
126.0
30
136.0
40
50
156.0
60
70
176.0
80
90
196.0



176' - 196' Shale, a little fine to very fine sand and some clay. Fair HCL reaction; fair induration. White to grayish-red color.

196' - 211' Sandy Shale, sand mostly very fine to fine, increasing clay fraction near bentonite consistency. Grades to ferruginous shale. Fair HCL reaction; fair induration. Reddish-gray color.

211' - 216' Ferruginous Shale, a little fine to very fine sand. Argillaceous content increasing as evidenced by thickening of drill mud. Contains some chalcopyrite and mica. Fair induration. Light reddish-brown color.

296' - 326' Ferruginous Shale, some fine to very fine sand, high argillaceous content. Fair HCL reaction; fairly good induration. A few mica-rich seams are interbedded. Light reddish-brown color.

326' - 356' Ferruginous Shale, some very fine sand to silt, fairly high argillaceous content. Fair HCL reaction; fair induration. Contains a few chalcopyrite crystals. Brownish-red color.

356' - 396' Ferruginous Shale, a few medium to coarse sand grains, fairly high argillaceous content. Seams of non-indurated clay interbedded, bentonitic consistency. Poor induration; slight HCL reaction. Brownish-red color.

396' - 436' Ferruginous Shale, a little medium to coarse sand. Contains a few chalcopyrite crystals. Fairly well indurated. Slight HCL reaction. Brownish-red color.

436' - 456' Ferruginous Shale, some fine to very fine sand interbedded. Contains some mica and chalcopyrite. Argillaceous content high. Slight HCL reaction; fair induration. Brownish-red color.

EXPLANATION

☐ CORE LOSS

CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2"; Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) .. Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .. Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-67)
Bureau of Reclamation

GPO 864-401

GEOLOGIC LOG OF DRILL HOLE

SHEET 3 OF 6

FEATURE .... PROJECT .... STATE ....
HOLE NO. DH-2 LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

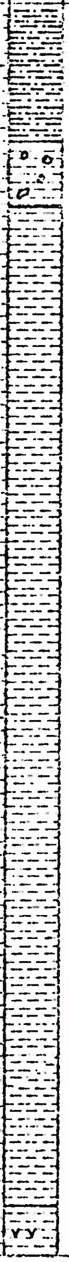
NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	4-3/4" Drag Bit											

Depth scale: 10, 20, 30, 40, 50, 60, 70, 80, 90

211.0

216.0

296.0



456' - 516' Ferruginous Sandy Shale. Some very fine sand to silt size particles. Argillaceous content high. Good HCL reaction; fairly good induration. Contains chalcopyrite crystals. Brownish-red color.

516' - 536' Ferruginous Siltstone, fairly sandy, fine to very fine sand. Argillaceous content lessening. Fair HCL reaction. Contains some chalcopyrite and mica flakes. Reddish-brown color.

EXPLANATION OF GRAPHIC LOG:

INDURATED ROCK

- ▦ Sandstone
- ☰ Shale
- ▤ Sandy shale
- ▩ Sandstone and shale

CONSTITUENT PARTICLES

- Clay
- ○ Pebbles, gravel, cobbles, or boulders
- · Sand
- Silt

MISCELLANEOUS SYMBOLS

- ▢ Pyrite
- v Mica
- ▬ Coal

EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole .... D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .. Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .. Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series). . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

7-1337 (9-63)
Bureau of Reclamation

GPO 864-401

GEOLOGIC LOG OF DRILL HOLE

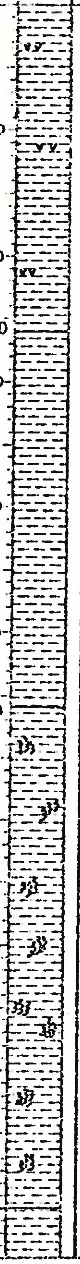
SHEET. . 4 . . . OF. 6 . . . .

FEATURE . . . . PROJECT. . . . . STATE. . . . .

HOLE NO. . . DH-2 . . . LOCATION. . . . . COORDS. N. . . . . E. . . . . GROUND ELEV. . . . . DIP (ANGLE FROM HORIZ.) . . . .

BEGUN . . . . FINISHED. . . . . DEPTH OF OVERBURDEN . . . . TOTAL DEPTH. . . . . BEARING. . . . .

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED. . . . . LOGGED BY. . . . . LOG REVIEWED BY. . . . .

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET) FROM (P, Ca, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
	$4^{3}/4$" Drag Bit 10 20 30 40 50 60 70 80 90								10 20 326.0 30 40 50 356.0 60 70 80 90 396.0			

E X P L A N A T I O N

CORE LOSS

CORE RECOVERY

Type of hole . . . . D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Ca = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3".
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series). . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 2"

FEATURE . . . . PROJECT . . . . STATE . . . . SHEET .4. . OF .6. . HOLE NO. DH-2 . . . .

7-1337 (9-69)
Bureau of Reclamation

GPO 824-401

GEOLOGIC LOG OF DRILL HOLE

SHEET . . 5 . . . OF . . 6 . . . .

FEATURE . . . . PROJECT . . . . STATE . . . .

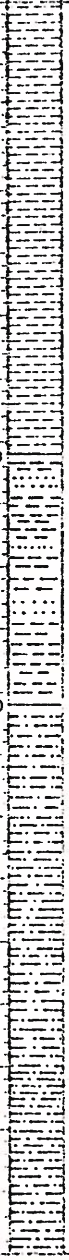
HOLE NO. DH-2 . . . . LOCATION . . . . GROUND ELEV. . . . . DIP (ANGLE FROM HORIZ.) . . . .

COORDS. N. . . . . E. . . . .

BEGUN . . . . FINISHED . . . . DEPTH OF OVERBURDEN . . . . TOTAL DEPTH . . . . BEARING . . . .

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED . . . . LOGGED BY . . . . LOG REVIEWED BY . . . .

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	4 3/4" Drag Bit											
	10								10			
	20								20			
	30								30			
									436.0			
	40								40			
	50								50			
									456.0			
	60								60			
	70								70			
	80								80			
	90								90			



EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE . . . . PROJECT . . . . STATE . . . . SHEET . 5 . . OF . 6 . HOLE NO. . . . DH-2 . . . . .

7-1337 (8-69)
Bureau of Reclamation

GPO 836-401

GEOLOGIC LOG OF DRILL HOLE

SHEET . 6 . . . OF . . 6 . . .

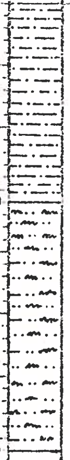
FEATURE . . . . PROJECT . . . . STATE . . . .

HOLE NO. DH-2 . . . . LOCATION . . . . COORDS. N. . . . . E. . . . . GROUND ELEV. . . . . DIP (ANGLE FROM HORIZ.) . . . .

BEGUN . . . . FINISHED . . . . DEPTH OF OVERBURDEN . . . . TOTAL DEPTH . . . . BEARING . . . .

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED . . . . LOGGED BY . . . . LOG REVIEWED BY . . . .

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	43/4" Drag Bit											
	10								10			
									516.0			
	20								20			
	30								30			
									536.0			
	40								40			
	50								50			
	60								60			
	70								70			
	80								80			
	90								90			



EXPLANATION

☐ CORE LOSS

▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE . . . . PROJECT . . . . STATE . . . . SHEET 6 OF 6 HOLE NO. . . DH-2 . . . . . .

7-1337 (6-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE POW-1

SHEET 1 OF 2

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico
HOLE NO. POW-1 LOCATION Below Ute Dam
COORDS. N. E. GROUND ELEV. 3,674.73' DIP (ANGLE FROM HORIZ.) 90.0°
BEGUN 9-23-77 FINISHED 10-13-77 DEPTH OF OVERBURDEN 26.5' TOTAL DEPTH 318.0' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Stapp-Hamilton Inc.
Austin, Texas

Solicitation No.
7-07-50-S0970

Damco 1250 Drilling rig.

Drill Fluid Additives and Drill Water Return.

(Ft.)	(%)
0.0- 6.0	0.0
(600.0 lbs. revert)	
6.0-40.0	90.0
40.0-120.0	100.0
120.0-140.0	70.0
140.0-142.0	35.0
142.0	0.0
(600.0 lbs. revert)	
142.0-210.0	100.0
210.0-220.0	80.0
220.0-230.0	30.0
[illegible]-240.0	60.0
([illegible].0 lbs. revert)	
240.0-258.0	50.0
(700.0 lbs. salt mud)	
258.0	0.0
(800.0 lbs. salt mud)	
(200.0 lbs. revert and 50.0 lbs. salt)	
[illegible]	0.0
(1,500.0 lbs. bentonite)	
286.0-[illegible]	0.0

Artesian flow below 294.0' between periods of drilling operations.

Sampled cuttings at approximately 10.0' intervals from drill fluid return ditch from 0.0' - 261.0'. Logged using binocular microscope.

Geophysical logging on 10-7-77.

Core samples obtained from 261.0' - 318.0'.

DEPTH (FEET) markers: 11.0, 15.0, 26.5, 28.7, 32.0, 58.0, 63.5, 68.0, 73.0, 78.4, 78.7, 86.0, 90.0, 200.0

CLASSIFICATION AND PHYSICAL CONDITION

0.0' - 26.5': QUATERNARY ALLUVIUM.

0.0' - 11.0': Sand.
Approximately 80% medium to coarse sand, approximately 20% fine gravel, hard, subrounded to subangular rock and mineral fragments, buff. SP

11.0' - 15.0': Clayey Gravel.
Approximately 70% fine, hard, subrounded to subangular rock and mineral fragments, maximum size 1.2", approximately 30% medium plasticity fines of medium dry strength, medium toughness, no dilatancy, weak to moderate reaction with HCl, reddish-gray. GC

15.0' - 26.5': Sand.
Approximately 75% medium to coarse, some clay, approximately 25% fine, hard, subrounded to subangular rock and mineral fragments, reddish-gray. SP

26.5' - 318,0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS)

26.5' - 90.0': Sandstone.
Medium to coarse-grained, silty, micaceous, moderately indurated, calcareous cement, layers and stingers of interbedded shale, buff to grayish-tan.

28.7' - 32.0', 58.0' - 63.5', 68.0' - 73.0', and 86.0 - 90.0': Shale
Argillaceous, sandy, small amount of gravel, sticky when wet, calcareous, red-brown and gray layers.

78.4' - 78.7': Soft Coal.

90.0' - 251.0': Sandstone.
Medium to very coarse-grained, silty, poorly sorted, calcareous, moderately indurated, conglomeritic from 203.5' - 208.0' and from 220.0' - 230.0', blue-gray.

251.0' - 271.0': Shale.
Argillaceous, sticky when wet, some calcareous cement, with interbedded sandstone, blue-gray.

256.0' - 258.0' and 263.0' - 264.0': Sandstone.
Medium to coarse-grained, silty, some calcareous cement, well indurated, very hard, blue-gray.

EXPLANATION

☐ CORE LOSS
▨ CORE RECOVERY

Used 6" rock bit to 261.0'; NX cure and standard split-tube penetration resistance to 318.0'; set 25' of 6" surface casing, with top 1.5' below ground surface; pulled surface casing 10-13-77, installed 79.0' PVC 1.25" well screen attached at bottom of 234.0' of 2" steel casing to 1.0' above surface, gravel packed to top of screen, sand packed 1.0' over gravel and neat cement grout to surface. Water-tight steel cover placed over stick-up of steel casing.

Type of hole . . . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . . . P = Packer, Cm = Cemented, C = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1 2", Ax = 1-7 8", Bx = 2 3 8", Nx
Approx. size of core (X-series) . . Ex = 7 8", Ax = 1-1 8", Bx = 1 5 8", Nx
Outside dia. of casing (X-series). Ex = 1-13 16", Ax = 2-1 4", Bx = 2 7 8", Nx
Inside dia. of casing (X-series) . . Ex = 1-1 2", Ax = 1-29 32', Bx

GPO 778-404

7-1337 (8-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE POW-1

SHEET 2 OF 2

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico
HOLE NO. POW-1 LOCATION Below Ute Dam GROUND ELEV. 3,674.73' DIP (ANGLE FROM HORIZ.) 90.0°
COORDS. N. E.
BEGIN 9-29-77 FINISHED 10-13-77 DEPTH OF OVERBURDEN 26.5' TOTAL DEPTH 318.0' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	220								200.0			271.0' - 318.0': Sandstone. Fine-grained, well sorted, very lightly indurated to well indurated, very slightly cemented to highly cemented, mica, thin intermittent shale seams with pyrite crystals and limonite staining, blue-gray.
	230								10			
	240								20			
									251.0			
									256.0			
									258.0			
	260								30			
		49							263.0			
									264.0			
		0										
		79							271.0			
	280	10							40			
		0										
		[illegible]										
		0										
		27										
	300	60							50			
		20										
		[illegible]										
		20										
	320	[illegible]							318.0 60			
	340								70			
	360								80			
	380								90			
	400								400.0			

EXPLANATION

CORE LOSS
CORE RECOVERY

Type of hole . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx - 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

[illegible]
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE OW-2

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico
HOLE NO. OW-2 LOCATION Below Ute Dam GROUND ELEV. 3,676.88' DIP (ANGLE FROM HORIZ.) 90.0°
COORDS. N. E.
BEGUN 10-27-77 FINISHED 1-4-78 DEPTH OF OVERBURDEN 20.0' TOTAL DEPTH 348.0 BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
Stagg-Hamilton Inc. Austin, Texas Solicitation No. 7-07-90-[illegible]970 Damco 1290 Drilling rig initially drilled to total depth; Failing Drilling rig reamed to total depth. Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0' - 300.0'. Logged using binocular microscope. Geophysical logging on 12-16-77. Core samples obtained from 300.0' - 348.0'. Hole completion included gravel pack around 6.0" casing from bottom of hole to unknown depth (248.0') according to as-built diagram in file). Added 88 cubic feet grout to G.L. in three stages, last two sacks 3-1-78. Special watertight cap placed on 6" steel casing.	40 10 80 20 120 30 160 40 200 50 240 60 280 70 320 80 360 90 400	55 18 51 95 0							20.0 10 20 91.0 30 40 50 232.0 60 261.0 70 333.0 348.0 400.0			0.0' - 20.0': QUATERNARY ALLUVIUM. 0.0' - [illegible].0': Silty Sand. Approximately 80% fine to coarse, angular to subrounded sand, maximum size 0.2", approximately 20% low to medium plasticity fines, low toughness, low dry strength, quick dilatency, strong to moderate reaction with HCl, buff. SM 20.0' - 348.0': SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS) 20.0' - 91.0': Sandstone. Medium to coarse-grained, silty, poorly sorted, calcareous cement, with layers of shale at 28.0' - 30.0' and 78.0' - 91.0', and small amount of coal within 80.0' - 90.0' interval, tan. 91.0' - 230.0': Sandstone. Medium to coarse-grained, silty, poorly sorted, calcareous cement, with gray shale layer 145.0' - 153.0' and very thin gray shale layers interbedded in 200.0' - 220.0' interval, blue-gray. 230.0' - 261.0': Shale. Sandy, blocky, sticky when wet, cuttings are Lean to Fat Clay, medium to high plasticity, medium toughness, with thin interbedded gray sandstone, gray. 261.0' - 333.0': Sandstone. Fine-grained, well-sorted, slightly cemented to highly cemented, with gray shale layer 288.0'- 291.0', light gray. 333.0' - 348.0': Shale. Sticky when wet, gray.

CORE LOSS

CORE RECOVERY

EXPLANATION

Used 4-1/2" rock bit 0.0' - 300.0'; NX core barrel with diamond bit from 300.0' - 348.0'. Set 2.0' of 12" surface casing 10-31-77. Set surface casing to 24.0' with 1.0' above G.L. on 11-2-77. Grouted 12" casing in hole on 2-9-78. Placed below G.L. 260.0' of 6" casing with 6.0' above G.L. and with 80.0' of 2" PVC screen attached to bottom. Driller did not measure casing or hole before placing 6" casing and subsequent measurements show bottom of 6" casing 272.7' below G.L.

Type of hole . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) . Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) . . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE Canadian River PROJECT Lake Meredith STATE New Mexico SHEET 1 OF 1 HOLE NO. OW-2

* GPO 778-404

Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE OW-3

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake M[illegible]th Salinity Study STATE New Mexico

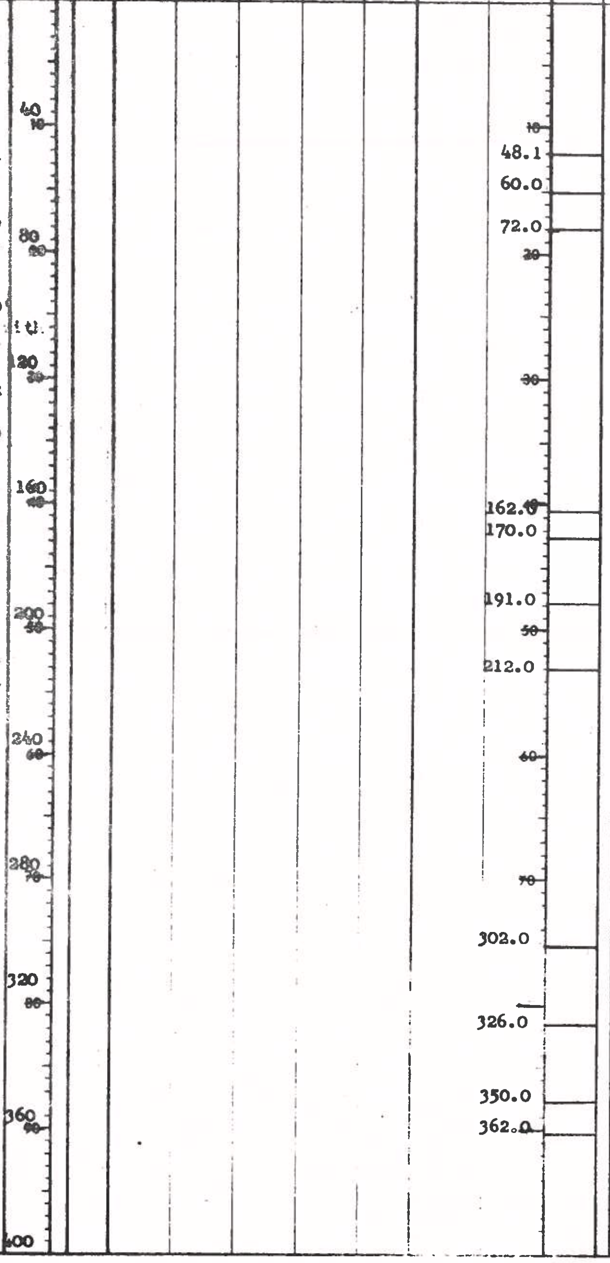
HOLE NO. OW-3 LOCATION Below Ute Dam

COORDS. N. E. GROUND ELEV. 3,672.81' DIP (ANGLE FROM HORIZ.) 90.0°

BEGUN 1-9-78 FINISHED 1-28-78 DEPTH OF OVERBURDEN 48.1' TOTAL DEPTH 362.0' BEARING

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM (P, Cs, or Cm)	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



Stapp-Hamilton Inc.
Austin, Texas

Solicitation No. 7-07-30-20970

Failing 1500 Drilling rig.

Used 7-7/8" tricone rock bit to 362.0'. Set 49.6' of 5" surface casing 1-12-78. Set 270.0' of 2" steel casing with 80.0' of 2" screen below to 350.0'. Gravel pack (0.7 cubic yards) from bottom of hole to 260.0' depth, cement grout emplaced to within 3/4" of G.L. Watertight steel cap placed on steel casing.

Geophysical logging on 1-20-78.

Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0' - 362.0'. Logged using binocular microscope.

Drilled with clear water.

0.0'- 48.1': QUATERNARY ALLUVIUM.

0.0' - 48.1': Silty Sand. Approximately 80% fine to coarse, angular to subrounded sand, approximately 20% none to low plasticity fines, low toughness, quick dilatancy, trace gravel, strong reaction with HCl, buff to tan. SM

48.1' - 362.0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATION OF TEXAS)

48.1' - 60.0': Sandstone. Fine to coarse-grained, subangular to subrounded grains, strong reaction with HCl, tan.

60.0' - 72.0': Gravelly Shale. Sticky when wet, medium to coarse sand and gravel up to 5/8" maximum size, gray.

72.0' - 162.0': Sandstone. Medium to coarse-grained, silty, poorly sorted, mica, calcareous cement, contains apatite, thin gray shale layers interbedded, blue-gray.

162.0' - 170.0': Shale. Sticky when wet, argillaceous, cuttings are Lean to Fat Clay with medium to high plasticity and high toughness, blue-gray.

170.0' - 191.0': Sandstone. Fine-grained, well-sorted, light gray.

191.0' - 212.0': Shale. Sticky when wet, argillaceous, cuttings are Lean to Fat Clay, medium to high plasticity, medium toughness, blue-gray.

212.0' - 302.0': Sandstone. Fine-grained, well-sorted, rounded to subrounded grains, mica, some 1.0 to 3.0' interbedded shale layers 258.0', 269.0', and 286.0', light gray.

302.0' - 326.0': Shale. Sandy, argillaceous, sticky when wet, gray.

326.0' - 350.0': Sandstone. Fine-grained, silty, red-brown.

350.0' - 362.0': No Sample.

EXPLANATION

☐ CORE LOSS
▨ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) . . Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) . . Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series). Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series). . Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

FEATURE Canadian River PROJECT Lake Meredith STATE New Mexico SHEET 1 OF 1 HOLE NO. OW-3

7-1337 (5-74)
Bureau of Reclamation

GEOLOGIC LOG OF DRILL HOLE OW-4

SHEET 1 OF 1

FEATURE Canadian River PROJECT Lake Meredith Salinity Study STATE New Mexico
HOLE NO. OW-4 LOCATION Below Ute Dam COORDS. N. E. GROUND ELEV. 3,675.51' DIP (ANGLE FROM HORIZ.) 90.0°
BEGUN 1-24-78 FINISHED 1-31-78 DEPTH OF OVERBURDEN 11.0' TOTAL DEPTH 382.0' BEARING
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED Artesian LOGGED BY Shirley Shadix LOG REVIEWED BY J. L. Jackson

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS (G.P.M.)	PRESSURE (P.S.I.)	LENGTH OF TEST (MIN.)					
			FROM (P, Cs, or Cm)	TO								
Stapp-Hamilton Inc. Austin, Texas Solicitation No. 7-07-50-S0970 Failing 1500 Drilling rig. Used 7-7/8" tricone rock bit 0.0-15.0'. Set 15.0' of 6-5/8" surface casing, with 1.0' above G.L. Used 4-1/2" tricone rock bit 15.0' to T.D. Set 293.0' of 2" steel casing, with 0.85' above G.L. and 84.0 of 2" slotted steel casing attached to bottom. Gravel packed from bottom of hole to 287.0', sand 287.0'-285.0', and neat cement to [illegible] ft surface [illegible] in hole. Watertight steel cap placed on steel [illegible]. Geophysical logging on [illegible]-78. Sampled cuttings at approximately 10' intervals from drill fluid return ditch from 0.0'-382.0'. Logged using binocular microscope. Drilled with clear water.	40 80 120 160 200 240 280 320 360 400								11.0 62.0 75.0 100.0 204.0 290.0 355.0 382.0			0.0' - 11.0': QUATERNARY ALLUVIUM 0.0' - 11.0': Sand. Predominantly fine to medium, maximum size 1/8", round to subangular, hard, rapid reaction with HCl, trace of fines, buff color. SP 11.0' - 382.0': TRIASSIC SANTA ROSA SANDSTONE. (TRUJILLO AND TECOVAS FORMATIONS OF TEXAS) 11.0' - 62.0': Sandstone. Fine to medium-grained, subangular to subrounded grains, moderately indurated, slightly to highly cemented, calcareous cement, hard, tan. 62.0' - 75.0': Sandstone. Fine to medium-grained, subangular to subrounded grains, silty, clayey, hard, blue-gray. 75.0' - 100.0': Shale. Very sticky when wet, well cuttings could be described as Lean to Fat Clay with high toughness, calcareous cement, with fine to medium gray sandstone layers interbedded, mostly gray, but some red-brown. 100.0' - 204.0': Sandstone. Fine to coarse-grained, angular to subangular grains, argillaceous, rock and mineral fragments, well indurated, approximately 1.0" seam of soft coal in upper 10.0' and thin bed of gray shale within interval 162.0' - 172.0', gray. 204.0' - 290.0': Shale. Thin lenses of gray shale, predominantly red-brown, sticky when wet. Well cuttings are Lean to Fat Clay, high toughness and medium to high plasticity. Thinly interbedded gray sandstone. Fine to coarse-grained, some calcareous cement. 290.0' - 355.0': Sandstone. Fine-grained, rounded to subrounded grains, well-sorted, mica, tan to gray. 355.0' - 382.0': Shale. Sandy, sticky when wet, blue-gray.

EXPLANATION

☐ CORE LOSS
■ CORE RECOVERY

Type of hole . . . . D = Diamond, H = Haystellite, S = Shot, C = Churn
Hole sealed . . . . P = Packer, Cm = Cemented, Cs = Bottom of casing

Approx. size of hole (X-series)	Ex = 1-1/2",	Ax = 1-7/8",	Bx = 2 3 8",	Nx = 3"
Approx. size of core (X-series)	Ex = 7/8",	Ax = 1-1/8",	Bx = 1-5 8",	Nx = 2 1 8"
Outside dia. of casing (X-series)	Ex = 1-13/16",	Ax = 2-1/4",	Bx = 2-7 8",	Nx = 3 1 2"
Inside dia. of casing (X-series)	Ex = 1-1/2",	Ax = 1-29/32",	Bx = 2 3 8",	Nx = 3"

* GPO 778-404