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NEW MEXICO ENERGY INSTITUTE

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MASTER

USE OF GEOTHERMAL ENERGY FOR DESALINATION IN NEW MEXICO - A FEASIBILITY STUDY

FINAL REPORT

DISCLAIMER

This research was conducted with the support of the New Mexico Energy and Minerals Department (EMD) and the New Mexico Energy Institute at New Mexico State University (NMEI-NMSU) under Contract ERB 76-261. However, any opinions, findings, conclusions or recommendations expressed within this report are those of the authors and do not necessarily reflect the views of EMD or NMEI-NMSU.

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USE OF GEOTHERMAL ENERGY FOR DESALINATION IN NEW MEXICO - A FEASIBILITY STUDY

Final Report

(1/1/77-5/30/79)

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June 1979

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Technical Completion Report

by

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June 1979

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CHAPTER 1

INTRODUCTION

Water Requirement and Availability

The availability of fresh water supplied in New Mexico and the southwestern United States has been a problem for many centuries. From the time of the early Pueblo Indians to the present, water has been the most important commodity in this arid region. Due to the lack of a large supply of surface fresh water, New Mexico has been slow to develop. This lack of development accounts for the clear skies and wide open spaces, and on the negative side, the low per capita income of New Mexico. However, in recent years, New Mexico's mineral wealth and climate have caused a rapid immigration of people and industry. If this rapid immigration continues, the demand for fresh water might become critical in the state.

Since 1950, population in New Mexico has grown at a more rapid rate than the national average, and due to the "energy crisis" this trend should continue or even accelerate. The projected increases in population in New Mexico for the next 40 years is presented in Figure 1. These projections are based on studies initiated by state and federal agencies (Bur. of Rec., 1976). Three different growth rates were used in making these projections for three time frames--1980, 2000, 2020. Considering the average of these projections, an assumed population of two million by the year 2000 is reasonable, which is almost double the 1970 state population.

New water supplied to accommodate this influx of people and to satisfy the potential of increased mining and manufacturing in the state must be found.

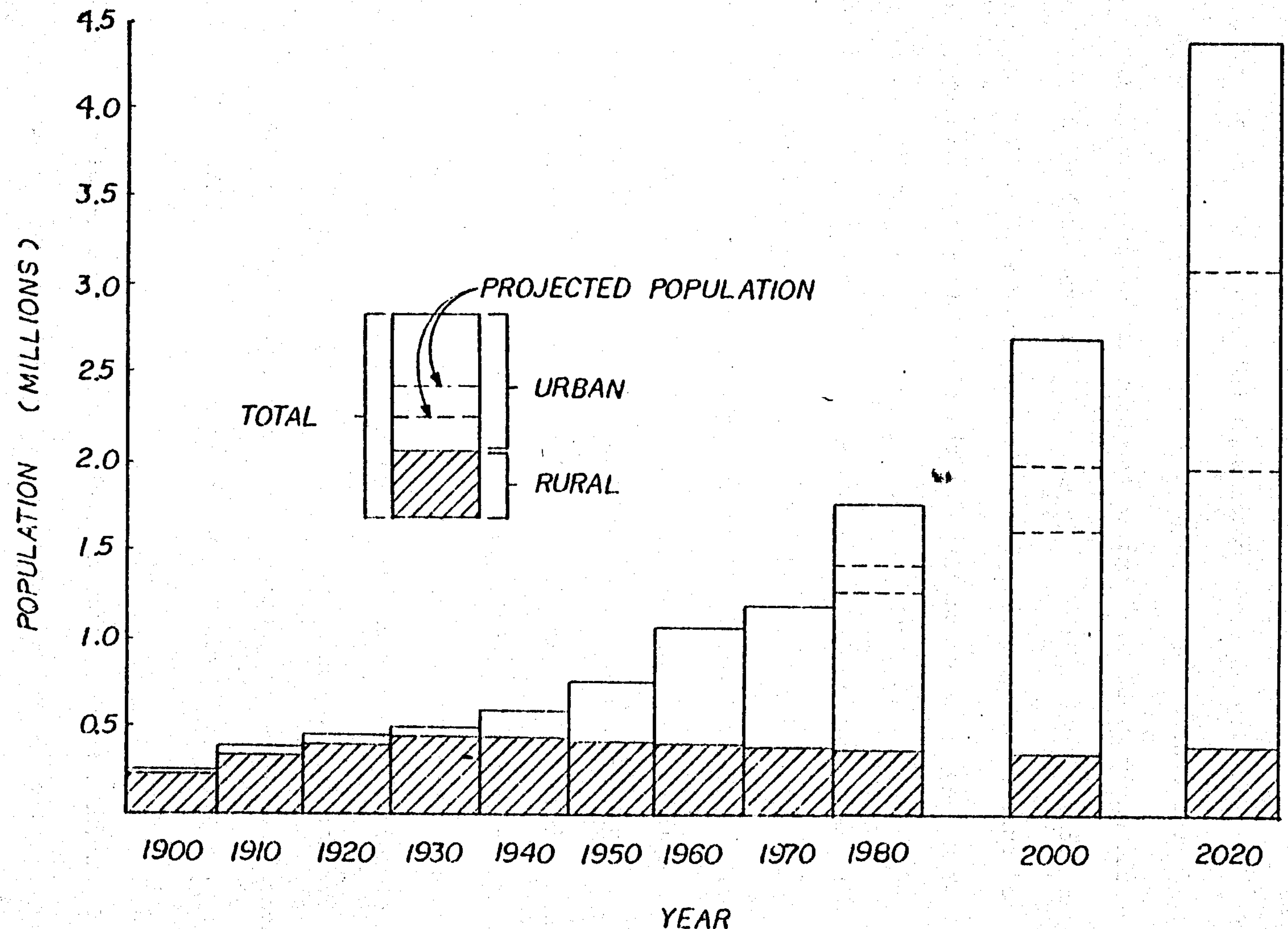


Figure 1 Population of New Mexico, 1900-1970; and three projected population levels for 1980, 2000, 2020. (Source: Bur. of Rec., 1976)

Water Consumption Trends

The present annual surface water supply for New Mexico is approximately 0.75 million hectare-meters (5.7 million acre-feet). New Mexico presently consumes 0.30 million hectare-meters (2.3 million acre-feet) and 0.45 million hectare-meters (3.4 million acre-feet) are passed downstream to Texas, as established by law (Bur. of Rec., 1976). The effect of increased industrial and population growth on water consumption in New Mexico is shown in Figure 2. This figure indicates that by the year 2000, New Mexico will consume an additional 0.13 million hectare-meters (1.0 million acre-feet) of water per year, about 44% increase over present consumption.

Surface Water Resources

In New Mexico, the surface water supplied is essentially appropriated, with some small amounts of surplus water available in the San Juan, Little Colorado, and Arkansas River systems. In the first report of the National Water Commission in 1969, it was reported that the Rio Grande-Pecos River systems, which drain approximately 60% of the State of New Mexico, had the greatest shortage of water in relation to expected demand. The Colorado River system, which drains the western portion of the State of New Mexico, is second with respect to the shortage of water relative to expected demand (Stucky, 1971). The projected irrigation water demand in the year 2000 equals the present surface water appropriation (Figure 2). This indicates that the increased water demand will have to be furnished either by groundwater supplied or by reappropriated surface water supplies.

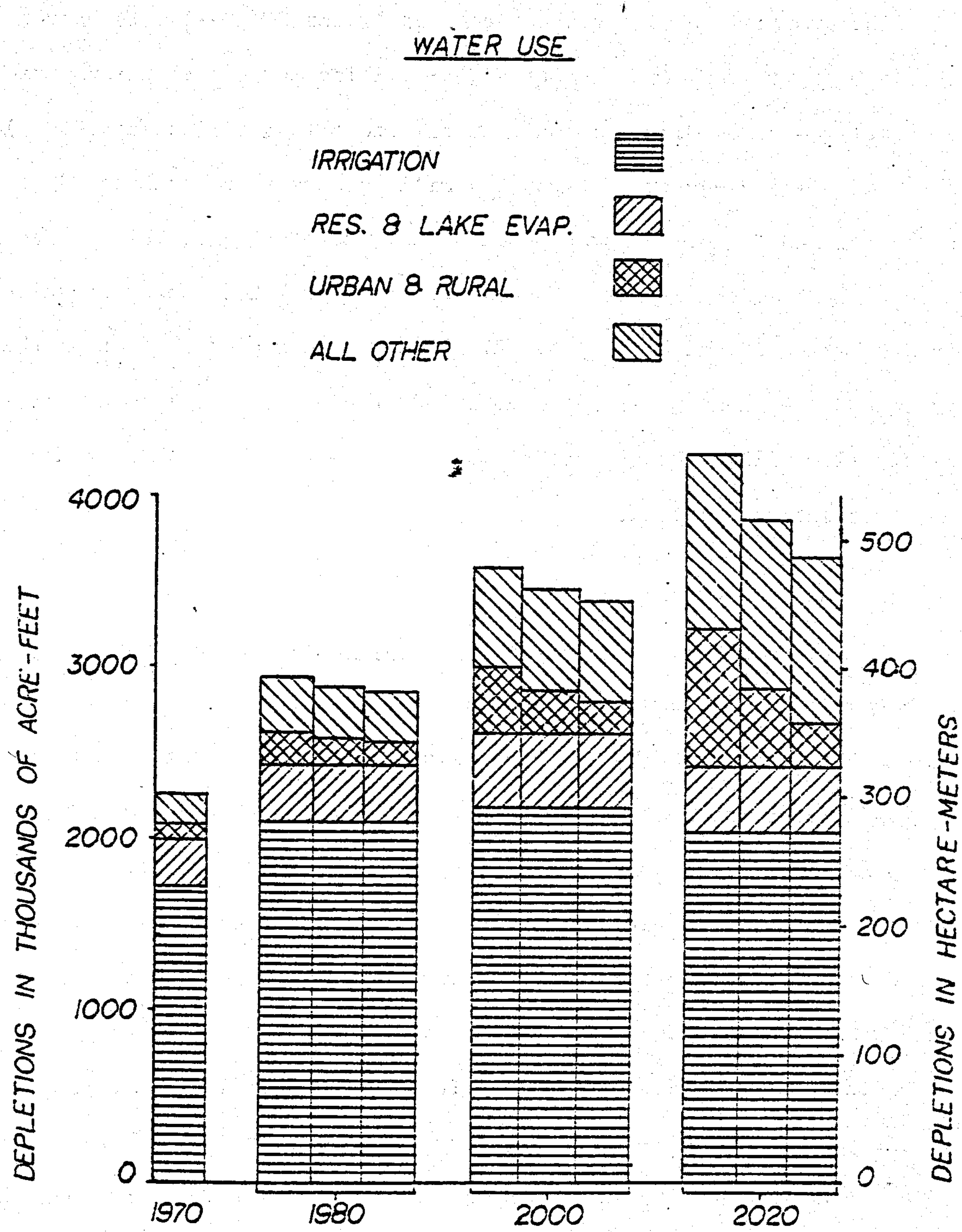


Figure 2
Present and estimated future water depletion requirements for New Mexico. (Source: Bur. of Rec., 1976)

Groundwater Resources

It has been estimated that New Mexico contains 0.39 billion hectare-meters (3.0 billion acre-feet) of fresh groundwater (<1000 ppm total dissolved solids) and 0.18 billion hectare-meters (1.4 billion acre-feet) of slightly saline (1000-3000 ppm total dissolved solids) groundwater (Bur. of Rec., 1976). This quality of groundwater would be ideal for urban and industrial consumption, since it could be directly consumed with little or no treatment. The problem with producing large quantities of the quality water is that the aquifers are widely dispersed throughout the state (see Chapter 2). In contrast, it has been estimated that over 2.0 billion hectare-meters (15 billion acre-feet) of saline groundwater (>3000 ppm total dissolved solids) exists in the state at relatively shallow depths, and underlies almost the entire state. However, this water may require either partial or total desalination, depending on the intended use of the water.

Justification for Desalting

At present, 90% of the urban water supplied in New Mexico come from groundwater sources, and costs range from \$.15/4000 liter (\$.15/1000 gal.) to \$.50/4000 liter (\$.50/1000 gal.), depending on the pumping costs and type of pretreatment required (Bur. of Rec., 1976 and Morris, 1971). Industrial users may pay even more, depending on the quantity and quality of the water required for their processes. Many desalination studies have been completed, and suggest that desalination costs range from \$.50/4000 l. (\$.50/1000 gal.) to \$1.50/4000 l. (\$1.50/1000 gal.), depending on the type of process and method of brine disposal used (Morris, 1971; Stucky, 1971; Dow Chemical, 1970; Le Gros, 1970; and Boegly, 1969).

As consumption continues to increase, municipal supplies will increase in cost as fresh water becomes harder to find. These increased costs should then make desalination for municipalities economically feasible. Also, since some industrial and mining processes do not require as high a quality of water as municipal consumption, partial desalination may now be more economical than pumping in fresh water from great distances.

Existing Non-Geothermal Desalination

The distillation process of desalination was the first process to be extensively studies by the Office of Saline Water (OSW, 1974). This process was found to have extensive energy requirements and a low product water recovery factor. Because of these facts, the OSW redirected its efforts toward the electrodialysis and reverse osmosis processes of desalination and closed all the major distillation test facilities in the United States (OSW, 1974). The electrodialysis and reverse osmosis processes are essentially filtration processes and can achieve 98% product water recovery. These processes are discussed in more detail in Chapter 3.

The distillation process could be more feasible if a cheap source of energy were available. Sources previously considered include waste heat from nuclear power plants, solar energy, and to a limited extent geothermal energy (Lansford, 1976; and OSW, 1974). The OSW has sponsored some research in this area and has recently built small scale geothermal distillation desalination test facilities (Bechtel, 1977 and Laird, 1971).

Various studies have been conducted in New Mexico on many desalination processes, such as distillation, electrodialysis, and reverse osmosis (Lansford et. al., 1976; Morris, 1971; Stucky, 1971; and Le Gros, 1970). However, no existing study in New Mexico has considered the geothermal desalination process.

Geothermal Desalination

Geothermal resources may be used in three basic ways to produce potable water. High quality geothermal steam can replace the steam sources in such distillation processes as Multistage Flash Evaporation, Vertical-Tube Evaporation, or the starting heat source in Vapor-Compressor Distillation. Geothermal steam can be used to produce mechanical work in a turbine to drive compressors in Vapor-Compressor Distillation, to drive pumps in a Reverse Osmosis operation, or to drive a generator to produce electrical power for Electrodialysis. Hot geothermal brines may be used as already preheated and usually deaerated feed streams for Multistage Flash Evaporation or Vertical-Tube Evaporation. For production of steam from geothermal resources, recent analyses have shown that the temperature of these resources must be above 150-200^{o}C (300-400^{o}F) with ideal conditions at about 300^{o}C (572^{o}F).

If geothermal resources of 200^{o}C (392^{o}F) and above could be found, Laird (1971) estimated that "...80 to 90 percent of the brine could be converted to freshwater by distillation at low cost." The cost would vary-depending upon the price charged for by-product electrical production from no cost to 30¢/1000 gal.

The U. S. Bureau of Reclamation has been exploring the geothermal resources on the East Mesa of Imperial Valley, California. The purpose of the Bureau's research and development program is to determine the feasibility of desalting mineralized geothermal fluids and the practicality of concurrent generation of electric power. According to Fernelius (1976), two test desalting units, a multistage flash (MSF) and a vertical tube evaporator (VTE), have been installed and are being operated to evaluate the distillation process for desalting geothermal fluids. Each unit was designed to produce 75 to 190 m^3/day of distilled water. Around the clock operations have been successful at both units, with minor scaling and corrosion problems. The Bureau of Reclamation has drilled and completed five deep test wells more than 1800 m in depth. Bottom hole temperatures of the deep holes range from 157 to 204°C (309 to 400°F). Initial operations show promise for feasible development of geothermal resources (at East Mesa, California) to provide an economical high-quality water supply (Fernelius, 1976). Figures 3, 4 and 5 show views of United States Bureau of Reclamation geothermal desalination facility in Imperial Valley, California.

Figure 3 High Altitude Photograph Looking Northwest Showing East Mesa Test Site, Imperial Valley, California (Bureau of Reclamation Photo).

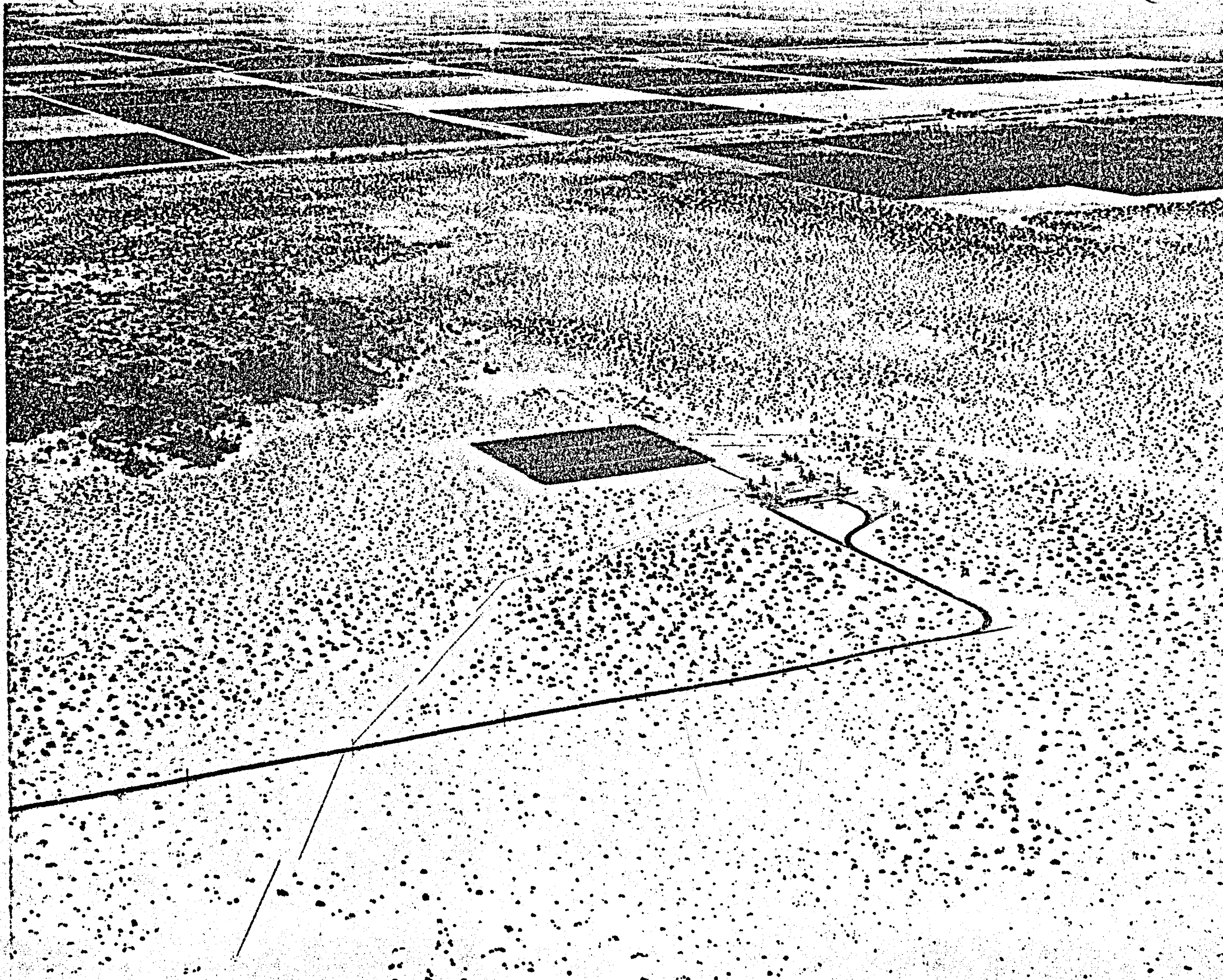


Figure 4 East Mesa Test Site (Imperial Valley, California) looking Northeast (Bureau of Reclamation Photo).

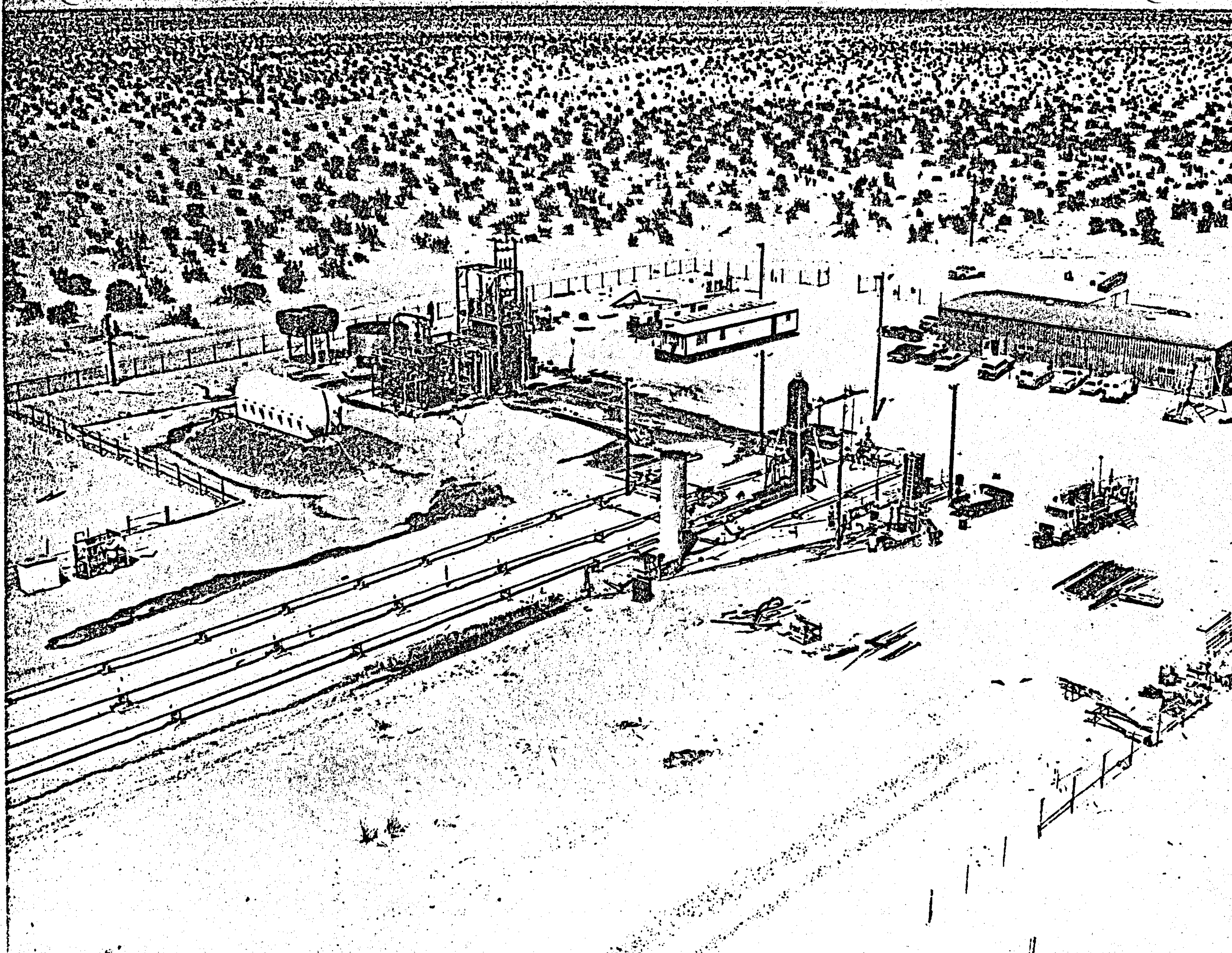
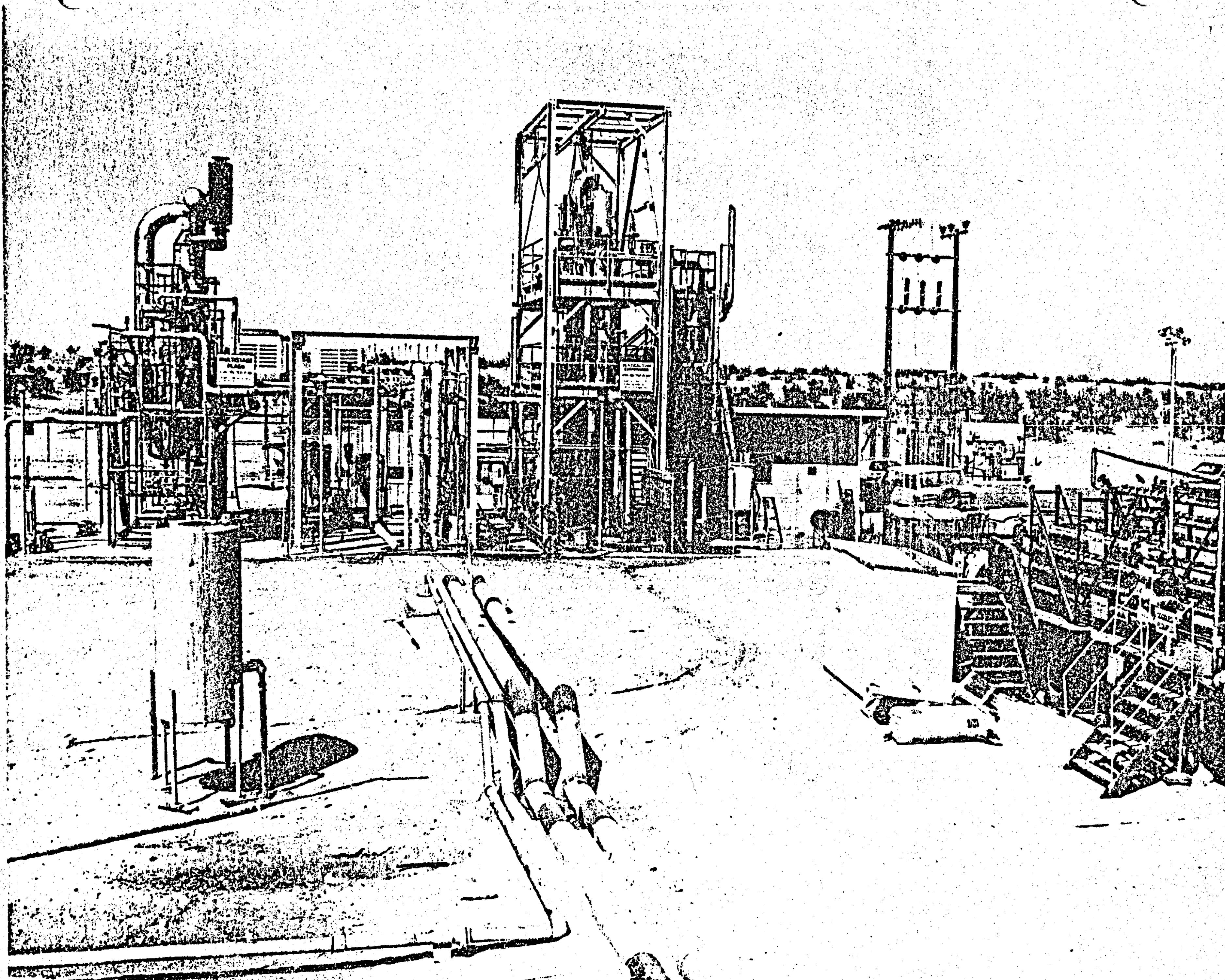


Figure 5 View of the Desalting Plants, East Mesa Test Site, Imperial Valley, California. Multistage Flash Unit is Seen at Left, Vertical Tube Evaporator, Center, and a Portion of the Bureau of Mines Corrosion Test Vehicle is at Right. (Bureau of Reclamation Photo).



CHAPTER 2

RESOURCE EVALUATION

Saline Water in New Mexico

The definition of the degree of salinity in water used here is the same as was first proposed by Winslow and Kister (1956) and later used by Hood and Kister (1962) and Bureau of Reclamation (1976). According to this system of classification, water containing more than 1,000 ppm of dissolved solids is termed "saline", although in many parts of New Mexico the only water available has higher salinity and is consumed by local residents. The saline water is further classified as follows:

Description	Dissolved Solids (in parts per million)
Slightly Saline	1000 - 3000
Moderately Saline	3000 - 10,000
Very Saline	10,000 - 35,000
Brine	More than 35,000

Bureau of Reclamation (1976) has compiled maps showing distribution of different categories of saline water in New Mexico. These maps, reproduced here in Figures 6, 7, 8 and 9 show estimated thickness of aquifers that contain slightly saline, moderately saline, very saline and brine, respectively. Figure 10 is a map of total dissolved solids in groundwater in New Mexico prepared by Swanberg (1979) on the basis of U. S. Geological Survey WATSTORE data supplemented by other collected data.

These maps referred above, do not provide the important parameter of depth with respect to the occurrence of saline water. We have,

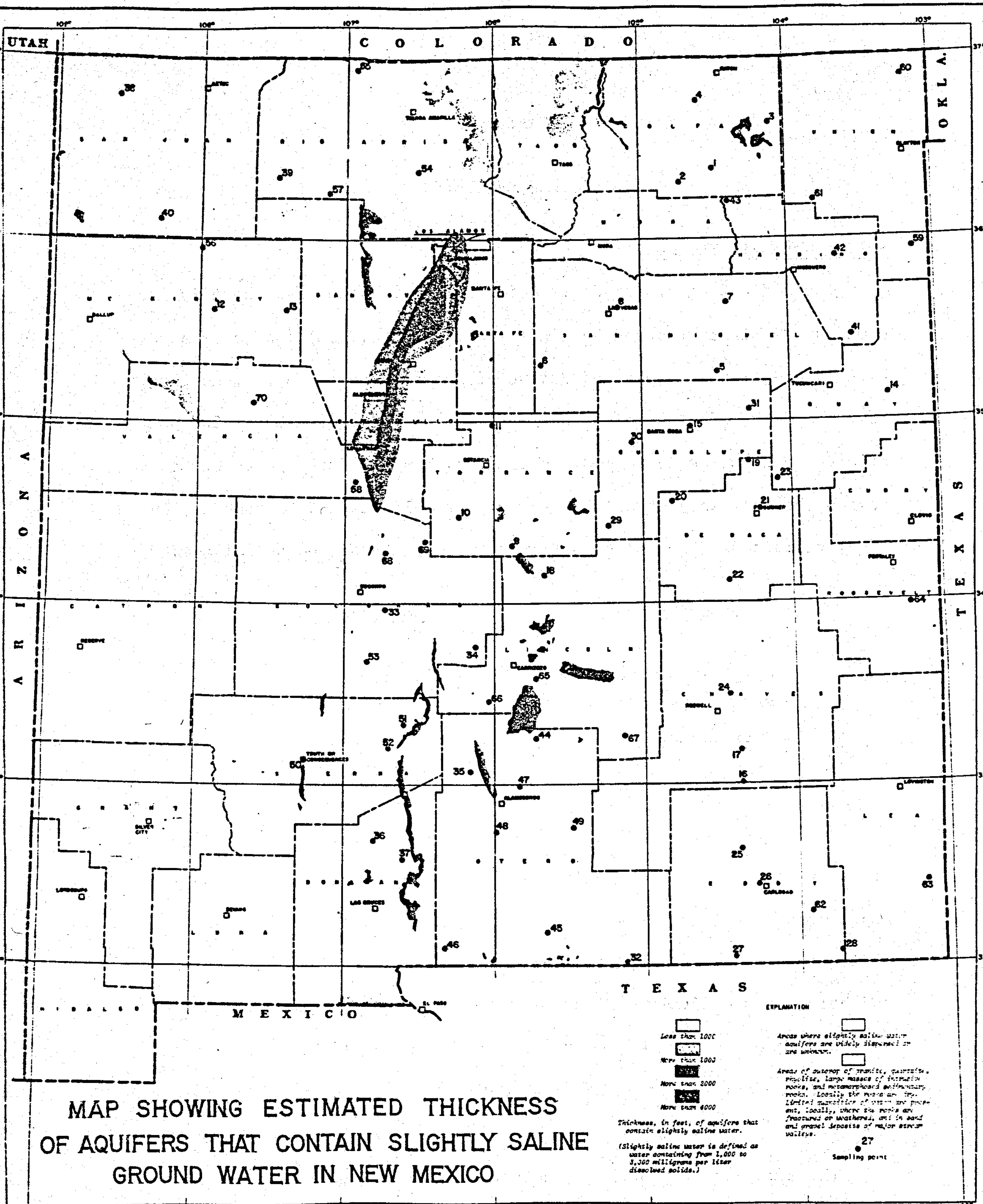


Figure 6 (Bureau of Reclamation, 1976)

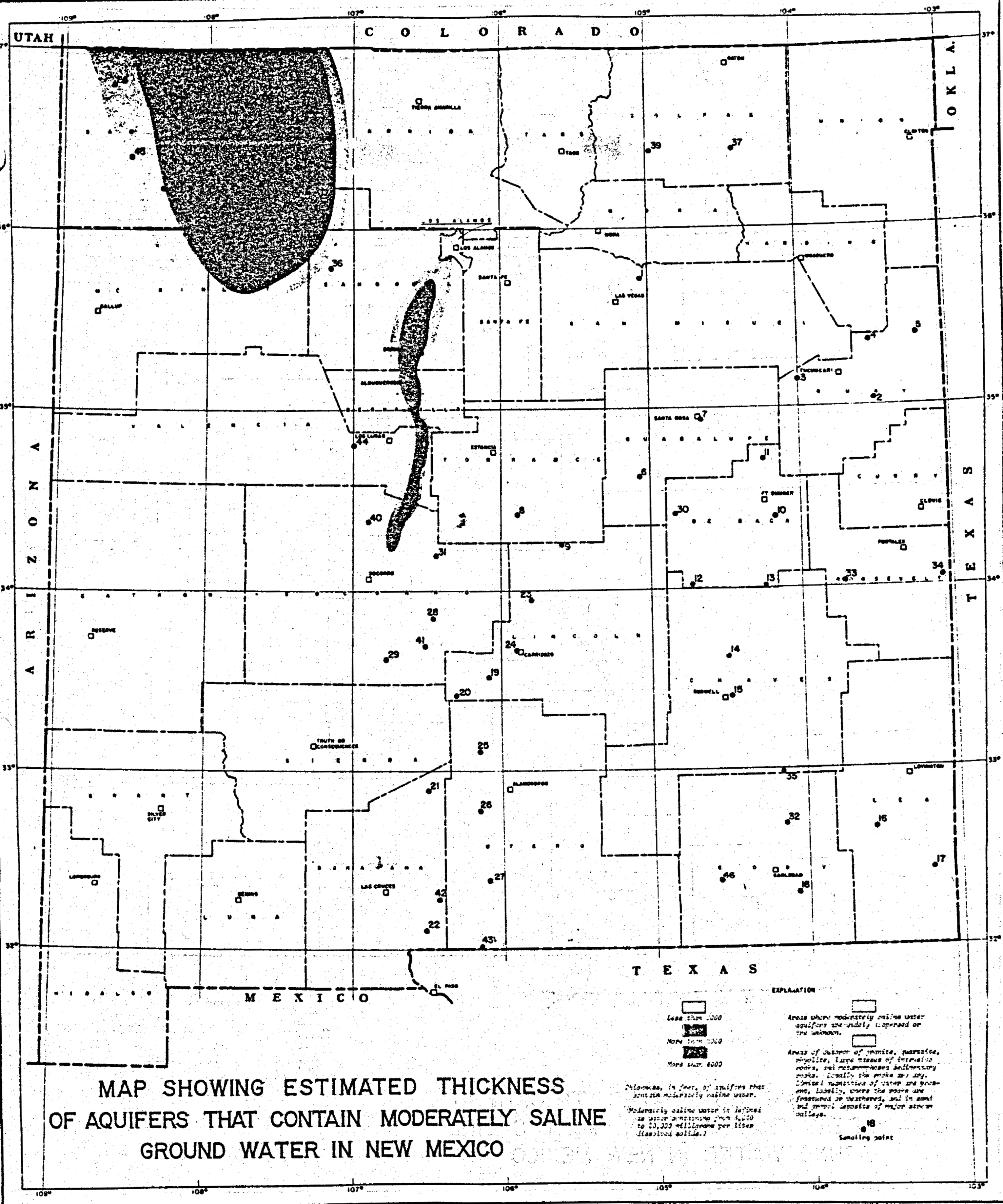


Figure 7 (Bureau of Reclamation, 1976)

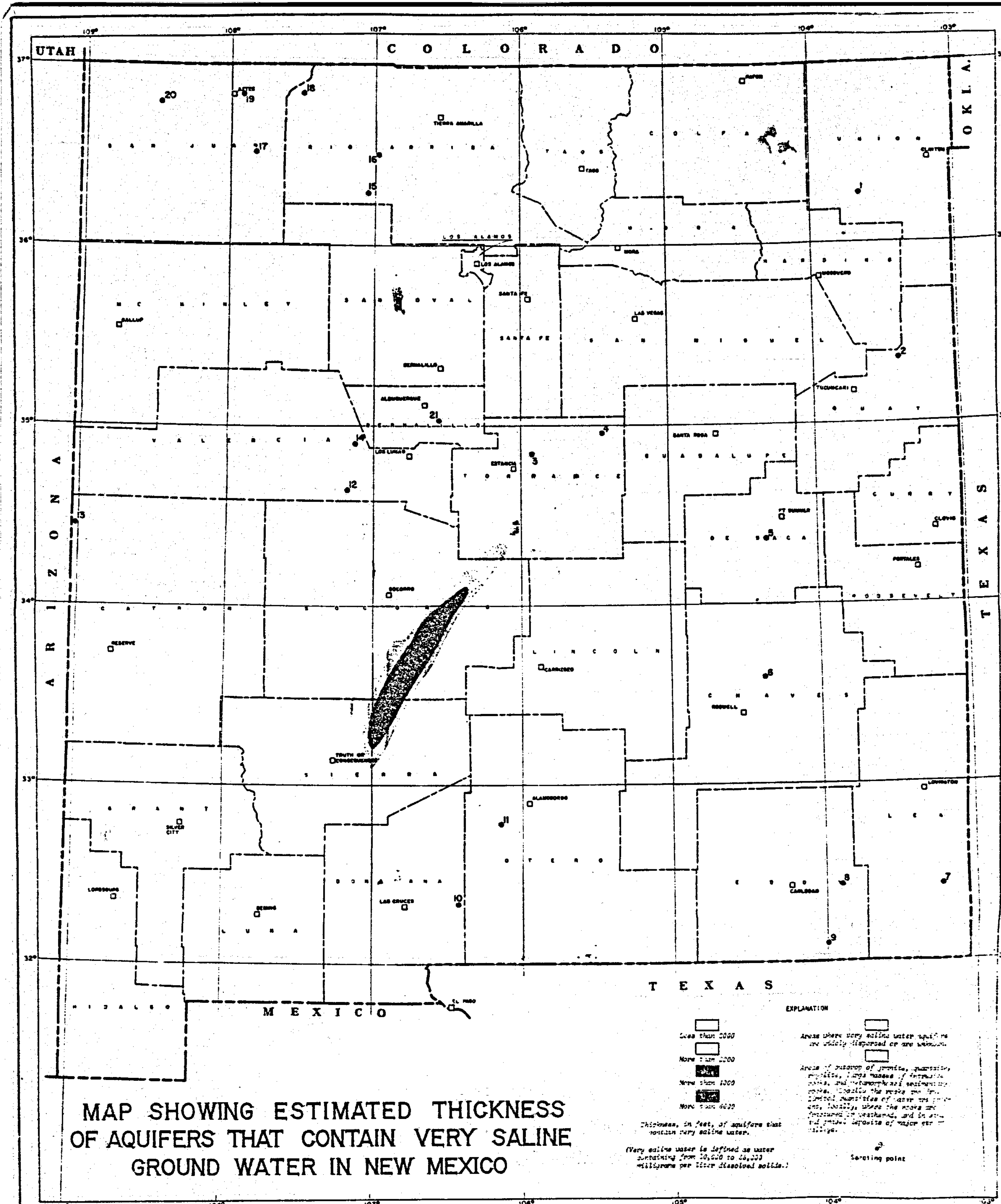


Figure 8 (Bureau of Reclamation, 1976)

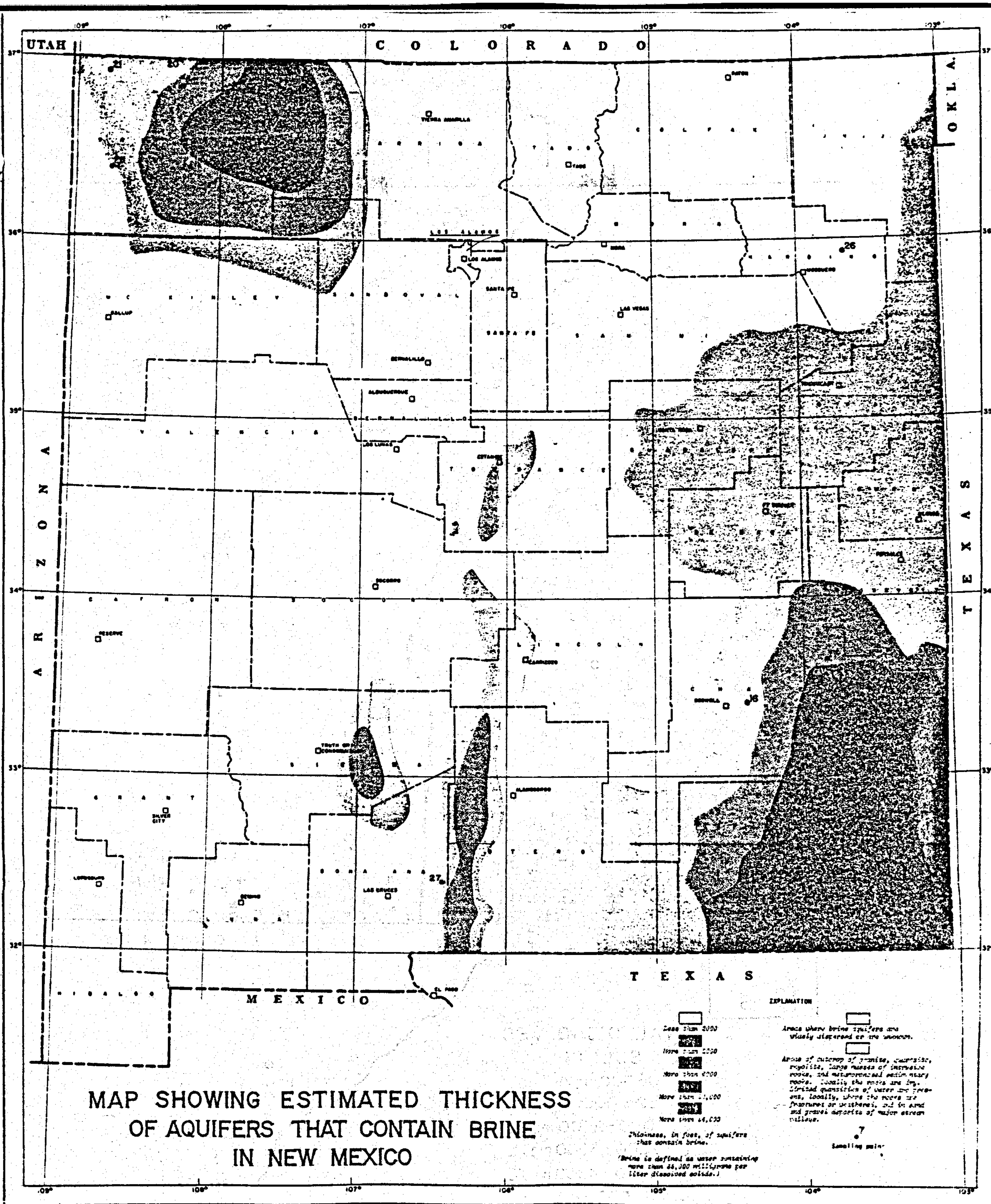


Figure 9 (Bureau of Reclamation, 1976)

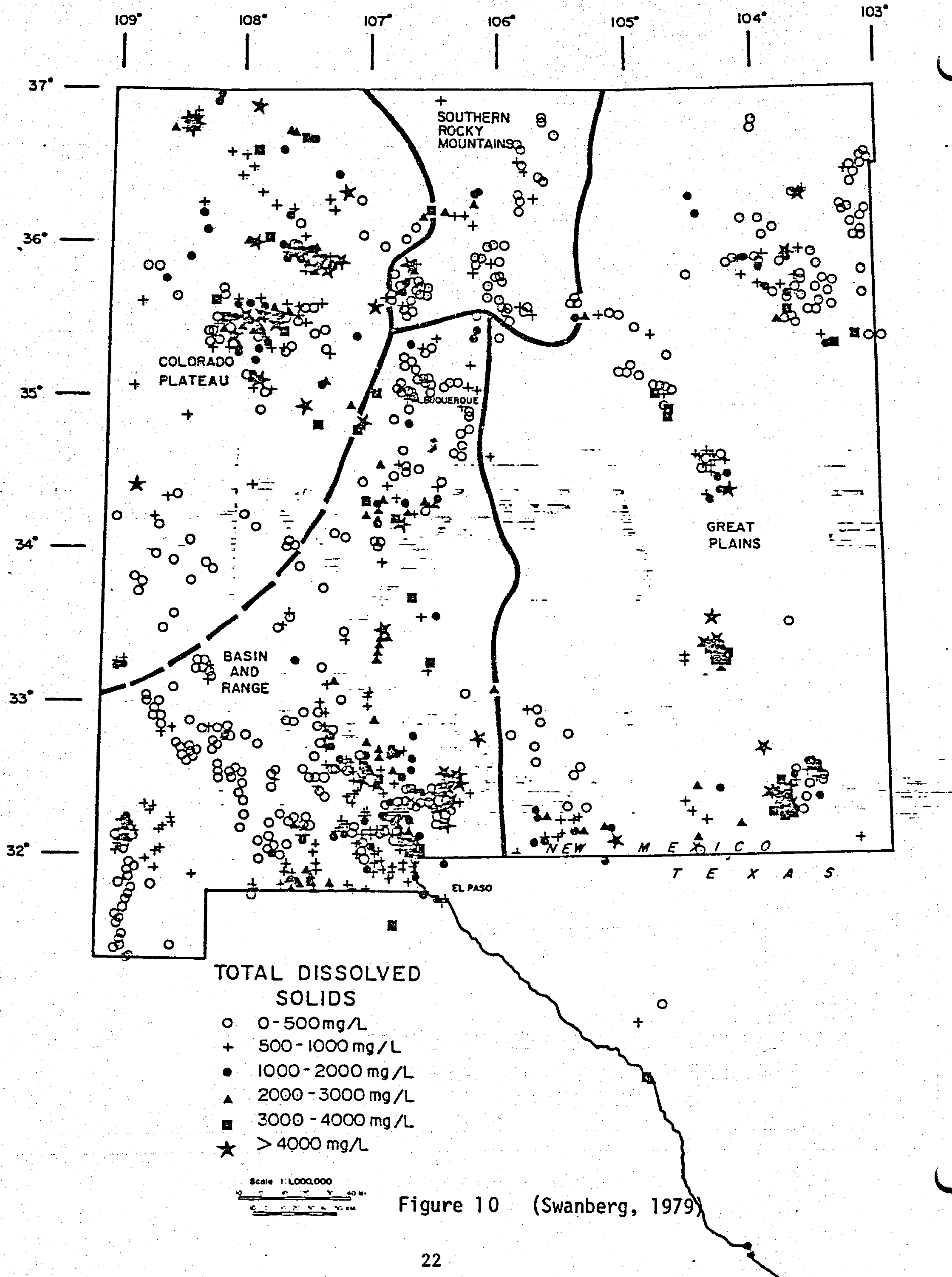


Figure 10 (Swanberg, 1979)

therefore, prepared a series of maps (Figures 11 thru 14) which show the distribution of different categories of saline water at depth zones of 500-1000 ft, 100-3000 ft., 2000-5000 ft and greater than 5000 ft.* Saline groundwater at depths less than 500 ft is found under a large part of the state. Figure 15 shows the distribution of saline aquifers with thickness greater than 2000 ft. This map has been prepared from Bureau of Reclamation (1976) data.

Hood and Kister (1962) have compiled information on the important saline water aquifers in New Mexico. This information is presented in Table 1. Most aquifers in New Mexico contain fresh water at one locality and saline water at another. This variation is due to the differences in lithology, rainfall, precipitation and infiltration.

Geothermal Resources of New Mexico

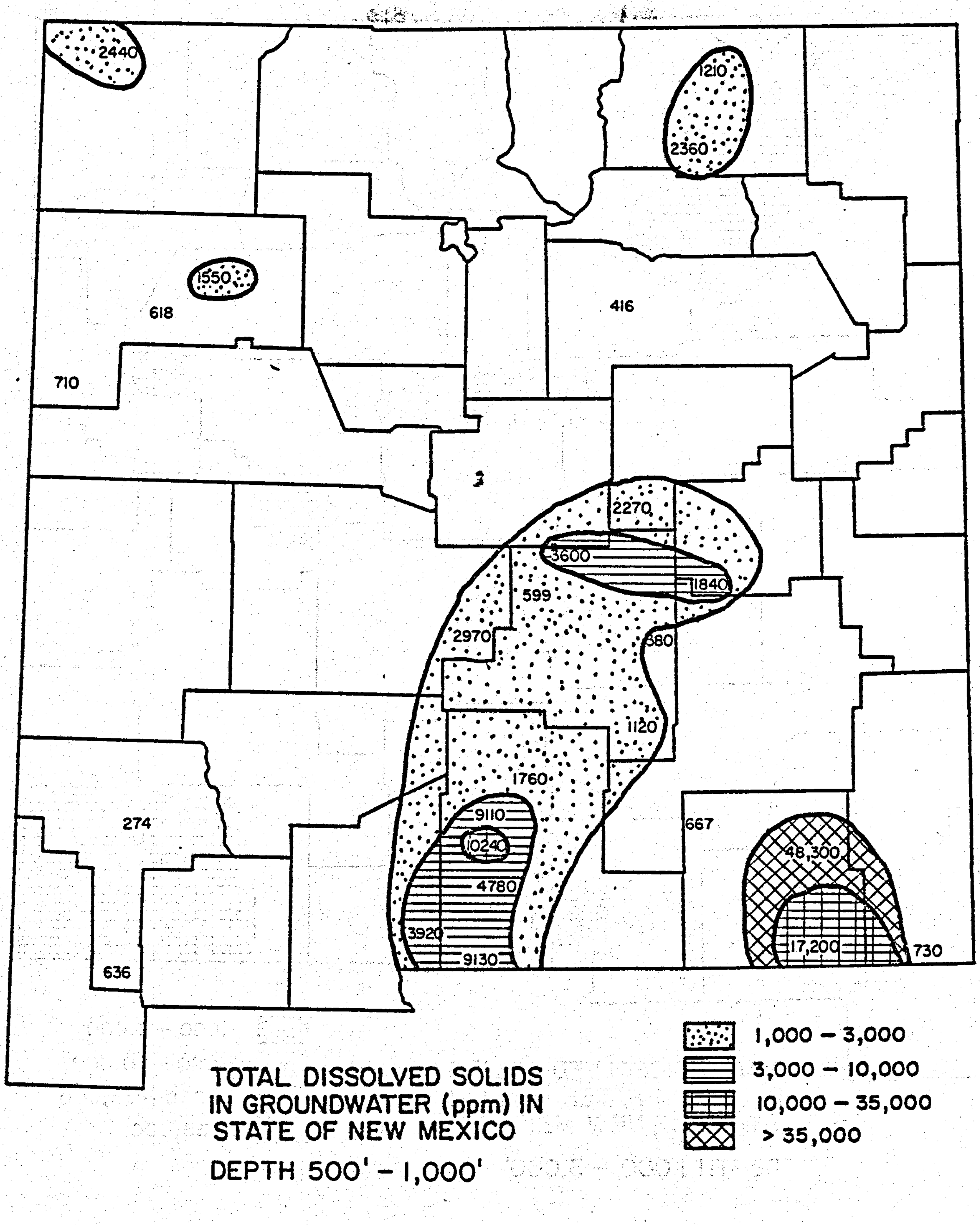
Much of the western half of New Mexico contains geothermal resources of varying quality and quantity. There are eight Known Geothermal Resources Areas (KGRA) in the state, so designated by the U. S. Geological Survey on the basis of resources known and commercial interest shown in their development. In addition, large parts of the state show geothermal anomalies in the form of hot springs, hot water in wells, geochemical thermometry, high heat flow, high bottom-hole temperatues, etc. Most of this information has been summarized in Figure 16 prepared by Swanberg (1979). In addition, recent work based on analysis of well data collected from several state and federal agencies in New Mexico has indicated several additional areas in the northwest and southwest parts of the

*Data for Figures 11 thru 14 were collected from published sources on the saline water occurrence in New Mexico (Bureau of Reclamation, 1976; Hood and Kister, 1962; Hood, 1965; Kelley, 1970; Morris and Prehen, 1971 and Krieger, et. al., 1957).

Saline-water aquifers in New Mexico

System	Series	Formation or group	Character of rocks	Saline-water supply
Quaternary	Recent and Pleistocene.	Alluvial and eolian deposits	Gravel, sand, silt, and clay.	Large supplies in Pecos and Rio Grande Valleys. Moderate to large supplies from alluvial fans in mountain areas in the Basin and Range provinces. Small to moderate supplies from terrace deposits and small stream valleys.
Tertiary and Quaternary	Middle Miocene(?) to Pleistocene(?)	Santa Fe group and related bolson fill.	Unconsolidated, or slightly consolidated gravel, sand, silt, clay, and tuffaceous rocks, some interbedded volcanic rocks.	Small to large supplies in intermontane basins of Basin and Range province.
Tertiary	Pliocene.	Ogallala formation.	Gravel, sand, and clay.	Moderate to large supplies in southern High Plains.
	Paleocene.	Nacimiento formation.	Sandstone, shale, and conglomerate.	Small to possibly moderate supplies in San Juan Basin.
Cretaceous	Upper Cretaceous.	Undifferentiated.	Shale, sandstone, limestone, and conglomerate.	Small supplies in the area of the Raton and Las Vegas Plateaus and in small areas of Basin and Range province. Small to moderate supplies in Colorado Plateau.
	Lower(?) and Upper Cretaceous.	Dakota sandstone.	Sandstone with some shale, conglomerate, and coal.	Small to moderate supplies in the areas of the Raton and Las Vegas Plateaus, the eastern edge of the Basin and Range province, and the Colorado Plateau.
Jurassic	Undifferentiated.	Undifferentiated.	Sandstone, siltstone, and shale, with some limestone and conglomerate.	Generally yields small to moderate supplies in the northern half of the State.
Triassic	Upper Triassic.	Dockum group.	Sandstone, siltstone, red shale, and some conglomerate.	Small to moderate supplies in the Canadian River valley, northern Pecos Valley, and Colorado Plateau; possible large supplies locally.
Permian	Ochoa.	Rustler formation.	Dolomite, anhydrite, and red shale.	Small to large supplies in southern Pecos Valley.
		Castile formation.	Anhydrite or gypsum, lesser amounts of salt and limestone.	Small supplies in southern Pecos Valley.
	Guadalupe.	Capitan limestone.	Reef limestone.	Moderate to large supplies in vicinity of Carlsbad.
		Undifferentiated.	Red beds, gypsum, limestone, dolomite, siltstone, and sandstone.	Small to large supplies in the Pecos Valley.
		San Andres limestone.	Limestone and dolomitic limestone with some gypsum and sandstone.	Large supplies in the Pecos Valley and in the vicinity of the Zuni uplift.
	Leonard.	Glorieta sandstone.	Sandstone and some limestone.	Generally yields small supplies, but locally yields large supplies, where fractured.
		Yeso formation.	Pink and yellow to white shales, siltstone, gypsum, limestone, and sandstone.	Small to moderate supplies in eastern Basin and Range province from Otero County northward to Southern Rocky Mountains and eastward to Canadian River valley. Capable of yielding large supplies locally, particularly in thick limestone section in southeastern Otero County.
	Leonard. / Wolfcamp.	Abo formation.	Red shale, siltstone, sandstone, and conglomerate.	Small supplies in Basin and Range province.
Pennsylvanian	Undifferentiated.	Undifferentiated.	Limestone, shale, and sandstone.	Small to moderate supplies in Basin and Range province and on flanks of Southern Rocky Mountains. Capable of yielding large supplies locally.

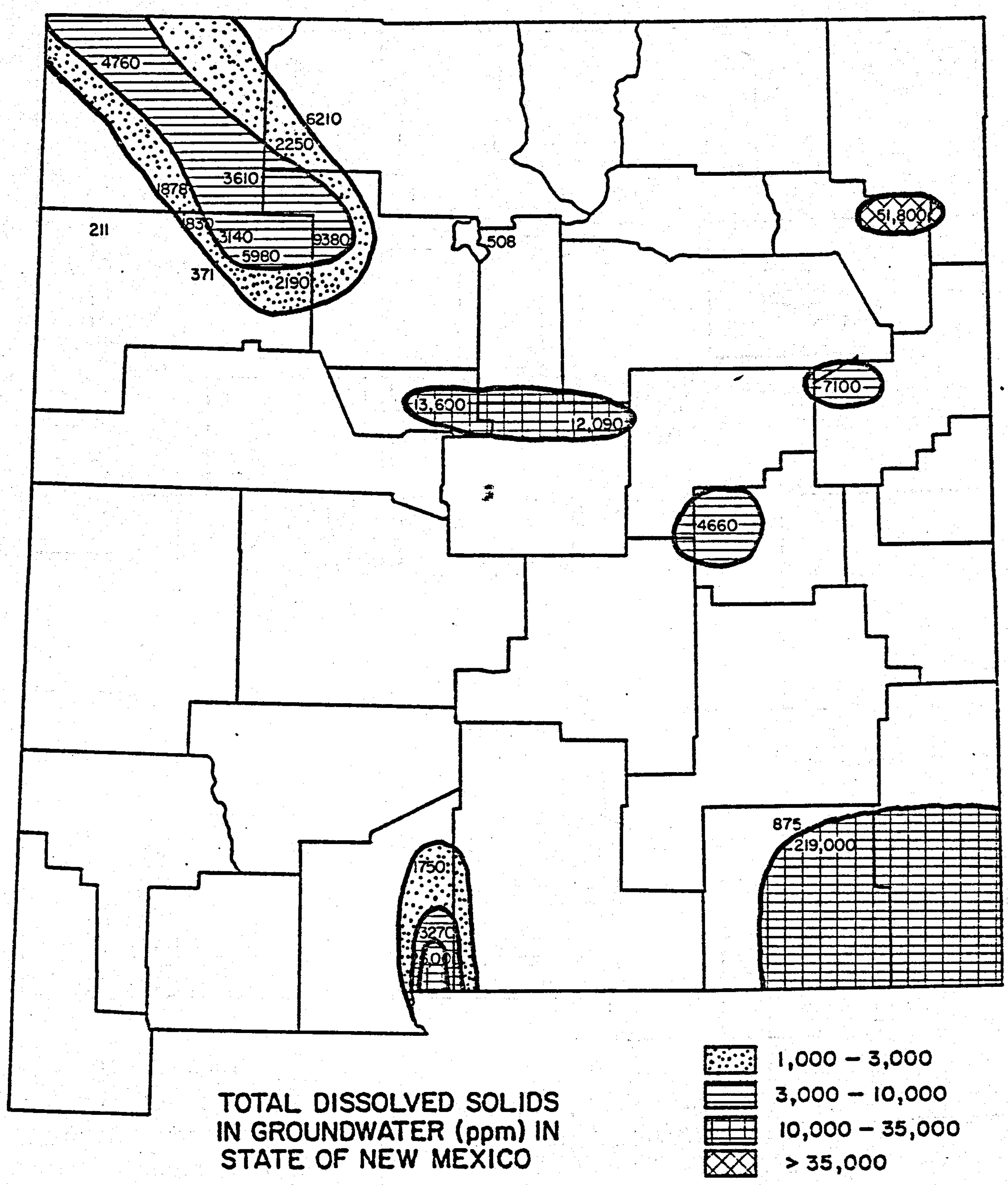
Table 1. Saline water aquifers in New Mexico (Hood and Kister, 1962)



TOTAL DISSOLVED SOLIDS IN GROUNDWATER (ppm) IN STATE OF NEW MEXICO

DEPTH 500' – 1,000'

Figure 11



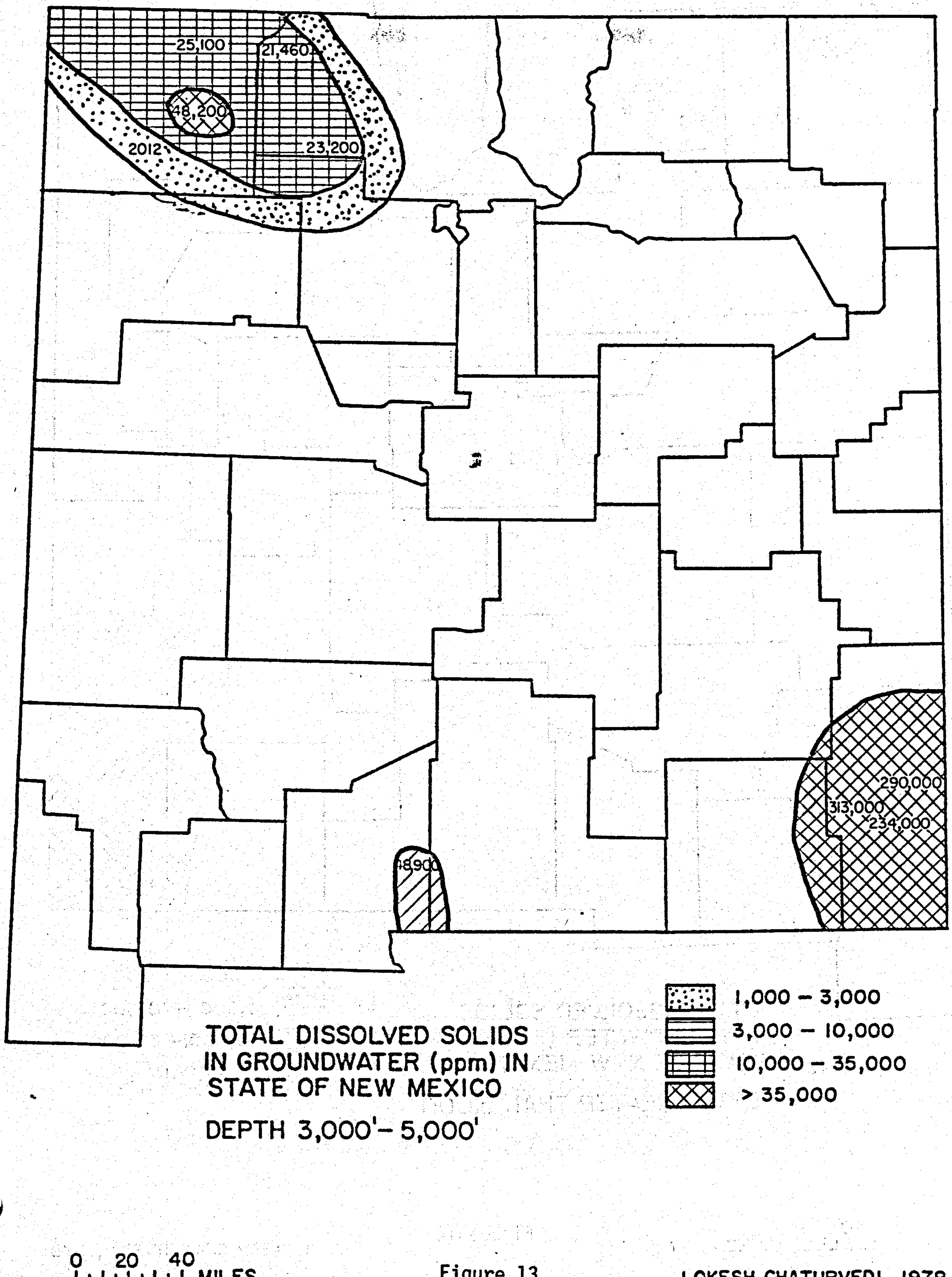
TOTAL DISSOLVED SOLIDS IN GROUNDWATER (ppm) IN STATE OF NEW MEXICO

DEPTH 1,000' – 3,000'

0 20 40 MILES

Figure 12

LOKESH CHATURVEDI, 1979

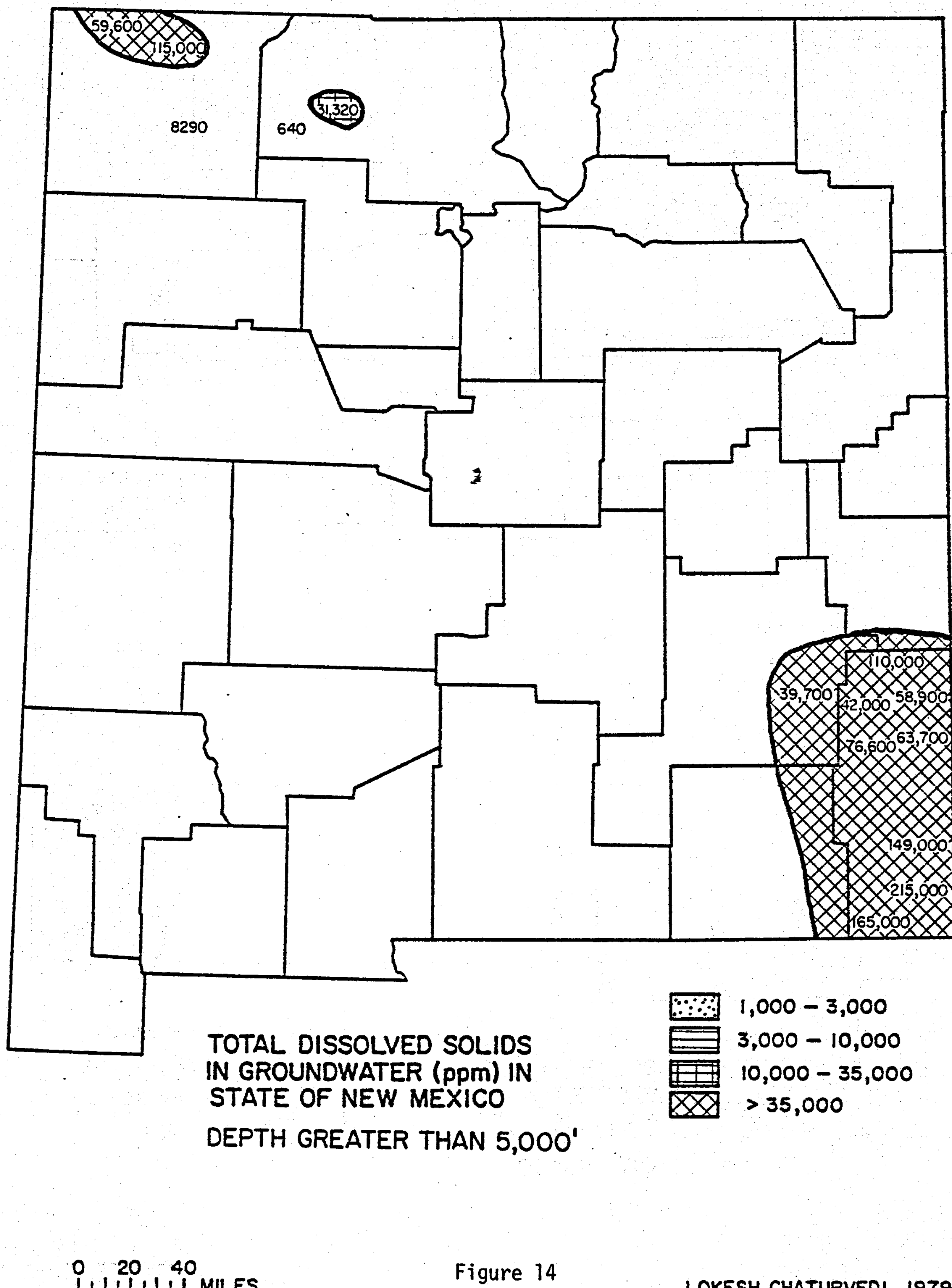


TOTAL DISSOLVED SOLIDS IN GROUNDWATER (ppm) IN STATE OF NEW MEXICO

DEPTH 3,000'– 5,000'

Figure 13

LOKESH CHATURVEDI ,1979

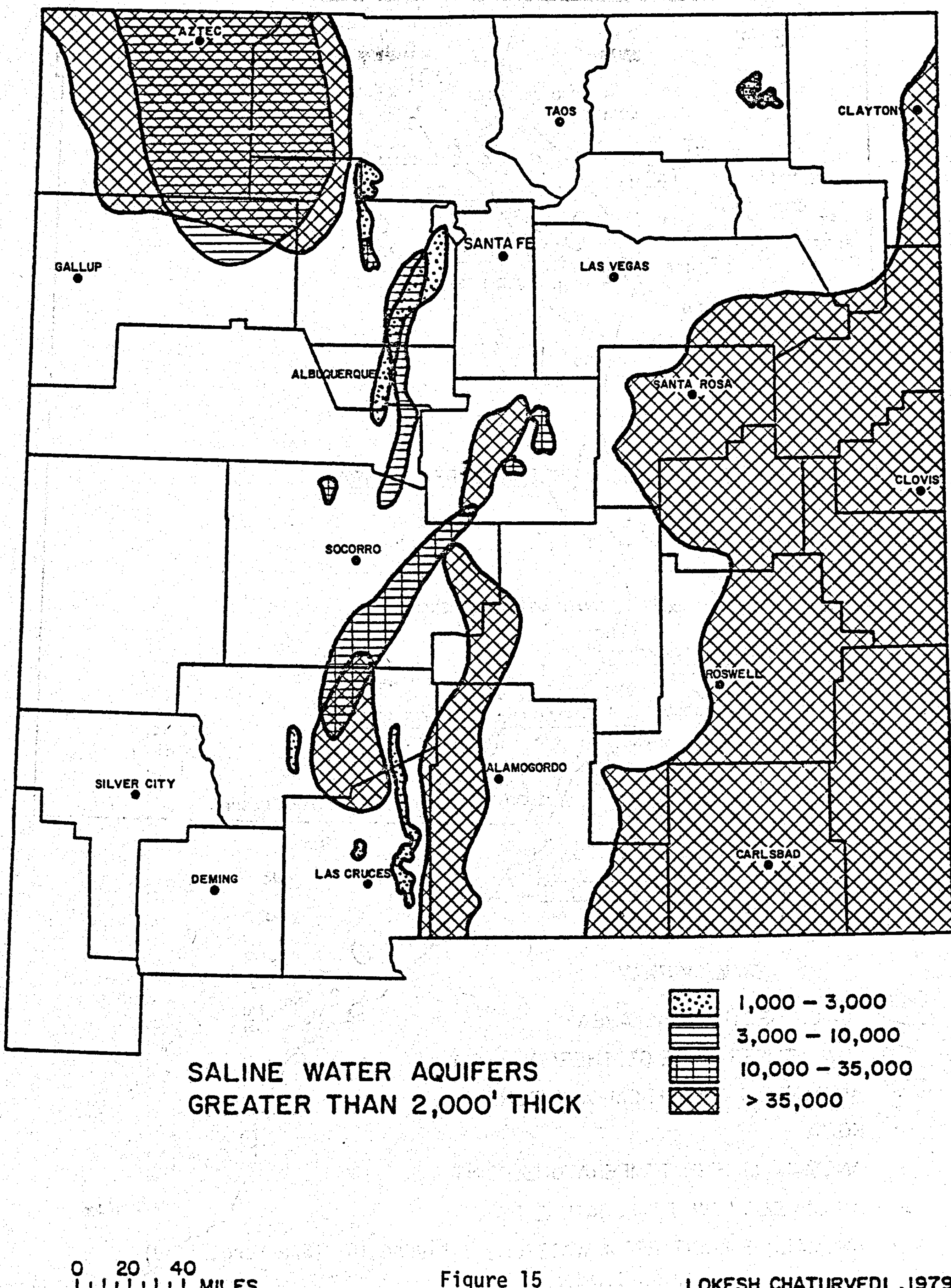


TOTAL DISSOLVED SOLIDS IN GROUNDWATER (ppm) IN STATE OF NEW MEXICO

DEPTH GREATER THAN 5,000'

Figure 14

LOKESH CHATURVEDI ,1979



SALINE WATER AQUIFERS GREATER THAN 2,000' THICK

Figure 15

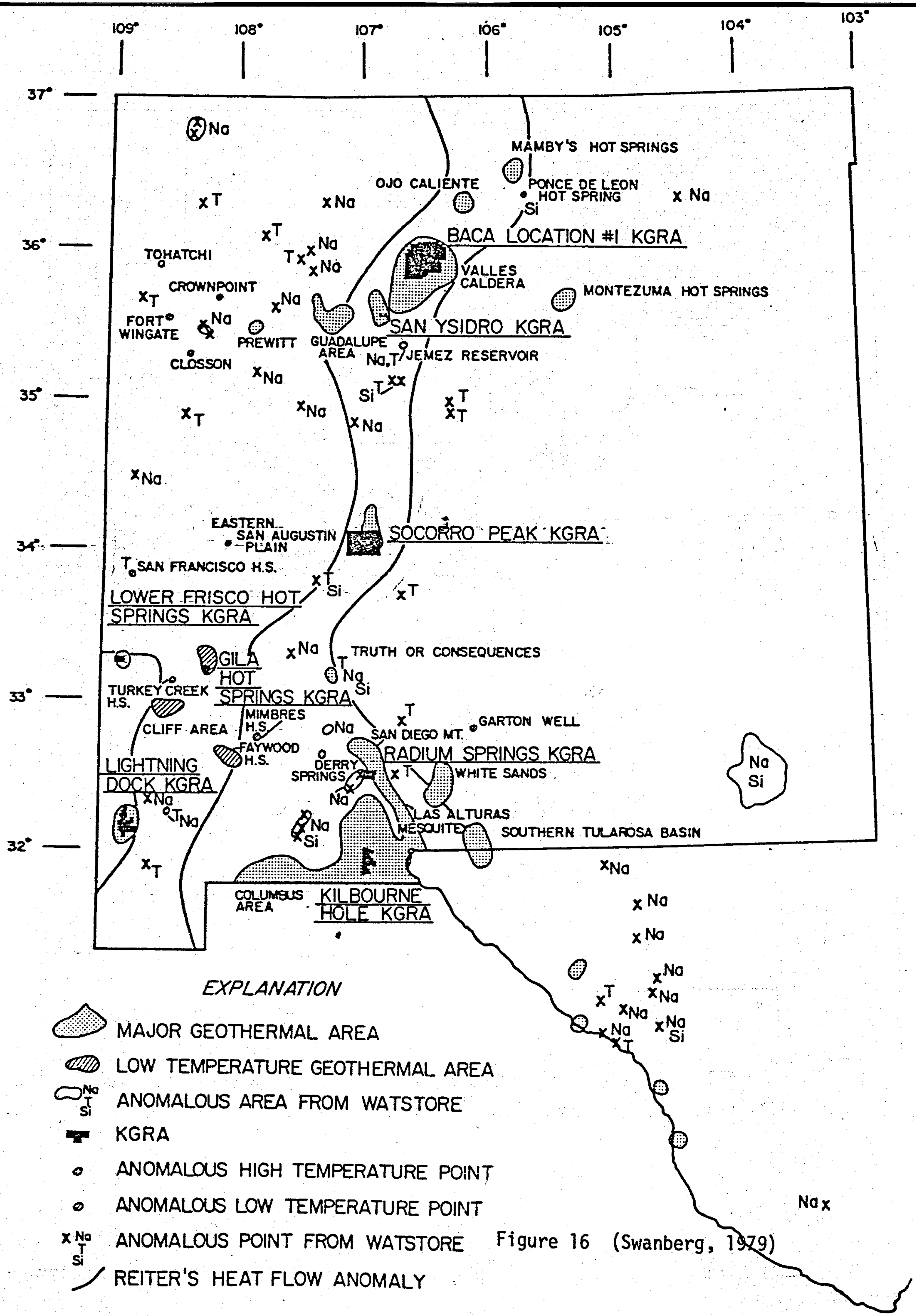


Figure 16 (Swanberg, 1979)

state which may prove to contain geothermal resource. These areas are shown in Figure 17. Table 2 provides a description of each of the area (numbered 1 thru 46) in Figure 17.

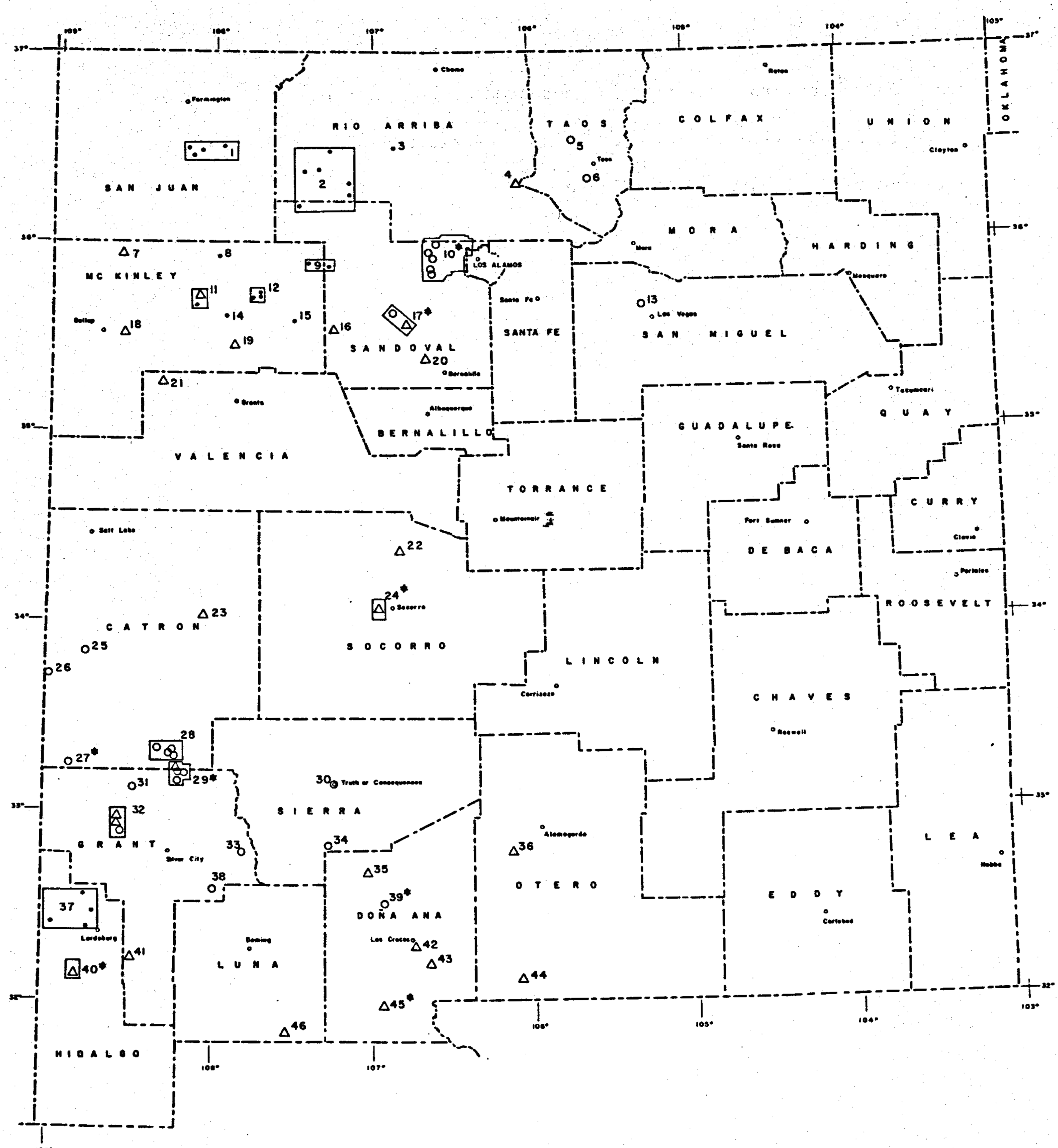
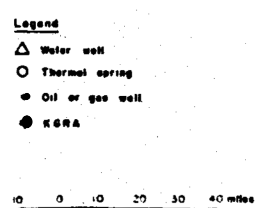


Figure 17 Geothermal Areas Based on Anomalous bottom hole temperatures in wells. See Table 2 for explanations. (Chaturvedi, 1979)



AREAS FAVORABLE FOR DEVELOPMENT OF LOW-TEMPERATURE (<90°C) GEOTHERMAL RESOURCES IN NEW MEXICO

Chaturvedi p.1

Area No.	Area Name	Wells Considered No.	Wells Considered Range of Depths (m)	Wells Considered Range of Temp. (°C)	Thermal Springs No.	Thermal Springs Range of Temp. (°C)	Representative Temperature Gradients (°C Km^{-1})	Measured or Estimated Reservoir Temp. (°C)	Depth (m)	Total Dissolved Solids (mg l^{-1})	Remarks	Approx. Location Lat (° ')	Approx. Location Long (° ')	References
1	Moncisco Mesa (x 20 mi. S. of Farmington)	11(4)	117-2055	27-72			64	>49	648			36 30	108 10	Chaturvedi
2	Jicarilla Apache Reservation	35(6)	666-4115	41-98			71	>76	763			36 20	107 20	"
3	Puerto Chiquita	1	904	55			60	>55	904			36 30	106 55	"
4	Ojo Caliente	3	13-27	15-56	5	32-45		130	C.G.	2500		36 20	106 00	Summers
5	Mamby's Hot Spring				1	34-38		125	C.G.	500	30 gpm	36 30	105 40	"
6	Ponce de Leon				1	31-35		105	C.G.		240 gpm	36 20	105 40	"
7	Tohatchi	2	244-762	39				>39			Morrison formation deeper well flows 900 gpm	35 55	108 35	"
8	Red Mountain Ranch	1	293	32			75	>32	293			35 55	108 00	Chaturvedi
9	Little Blue Mesa	2	304-686	32-48			70	>48	686			35 55	107 25	"
10	Valles Caldera	12	780-2125	120-240	5	32-70	very high	240		5000		35 40	106 30	Swanberg
11	Crownpoint	1	614	42			52	>42	614			35 40	108 10	"
12	Hospah	4(3)	497-904	41-56			59	>56	904			35 40	107 50	Chaturvedi
13	Montezuma				26	38-58		130	C.G.	530	325 gpm	35 40	105 20	Summers
14	Canada Marcelina	1	639	43			52	>43	639			35 35	108 00	Chaturvedi
15	White Mesa	1	271	28				>28	271			35 35	107 30	"
16	Guadalupe Area	1	?	35				170	C.G.			35 30	107 15	Swanberg
17	San Ysidro	2	167-		3	25-45		100	C.G.			35 35	106 50	"
18	Fort Wingate	1	593	61				>61	593			35 30	108 35	"
19	Prewitt Area	1	?	46				150	C.G.			35 25	106 25	"
20	Jemez Reservoir							150	C.G.			35 25	106 35	"
21	Closson	?	?	61				61				35 15	108 20	"
22	North of Socorro			41				150	C.G.			24 20	106 50	"
23	E. San Augustin Plains			35				35				34 00	108 05	"
24	Socorro	1	81	33	3	35		35		230	TDS for Socorro gallery	34 05	107 00	Summers
25	San Francisco Hot Springs				1	37		40		200	6.9 gpm	33 50	108 50	"
26	Frieborn Canyon Spring				1	33		33		150	9.4 gpm	33 45	109 00	"
27	Lower Frisco				11	35-49		150	C.G.	650	50 gpm	33 15	108 50	"

Table 2.

AREAS FAVORABLE FOR DEVELOPMENT OF LOW-TEMPERATURE (<90°C) GEOTHERMAL RESOURCES IN NEW MEXICO

Area No.	Area Name	Wells Considered No.	Wells Considered Range of Depths (m)	Wells Considered Range of Temp. (°C)	Thermal Springs No.	Thermal Springs Range of Temp. (°C)	Representative Temperature Gradients (°C Km⁻¹)	Measured or Estimated Reservoir Temp. (°C)	Depth (m)	Total Dissolved Solids (mg l⁻¹)	Remarks	Approx. Location Lat (° ')	Approx. Location Long (° ')	References
28	The Meadows				4	27-34		34		150		33 20	108 20	Summers
29	Gila Hot Spring				5	36-66		66		450	460 gpm	33 10	108 10	"
30	T or C				3	40-43		100	C.G.	2500		33 10	102 15	"
31	Turkey Creek Hot Spring				?	74		74				33 05	103 30	Swanberg
32	Cliff Area	2	11-91	30-33	1	25		>35	91	500		35 50	108 35	Summers
33	Mimbres H.S.				24	34-62		>60		250		32 45	107 50	"
34	Derry Springs				1	34		100	C.G.	1000		32 50	107 15	Summers/Swanber
35	San Diego Mtn.			warm				125	C.G.			32 40	107 00	Swanberg
36	Garton Well	1	301	34				>45	301	9000		32 46	106 10	Summers
37	North of Lordsburg	4	29-147	27-35				>35	147			32 30	108 55	Chaturvedi
38	Faywood H. S.				1	55		55		380		32 35	108 00	Summers
39	Radium H. S.	3	3-10	26-60				130	C.G.	3500		32 30	106 55	Summers/Swanber
40	Lightning Dock			99				170	C.G.	1500		32 10	108 50	Swanberg
41	Lordsburg			33				150	C.G.			32 15	108 30	Swanberg
42	Las Alturas	8	90-240	25-60?				120	C.G.	1600		32 15	106 45	Chaturvedi/USGS
43	Mesquite-Berino	2	153-219	31-35				120	C.G.	1000		32 10	106 40	Chaturvedi/USGS
44	Southern Tularosa Basin	1	?	71				150	C.G.			32 05	106 05	Swanberg
45	Kilbourne Hole	1	2239	45				155	C.G.		500 gpm from (190-205 m) at 45°C	31 55	106 55	Swanberg
46	Columbus Area			31				155	C.G.			31 50	107 30	Swanberg

NOTE: C.G. = Chemical Geothermometer by Swanberg

Table 2. (Contd.)

Lokesh Chaturvedi, 1978

CHAPTER 3

GEOTHERMAL DESALINATION TECHNOLOGY

Introduction

Salt can be removed from water by various chemical or physical processes, the most important of which are the following.

Process(es)	Constituent Removed from Saline Water	Phase to which Transported
Distillation	Water	Vapor
Membrane		
Reverse Osmosis	Water	Liquid
Electrodialysis	Salt	Liquid
Freezing	Water	Solid
Hydrate	Water	Solid

Distillation Processes

Distillation is the most commonly used desalination process with Multistage Flash Evaporation being the most popular method.

Multistage Flash Evaporation (MFE). In the Multistage Flash Evaporation process, saline water is mixed with scale-control chemicals, deaerated, and then combined with recycled brine. The saline solution is pumped through tubes positioned in the upper portion of horizontal vessels. Separate chambers (stages of the process) are formed in each vessel by a series of vertical baffles. The coolest stage is the nth and the hottest is the 1st with the entire process operating at more than 65°C (150°F) range. The saline water is thus heated gradually as it passes in the tubes of each stage, but because the water is under pressure, it does not boil. After leaving the 1st stage the saline solution is further heated in the feed heater by conventional boiler or nuclear or geothermal generated steam. The saline solution is then fed to the shell side of the first stage where it flashes and releases steam. This steam rises, condenses on the tubes and passes off its heat to the saline water in the tubes, then drips into troughs under the tubes. The second stage is operated at a slightly lower pressure than the first causing the brine and the pure water to spontaneously flow through liquid pressure seals. The flashing/condensing procedure repeats in the many stages of the system drawing all the available heat from the brine. Excess brine beyond that needed for recycling is disposed and the pure freshwater in the troughs is the product. It is possible to achieve 21 lb of freshwater per lb of steam used.

Vertical-Tube Evaporator (VGE). Saline water is deaerated and mixed with scale-control chemicals, heated in several preheaters, fed into the top of a VTE or the first effect where boiler steam passes on the shell-side of the tubes. The saline water falling within the tubes is boiled by the heat from the condensing shell-side steam. The first effect condensate is returned to the boiler as feedwater. The steam from the boiling saline water condenses in the shell side of the second effect to form product water and boil the brine falling inside the tubes of the second effect. In each of the effects, some of the brine is bottom of the next effect where it is flashed, producing steam, because of a pressure reduction. Each effect is operated at a lower pressure than the previous effect.

Vapor-Compressor Distillation. Vapor-compression can be integrated into either the MFE or the VTE processes. Saline water is fed into and boiled in a tubular heat exchanger within the evaporation chamber. The resulting steam is transferred to a compressor, which increases both the pressure and heat content of the steam which is condensed on the shell-side of the evaporator tubes to produce fresh water and boil the saline water within the tubes.

Solar Distillation. Vaporized saline water condenses on the film of plastic, collects in troughs, and this product is removed. The stills require large land areas and operate at slow rates and can also be used to produce salt in addition to the freshwater.

Membrane Processes

Both Rverse Osmosis and Electrodialysis are membrane processes which do not involve a phase change and generally require less energy than distillation. Energy requirements are proportional to the level of dissolved salts present and thus are most popular for lower levels of salts (less than 3000-4000 ppm). A membrane may, in general, be defined as a selective filter.

Reverse Osmosis. In the reverse osmosis process pure water and saline water are placed on opposite sides of a membrane. A pressure is applied to the saline solution in excess of the osmotic pressure. Freshwater passes through the membrane from the saline water to the freshwater side. The required pressure to overcome the osmotic pressure is a function of the salt level in the saline water and is typically 300-800 psig. The process has a potentially high thermodynamic efficiency, but one problem is that a membrane with a flux rate high enough to reduce capital costs to an appropriate level has yet to be found.

Electrodialysis. An electrodialysis cell is composed of an alternating cation - and anion-permeable membranes. An electric current is applied which causes the sodium (and other positively charged ions) to pass through the cation-permeable membranes while the chloride (and other negatively charged ions) passes through the anion-permeable membranes. Water in the center chamber of each membrane sandwich is salt-depleted and water in the adjacent chambers is salt-enriched. Demineralization cost consists mainly of the amount of electric current needed which is proportional to the salt amounts to be removed. Therefore, electrodialysis is the favored process for saline waters up to 2500 ppm.

Freezing Processes

The solid component of partially frozen saline water is pure ice with the remaining liquid more concentrated in salt. The ice is separated, adhering salt water removed as best as possible, with the ice then to be melted to yield product water. The two main freezing processes are the direct and the secondary refrigerant processes.

Direct Freezing. Cold saline water is sprayed into a vacuum chamber to form a mixture of ice crystals in brine. Approximately one-half of the incoming saline solution is frozen. The brine and ice mixture is transferred to the bottom of a separation column where the ice crystals float to the top, brine is drawn off at the column's sides, and the rising ice is washed with small amount of product water before being removed to a melting tank. Vapor from the freezing chamber is condensed and fed to the top of the separation column.

Secondary Refrigerant Freezing. The saline water is deaerated, cooled in brine and product coolers, and then flashed in direct contact with a hydrocarbon such as butane or isobutane. The resulting ice and brine mixture is pumped to a separation column where the brine is removed, ice washed, and the ice mechanically transferred to the melter. The flashed hydrocarbon vapor is compressed and recycled to the freezing section.

Hydrate Process

A low-molecular-weight hydrocarbon, such as propane, is combined with water to form hydrate crystals which reject ionic components. Excess propane is vaporized and then recycled after it is compressed and condensed. The hydrate crystals are washed with product water, decomposed to water and propane, which are separated by either decanting or centrifuging.

Feasibility of Geothermal Desalination

The geothermal resource potentially available for desalination in New Mexico consists of low temperature (60-90°C) water. For this reason, of the chemical and physical processes of desalination mentioned above, only the distillation methods will be suitable. In this section, the feasibility of geothermal desalination in New Mexico is examined by making certain cost assumptions and without regard to a particular location.

In our study we find that the best way of using geothermal water as a heat source is to directly mix the geothermal water with the saline water if the TDS (Total Dissolved Solids) of both are approximately the same. Calculations are here made for the following two cases.

Case 1: Where geothermal water is mixed with saline water in a 1.3 ratio with the temperature of geothermal water equal to 60°C (140°F) and the temperature of the saline water equal to 20°C (68°F). This case is referred as our "worst case" since we are using both a low geothermal to saline water ratio and a low geothermal water temperature.

Case 2: Where geothermal waters alone are desalinated at a feed temperature of 120°C (194°F). This may be referred as our "best case" since the temperature of the geothermal water is assumed to be about the highest at reasonable depths found in New Mexico.

By choosing these two cases we have set the upper and lower limits for use of geothermal waters in distillation desalination for a MSF (Multistage Flash) type process. The qualification of our "worst case" as being feasible to the extent of demonstrating a sizable energy savings would indicate that any better case (higher geothermal feed temperature, higher geothermal to saline water ratio; etc.) will prove to be even more feasible.

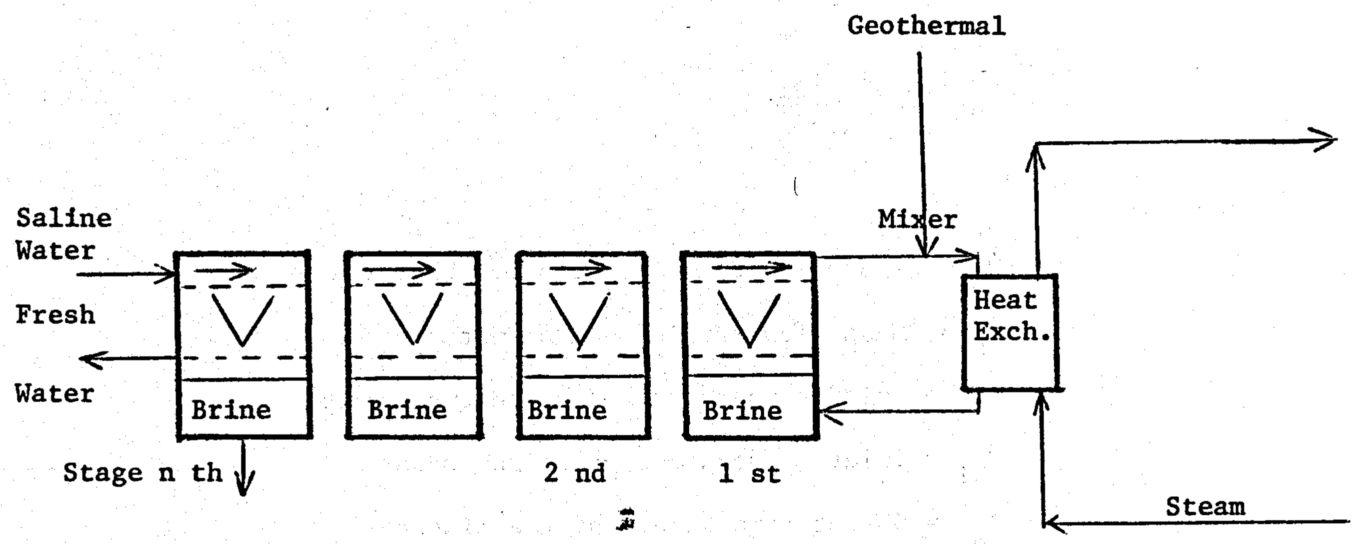
Due to the low temperatures for geothermal waters found in New Mexico, the best we can hope for is that the geothermal energy be used as a source of preheating so as to increase the feed temperature of the saline water.

For a geothermal feed temperature of 60°C (140°F) and a saline water feed temperature of 20°C (68°F), we obtain for a 10 MGD (million gallons per day) product water plant a final temperature of the mixed streams (geothermal and saline (in 1:3 ratio) equal to 30°C (86°F). This value is obtained as follows:

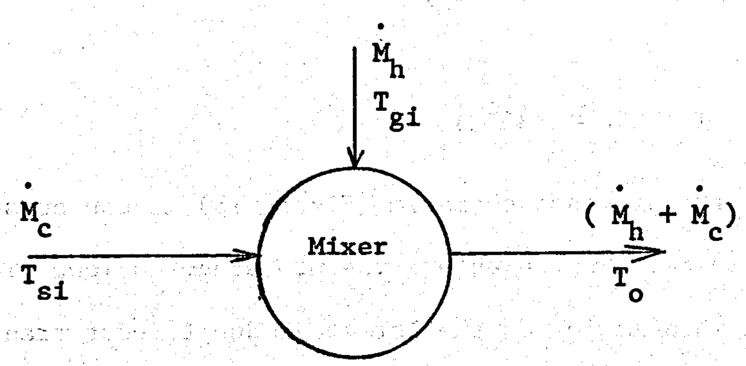
Energy balance about the mixer (Figure 18) assuming negligible heat losses yields:

Heat gained by saline water = Heat lost by geothermal water

Assuming the heat capacities of the two streams (geothermal and saline feeds to the mixer) to be the same, we can write:



Process Schematic



Mixing Schematic

Figure 18. Desalination of Geothermal Saline Mixture ("Worst case")

$$\dot{M}_h(T_{GI}-T_o) = \dot{M}_c(T_o-T_{SI})$$

or

$$\dot{M}_h = \dot{M}_c \frac{T_o-T_{SI}}{T_{GI}-T_o} \qquad (1)$$

Where

$\dot{M}_h$ = Mass flow rate of geothermal water

$\dot{M}_c$ = Mass flow rate of saline water

T_{GI} = Inlet temperature of geothermal water

T_{SI} = Inlet temperature of saline water

T_o = Outlet temperature of the mixture

Since

$\dot{M}_h/\dot{M}_c$ = 1/3, we obtain

$$1 = \frac{3(T_o-68)}{(140-T_o)}$$

or

$$T_o = 86^oF\ (30^oC)$$

NOTE: From the process schematic (Figure 18) it can be seen that the saline water which enters the nth stage is lower in temperature than when it leaves the 1st stage due to heat transfer from condensing steam. In our calculations, we let the value of T_{SI} equal to the saline water exiting the 1st stage.

The heat required to bring the temperature of saline water from 68^oF (20^oC) to 482^oF (250^oC) is given by "q":

$$q = \dot{m}_c\ C_p\ (482-68)$$

Now

$$\dot{M}_c = (10 \text{ MGD}) \frac{1 \text{ ft}^3}{7.48 \text{ gal}} (\rho(\text{lbm/ft}^3))$$

$$C_p = \text{heat capacity (Btu/lbm-}^\circ\text{F)}$$

$$\rho = \text{density (lbm/ft}^3)$$

Here

$$C_p = 1.0 \text{ Btu/lbm-}^\circ\text{F}$$

$$\rho = 62.0 \text{ lbm/ft}^3$$

$$q = (10x10^6)\ (1/7.48)\ (62.0)\ (1.0)\ (482-68)$$

$$q = 3.43x10^{10} \text{ Btu/Day}$$

Since in the present case the water has already been heated up to "T_o" by using geothermal energy as preheat, the energy savings is given by "q_s"

$$q_s = (10x10^6)\ (1/7.48)\ (62.0)\ (T_o-68)$$

$$T_o = 86^\circ\text{F } (30^\circ\text{C})$$

$$q_s = (10x10^6)\ (1/7.48)\ (62.0)\ (86-68)$$

$$q_s = 1.49x10^9 \text{ Btu/Day}$$

Percent savings is:

$$\text{Percent savings} = (q_s/q)X100$$

$$= \frac{1.49x10^9}{3.43x10^{10}} X100 = 4.34\%$$

Using the above procedure, the energy savings and percent savings are also calculated for various cases where for a 10 MGD product water capacity, the effect of both a .75 and 0.50 ratio geothermal water to saline water were calculated for geothermal feed temperature of 140, 194, and 248 (^{o}F) and saline feed temperatures of 70^{o}F and 90^{o}F. These results are reported in Table 3.

Case 2 - Desalination of Geothermal Water Alone - -

Using the methods outlined for Case 1, for a liquid feed at a temperature of 120^{o}C (248^{o}F), the amount of heat energy saves is

$$q = 8.289X10^{7}(248-68) = 1.492X10^{10}(Btu/Day)$$

Hence the percent of energy saved due to the use of geothermal energy is:

$$\text{percent of energy saved} = \frac{1.492X10^{10}X100}{3.432X10^{10}} = 43.47\%$$

Conclusions and Recommendations

We find through our analysis that the use of geothermal waters can indeed reduce the energy costs for the distillation (MSF) process up to 43%. It has been shown (Clark, et. al., 1969; Prehn, et. al, 1970) that the operation and maintenance costs account for 66.4% of the total costs, and that steam costs account for 54.25% of the operating and maintenance costs (or 36% of the total). Thus we can see that the use of geothermal energy has the potential for decreasing the total costs by as much as 15% (43% of 66%).

T_{SI} (°F)	M_h/M_c	T_{GI} (°F)	T (Mix)	q (Btu/Day)	qs (Btu/Day)	% Energy Shavings
70	0.50	140	93	3.42	1.91	5.58
70	0.50	194	111	3.42	3.40	9.95
70	0.50	248	129	4.89	3.42	14.32
70	0.75	140	100	2.49	3.42	7.28
70	0.75	194	123	4.39	3.42	12.86
70	.075	248	146	6.30	3.42	18.45
90	0.50	140	108	1.38	3.25	4.26
90	0.50	194	125	2.88	3.25	8.85
90	0.50	248	143	4.37	3.25	13.45
90	0.75	140	111	1.77	3.25	5.46
90	0.75	194	135	3.70	3.25	11.38
90	0.75	248	158	5.61	3.25	17.27

Table 3. Energy saving calculations for the "worst case".

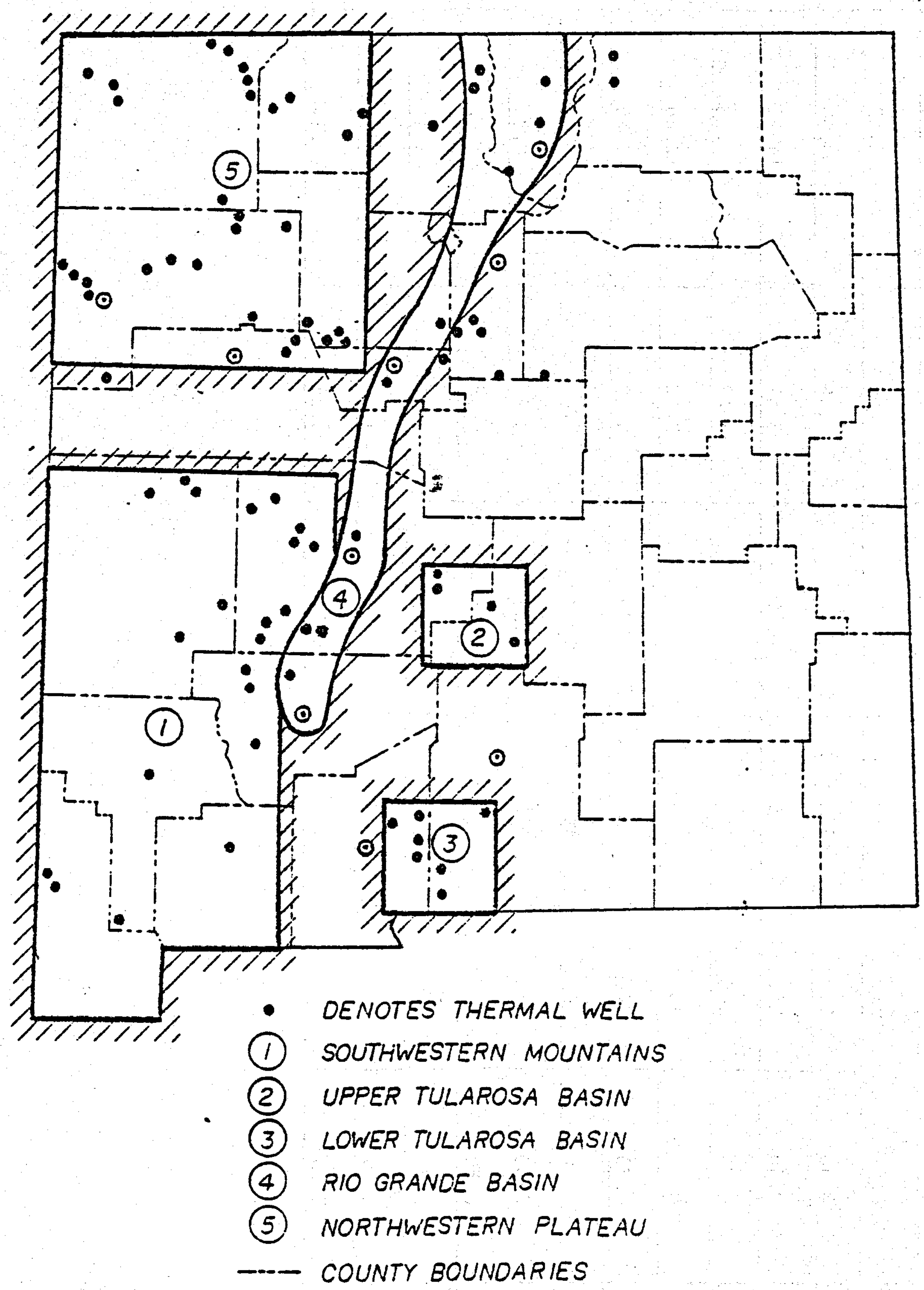


Figure 19 Location of known thermal wells and associated thermal areas in New Mexico

CHAPTER 4

POTENTIAL GEOTHERMAL DESALINATION SITES IN NEW MEXICO

Initial Screening

For the purpose of analysis of site-specific geothermal desalination potential in New Mexico, the state has been divided into five regions (Figure 19). These are, the Southwestern Mountains, Upper Tularosa Basin, Lower Tularosa Basin, Rio Grande Basin and the Northwestern Plateau. Tests performed at the East Mesa Test Site (Imperial Valley, California) indicate that no corrosion has been observed from geothermal brines ranging in temperature up to 180°C (350°F) and with salinities of 2000 ppm to 5000 ppm total dissolved solids. Tests also show that "threshold" treatment with amino-methylene phosphates (AMP) prevents silica scaling thereby eliminating pretreatment (Bechtel, 1977). On the basis of known salinities of groundwater, most thermal water in the five areas should contain between 3000 to 10,000 ppm total dissolved solids (kelly, 1970; McLean 1970). Estimated temperature of geothermal water ranges from 30°C to 120°C (86°F-248°F) with most common values below 60°C. The estimated temperatures and salinities of the thermal waters in New Mexico indicate that most probably pretreatment of these thermal brines will not be required unless excessive concentrations of silica are found.

Out of the five regions listed above and shown on Figure 19, the southwest mountain region is eliminated from consideration on the basis of abundant availability of fresh water and therefore no apparent need for desalination. The other four regions are considered below for their suitability as potential geothermal desalination sites.

Rio Grande Basin. A water resource study done in the Rio Grande Basin indicates that this area contains abundant supplies of both fresh and saline water (Kelly, 1970). A cross-section of this basin showing the approximate depth and quality of the groundwater is presented in Figure 20. This study estimates that the thicknesses of the fresh water vary between 900 m-1200 m (3000 ft-4000 f5) in the middle basin near Albuquerque to 2400 m (8000 ft) in the upper basin near Taos. The extensive fresh water aquifers in this basin are directly attributed to the yearly recharge by the Rio Grande. The study also estimates that these fresh water aquifers are underlain by extensive saline water aquifers of approximately the same thickness, 900 m-1200 m (3000 ft-4000 ft). Because the fresh water resources of this area are so extensive and more easily accessible than the saline water resources, this area has a minimal need for desalination.

A small potential for desalination in this area is the Rio Grande itself. The salt content of the Rio Grande has continued to increase over the past few decades as the amount of land under irrigation and the amount of inorganic salts used as fertilizers has continued to increase (USGS, 1970; USGS, 1965; USGS, 1961).

Upper and Lower Tularosa Basins. The Tularosa Basin is a bolson, bounded by the Organ and San Andres Mountains on the west and the Sacramento Mountains on the east (Figure 21). This basin extends northward from the Texas-New Mexico state line for 250 km (150 miles) and is up to 75 km (45 miles) wide. Because of the geology of this basin there is no surface water outflow and all surface water inflow either evaporates or infiltrates into the soil. For this reason, the water is typically saline and the entire basin is underlain by extensive aquifers (Kelly,

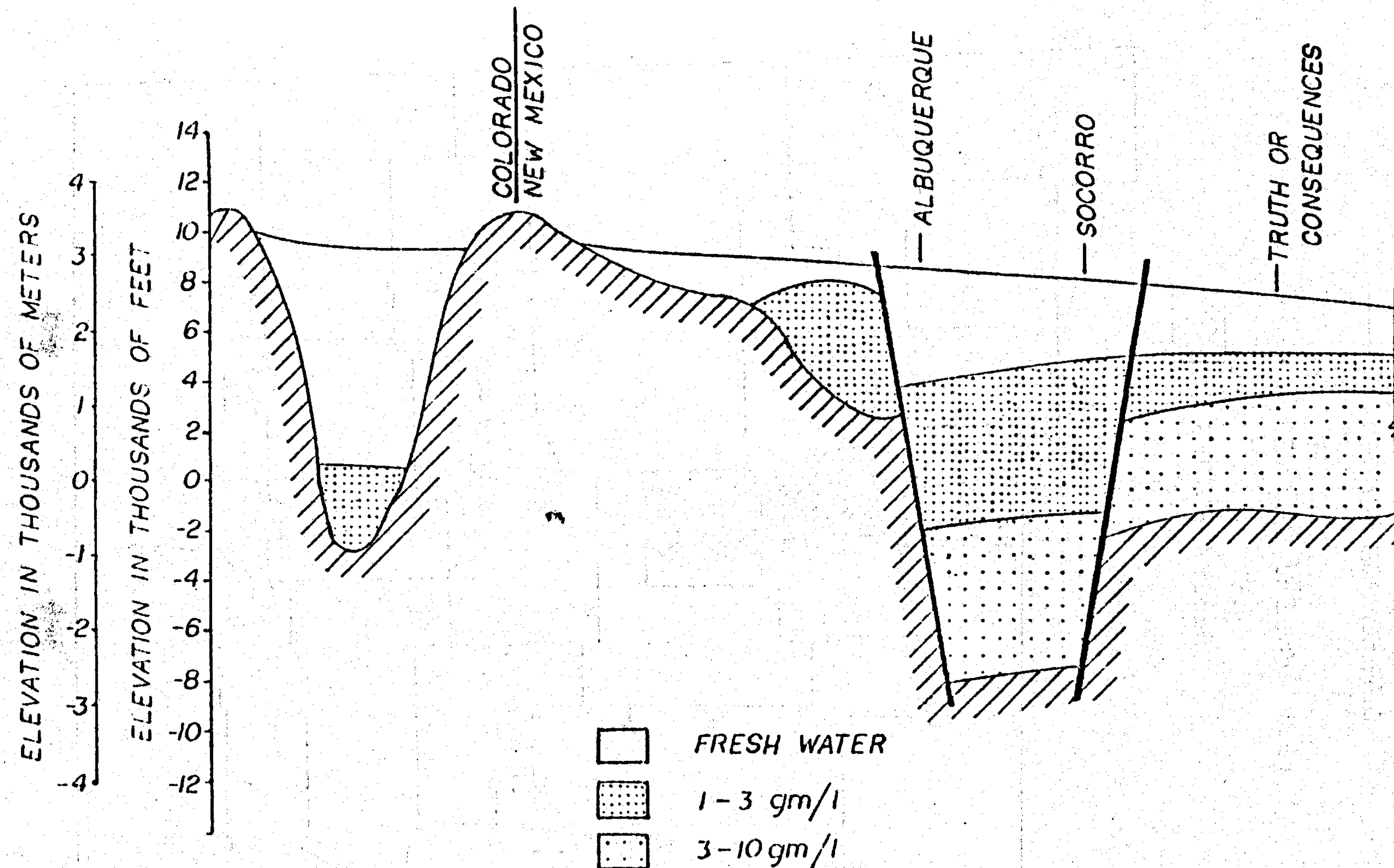


Figure 20 Typical cross-section of the middle Rio Grande Basin. (Source: Kelly, 1970)

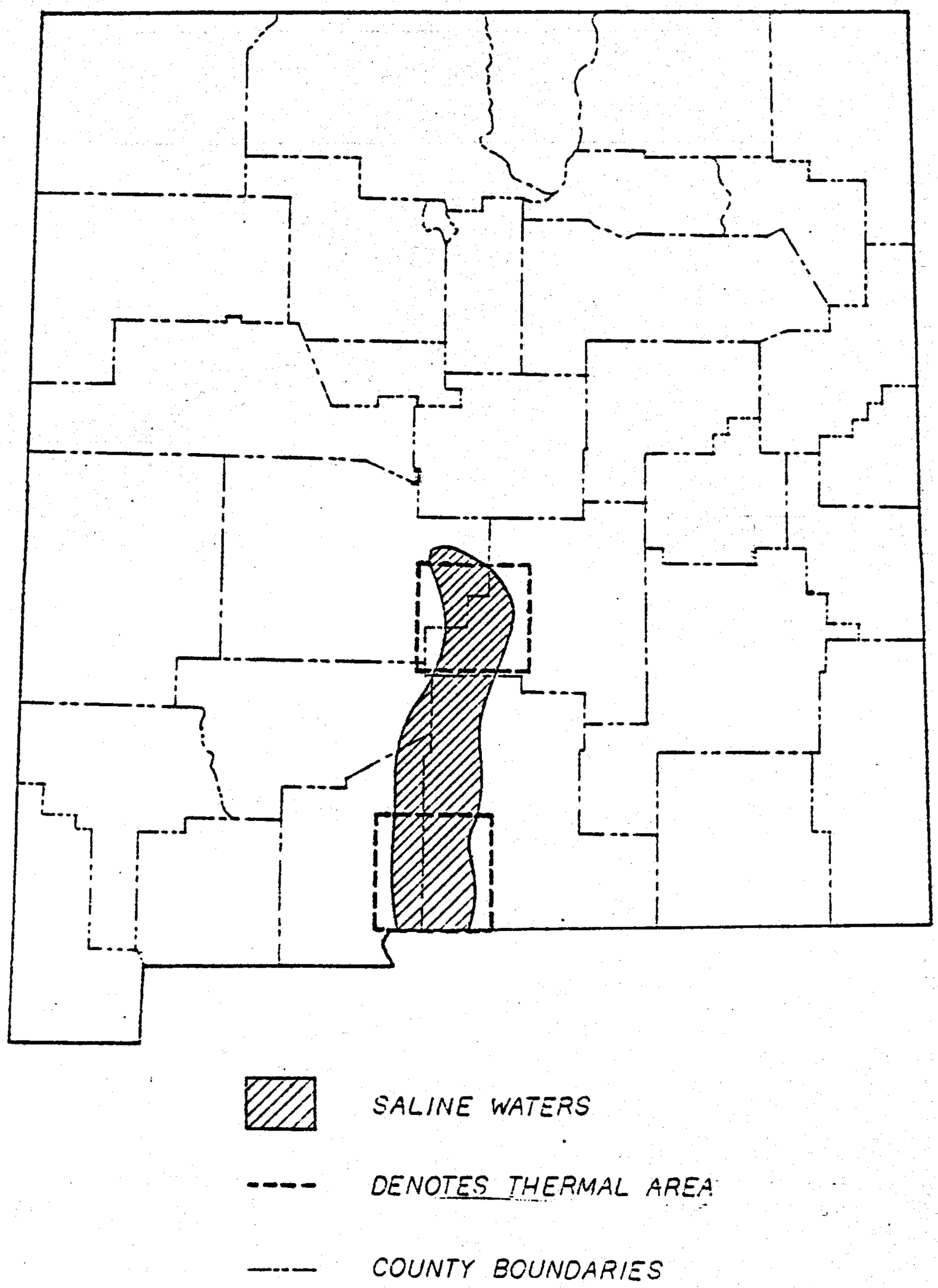


Figure 21 Extent of saline groundwater resources in the Tularosa Basin of New Mexico. (Source: McLean, 1970)

1970 and McLean, 1970). A typical cross-section of the Tularosa Basin is shown in Figure 22, which shows the extent of the fresh and saline water resources of this area.

Studies have indicated that only about 0.2% of the water in the basin is fresh and is found only at the edges of the basin at the edges of the mountain ranges (Kelly, 1970). Most of the water in the basin, approximately 98%, is classified as brine since it contains over 35,000 ppm TDS. About 2% of the water, or 12 million hectare-meters (95 million acre-feet), contains 1000 ppm to 35,000 ppm TDS (Kelly, 1970). Throughout the basin the water table is between 50 m and 150 m (166 ft and 500 ft) below the ground surface, which makes the water easily accessible (Kelly, 1970 and McLean, 1970).

The limited fresh water resources of the Tularosa Basin indicate a need for new sources of fresh water. Though most of the saline water in this basin is brine and difficult to desalinize, sufficient quantities of slightly saline, and moderately saline water, are available to allow for more efficient large scale desalination.

<u>Northwestern Plateau</u>. The fresh water resources in the northwestern corner of New Mexico are somewhat limited. Fresh groundwater is more abundant in the northern section due to recharge by the San Juan River, while in the Gallup-Grants area the fresh groundwater supplies are just adequate for present consumption (Morris, 1971 and Le Gros, 1970). The San Juan River has some unappropriated water which could possibly be used to supplement fresh water supplies in the northwestern plateau. In contrast to the amount of fresh water resources in this area, the northwestern corner of New Mexico is underlain by extensive saline water resources, as shown in Figure 23. Almost all of the northwestern

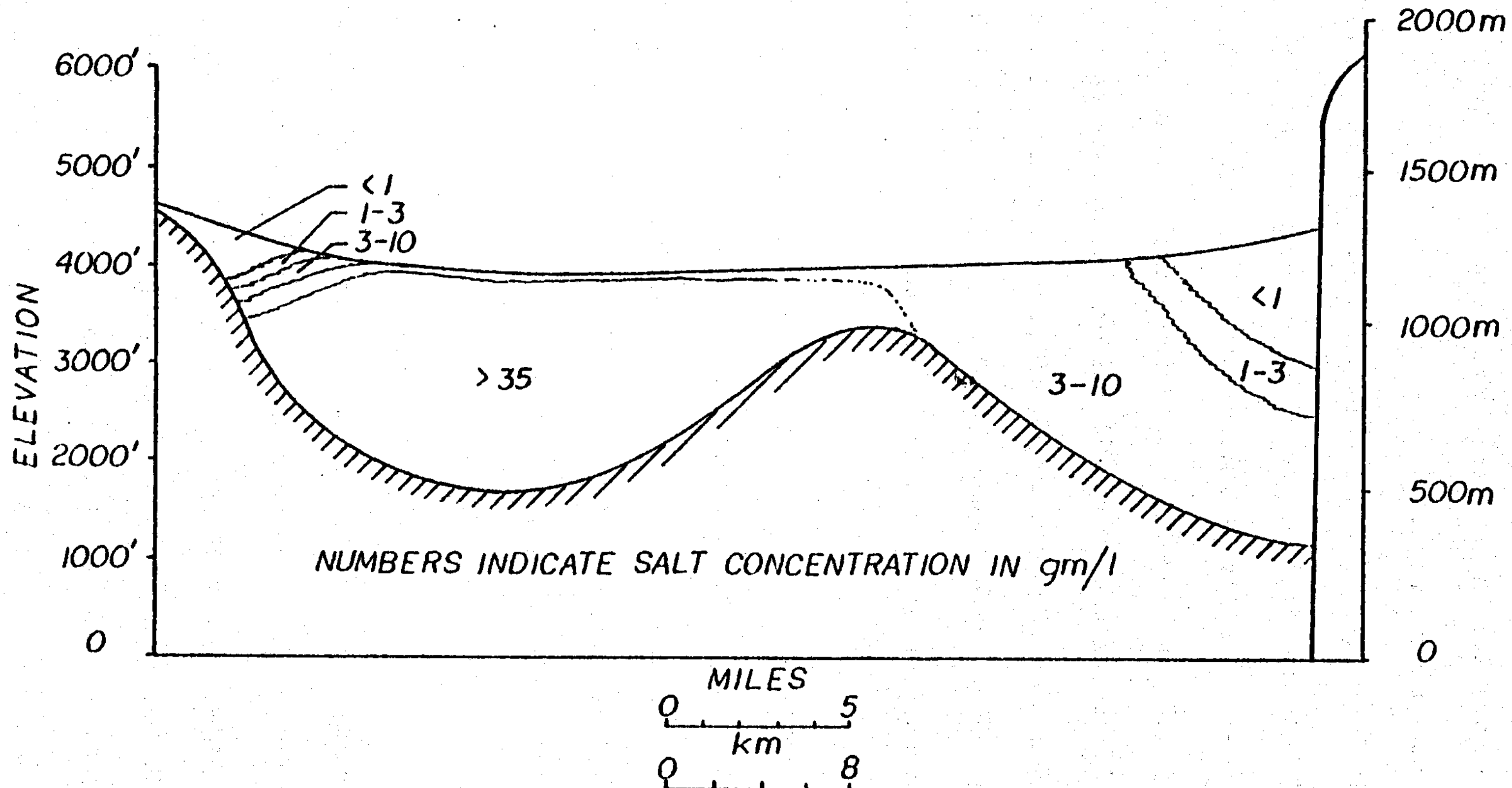


Figure 22 **Typical cross-section of the Tularosa Basin. (Source: McLean, 1970)**

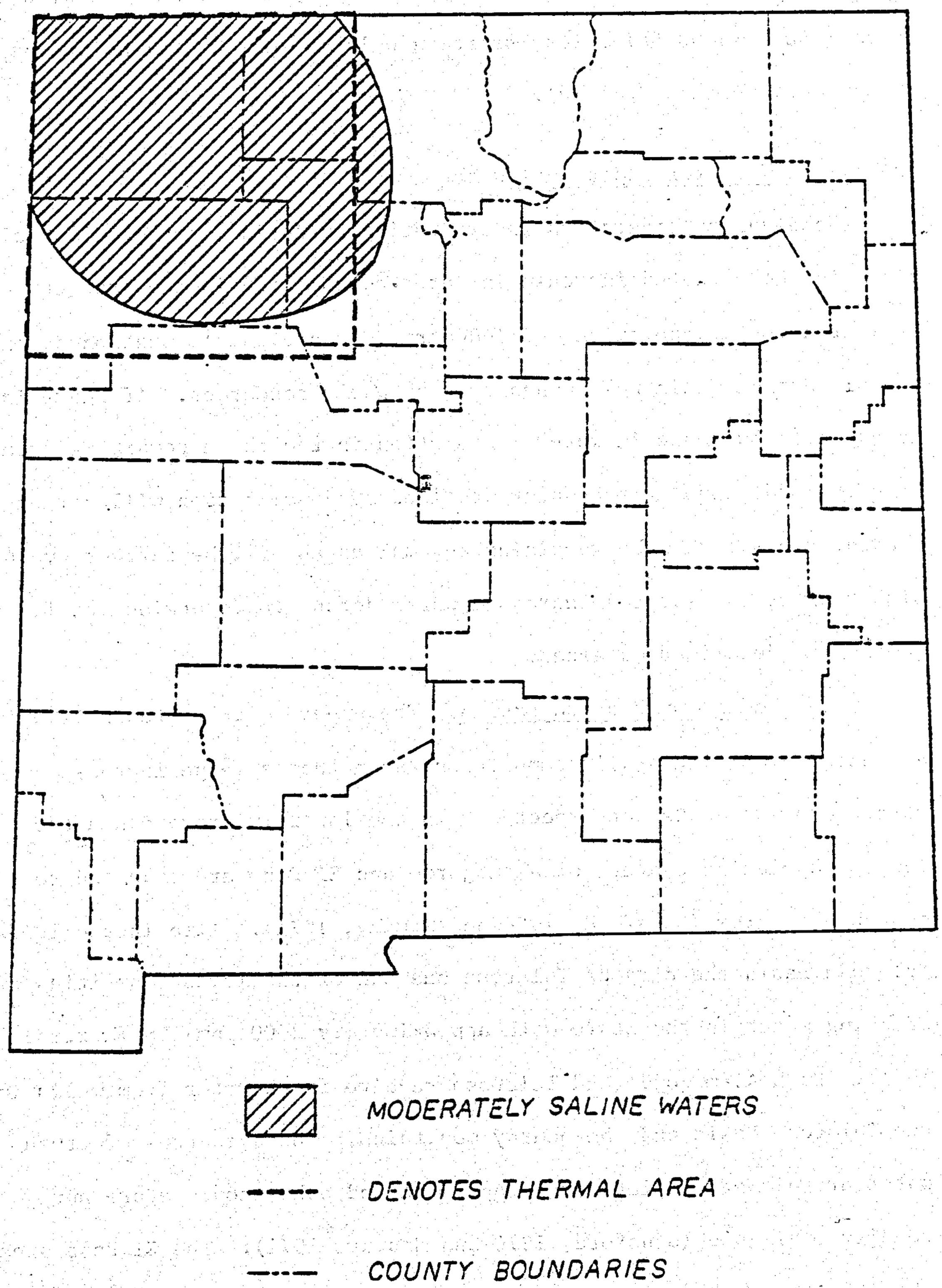


Figure 23 Extent of moderately saline water resources in the Northwestern Plateau Thermal Area of New Mexico. (Source: Kelly, 1970)

plateau thermal area is underlain by moderately saline water aquifers up to 1500 m (5000 ft) thick, starting only 150 m (500 ft) below the ground surface (Kelly, 1970).

Areas with Need for Additional Water

The final consideration in evaluating potential geothermal desalination sites is the expected increase in water consumption in the area caused by increases in population and industry. As previously mentioned, only the Rio Grande Basin has abundant fresh water resources. If there is no expected increase in water consumption in the three remaining areas, then the additional fresh water provided by desalination will not be needed. Therefore, the remaining thermal areas will be further evaluated with respect to expected increased water demand to determine the final geothermal desalination sites.

Upper and Lower Tularosa Basins. The upper Tularosa Basin is primarily a grazing area with small communities, such that a large increase in water consumption is not expected. In the lower Tularosa Basin the larger population centers of Alamogordo and El Paso are expected to continue to grow (Lansford, 1976 and Stucky, 1971). Also in the lower Tularosa Basin the city of Tularosa has one of the lowest qualities of drinking water in the state with approximately 2000 ppm TDS (Morris, 1971). Both Alamogordo and Tularosa receive fresh water from wells in the Tularosa Basin and the nearby mountains. These sources of fresh water are almost completely appropriated and other sources are not readily available (Lansford, 1976 and Stucky, 1971). The El Paso area obtains its fresh water supplies from the Rio Grande Basin, either as surface water or groundwater. The surface water supply is limited and increased growth will require additional groundwater supplies. A large desalination plant in the lower Tularosa Basin could provide fresh water for these three areas and may indeed be more economical than developing other distant sources of fresh water.

Northwestern Plateau. This area will probably experience the largest growth rate in the state and will therefore have the most significant need for the development of fresh water resources. As energy production becomes more important, this area with vast coal fields and uranium deposits will continue to expand industrially in mining and in population (Bur. of Rec., 1976). The cities expected to realize most of the growth are Farmington, Gallup, and Grants, the largest cities in the area. Farmington should be able to meet the expected increase in water consumption because of abundant fresh water resources in the area. A large growth at Gallup and Grants, however, could severely deplete fresh water supplies in these two cities. The water requirements of increased industry and mining in the area must also be met. A large desalination plant in either or both cities could provide fresh water for industrial, mining, and municipal consumption.

Regions with Greatest Potential for Geothermal-Desalination

Each potential geothermal desalination area in New Mexico was evaluated for the quality and quantity of the geothermal waters, the availability of fresh and saline water resources, and the expected population, industrial and water consumption trends. A summary of the evaluations of the final site selections is presented in Tables 4 and 5. On the basis of this analysis, five potential geothermal desalination sites are selected. These are shown in Figure 24.

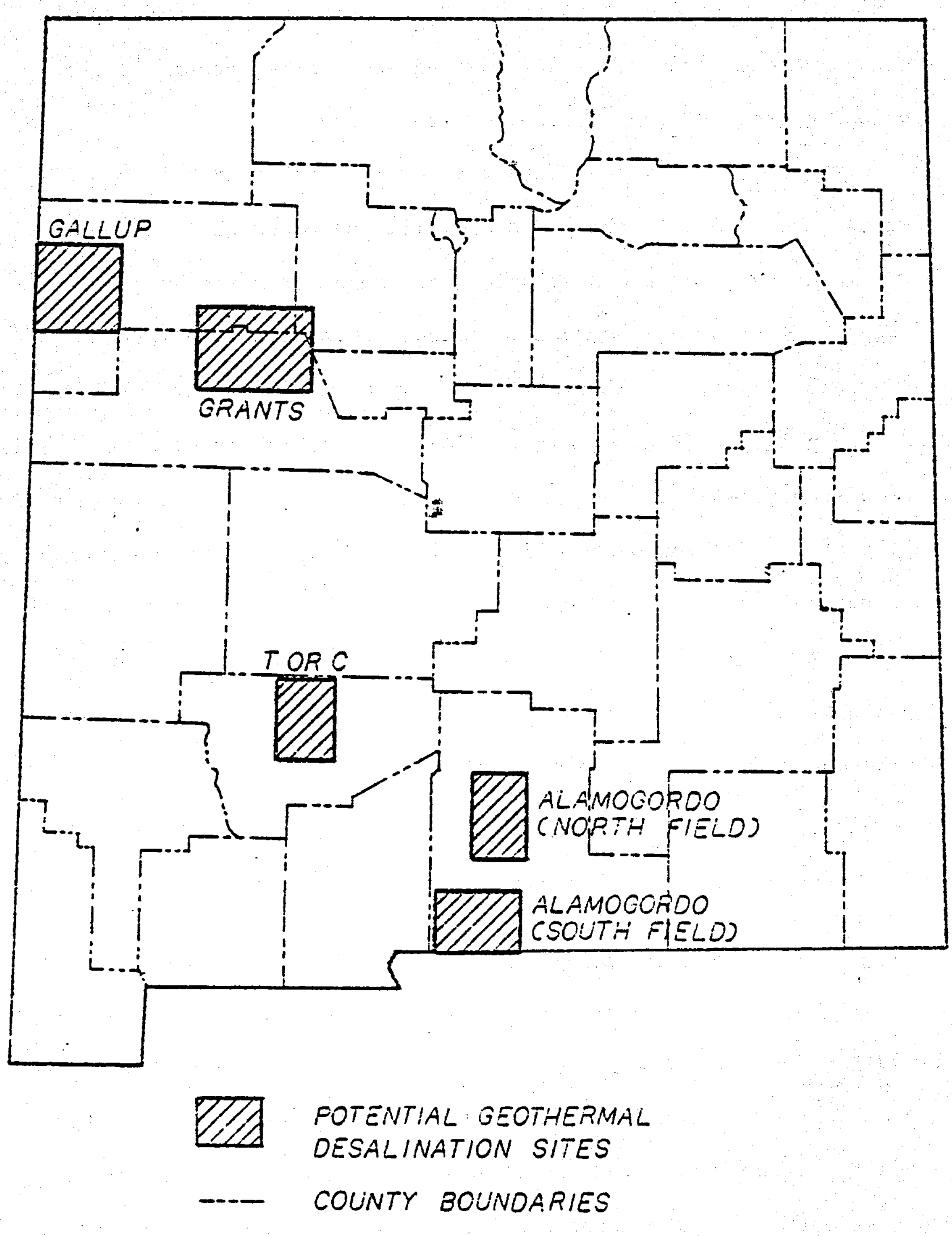


Figure 24 Location of potential geothermal desalination sites in New Mexico.

SITE	GEOTHERMAL DESALINATION SITE SELECTION FACTORS			
	GEOTHERMAL WATER RESOURCES	INADEQUATE FRESH WATER RESOURCES	EXTENSIVE SALINE WATER RESOURCES	EXPECTED RAPID GROWTH
Northwestern Plateau				
Farmington	X		X	X
Aztec	X		X	X
Gallup	X	X	X	X
Grants	X	X	X	X
Rio Grande Basin				
Taos	X		X	
Albuquerque	X		X	X
Socorro	X		X	
T or C	X		X	
Tularosa Basin				
Alamogordo	X	X	X	X
Carrizozo	X		X	
Tularosa	X	X	X	
El Paso	X		X	X

X Denotes positive factor for geothermal site selection.

Table 4. Evaluation of different sites in New Mexico as potential geothermal desalination sites.

NORTHWESTERN PLATEAU THERMAL AREA

Gallup	Expected large growth due to increased coal mining Inadequate water supply for large population growth Extensive saline water resources Possibly share expenses and product water from desalination with industry Close proximity of thermal and saline water to city
Grants	Expected large growth due to increased uranium and coal mining Possible critical demand on the water supply if a large population growth Extensive saline water resources Possibly share expenses of desalination with uranium industry Close proximity of thermal and saline water to city

RIO GRANDE BASIN THERMAL AREA

Truth or Consequences	Possible salt reduction required in Rio Grande River in the future Elephant Butte Reservoir provides constant intake water source Extensive thermal water resources nearby

LOWER TULAROSA BASIN THERMAL AREA

Tularosa Alamogordo El Paso	Expected continued growth rate Minimal fresh water resources Most extensive saline water resources in the state Extensive thermal water resources Possibly share expenses between the three cities for a large scale desalination plant.

Table 5. Final geothermal desalination site selections with evaluation summaries.

Geothermal Hydrology of the Selected Sites

The geothermal hydrology of the final geothermal desalination sites is probably the most important consideration in establishing the locations of geothermal, saline, and brine disposal wells in these areas. The hydraulic characteristics of the aquifers in these areas govern the number, depth, and diameter, and therefore the cost, of each type of well drilled. To estimate the projected cost of geothermal desalination in each area, the groundwater hydrology of the area should be understood as much as possible. Unfortunatley, this is difficult since the two major resources that will be brought into production, thermal and saline waters, have until recently been considered nuisances and aquifers containing these types of water were usually plugged off. Because of the rather limited knowledge of the groundwater hydrology of these types of aquifers, the hydraulic properties will be given as ranges. Combinations of the ranges of these hydraulic properties will give a better idea of the possible variance which can be expected in producing a particular aquifer.

Gallup: The Gallup area has been previously considered as a potential desalination site (Le Gros, 1970). In that study, the potential saline water recovery and disposal wells were located north of Gallup. Recent work (Chaturvedi, unpublished data) indicates the presence of geothermal resource near Gallup (one well east of Gallup shows 63°C temperature at 1800 ft).

According to Le Gros (1970), the most easily accessible saline water in the Gallup area occurs in the Dakota and Westwater sandstones and the upper Morrison, at a maximum depth of 525 m-600 m (1700 ft-2000 ft). The water has greater than 1000 ppm TDS, and probably ranges up to 3000 ppm TDS. The combined aquifer is over 150 m (500 ft) thick, is relatively porous, and has pumping capabilities as high as 2800 l/min (700 gal/min). The combined aquifer characteristics are listed in Table 6.

The estimated temperatures of thermal waters in the Gallup area at a depth of one km (3300 ft) are between 30°C-70°C (86°F-150°F). The average temperature at that depth is approximately 50°C (122°F), and the number of thermal wells indicate an extensive thermal aquifer. A new well field north of Gallup has produced high quality water from a thick sandstone aquifer at this depth. Le Gros (1970) predicts the net thickness of this aquifer to be 150 m - 180 m (500 ft - 600 ft), at a depth of 1000 m - 1300 m (3300 ft - 4250 ft). The pumping capacity exceeds 2800 l/min (700 gal/min). The combined sandstone aquifer characteristics are listed in Table 6.

Grants: In the Grants area, most geothermal wells are located northeast of Grants, while the extensive saline aquifers are located north of Grants. In addition, there are persistent but as yet unconfirmed reports of high temperatures encountered in several of the recently drilled exploration wells for uranium in the area.

The Gallup and Grants areas have approximately the same geology and similar geologic formations. Because the actual aquifer characteristics are not known and are listed as ranges, the same aquifer properties as Gallup will be used for this location. The Grants area has an added consideration in supplying feed water to a desalination plant. It may be more economical to buy excess water from nearby uranium mine dewatering systems and desalinize it, than to pump saline water and desalinize it. In this case, only the available quantity of water needs to be known.

Crudely estimated temperatures of the thermal waters in the Grants area at a depth of one km (3300 ft) are between 30°C-50°C (86°F-122°F),

Table 6. Saline and geothermal process water aquifer properties for potential geothermal desalination sites in New Mexico.

Plant Location and Type of Aquifer	Saline and Geothermal Process Water Aquifer Properties						
	Average Depth m (ft)*	Average Thickness m (ft)	Average Porosity %	Average Permeability MPD (FPD)	Maximum Pumping Capacity LPM (GPM)	Water Quality gm/l	Temp. °C
GALLUP - GRANTS							
Saline	525-600 (1700-2000)	150 (500)	20	.0864 (.29)	2800 (700)	1-3	
Geothermal	1000-1300 (3300-4250)	150-180 (500-600)	20	.0864 (.29)	2800-4000 (700-1000)	1-3	30-70
T OR C							
Geothermal	1000-1100 (3300-3600)	300 (1000)	10	0.864 (2.9)	2000-2800 (500-700)	1-3	60
TULAROSA BASIN							
North-Saline	150	200-300	8	2	1200-2800	3-10	
South-Saline	(500)	(660-1000)		(6.6)	(300-700)	1-3	
North-Geothermal	1000-1200 (3300-4000)	100-300 (330-1000)	6	1-2 (3.3-6.6)	1200-2800 (300-700)	3-10	50
South-Geothermal	150-200 (500-650)	100-300 (330-1000)	6	1-2 (3.3-6.6)	1200-2800 (300-700)	3-10	50-70

* - Numbers in parentheses are in the given English System units.
m - meters, ft - feet, LPM - liters/minute, GPM - gallons/minute, gm/l - grams/liter
MPD - meters/day, FPD - feet/day

with an average temperature of approximately 45°C (113°F). Because of the similar geology and similar temperatures of this area and the Gallup area, the same thermal aquifer properties have been assumed.

<u>Truth or Consequences</u>: The most logical place for a desalination plant to improve river quality would be on the river at a reservoir so that a constant source of water is available. This condition exists at Elephant Butte Dam, 5 km (3 miles) east of Truth or Consequences (T or C). Assuming smaller quanties of geothermal water are needed for desalination, it would be easier to locate the plant at T or C and pump the geothermal water to the plant.

Elephant Butte Reservoir has a capacity of approximatley 0.26 million hectare-meters (2 million acre-feet). Even filled to one-half capacity this reservoir is capable of supplying sufficient water supplies to operate a desalination plant of the size now being built on the Colorado River.

The estimated water temperature of the thermal water in this area at a depth of one km (3300 ft) is at least 60°C (130°F). For wells in the extensive Rio Grande Basin, high porosities and permeabilities are common and maximum yields should be between 2000 l/min-2800 l/min (500 gal/min-700 gal/min) (Kelly, 1970). The estimated thermal water quality is between 1000-3000 ppm. The thermal aquifer characteristics are listed in Table 6.

<u>Lower Tularosa Basin</u>: The Tularosa Basin has extensive saline water resources and the location of the saline water well field can be shifted considerably without affecting the yields significantly. Therefore, these saline water well fields should be located near a thermal source and in an area with the lowest salinity groundwater. Known thermal wells

are located in both the northern and southern portions of the Lower Tularosa Basin. Because of the locations of these thermal wells, two well field locations have been chosen. The southern well field is approximately 100 km (60 miles) south and 20 km (12 miles) west of Alamorgordo, i.e. 45 km (27 miles) east and 35 km (20 miles) north of El Paso. A large scale desalination plant in this area could supply water to both cities. The northern well field is approximately south of Alamogordo.

The southern well field is in an extensive aquifer of slightly saline water, (1000-3000 ppm), between 100 m - 300 m (330 ft - 1000 ft) thick at a depth of only 150 m (500 ft) (McLean, 1970). The northern well field is in an aquifer of moderately saline water, (3000-10,000 ppm) (McLean, 1970). Transmissivities in the basin range from 100 m^2/day-200 m^2/day (1100 $ft.^2$/day-2200 ft^2/day) at the center of the basin up to 400 m^2/day (44,000 ft^2/day) at the edges of the basin, while specific yields range from 6% to 10% (McLean, 1970). Maximum yields range from 1200 l/min-2800 l/min (300 gal/min-700 gal/min) (Kelly, 1970 and McLean, 1970). The saline aquifer characteristics of the two well fields are listed in Table 6.

The estimated temperatures of the thermal waters in this basin are 50°C-70°C (122°F-158°F) in the southern portion, and 50°C (122°F) in the northern portion. In the southern portion these thermal waters are at a depth of only 150 m (500 ft), while in the northern portion these temperatures are estimated for a depth of one km (3300 ft). The thermal aquifer characteristics should be similar to the saline aquifer characteristics, with the only difference being a slightly higher salt content. The thermal water aquifer characteristics are also listed in Table 6.

CHAPTER 5

SALINE AND GEOTHERMAL AQUIFER WELL FIELDS DESIGN

Introduction

The size and efficiency of a desalination plant and the type of geothermal distillation process used determine the quantities of saline and geothermal process water required and fresh product water obtained. The quantities of saline and geothermal water required and the hydraulic properties of these aquifers determine the size and areal extent of the process water supply systems or well fields. These supply systems can significantly affect the cost of desalination, and therefore must be properly designed. To obtain an accurate estimate of the well fields required for multiple types of geothermal desalination processes, various plant sizes, ratios of geothermal water to saline water, and sustained pumping rates will be considered.

Plant Sizes and Process Water Requirements

After considering the present water consumption trends in each of the four desalination areas, four desalination plant capacities were chosen: 4.0 MLD, 20 MLD, 40 MLD, and 80 MLD (1.0 MGD, 5.0 MGD, 10 MGD, and 20 MGD, respectively). The large scale plants were considered specifically for the Lower Tularosa Basin south field and the T or C area, where large quantities of saline water are easily available and large quantities of fresh water are needed. The smaller size plants can be used for either municipal or industrial or combined municipal-industrial consumption.

The ratios of geothermal water to saline water considered are based on the most probable distillation processes. The maximum thermal water requirement would equal the plant capacity if the plant were designed to desalinate only the geothermal water, as is presently done at the East Mesa Test Facility (Bechtel, 1977). The lowest range assumed possible, due to the low temperatures determined, is a ratio of one to five, geothermal water to saline water.

The maximum pumping capacities for the saline and geothermal aquifers at each desalination site are listed in Table 6. The sustained pumping capacities are primarily a function of the thickness of the aquifer and the period of time the well is continuously pumped. Therefore, for shallow aquifers, the sustained pumping capacity could be significantly lower than the maximum pumping capacity. For this reason the sustained pumping capacities considered vary from 800 l/min to 3600 l/min (200 gal/min-900 gal/min).

Table 7 shows the number of wells required for both the saline and geothermal aquifers for different plant sizes, ratios of geothermal water to saline water, and sustained pumping rates. The number of wells required includes one auxiliary well, such that production capacity is not lost during well repair.

Well Field Sustained Pumping Capacities and Drawdowns

From the information in Tables 6 and 7, the saline and geothermal well fields for each desalination site can be designed. With the number of wells required and aquifer hydraulic characteristics known, an array can be chosen and the well field drawdowns calculated for different well spacings and sustained pumping rates. The most widely used unsteady state drawdown equation for a single well was introduced by Theis (1935) and Wenzel (1942) and is given below:

TABLE 7. Number of wells required for various saline and geothermal aquifers for different plant sizes, ratios of geothermal water to saline water, and sustained pumping rates.

	Number of Wells Required			
	Plant Capacity			
	4 MLD (1 MGD)*	20 MLD (5 MGD)	40 MLD (10 MGD)	80 MLD (20 MGD)
SALINE WATER PUMPING RATES				
800 LPM (200 GPM)	5	19	36	71
1200 LPM (300 GPM)	4	13	25	48
2000 LPM (500 GPM)	3	8	15	29
2800 LPM (700 GPM)	2	6	11	21
3600 LPM (900 GPM)	2	5	9	17
GEOTHERMAL WATER PUMPING RATES				
<u>No Saline Water Required</u>	SAS	SAS	SAS	SAS
<u>Ratio 1:5</u>				
800 LPM (200 GPM)	2	5	8	15
1200 LPM (300 GPM)	2	4	6	11
2000 LPM (500 GPM)	2	2	3	6
2800 LPM (700 GPM)	2	2	3	5
3600 LPM (900 GPM)	2	2	3	4

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day
LPM - liters/minute, GPM - gallons/minute
SAS - same as saline wells

$$h' = \frac{Q}{4\pi T} \int_{\frac{r^2 S}{4Tt}}^{\infty} e^{-U} \frac{du}{u} \qquad (5.1)$$

$$h' = \frac{Q}{4\pi T} W(u) \qquad (5.2)$$

where h' is the drawdown, Q is the well discharge, T is the transmissivity, r is the radius at which the drawdown is determined, S is the storage coefficient, t is the time since pumping began, and W(u) is the well function, which is equal to the integral in Equation 5.1. Using the theory of superposition, the drawdown at any point in a well field would equal the summation of the drawdowns at that point of each well in the field. The equation for the drawdown at any point in a well field can therefore be written:

$$h = \sum_{i=1}^{n} h'i = \sum_{i=i}^{n} \frac{Qi}{4\pi T} W(ui) \qquad (5.3)$$

where h is the total drawdown at a particular point, h'i is the drawdown at that point due to the i^{th} well, Qi is the discharge of the i^{th} well, W(ui) is the well function of the i^{th} well, and n is the total number of wells in the field (Viessman, 1972 and Stucky, 1971). Using Equation 5.3 and well spacings of 400 m (0.25 miles), 800 m (0.50 miles), 1600m (1.0 mile), and 2000 m (1.25 miles), and the number of wells required for each pumping rate, the maximum drawdown for the life of a desalination plant, 30 years, for each well field can be calculated. From these calculations the most feasible size plant for each area will be chosen.

<u>Gallup and Grants</u>: The saline and geothermal aquifers in the Gallup and Grants areas have essentially the same hydraulic characteristics. The low permeabilities and relatively shallow thicknesses cause substantial drawdowns for high pumping rates. The maximum allowable sustained pumping rate for these aquifers is 800 l/min. (200 gal/min) at a well

spacing of 2000 m (1.25 miles), which makes only small scale plants feasible for these areas. The maximum drawdowns for both saline and geothermal aquifers for 4.0 MLD (1.0 MGD) and 20.0 MLD (5.0 MGD) plants are 102 m (330 ft) and 104m (340 ft), respectively.

Truth or Consequences: Due to the large quantities of fresh water needed to reduce the salinity of the Rio Grande, only the large scale, 80 MLD (20 MGD) plant will be considered. Because of the relatively thick aquifers in the Rio Grande Basin and the higher permeabilities, higher sustained pumping rates and closer well spacings can be used in this area. At a sustained pumping rate of 2800 1/m (700 gal/min) and a well spacing of 400 m (one-quarter mile), the drawdown for a one to five ratio geothermal water to saline water plant is 100 m (330 ft). For a plant using a one to one ratio, the maximum drawdown is 220 m (660 ft).

Lower Tularosa Basin: In this area two separate plant site locations have been considered. The hydraulic characteristics and aquifer thicknesses of both locations are very similar, though the size of the plant at each location will differ. The southern site will be considered for a high production plant of either 40 MLD (10 MGD) or 80 MLD (20 MGD) to supply fresh water to both Alamogordo and El Paso or possibly only El Paso. The northern site will be considered for a medium size plant of either 20 MLD (5 MGD) or 40 MLD (10 MGD) capacity to supply fresh water to Alamorgordo and Tularosa.

Because of excellent hydraulic characteristics and extensive and thick aquifers, both the north and south saline water well fields can be pumped at higher sustained rates and at closer spacings. The northern field can be pumped at a sustained rate of 2800 1/min (700 gal/min) and at a well spacing of 400 m (one-quarter mile) with maximum drawdowns of

24 m (80 ft) and 40 m (132 ft) for the 20 MLD (5 MGD) and 40 MLD (10 MGD) plants. The southern field can be pumped at the same sustained capacity and well spacing with a maximum drawdown of 56 m (185 ft) for the 80 MLD (20 MGD) plant.

The geothermal aquifer drawdowns can be expected to be about the same as the saline aquifer drawdowns for the desalination process requiring only geothermal water, since the aquifer characteristics and the number of wells required are the same. Assuming the same pumping rates and well spacings as the saline aquifers, the maximum drawdowns of the geothermal aquifers at a one to five ratio geothermal water to saline water are 10 m (33 ft), 15 m (48 ft), and 20 m (66 ft) for the 20 MLD (5.0 MGD), 40 MLD (10.0 MGD), and the 80 MLD (20.0 MGD) plants, respectively.

A summary of the maximum drawdowns for the saline and geothermal aquifers for the most feasible plant capacities at each potential geothermal site is shown in Table 8.

TABLE 8. Maximum drawdowns for saline and geothermal aquifers at each potential geothermal desalination site in New Mexico.

Plant Location and Type of Aquifer	Plant Capacity MLD (MGD)*	Sustained Pumping Rate LPM (GPM)	Well Spacing m (ft)	Maximum Drawdown m (ft)
GALLUP - GRANTS				
Saline Aquifer	4.0	800 (200)	2000 (6600)	102 (336)
	20	800 (200)	2000 (6600)	104 (340)
Geothermal Aquifer Ratio 1:5 Geothermal to Saline Water	4.0 (1.0)	800 (200)	2000 (6600)	100 (330)
	20 (5.0)	800 (200)	2000 (6600)	200 (330)
Geothermal Water Only	4.0 (1.0)	800 (200)	2000 (6600)	102 (336)
	20 (5.0)	800 (200)	2000 (6600)	104 (340)
T OR C				
Geothermal Aquifer Ratio 1:1 Geothermal to Saline Water	80 (20)	2800 (700)	400 (1320)	220 (660)
Ratio 1:5 Geothermal to Saline Water	80 (20)	2800 (700)	400 (1320)	100 (330)
TULAROSA BASIN				
Saline Aquifer	20 (5)	2800 (700)	400 (1320)	24 (80)
	40 (10)	2800 (700)	400 (1320)	40 (132)
	80 (20)	2800 (700)	400 (1320)	56 (185)
Geothermal Aquifer Ratio 1:5 Geothermal to Saline Water	20 (5)	2800 (700)	400 (1320)	10 (33)
	40 (10)	2800 (700)	400 (1320)	15 (48)
	80 (20)	2800 (700)	400 (1320)	20 (66)
Geothermal Water Only	20 (5)	2800 (700)	400 (1320)	24 (80)
	40 (10)	2800 (700)	400 (1320)	40 (132)
	80 (20)	2800 (700)	400 (1320)	56 (185)

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day
m - meter, ft - feet
LPM - liters/minute, GPM - gallons/minute

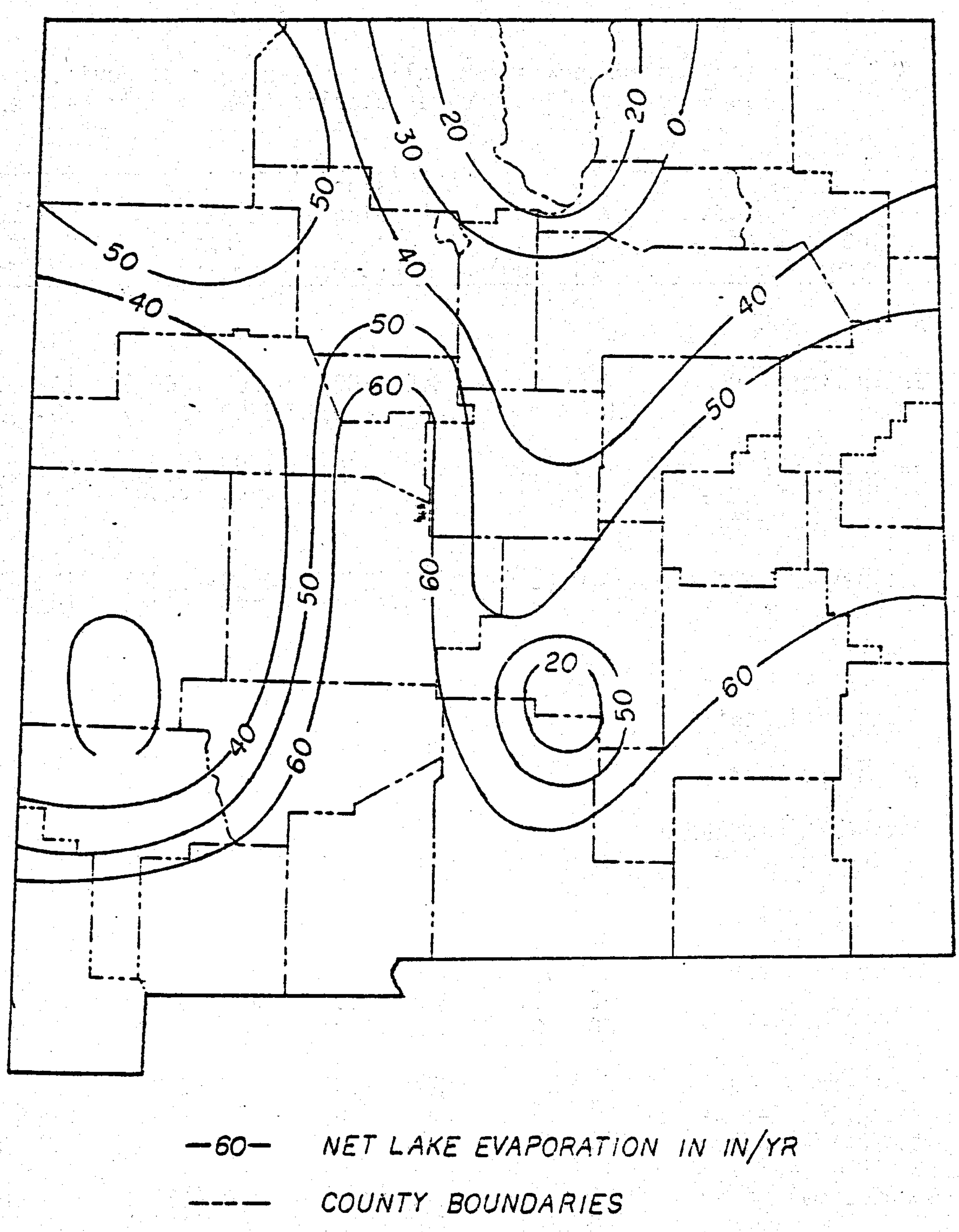


Figure 25 Average net lake evaporation in New Mexico. (Source: Bur. of Rec., 1976)

CHAPTER 6

GEOTHERMAL DESALINATION PLANT WASTE BRINE DISPOSAL

Introduction

A by-product of all desalination plants is a usually highly saline brine. Disposal of this brine poses serious environmental and economic problems. Environmentally, proper disposal of this brine is required to prevent contamination of any fresh surface water or groundwater supplies. Economically, the requirement for proper disposal and the extremely corrosive nature of the brine make disposal usually very costly.

Various methods have been considered to solve the problems of brine disposal. Such processes as evaporation, subsurface injection, refrigeration, and mineral recovery have been evaluated (Lansford, 1976; Morris, 1971; Dow Chemical, 1970; Ganiaris, 1970; Keyes, 1970; Le Gros, 1970; Riley, 1970; Standord, 1970; Boegly, 1969; De Puy, 1969; Le Gros, 1969). Evaporation and subsurface injection are the two most popular methods of disposal, while refrigeration and mineral recovery are relatively new methods of disposal. Refrigeration is more expensive than the other disposal processes, and mineral recovery is only applicable in very large capacity plants (Lansford, 1976; Dow Chemical, 1970). Studies have indicated that brine disposal by evaporation is only feasible in areas with over approximately 80 cm (30 in) net evaporation per year (Lansford, 1976; Le Gros, 1969). The average net lake evaporation in New Mexico is shown in Figure 25. This figure indicates that the areas under consideration as desalination sites have adequate net evaporations for this process to be feasible. The most common disposal process for brines is subsurface injection, which has been successfully used for over 60 years in the oil fields (Boegly, 1969). This process is most widely used because most areas do not have enough net evaporation in a year to effectively dispose of the brine by evaporation. Also, most states require injection to guard against possible fresh water contamination (Le Gros, 1969).

In this study three methods of brine disposal will be considered: evaporation, subsurface injection, and combined evaporation and injection. The number of evaporation ponds or injection wells needed at each site will depend on the quantity and quality of the waste brine. Such factors as the desalination plant capacity and concentration factor and the saline and geothermal process water quantities and qualities will govern the amounts and properties of the waste brine. The relationship between these factors will be evaluated, such that each brine disposal system can be accurately designed.

Geothermal Desalination Waste Brine Quantities and Qualities

In a typical desalination plant, the quantity and quality of the disposal brine are related to the plant concentration factor as shown below:

$$Qbs = Qd/CF \tag{6.1}$$

$$Cbs = Cs(CF) \tag{6.2}$$

where Qbs is the saline water brine flow rate, Qd is the flow rate of the water to be desalinized, Cbs is the saline brine TDS concentration, Cs is the initial TDS concentration of the water to be desalinized, and CF is the concentration factor. If mixing of the high quality desalinized water with the low quality saline process water is considered, the mixing equation must first be considered. This is given in Equation 6.3.

$$Qp\ Cp = Qd\ Cd + Qnd\ Cnd \tag{6.3}$$

where Qp is the product water flow rate, Qd is the desalinized water flow rate, Qnd is the non-desalinized water flow rate, Cp is the product water TDS concentration, Cd is the final desalinized water TDS concentration, and Cnd is the non-desalinized water TDS concentration, remembering that:

$$Qs = Qd + Qnd \tag{6.4}$$

$$Qp = Qs - Qbs \tag{6.5}$$

$$Cnd = Cs \tag{6.6}$$

where Qs is the saline process water flow rate and Cs the TDS concentration. Substituting these values into Equation 6.3, the following equation can be obtained:

$$Qs = Qd \left[\frac{(Cs - Cd)}{(Cs - Cd)} - \frac{1}{CF} \frac{(Cp - Cd)}{(Cs - Cp)} \right] \tag{6.7}$$

or

$$Qd = (MF)Qs \tag{6.8}$$

where (MF) is called the mixing factor and is the reciprocal of the quantity in brackets in Equation 6.7. Therefore, when considering mixing the desalinized water with a portion of the saline process water, the quantity of brine will be as shown in Equation 6.9.

$$Qbs = Qd/CF \tag{6.1}$$

$$\text{for mixing } Qd = (MF)Qs \tag{6.8}$$

$$\text{and } Qbs = (MF)Qs/CF \tag{6.9}$$

In a geothermal desalination plant, the waste brine is composed of both saline and geothermal brines. Therefore, the final brine quantities and qualities are governed by the mixing equation, such that:

$$Qbt + Cbt = Qbs\ Cbs + Qbg\ Cbg \qquad (6.10)$$

where Qbt is the total brine flow rate, Qbs is the saline water brine flow rate, Qbg is the geothermal brine flow rate, Cbt is the total brine TDS concentration, Cbs is the saline brine TDS concentration, and Cbg is the geothermal brine TDS concentration. Knowing that Qbt = Qbs + Qbg and substituting Equation 6.9 into Equation 6.10, the following equation can be obtained for the total brine concentration:

$$Cbt = \frac{(MF)QsCs + Qbg\ Cbg}{(MF)Qs/CF + Qbg} \qquad (6.11)$$

Using Equation 6.11, the quality and quantity of brine can be calculated for each desalination site for all ranges of plant size and concentration factor, quantity and quality of saline and geothermal process water, quality of desalinized water, and final product water quality. Table 9 gives the quantities and qualities of brine to be disposed at each desalination site. The following parameters were used in calculating these values from Equation 6.11. The plant sizes and the saline and geothermal process water quantities were taken from Table 8. The saline and geothermal process water qualities were taken from Table 6. The concentration factors for a geothermal desalination plant vary between two and three (Bechtel, 1977), so allowing for more efficient processes, factors varying from two to four were considered. Theoretically, the final water quality for a desalination process should be zero. A recent study indicates that the final quality of a desalinized water will be approximately 25 mg/l TDS (Lansford, 1976). This is negligible when

TABLE 9 Quantities of brine and product water and brine qualities for varying geothermal and saline water qualities and plant concentration factors for a 4.0 MLD (1.0 MGD) geothermal desalination plant.

		Desalination Plant Concentration Factors								
		2			3			4		
Cg gm/l	Cs gm/l	[a]Qtb MLD (MGD)*	Ctb gm/l	Qp MLD (MGD)	Qtb MLD (MGD)	Ctb gm/l	Qp MLD (MGD)	Qtb MLD (MGD)	Ctb gm/l	Qp MLD (MGD)
Ratio 1:0 Geothermal to Saline Water										
3	2	2.51 (0.62)	3.7	2.29 (0.58)	1.89 (0.47)	4.7	2.91 (0.73)	1.60 (0.40)	5.5	3.2 (0.80)
7	2	2.51 (0.62)	4.7	2.29 (0.58)	1.89 (0.47)	6.4	2.91 (0.73)	1.60 (0.40)	7.5	3.2 (0.80)
3	4	2.67 (0.67)	6.9	2.13 (0.53)	2.02 (0.50)	7.7	2.78 (0.70)	1.71 (0.43)	9.9	3.06 (0.77)
7	4	2.67 (0.67)	7.7	2.13 (0.53)	2.02 (0.50)	10.0	2.78 (0.70)	1.71 (0.43)	11.8	3.06 (0.77)
3	6	2.71 (0.68)	9.3	2.09 (0.52)	2.06 (0.51)	12.2	2.74 (0.69)	1.74 (0.43)	14.3	3.06 (0.77)
7	6	2.71 (0.68)	10.5	2.09 (0.52)	2.06 (0.51)	13.7	2.74 (0.69)	1.74 (0.43)	16.2	3.06 (0.77)
3	8	2.73 (0.68)	12.2	2.07 (0.52)	2.07 (0.52)	15.9	2.73 (0.68)	1.74 (0.43)	18.7	3.06 (0.77)
7	8	2.73 (0.68)	13.4	2.07 (0.52)	2.07 (0.52)	17.4	2.73 (0.68)	1.74 (0.43)	20.5	3.06 (0.77)
Geothermal Water Only										
3		2.0 (0.5)	6.0	2.0 (0.5)	1.33 (0.33)	9.0	2.66 (0.66)	1.0 (0.25)	12.0	3.0 (0.75)
7		2.0 (0.5)	11.0	2.0 (0.5)	1.33 (0.33)	21.0	2.66 (0.66)	1.0 (0.25)	28.0	3.0 (0.75)

[a] - Values are based on a mixed product water quality of 500 mg/l.
* - Numbers in parentheses are in the given English System units.
Cg - geothermal water quality, Cs - saline water quality, Ctb - total brine quality
Qtb - total brine quantity, Qp - product water quantity
MLD - million liters/day, MGD - million gallons/day
gm/l - grams/liter

compared to the high salt concentration initially found in the saline process water, and therefore the concentration will be considered to be zero. The final product water quality can be varied depending on the expected usage of the water. Considering the water for municipal usage at Gallup, Grants, and in the Tularosa Basin, a final quality of 500 mg/1 was considered. Considering the water for agricultural use at T or C, a final quality between 800 mg/1-1000 mg/1 was considered.

Brine Disposal by Evaporation

Brine disposal by evaporation has been extensively studied, and design parameters for disposal ponds essentially completed by previous workers. The most extensive design manual has been written by the OSW entitled, Brine Disposal Pond Manual; and authored by Day, 1970. The following design parameters were taken from this manual.

Pond:

Max. area per pond	= 40.5 hectares (100 acres)
Length to width ratio	= 2:1
Freeboard	= 0.6 m (2.0 ft)
Brine Height	= 0.4 m (1.3 ft)
Salt accumulation @30 yrs.	= see Appendix, Figure 1

Berm:

Top width	= 4 m (12 ft)
Side slopes	= 2:1

Morrison, 1971 and 1970, suggests that the only ways to prevent evaporation pond seepage is to line the pond with either PVC or butyl rubber, since oil sealant has been shown to be unreliable. Also, in calculating net evaporation, a correction factor must be used to compensate for the decrease in the evaporation of saline water relative to fresh water (De Puy, 1969). Figure 26 gives the decrease in net evaporation expected due to different qualities of saline water, relative to fresh water evaporation. From the waste brine data given in Table 9 and the above design parmeters, the number and sizes of brine disposal ponds needed for each desalination site were calculated. These values are shown in Table 10.

Brine Disposal by Subsurface Injection

As mentioned earlier, brine injection systems have been successfully used for many years with little fresh water contamination, when properly designed, maintained, and operated (Wood, 1974). The major problems with injection systems are controlling corrosion and finding a suitable aquifer for the disposal of the usually highly saline waste brine. Design problems associated with an injection system include clogging or fracturing of the disposal aquifer formation. The only environmental problem associated with a properly designed and operated system is the possibility that chemicals used in the desalination process, such as for corrosion control or to prohibit scale information, could contaminate the disposal aquifer (Bechtel, 1977).

Before design parameters were established for injection systems at each of the desalination sites considered, a review of the characteristics of existing disposal systems was undertaken. A short summary of these characteristics follows. The injection rates of most brine disposal wells are relatively low, usually less than 1600 l/min (400 gal/min) (Boegly, 1969). To prevent clogging of the disposal formation, most brines are pretreated before injection, usually only consisting of sedimentation or filtration (Boegly, 1969). One study has shown

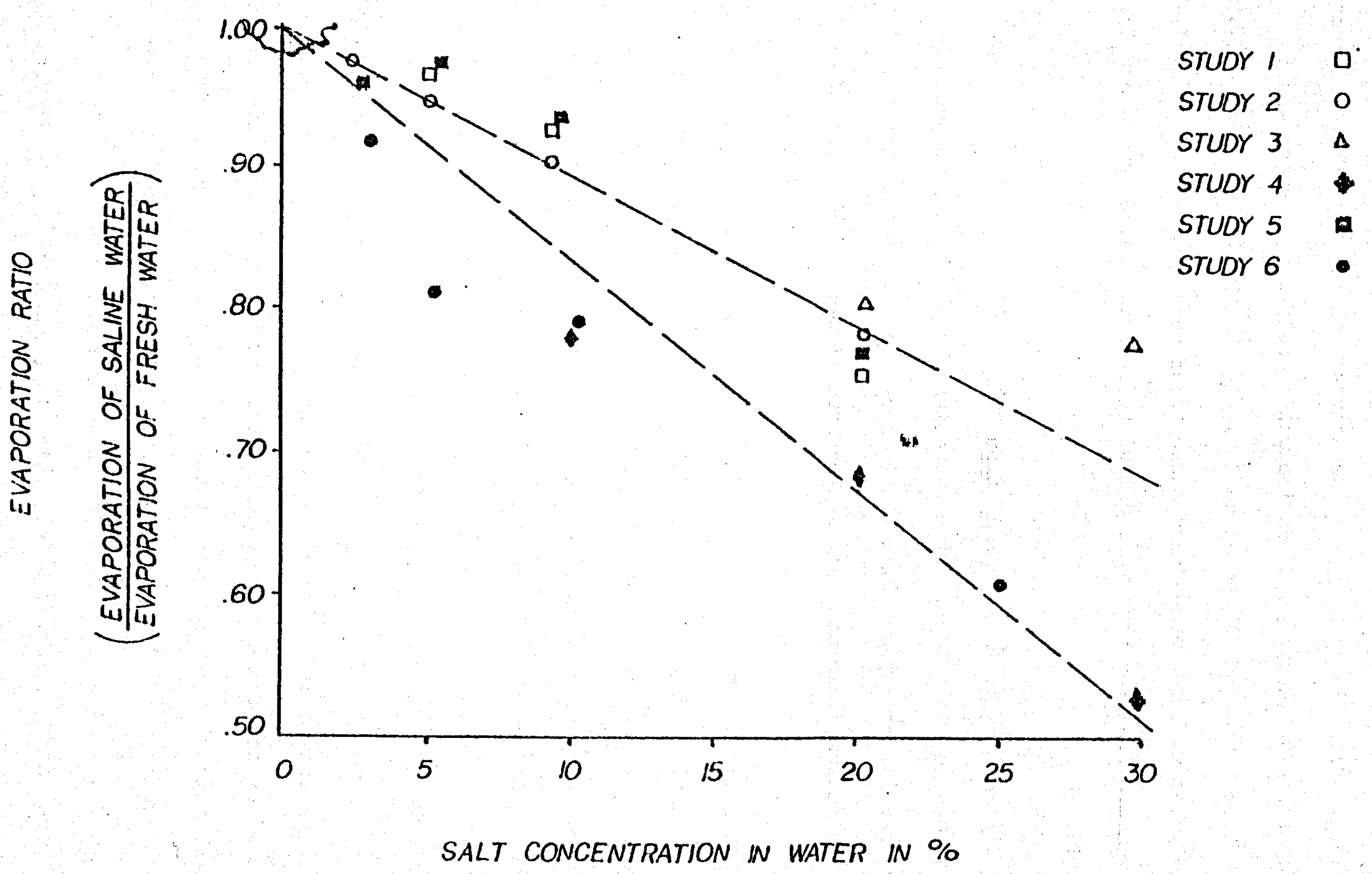


Figure 26 Ratio of evaporation of saline water to fresh water for varying salt concentrations in water. (Source: DePuy, 1969)

TABLE 10. Number of 20 hectare (50 acre) evaporation ponds required for brine disposal for various saline process water qualities, plant capacities, and concentration factors.

Plant Location	Saline Water Quality gm/l	Plant Capacity MLD (MGD)*	Number of 20 hectare (50 acre) ponds Concentration Factors 2	3	4
GALLUP - GRANTS					
Ratio 1:5 Geothermal to Saline Water	2.0	4.0 (1.0)	4	3	3
		20 (5.0)	21	16	13
	4.0	4.0 (1.0)	4	3	3
		20 (5.0)	22	17	14
Geothermal Water Only		4.0 (1.0)	4	2	2
		20 (5.0	17	11	9
T OR C					
Ratio 1:5 Geothermal to Saline Water	1.0	80 (20)	68	52	44
Ratio 1:1 Geothermal to Saline Water	1.0	80 (20)	146	129	122
TULAROSA BASIN					
Ratio 1:5 Geothermal to Saline Water	4.0	20 (5.0)	16	13	11
		40 (10)	33	25	21
		80 (20)	65	50	42
	6.0 and greater	20 (5.0)	17	13	11
		40 (10)	33	25	22
		80 (20)	66	50	43
Geothermal Water Only		20 (5.0)	12	8	6
		40 (10)	24	16	12
		80 (20)	48	33	25

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day, gm/l - grams/liter

that pretreatment of desalination plant waste brines is not required (Le Gros, 1969). To prevent fracturing of the disposal formation, injection pressures of 0.12 kg/Cm^2/m (0.5 psi/ft) of depth greater than the formation pressures are normally used (Boegly, 1969). To prevent corrosion of the injection well, 20 mm (7.5") main casing is used with the brine injected through coated tubing. Most of the injection wells are between 300 m - 1500 m (1000 ft-5000 ft) in depth (Boegly, 1969).

Brine Disposal Formation Properties. The disposal aquifers at each of the desalination sites have hydraulic characteristics similar to the saline water production aquifers. The main differences in the two aquifers are the depth and water quality.

At Gallup and Grants, the Meseta Blanca and Abo sandstones at a depth of 1500 m - 1900 m (5000 ft-6300 ft) have been previously used as disposal aquifers (Le Gros, 1970). These two formations will also be considered as disposal aquifers in this study. The effective thickness of these combined formations is between 100 m - 130 m (330 ft-430 ft), with hydraulic characteristics the same as the Dakota sandstone (Le Gros, 1970). The formation pressure of this confined aquifer is 200 kg/cm^2 (2800 psi) (Le Gros, 1970). The combined aquifer properties are listed in Table 11.

At Truth or Consequences and in the Lower Tularosa Basin, the hydraulic characteristics of the disposal aquifers will be considered to be the same as the saline and geothermal water production aquifers because of the extensive unconfined aquifers in these areas. At T or C, the disposal aquifer considered is at a depth of 900 m (3000 ft) with a water quality of 3.0 gm/l-10.0 gm/l, an injection capacity of 2000 l/min (500 gal/min), and an effective thickness of 1800 m (4000 ft) (Kelly, 1970).

TABLE 11 Injected brine disposal aquifer properties for potential geothermal desalination sites in New Mexico.

Plant Location	Injected Brine Disposal Aquifer Properties					
	Average Depth m (ft)*	Average Thickness m (ft)	Average Porosity %	Average Permeability MPD (FPD)	Injection Rate LPM (GPM)	Water Quality gm/l
GALLUP - GRANTS	1500-1900 (5000-6300)	120 (400)	20	.0864 (.29)	1600 (400)	-
T OR C	600 (2000)	1200 (4000)	10	.864 (2.9)	2000 (500)	3-10
TULAROSA BASIN	600 (2000)	300 (1000)	6	1 (3.3)	2000 (500)	10-35

* - Numbers in parentheses are in the given English System units.
m - meters, gm/l - grams/liter
MPD - meters/day, FPD - feet/day
LPM - liters/minute, GPM - gallons/minute
ft - feet

In the Lower Tularosa Basin the disposal aquifers considered for both the northern and southern plant sites are at a depth of 900 m (3000 ft) with an effective thickness of 300 m (1000 ft), a water quality of 20.0 gm/1-35.0 gm/1, and an injection capacity of 2000 1/min (500 gal/min) (McLean, 1970). Since the aquifers in the T or C and Lower Tularosa Basin areas are essentially unconfined, no formation pressures were considered. The properties of these aquifers are listed in Table 11.

Brine Injection System Design. From the information available on existing brine injection systems and the disposal aquifer properties listed in Table 11, a brine injection rate of 1600 1/min (400 gal/min) was chosen for each desalination site. To reduce the maintenance problems of three separate well fields, saline water recovery, geothermal water recovery, and brine disposal, the brine disposal well fields were considered to be superimposed over the saline water recovery well fields. The disposal wells were considered spaced between the saline water wells and therefore have the same well spacing as the saline water recovery field. Using the indicated injection rate and the brine quantities from Table 9, the number of disposal wells required at each desalination site was calculated, and is listed in Table 12. This number includes one extra well to maintain the disposal capacity during well maintenance.

Using Equation 5.1, the maximum increase in the formation pressure in units of length can be obtained for an injection well. Using Equation 5.3, the pressure increase at any well in a well field can be obtained. Using Equation 5.3, the maximum increase in the formation pressure at each desalination site was calculated and is listed in Table 13.

TABLE 12 The number of brine disposal wells required at an injection rate of 1600 l/min. (400 gal/min.) for different plant capacities and concentration factors at the potential geothermal desalination sites in New Mexico.

Plant Location	CF	Number of Injection Disposal Wells Required — Plant Capacity			
		4 MLD (1 MGD)*	20 MLD (5 MGD)	40 MLD (10 MGD)	80 MLD (20 MGD)
GALLUP - GRANTS					
Ratio 1:5 Geothermal to Saline Water	2	2	7	-	-
	3	2	5	-	-
	4	2	5	-	-
Geothermal Water Only	2	2	6	-	-
	3	2	4	-	-
	4	2	4	-	-
T OR C					
Ratio 1:5 Geothermal to Saline Water	2	-	-	-	26
	3	-	-	-	20
	4	-	-	-	17
TULAROSA BASIN					
Ratio 1:5 Geothermal to Saline Water	2	-	7	13	25
	3	-	6	10	19
	4	-	5	9	16
Geothermal Water Only	2	-	6	10	19
	3	-	4	7	13
	4	-	4	6	10

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day
CF - Concentration Factor

TABLE 13 Maximum pressure increases for brine disposal aquifers at each potential geothermal desalination site in New Mexico.

Plant Location	Plant Capacity MLD (MGD)*	Injection Rate LPM (GPM)	Well Spacing m (ft)	Maximum Increase in Head m (ft)
GALLUP - GRANTS	4 (1.0) 20 (5)	1600 (400) 1600 (400)	2000 (6600) 2000 (6600)	200 (660) 200 (660)
T OR C	80 (20)	1600 (400)	400 (1320)	56 (165)
TULAROSA BASIN	20 (5) 40 (10) 80 (20)	1600 (400) 1600 (400) 1600 (400)	400 (1320) 400 (1320) 400 (1320)	32 (100) 48 (100) 120 (400)

* - Numbers in parentheses are in the given English System units.
MLP - million liters/day, MGD - million gallons/day
m - meters, ft - feet
LPM - liters/minute, GPM - gallons/minute

Brine Disposal by Combined Evaporation and Injection

A possible system for brine disposal not considered previously, includes partial waste brine evaporation followed by subsurface injection. The possible advantage of this type of disposal system is dependent on the concentration factor of the desalination plant. For plants with small concentration factors, less than 4, large quantities of slightly saline brine are produced. Complete disposal by injection would require a large number of wells, while complete disposal by evaporation would require a significant area for evaporation ponds. If the large quantities of slightly saline brine could be reduced and concentrated by evaporation and then disposed by injection, the number of injection wells and evaporation ponds required would be reduced. Depending on injection well costs and land costs, this combined process might be less expensive than total disposal by either of the commonly used systems. Since the probable concentration factors of geothermal distillation are less than five, this combined system of brine disposal will be evaluated.

To prevent clogging of the injection formation, the brine was considered evaporated to a concentration of 50 gm/l TDS and 100 gm/l TDS. A concentration of 100 gm/l TDS is approximately half the concentration of saturation (Boegly, 1969). From Figure 26, this gives an average evaporation factor of 0.925, or an increase of approximately 10 percent over the evaporation factor for total disposal by evaporation.

The ratio of the initial waste brine concentration to the final injection concentration gives the percentage of the brine disposed by injection in this combined disposal system. The remaining portion of the waste brine must be placed in evaporation ponds. Using the quantities and qualities of the waste brine for each of the desalination sites given in Table 9, the amounts of brine to be injected and evaporated for combined disposal were calculated, and are given in Table 14. From these values the size and number of evaporation ponds and the number of injection wells for combined disposal were calculated, and are given in Table 15.

TABLE 14 Quantities of brine injected and evaporated for combined disposal at each potential geothermal desalination site in New Mexico for a 4 MLD (10 MGD) plant.

Cg gm/l	Cs gm/l	CF	Ctb gm/l	Qtb MLD (MGD)*	Quantity of Brine Injected MLD (MGD) — Concentration of Brine Injection 50 gm/l	Quantity of Brine Injected MLD (MGD) — Concentration of Brine Injection 100 gm/l	Quantity of Brine Evaporated MLD (MGD) — Concentration of Brine Injection 50 gm/l	Quantity of Brine Evaporated MLD (MGD) — Concentration of Brine Injection 100 gm/l
Ratio 1:5 Geothermal Water to Saline Water								
3	2	2	3.7	2.51	.19 (.05)	.10 (.03)	2.32 (.58)	2.41 (.60)
7	2	2	4.7	(.63)	.24 (.06)	.12 (.03)	2.27 (.57)	2.39 (.60)
3	2	3	4.7	1.89	.18 (.04)	.09 (.02)	1.71 (.43)	1.80 (.45)
7	2	3	6.4	(.47)	.24 (.06)	.12 (.03)	1.65 (.41)	1.77 (.44)
3	2	4	5.5	1.60	.18 (.04)	.09 (.02)	1.42 (.36)	1.51 (.38)
7	2	4	7.5	(.40)	.24 (.06)	.12 (.03)	1.36 (.34)	1.48 (.37)
3	4	2	6.9	2.67	.37 (.09)	.19 (.05)	2.30 (.58)	2.48 (.62)
7	4	2	7.7	(.67)	.41 (.10)	.21 (.05)	2.26 (.57)	2.46 (.61)
3	4	3	7.7	2.02	.31 (.08)	.16 (.04)	1.71 (.43)	1.86 (.47)
7	4	3	10.0	(.51)	.40 (.10)	.20 (.05)	1.62 (.41)	1.82 (.46)
3	4	4	9.9	1.71	.34 (.09)	.17 (.04)	1.57 (.32)	1.54 (.38)
7	4	4	11.8	(.43)	.40 (.10)	.20 (.05)	1.31 (.33)	1.51 (.38)
3	6	2	9.3	2.71	.50 (.12)	.25 (.06)	2.21 (.55)	2.46 (.62)
7	6	2	10.5	(.68)	.57 (.18)	.29 (.07)	2.14 (.57)	2.42 (.61)
3	6	3	12.2	2.06	.50 (.12)	.25 (.06)	1.46 (.37)	1.81 (.45)
7	6	3	13.7	(.52)	.57 (.18)	.29 (.07)	1.49 (.37)	1.77 (.44)
3	6	4	14.3	1.74	.50 (.12)	.25 (.06)	1.24 (.31)	1.49 (.37)
7	6	4	16.2	(.44)	.56 (.18)	.28 (.07)	1.18 (.40)	1.46 (.37)
Geothermal Water Only								
3	-	2	6	2	.24 (.06)	.12 (.03)	1.76 (.44)	1.88 (.47)
3	-	3	9	1.33	.24 (.06)	.12 (.03)	1.09 (.27)	1.21 (.30)
3	-	4	12	1.0	.24 (.06)	.12 (.03)	0.76 (.14)	0.88 (.22)
7	-	2	14	2	.56 (.14)	.28 (.07)	1.44 (.36)	1.72 (.43)
7	-	3	21	1.33	.56 (.14)	.28 (.07)	0.77 (.19)	1.05 (.26)
7	-	4	28	1.0	.56 (.14)	.28 (.07)	0.44 (.11)	0.72 (.18)

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day, gm/l - grams/liter

TABLE 15 Number of 20 hectare (50 acre) evaporation ponds and 1600 l/min. (400 gal/min.) injection wells required for combined brine disposal at each potential geothermal desalination site in New Mexico.

Plant Location	Saline Water Quality gm/l	Plant Capacity MLD (MGD)*	Number of Evaporation Ponds and Injection Wells — Brine Concentration at Injection — 50 gm/l — Concentration Factors 2 — Ponds	50 gm/l, 2 — Wells	50 gm/l, 3 — Ponds	50 gm/l, 3 — Wells	50 gm/l, 4 — Ponds	50 gm/l, 4 — Wells	100 gm/l — Concentration Factors 2 — Ponds	100 gm/l, 2 — Wells	100 gm/l, 3 — Ponds	100 gm/l, 3 — Wells	100 gm/l, 4 — Ponds	100 gm/l, 4 — Wells
GALLUP - GRANTS														
Ratio 1:5 Geothermal to Saline Water	2.0	4.0 (1.0)	4	2	3	2	2	2	4	2	3	2	3	2
		20 (5.0)	18	2	13	2	11	2	19	2	14	2	12	2
	4.0	4.0 (1.0)	4	2	3	2	2	2	4	2	3	2	3	2
		20 (5.0)	14	2	13	2	10	2	19	2	14	2	12	2
Geothermal Water Only		4.0 (1.0)	3	2	2	2	1	2	3	2	2	2	2	2
		20 (5.0)	14	2	9	2	6	2	15	2	9	2	7	2
T OR C														
Ratio 1:5 Geothermal to Saline Water	1.0	80 (20)	58	2	44	2	36	2	59	2	45	2	38	2
TULAROSA BASIN														
Ratio 1:5 Geothermal to Saline Water	4.0	20 (5.0)	13	2	9	2	7	2	14	2	10	2	9	2
		40 (10)	25	3	19	3	17	3	27	2	20	2	14	2
		80 (20)	50	5	37	5	28	5	54	3	40	3	33	3
	6.0 and greater	20 (5.0)	12	3	8	3	7	3	13	2	10	2	8	2
		40 (10)	24	4	16	4	17	4	27	3	20	3	16	3
		60 (20)	47	6	32	6	27	6	53	4	39	4	32	4
Geothermal Water Only		20 (5.0)	10	2	6	2	4	2	10	2	7	2	5	2
		40 (10)	19	2	12	2	9	2	20	2	13	2	10	2
		80 (20)	38	2	24	3	17	3	41	2	26	2	19	2

* - Numbers in parentheses are in the given English System units.
MLD - million liters/day, MGD - million gallons/day, gm/l - grams/liter

CHAPTER 7

PROCESS WATER PUMPING AND BRINE DISPOSAL UNIT COSTS

Introduction

For each of the potential desalination sites selected in New Mexico, various process water recovery systems and brine disposal systems were designed in Chapters 5 and 6. Using these designs, the unit costs of each process water and brine disposal system can be estimated. In the design of these various systems, the possible variation in design parameters were considered, and therefore the unit costs of any system at a particular desalination site can be given in ranges. With these ranges of unit costs, the feasibility of geothermal desalination in New Mexico can be more accurately determined. In this chapter the various ranges of expected unit costs for process water recovery and brine disposal will be calculated.

These unit costs will be based on a plant life of 30 years with an interest rate of 8% per year. The unit costs will include the capital, operating, and maintenance costs for each system and will be given as a function of the product water quantity. These costs are at the plant site and do not include any product water pipeline costs, since the use and destination of the product water is variable. These costs also do not include the costs of the geothermal desalination plant.

Process Water Pumping Unit Costs

In the design of the process water well fields, two types of systems were considered. One system consisted of both geothermal process water and saline process water wells in the ratio of one to five. The other system consisted only of geothrmal process water wells. The two systems were considered to estimate the unit costs of highly efficient and relatively inefficient geothermal desalination processes. The unit costs of these two systems then give an estimate of the maximum and minimum unit costs that can be expected for geothermal desalination.

The capital, operating, and maintenance costs for both geothermal and saline wells is listed in the Appendix, Table 1. Using these costs and the information listed in Chapters 5 and 6, the process water unit costs were calculated for each desalination site. These unit costs are shown in Figures 27 thru 30.

The T or C site was considered differently from the other sites because of the use of the product water. At this site geothermal water to saline water ratios of 1 to 5 and 1 to 1 were considered. Geothermal pumping alone was not considered since the purpose of the desalination plant was to improve the quality of the Rio Grande, and not augment the flow. Also, the process water unit costs for this plant site do not take into consideration pretreatment of the process water from the Rio Grande.

Brine Disposal Unit Costs

In the design of the brine disposal systems, three processes were evaluated: evaporation, injection, and combined evaporation and injection. These three processes were considered since the concentration factor of a geothermal desalination plant can alter the feasibility of a disposal process. With the unit costs of these three processes calculated over a range of concentration factors, the most feasible disposal method at a given concentration factor can be obtained.

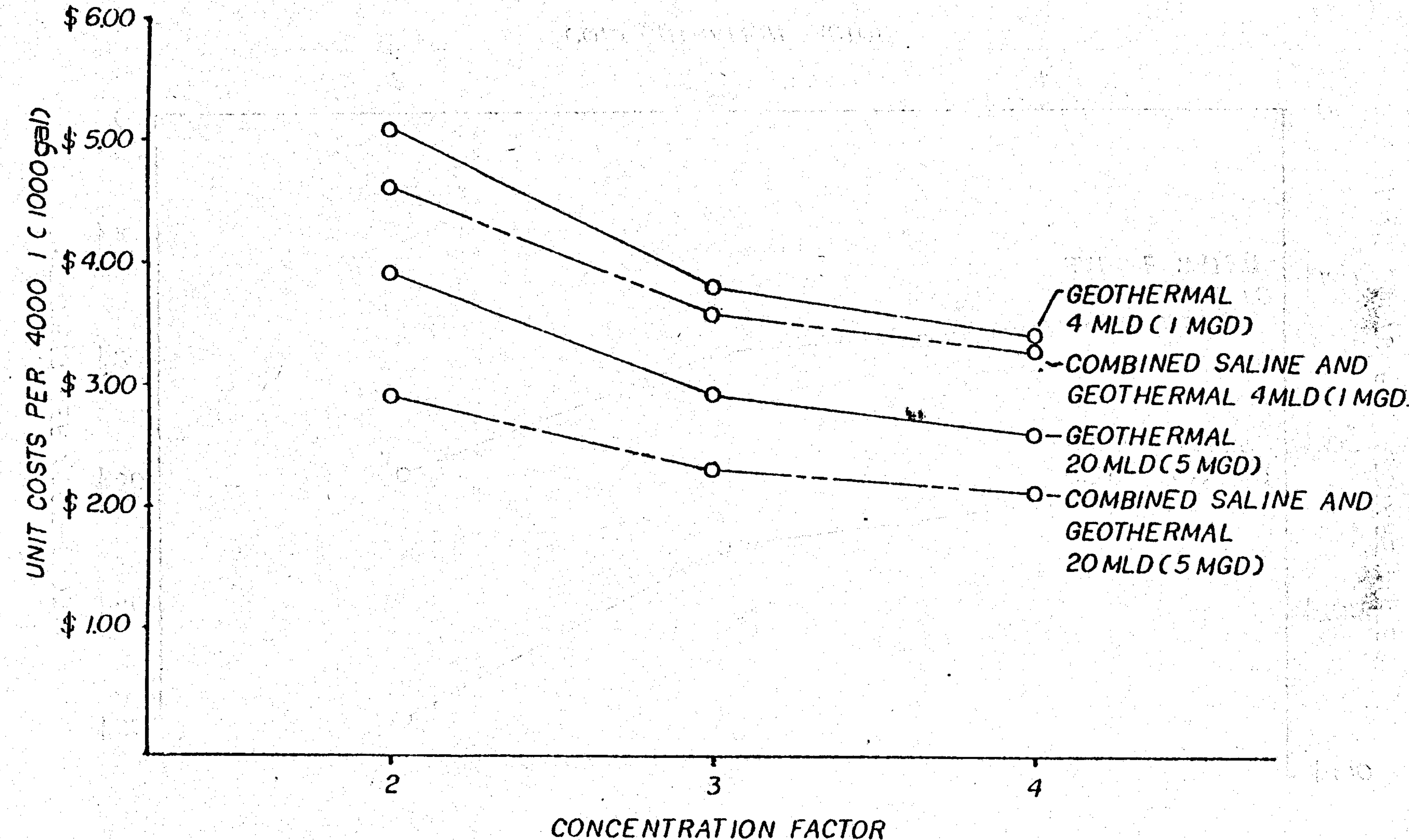


Figure 27 Estimated process water unit costs for a geothermal desalination plant at either Gallup or Grants, New Mexico.

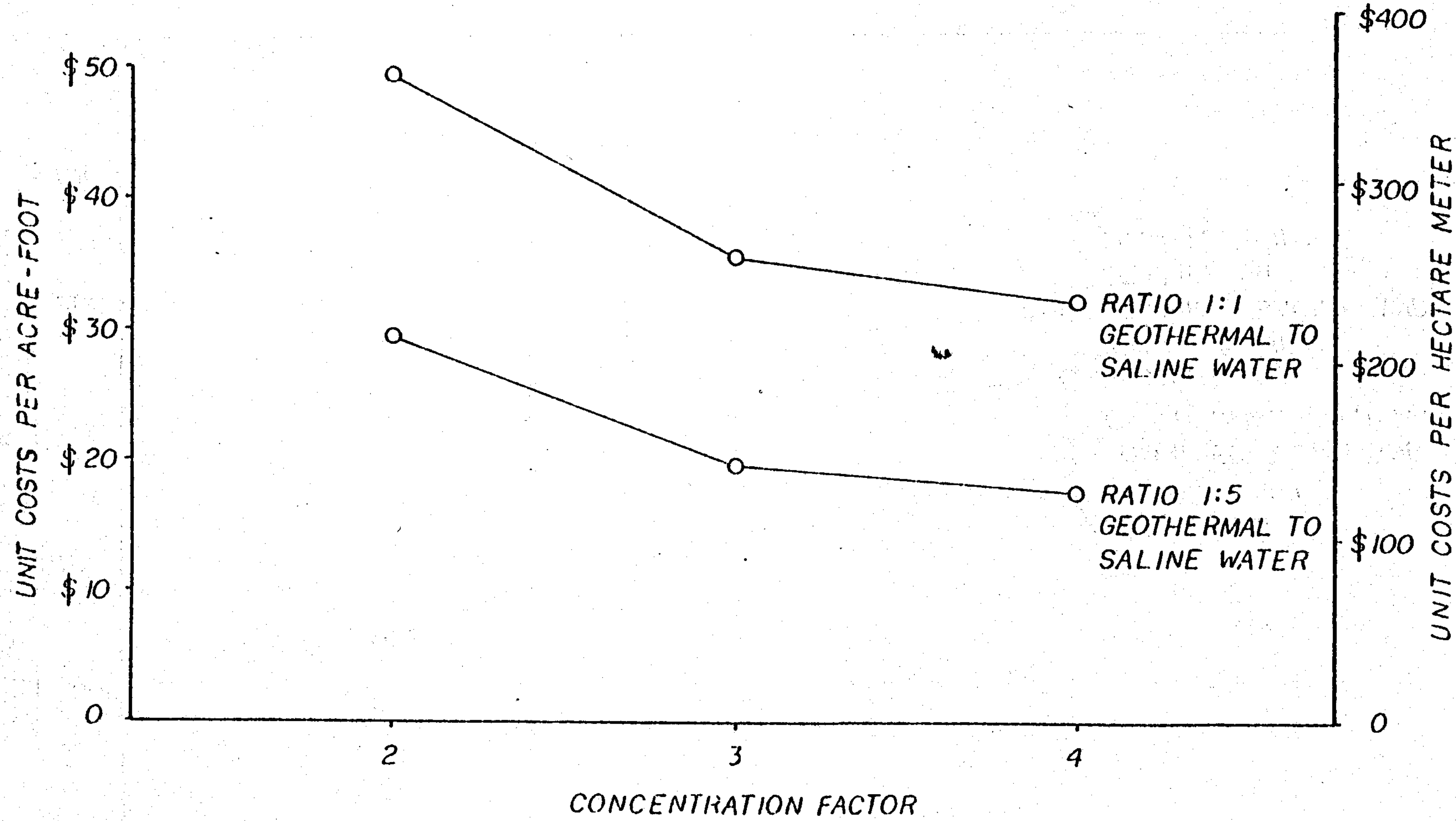


Figure 28 Estimated process water unit costs for a geothermal desalination plant at Truth or Consequences, New Mexico.

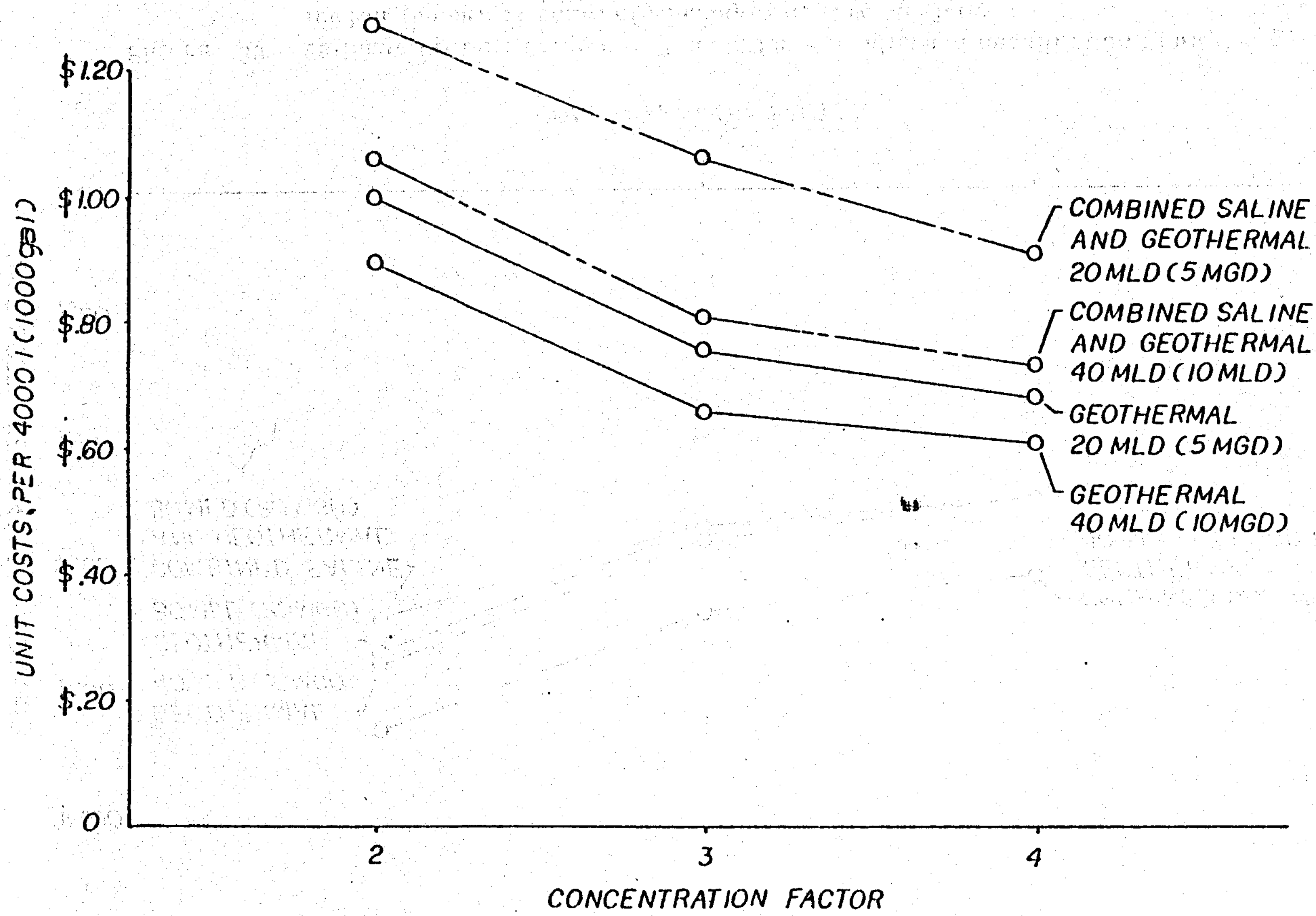


Figure 29 Estimated process water unit costs for a geothermal desalination plant 30 km (18 miles) south of Alamogordo.

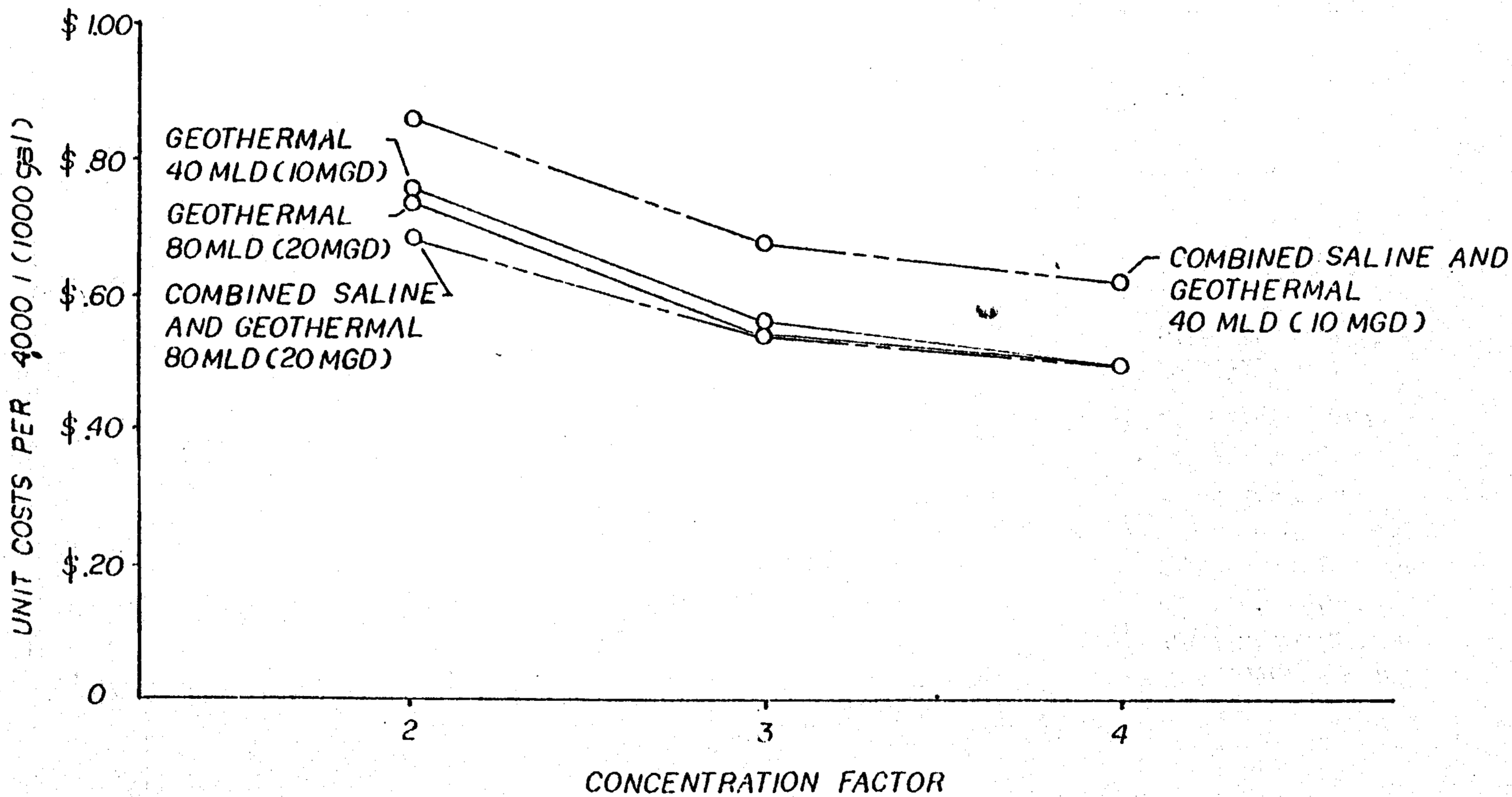


Figure 30 **Estimated process water unit costs for a geothermal desalination plant 100 km (60 miles) south of Alamogordo, New Mexico.**

The capital, operating, and maintenance costs for evaporation ponds and injection wells is listed in the Appendix, Table 2. Using these costs and the information listed in Chapter 6, the brine disposal unit costs for each desalination site are shown in Figures 31 thru 34.

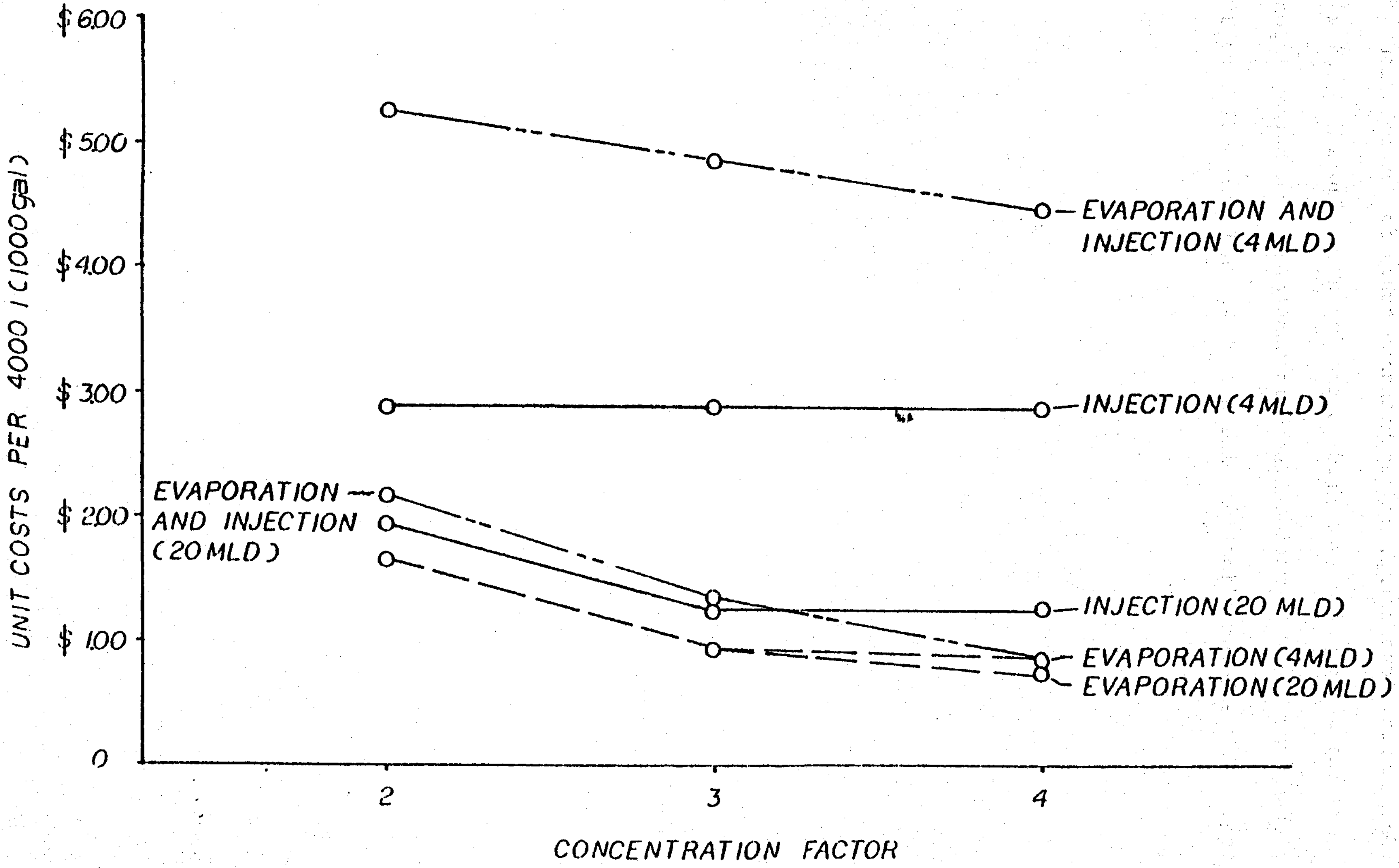


Figure 31 Estimated brine disposal unit costs for a geothermal desalination plant at either Gallup or Grants, New Mexico.

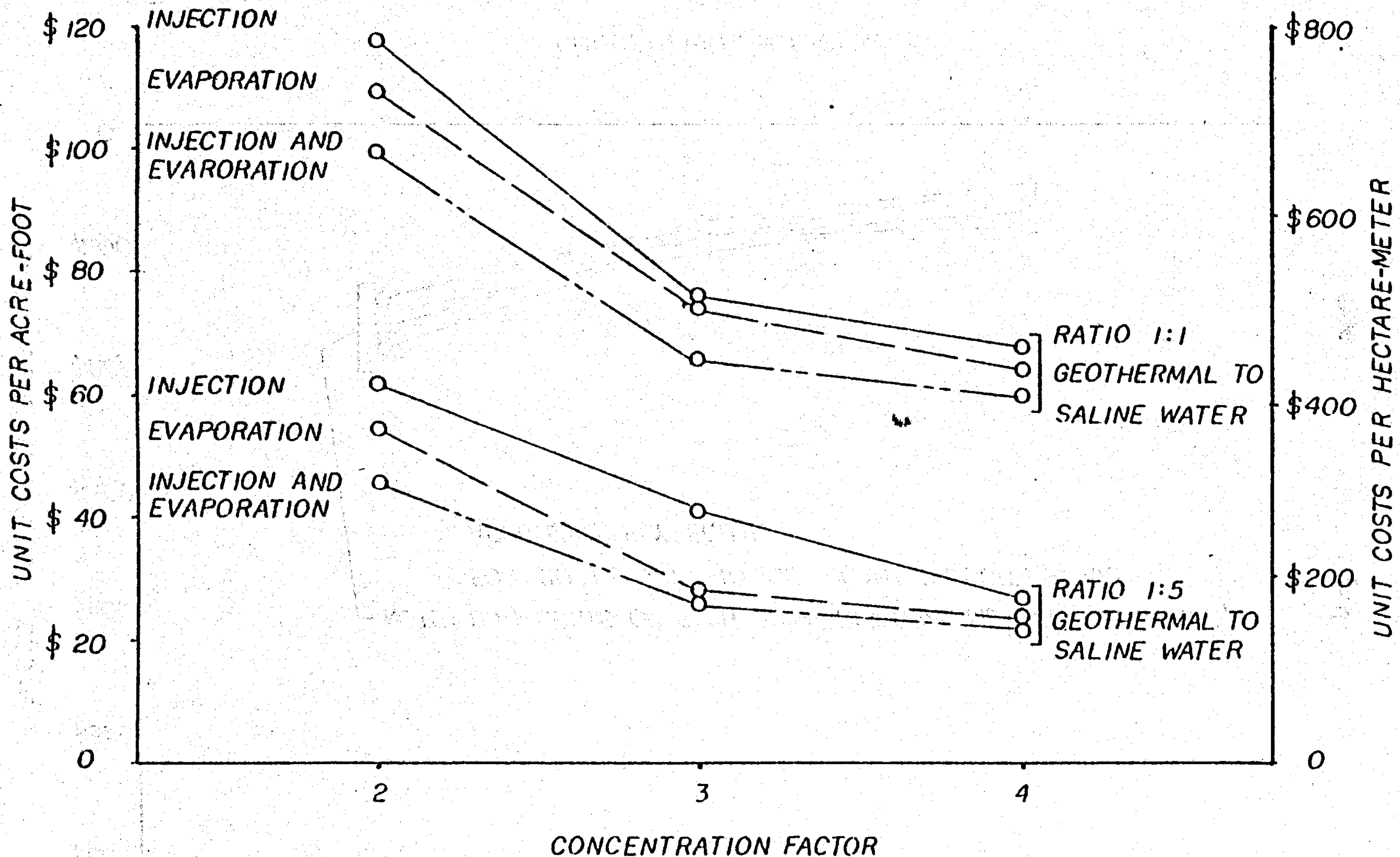


Figure 32 Estimated brine disposal unit costs for a geothermal desalination plant at Truth or Consequences, New Mexico.

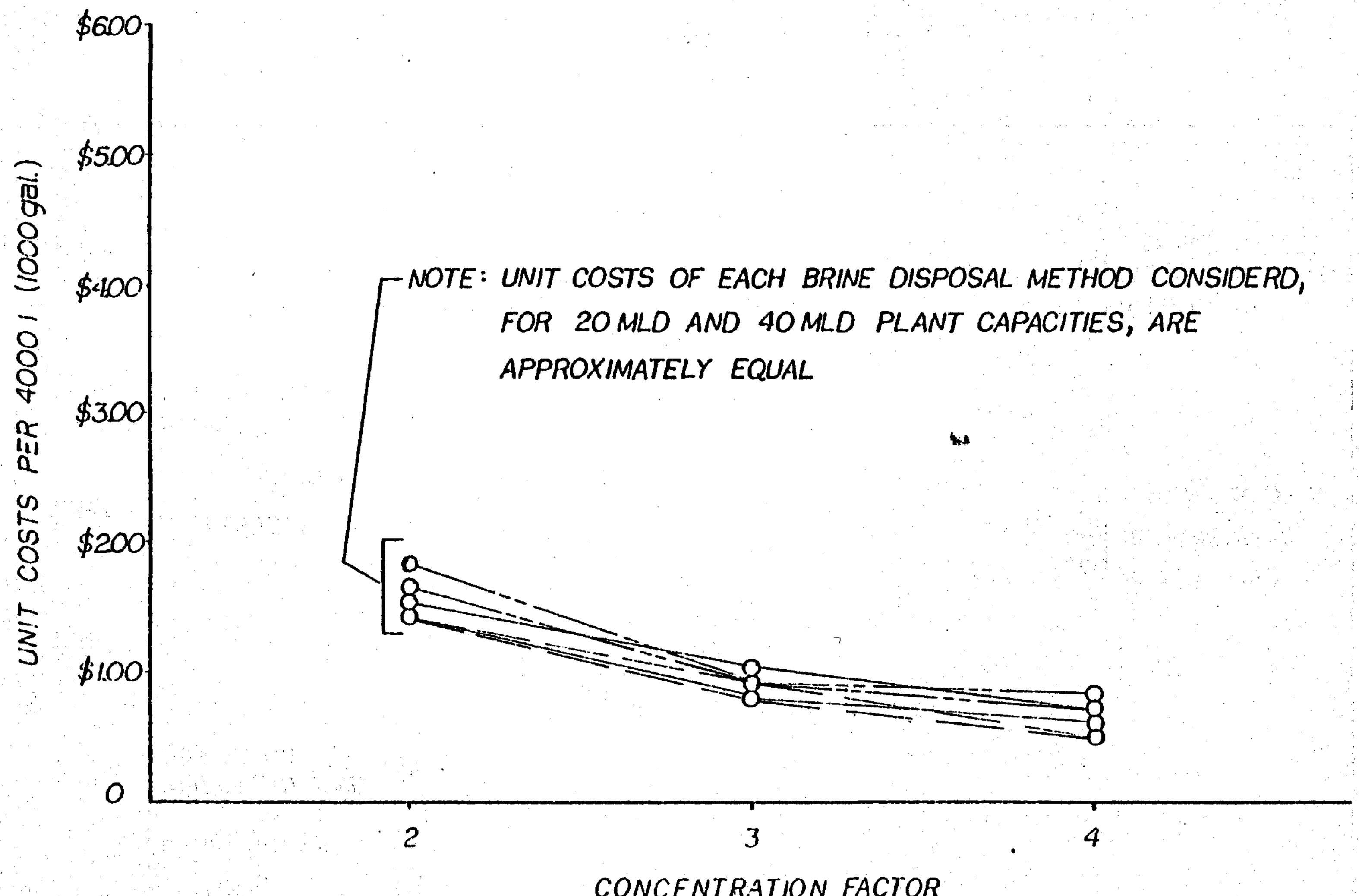


Figure 33 Estimated brine disposal unit costs for a geothermal desalination plant 30 km (18 miles) south of Alamogordo, New Mexico.

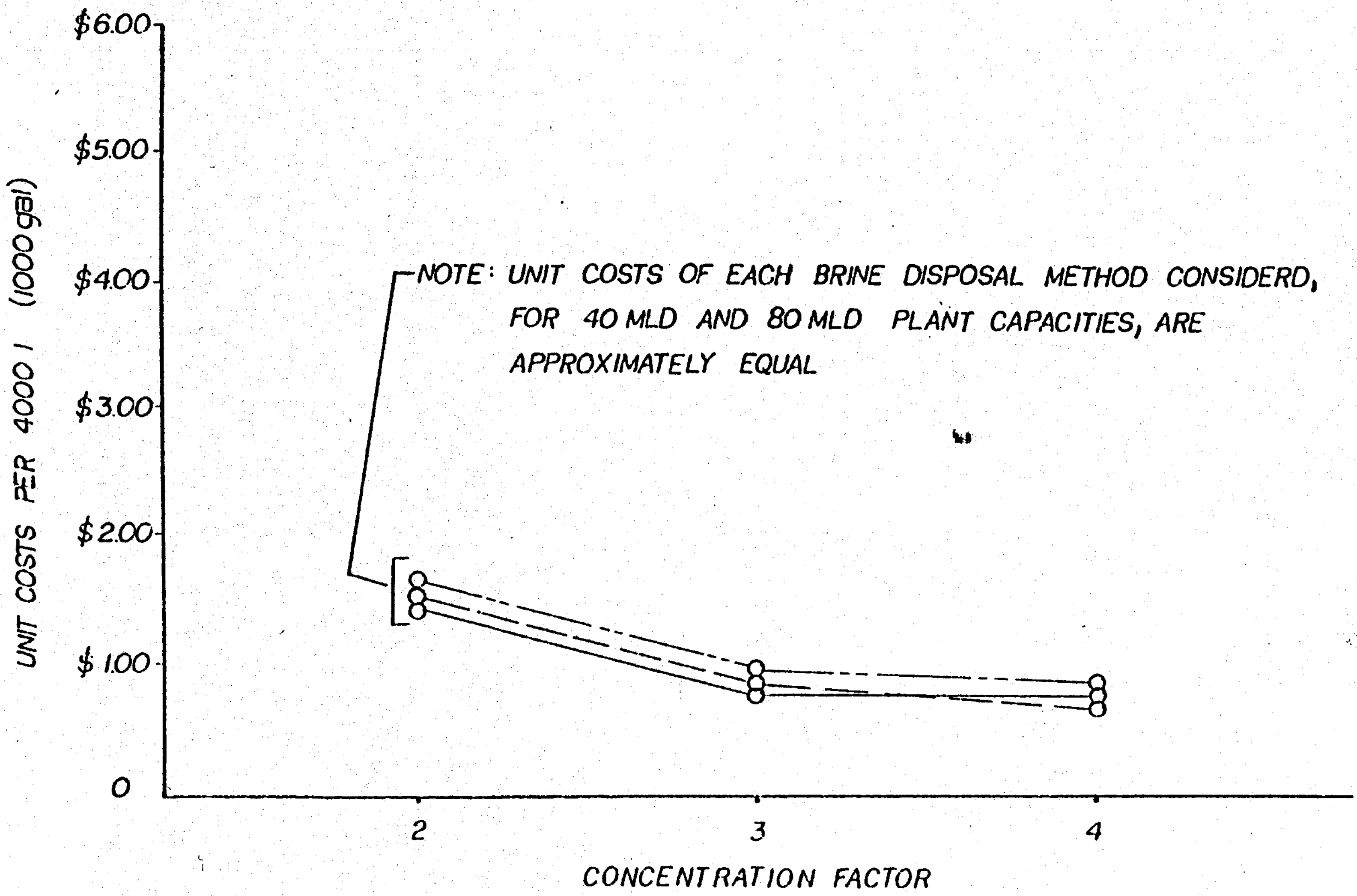


Figure 34 Estimated brine disposal unit costs for a geothermal desalination plant 100 km (60 miles) south of Alamogordo, New Mexico.

CHAPTER 8

ENVIRONMENTAL CONSIDERATIONS

Introduction

Most geothermal fields in production today were designed for use when environmental concern and regulatory laws were at lower levels. The environmental effects of developing this resource are varied and unique to each site. There is a need for general information concerning what problems one might expect at a particular site before production begins. In knowing this, the engineer can optimally design his alternatives into the plant at a lower cost. Factors that should be taken into account would be: state and federal regulations, land use in surrounding areas, geologic history of area with detailed geophysical and survey monitoring, type of reservoir, and possible economic markets for the byproducts resulting from the cleansing of the effluent.

Although each site is different, general difficulties will be expected in varying degrees regarding the chemical and physical aspects of pollution. Some of the chemical effluents to be dealt with would include: Carbon dioxide, hydrogen sulfide, ammonia, arsenic, boron, silica, and possible trace elements of mercury, thorium, radon, and uranium. These are dependent upon the geochemistry and previous utilization of the reservoir. "Physical" pollutants could include: thermal contamination, subsidence of land, increase of seismic activity, noise, and aesthetic impact.

Because large scale geothermal exploitation is in a relatively infant stage, much more testing and research is needed to deal more effectively with its harmful results. The following is a review of what is being done with present technology to minimize the above problems.

Chemical Effluents

The geochemistry of hydrothermal reservoirs is a function of the exploitation of the site. Reports indicate that total gas declines with continuing use of a reservoir (Axtmann, 1975). Although it is easy to gather data on the instantaneous emission rates of a plant in operation, it is often difficult to interpret these as a guide to the true environmental impact. What must be taken into account is the lengthy drilling time of new wells where bleed lines are needed, possible discharging from blow wells in the borefield, and the time during routine maintenance on turbines. At each of these times, the gas effluents normally treated at the power plant are discharged directly into the atmosphere. A more detailed analysis is needed to know what effect the geothermal site is producing in the local environment.

Of the nocondensable gas effluents, carbon dioxide is by far the main component (78-95%). This along with methane, nitrogen, and hydrogen are considered natural components of the atmosphere. If these concentrations are found to be small enough in the ambient air, and they usually are, they are not considered to be harmful. The gas of primary concern and the one most environmentally regulated is hydrogen sulfide. Hydrogen sulfide has an objectionable odor and is highly corrosive to plant equipment. The effect of extreme dosages on humans is known, but long term exposure to small amounts is not. Hydrogen sulfide will escape into the atmosphere through the gas ejector system in turbine use and by air-stripping of the waters in the cooling towers. Abatement programs generally consist of trying to reduce hydrogen sulfide to sulfur. At the Cerro Prieto plant in Mexico, because of its location, cooling towers are built downwind from the plant. Besides plating and insulation of the equipment, this is all that is done (Mercado, 1975). Of course on windless days, personnel are required to wear gas masks. This method would be unacceptable in the United States. An interesting possibility is a hybrid chemical-geothermal plant based on a modified claus process (Axtmann, 1975) for the economical production of sulfur. The technology for this is feasible, but its implementation would depend on local economic markets and predicted tonnage produced from the individual plant. There are two methods now employed at the Geysers to control the gas ejector emissions (Allen and McCluer, 1975). One method employs the burning of hydrogen sulfide to sulfur dioxide, which is then scrubbed into the cooling towers. The other consists of scrubbing the gas with a water solution containing a metal catalyst. The hydrogen sulfide is dissolved and oxidized to sulfur. Because of impurities the solids are buried at landfill sites. There is research now being done on the feasibility of removing the hydrogen sulfide upstream from the turbine (Allen and McCluer, 1975) Reinjection of the geothermal waters back into the reservoir is the most promising way, not only of removing noncondensible gases, but also other polluting elements like boron or arsenic. This has been successfully tried at various plants around the world. This method has many advantages and a few drawbacks that will be discussed later on.

There is a natural pollution of mercury and radioactive elements occurring in the atmosphere and waters around geothermal areas. These trace elements combined with the effluents of a production plant can be of significant concern (Axtmann, 1975). More analyses are needed in the parts-per-billion range instead of the conventional ppm. Again, reinjection is the most promising area for the control of these elements.

Silication is one of the most difficult engineering problems facing geothermal development. Silication is the scaling and deposition in pipes or trenches of silica. Silica concentration of hydrothermal waters is a function of the solubility of silica at certain temperatures. This fact is used as a tool in determining the underground temperatures of deep reservoirs. When the fluid is pumped out of the ground and processed, its temperature drops considerably. At this time the water is supersaturated in Silica and rapid deposition occurs. This has been a major impediment of economic reinjection.

With improved alloys and research into silica polymerization, this problem should be alleviated. Monomer silica will not precipitate or adhere to surfaces until it begins polymerization. This implies two means to avoid deposition. One can either reduce polymerization or encourage it at a point where cleaning can easily be done. Reduction can take place by keeping the temperature of the effluent waters above the saturation point or lowering the water to a 6.5 ph or below Cuellar, 1975). To increase polymerization the water should be held in storage tanks for a sufficient length of time. At the Ahuachapan plant in El Salvador waters have been economically kept at 150°C and reinjected without scaling (Einarsson, et. al., 1975). Each reservoir will have its own point of saturation. At the Wairakei and Broadlands fields of New Zealand the discharge waters are first held in storage tanks for polymerization and the slaked lime (CaO) is added (Rothboum and Anderson, 1975). What follows is the precipitation of a calcium silicate gel. In addition, arsenic is precipitated if it is first preoxidized. The gel is then dried and sold. The remaining water can now be flushed through drainage canals with little danger of deposition. Depending upon the kind of reservoir and its chemistry, an economically acceptable means should be able to be worked out.

Effects of Corrosive Brine

Corrosion rates on materials are a function of the aeration of the steam, flow velocity of condensate (Tolivia, et. al., 1975), and pH of condensate (Yasutake and Hirashima, 1975).

Materials testing at Cerro Prieto (Tolivia, et. al., 1975) was run in an aerated and nonaerated steam environment. Corrosion in non-aerated steam was generally low, 0.020 + 00.044 mm/yr, for all materials. Aluminum showed more of a problem with local attacks than with general corrosion. Nitrided steel showed rapid growth of pits and was found ineffective in controlling corrosion. The rate in aerated steam increased 2.9-15 times that found in nonaerated steam. The low alley steel, 3.5 Ni - 1 3/4 Cr - 0.5 Mo - 0.1 V, showed the greatest increase in corrosion rate. High chromium steels and aluminum, that had showed excellent resistance in a nonaerated environment, showed a significant increase in pitting. Trends in data indicate a higher chromium content in steels would be effective in improving corrosion resistance.

The condensate showed a higher corrosive environment than the separated steam (Tolivia, et. al., 1975). The only material that showed good resistance to corrosion was stainless steel. This was confirmed in other tests run at Otake (Yasutake and Hirashima, 1975) and the Geysers (Dodd, et. al., 1975). Scale deposition and corrosion of the cooling system was reduced significantly at Otake through the addition of caustic soda (NaOH) in neutralizing the H_2So_4 to a pH of ~6.8 (Yasutake and Hiroshima, 1975).

Although corrosion on turbine blades (12% Cr, low-carbon steel) is not excessive. It contributes greatly to fatigue failure (Tolivia, et. al., 1975; Dodd, et. al., 1975). Research and testing are going on at the Geysers to investigate heat treatment or coating of turbine blades to increase fatigue failure (Dodd, et. al., 1975).

Carbon steel is an effective material (corrosion rate 0.040 mm/yr) for shell and piping separated steam. The corrosion rate increases greatly (0.11 mm/yr) in aerated steam and 0.66 mm/yr in condensate. In these conditions the use of an epoxy resin coating or stainless steel would be required (Tolivia, et. al., 1975). Initial tests (at Geysers) lead to the selection of conventional turbine, stator, rotor, and blading materials, aluminum and austenitic stainless steels for the condensate system; and aluminum for line hardware (Dodd, et. al., 1975). Deoxidized copper and aluminum have been found unacceptable for the heat exchanger tubes, with titanium being the best choice (Tolivia, et. al., 1975).

Effects of Drilling

The main effect of drilling is noise and scarring of landscape. Before a producing well is drilled, at least three deep test wells are needed to confirm the geothermal potential. And before test wells are drilled, many shallow exploratory wells (150-300m) are drilled. Exploratory holes cause minimum landscape damage, only sometimes needing temporary narrow access roads. To drill test and producing wells, wide gravel roads are needed along with sump ponds and temporary holding tanks. Bleed lines are in operation to prevent condensation of steam in the well and damage to the producing zone. The average flow through a bleed line at the Geyesers is about 450 kg steam per hour (Reed and Campbell, 1975).

This results in noise and emission of hydrogen sulfide. Recontouring and the planting of new overgrowth helps in the control of erosion resulting from scarring of the landscape.

Noise is highest during drilling and testing of a well. It ranges from 90-130 decibels, which is past the threshold of pain. With the use of mufflers, noise can be held to an acceptable 60-90 dB. The effects on humans can be loss of hearing, troubled sleep, reduced job performance, and psychological disorientation (Jhaveri, 1975). Zoning restrictions and new designs in mufflers should minimize this problem in the future.

Thermal Effects

Thermal pollution is caused by the escaping of heat into the atmosphere and/or rivers. The injected heat into the surrounding ecosystems will upset the natural balance and produce weather modification. The same types of problems can be expected from a fossil or nuclear type plant. Thermal pollution form geothermal plants can be effectively removed. One method to eliminate thermal contamination of surface waters is to hold the effluent in tanks and then recirculate the water to cool the condensers, with the water then reinjected into the formation. This has the advantage of not using local water to maintain production in arid climates. Another possibility would be to use the hot waters for open space heating and industrial use. Again, total reinjection would virtually eliminate all forms of thermal pollution.

Land Subsidence

Land subsidence is the vertical and horizontal movement of land due to the compaction of rock formations below the surface. Natural tectonic activity, which is associated with geothermal sites, will produce land deformation. In dry steam reservoirs, such as the Geysers, there is no problem concerning subsidence because the vapor is not part of the structural stability of the formation. Problems occur when large volumes of water are withdrawn from wet steam reservoirs. There has been a maximum vertical subsidence of 4 meters at the Wairakei plant since production started over 20 years ago (Stilwell, et. al., 1975). Luckily, in this instance, the subsided area has lain outside the plant area. Special designs to allow for lateral movements of pipes and culverts has reduced the impact of this problem. Future plants in similar reservoirs might have to deal more effectively with land subsidence. Detailed geophysical and survey monitorings of a prospective area should be carried out before planning and during development. There is a need to know the effects caused by natural acitivty and those by geothermal exploitation. Knowing the natural causes will help in location and design of the plant. The only way to stop land subsidence in liquid reservoirs is to reinject the effluent. This brings us to another potentially major problem.

Seismicity

Geothermal reservoirs are generally found around tectonically active areas. Not only is natural seismic activity a danger, but the fact that geothermal development entails decreasing (or, with reinjection, increasing) bore pressure, is an added complication.

The withdrawal of fluids from a reservoir causes stress to build up. This might contribute to a large earthquake in the future. On the other hand, reinjection reduces friction which might trigger immediate rupture. This is a major uncertainty in reinjection. Reinjection has been in progress at Ahuachapan (Einarsson, et. al., 1975), Viterbo Region (Cameli and Carabelli, 1975), Otake (Kubora and Aosaki, 1975), and parts of the Geyser fields (Allen and McCluer, 1975) with no increase in seismic activity. All this is very promising, but any use of this method should proceed with utmost caution and planning.

Summary

Nothing has been said of the aesthetic impact which borefields and power plants will have on areas that are considered virginal. This question, whether to develop an area or to leave it in a natural state, will be decided by what people think they value more, energy and comfort or beauty.

One advantage in trying to deal with the environmental effects of geothermal exploitation is that all activities are in the immediate vicinity of borefields and the plant. Reinjection is a superior method in solving the problems of the chemical and physical aspects of pollution. In using reinjection, several things should be taken into account; the structural effect on the geothermal field, the effect on adjacent aquifers, and prevention of silica deposition. On the future horizon is the possible use of downhole heat exchangers. This will almost totally eliminate the detrimental effects of geothermal development. There is still an unquestionable need for more research and experimentation to further advance technology and awareness of the influencing effect of this energy source on the environment.

CHAPTER 9

LEGAL AND INSTITUTIONAL CONSIDERATIONS

Resource Access

Administrative agencies of the federal and New Mexico governments exercise an important degree of authority over access to rights to use saline waters and to develop geothermal energy resources.

Saline Waters

New Mexico's groundwater statute which originally was enacted in 1927 was one of the earliest state laws regulating access to underground waters. It was passed in response to economic needs of farmers in the Roswell basin where lack of control over wells was causing artesian pressures to drop. Control over pumping gave them the economic security they needed (Clark, 1977).

The present New Mexico groundwater code may be found at New Mexico Statutes Annotated sections 75-11-1 et seq. They are administered by the State Engineer whose discretionary authority is subject to judicial review only as to whether (1) his determination are not arbitrary, (2) his action is supported by substantial evidence, (3) it was within the scope of this authority, and (4) it was not based on an error of law. Kelley v. Carlsbad Irrigation Dist., 415 P. 2d 849, 76 N.M. 466, 472 (1966). The judiciary will not overturn decisions by the State Engineer merely because they disagree with his actions.

In a study of southwestern groundwater law (Chalmers, 1974), the author commented: "In summation, the New Mexico groundwater code and its patterns of implementation may be presented as follows:

1) groundwaters are statutorily declared to be public and subject to appropriation, 2) after the State Engineer identifies and declares basins to have reasonably ascertainable boundaries, his office must review and approve applications for new appropriations, 3) management plans for timed exploitation of non-rechargable basins have been court-approved as in the public's best interest, 4) the judiciary has approved requiring retirement of surface rights by new appropriators whose actions would eventually impair surface rights intimately related to the groundwater sources."

According to section 75-11-3, applicants for permits to use groundwater must supply the State Engineer with information on the source from which it will be taken, the use to which it will be put, the location of the well, the amount of water applied for, and other data. Notice by publication in a newspaper in the county in which the well is to be located is provided for. If there are no objections and unappropriated waters are available or the proposed pumping would not impair existing water rights, the application will be granted, subject to the rights of prior appropriators. If there are protests, it may be denied or granted with or without a hearing.

By statute, section 75-11-37, underground water basins do not include "water in an aquifer, the top of which aquifer is at a depth of twenty-five hundred feet or more below the ground surface at any location at which a well is drilled and which contains nonpotable water." Waters with a thousand parts per million of dissolved solids are considered "nonpotable." Waters which will be pumped for geothermal desalinization will probably not be excluded from regulation under this exception to the scope of the law because they will come from relatively shallow depths. The State Engineer will determine access to the saline waters.

Geothermal Energy

1. Federal legislation. Prior to passage of the Geothermal Steam Act of 1970, Public Law 91-581, Title 30 U.S.C. secs. 1001-25, there was no specifically established system for acquisition of rights to geothermal resources on federal lands. Commentators on the legal scene during the late 1960's (Brooks, 1966; Olpin, 1968) looked to various federal and state mining and water laws, regulations, and cases. They were dismayed by the uncertainties. Potential developers expressed their unhappiness about the legal situation by staying away from federal lands and by pushing for a federal geothermal steam law. Public Law 91-581 to a large extent both clarified the law and opened federal lands to geothermal exploitation (Futures Group, 1975). Areas of vagueness and uncertainties, however, remain (Aidlin, 1974; Allen, 1972; Fjorge, 1974; Schlauch, 1974).

The Geothermal Steam Act is administered by the Secretary of the Interior who under section 24 has broad power to make rules and regulations to carry out the act. Several of the key provisions of the law are:

1) Definition of geothermal resources. Section 2 broadly defines them as all products of geothermal activity, including steam, water, gases, brines, heat, and associated energy in geothermal formations; energy from artificially injected fluids and by-products were also included. The law, however, did not clarify the status of mineral reservations by the United States in deeds under various homestead acts in the past. In the future they will be reserved from inclusion within such deeds.

2) Lands available for leasing. The act covers federal lands, but excludes several categories such as national parks and

recreation areas, and fish and wildlife refuges, management areas, and ranges. Indian lands are not included. Consent is needed from the Department of Agriculture to lease forest service-administered lands. And the Secretary of Interior can withdraw other lands. See section 15.

3) Bidding for leases. Bidding is on a competitive basis within known geothermal resource areas which have been so designated by the Secretary. If lands are outside such an area, the first qualified person applying is entitled to the lease without competitive bidding. See section 4.

4) Royalty. Section 5 provides that royalties shall range between 10 and 15 percent of the value of the steam or any form of heat or energy produced which can be sold or used.

5) Term. Section 6 sets the term of leases at 10 years, with renewal for producing areas which will not exceed 40 additional years.

6) Area. According to section 7 a lease embraces a reasonably compact area not to exceed 2560 acres. The current maximum holding is 20,480. After 1985 the Secretary, after public hearing, may increase the maximum holding in any one state to an area not to exceed 51,200 acres.

7) Multiple uses of land. Other types of federal leases can coexist on the land according to section 17.

8) Unitization. Leaseholders in the same area may enter into cooperative drilling and operation agreements, and the Secretary may make such unitization compulsory. See section 18.

In addition to the 1970 act, Congress has passed the Geothermal Energy Research, Development, and Demonstration Act of 1974, Public Law 93-410, Title 30 U.S.C. secs. 1101 et. seq., which is intended to further the conduct of research, development, and demonstrations in geothermal energy technologies (Cox, 1976). Also Congress has specifically singled out geothermal resources for continuation of the 22 percent depletion allowance under section 613A of the Internal Revenue Code (Alexander, 1976).

2. New Mexico legislation. A study of setting up the geothermal development at The Geysers, California (Peters, 1974) listed nine different state and local agencies from which it was necessary to obtain permits and licenses. In New Mexico the process would not be so complicated, but operation of a geothermal project would be subject to regulation by the New Mexico Oil Conservation Commission. According to the Geothermal Resources Conservation Act, New Mexico Statutes Annotated section 65-11-1 et. seq., the commission has authority to bar waste, allocate production, and require pooling. Enforcement of the law and regulations made under it may be by getting a court injunction, seeking criminal sanctions, or suing for civil damages.

In 1967 New Mexico and California became the first two states to enact legislation authorizing the leasing of state-owned lands for the development of geothermal resources (Olpin, 1968). Article XXIV, section 1 of the state constitution was amended that year to add geothermal resources to mineral resources as available for leasing under a roylaty system. New Mexico Statutes Annotated section 7-15-5C provides for issuance of a lease to the first qualified applicant for unproved lands. There is competitive bidding in a known area. (Sec. 6) Annual rental is $1 an acre, and royalty is 10 percent on steam and brines and not less than 2 percent or more than 10 percent on minerals or chemicals recovered from geothermal fluids. In addition there is an 8 percent royalty for revenue received from the operation of an energy producing plant. (Sec. 7A) The term is 5 years, with right to renew for succeeding similar terms so long as the resource can be used in commercial quantitites. (Sec. 11)

Operational Regulation

A technology assessment of geothermal energy development (Futures Group, 1975) lists a wide variety of environmental considerations in utilization of this energy source. Among them are land use, gaseous emissions, liquid and solid waste disposal, surface and groundwater contamination, heat rejection, land surface subsidence, noise, induced earthquakes, safety, fog plume, and aesthetics. Several of these environmental impacts are shared by desalinization. These consequences sometimes have legal ramifications. Two areas will be focused on: resource withdrawal, and waste disposal.

Resource Withdrawal

Withdrawal of gases on fluids from undergound may be a factor in land subsidence. An authoritative compilation of legal liability principles, The Restatement of Torts, in section 818 states: "One who is privileged to withdraw subterranean water, oil, minerals or other substances from under the land of another is not for that reason privileged to cause a subsidence of the other's land by such withdrawal." A property owner suffering from subsidence can recover damages from someone who has withdrawn saline water or geothermal steam or water if a causal relationship can be established between the withdrawal and the subsidence. Also in appropriate cases such a plaintiff might obtain a court order enjoining further withdrawals which would bring about more subsidence (Davis, 1976; Prosser, 1971).

Waste Disposal

Disposal may be accomplished by injection underground of the brines and minerals which for the most part will be unwanted by-products of desalinization and use of geothermal steam and water. Lined ponds or ponds with highly impacted clay bottoms may be used for holding wastes. Two kinds of problems illustrate the legal ramifications of these disposal methods: pollution and seismic disturbances. Escape of mineralized water can pollute ground and surface waters, and injection of wastes has been alleged to be related to seismic activity (Futures Group, 1975).

1. Common. Law. In Groff v. Circle K. Corporation, 525 P.2d 891, 86 N.M. 531 (1974), the defendant changed the grade of the land and paved a parking lot. This produced an "artificial channel" where water was being collected and discharged onto the plaintiff's property. He was permitted to recover for the resultant harm to his house. Courts will give relief to property owners whose interests have been harmed by man-made flooding and pollution.

In order to recover in common law actions, it is necessary to establish that the conduct of the defendant came within one of the recognized liability theories, that the plaintiff was harmed, and that there was a causal relationship between the act and the injury. One liability theory applicable to geothermal desalinization is negligence. Negligence is carelessness, the failure to live up to the standard of care of operators of wells and desalinization facilities (Kionka, 1977). Another possibility is nuisance (Fink, 1974). This concept permits a plaintiff whose property has suffered from a substantial invasion of this right of its use to recover from a defendant who has intentionally carried out an act if on the balance the gravity of the harm to the plaintiff outweighs the value of the activity to the defendant. Balancing the interests is the key to decision in nuisance cases.

These private remedies may well fit the fact in groundwater pollution, salt intrusion into adjoining land or water (Darling, 1975), or earth movements. The liability theories may apply. But an injured plaintiff still has the formidable burden of establishing the causal relationship betweeen the harm and the conduct of the defendent. The New Mexico Supreme Court has ruled that mere co-existence of a loss and of conduct by a defendant does not prove that the defendant caused the loss. However, in Rix v. Town of Alamogordo, 77 P.2d 765, 42 N.M. 325 (1938), it was also made clear that the defendant will be liable for negligence which commingles with and operates as a contributive element proximate to the injury. In that case heavy rains, an act of God, coupled with an inadequate city storm drainage system brought about heavy flooding. The city was liable. Heavy rains were not so unusual as to "break the causal chain" and insulate the defendant from liability. Thus geothermal desalinization operations which can be related to pollution losses will not escape responsibility when some foreseeable event intervenes between them and the loss complained of.

2. Federal Legislation. The Safe Drinking Water Act, Public Law 93-523, Title 42 U.S.C. secs. 300f et. seq., sets up a federal-state system for regulation of underground injection of wastes. The Administrator of the Environmental Protection Agency determines whether a state must develop a control program. The Administrator either approves the state's program or develops one of his own. Any such program must

by the end of 1977 either require permits for all underground injection or set up rules governing such injection (Eckert, 1976). Deep well injection of wastes from geothermal desalinization would doubtless come within the scope of such a system.

The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500, Title 33 U.S.C. secs. 1251 et. seq., provides for a system of permits for discharges of pollutants into waters. The Administrator of the Environmental Protection Agency issues such permits, but may approve substitution of a state permit system which meets minimum requirements. Included are "permits which . . . control the disposal of pollutants into well." The law is ambiguous as to whether such discharge might be subject to the Administrator's, as well as the State's, authority (Eckert, 1976).

3. New Mexico Legislation. Pollution associated with geothermal desalinization might be regulated by the State Engineer in decisions about issuance of permits to appropriate saline waters and by the New Mexico Water Quality Control Commission. As has been noted, impairment of existing rights is a basis for refusal of an appropriation permit. Cases about impairment have talked of the impact of issuance of a permit for fresh water appropriation upon neighboring wells. See City of Roswell V. Reynolds, 522 P.2d 796, 86 N.M. 249 (1974); City of Roswell v. Reynolds, 522 P.2d 796, 86 N.M. 249 (1974); City of Roswell v. Berry, 452 P.2d 179, 80 N.M. (1969). Similar concern might be seen when permits are sought for appropriation of saline waters..

The New Mexico Water Quality Act, New Mexico Statutes Annotated, secs. 75-39-1 et. seq., authorizes the commission to set water quality standards (Pease, 1969). The intent is to bring about abatement of surface and groundwater pollution. Escape of wastes from geothermal desalinization could well come within the ban on discharges.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From Figures 27 to 30, the unit costs of various process water and brine disposal systems for potential geothermal desalination sites in New Mexico can be obtained. The combined unit costs of these systems range from $1.00/4000 liters ($1.00/1000 gal.) to $5.00/4000 liters ($5.00/1000 gal), neglecting the cost of the geothermal desalination plant. These costs are considerably above the present fresh water production costs of communities in New Mexico, and therefore this type of desalination is presently uneconomical. For cities such as Gallup and Alamorgordo that are rapidly depleting their fresh water resources, this type of desalination may perhaps be more economical in the future than bringing in fresh water from great distances.

Recommendations

If the population in New Mexico continues to grow at its present rate, shortages of fresh water should be expected. Changes in water use might be able to eliminate shortages in some areas of the State, but this is not applicable throughout the State. Since desalination is continually considered as a solution to the possible shortage of fresh water, more accurate information on this resource must be obtained. At present, only two large scale studies have been done on saline water in New Mexico, and these only give generalizations of the saline aquifer characteristics. A more comprehensive study of the saline resources in the State should be undertaken, such that the hydraulic characteristics and the actual extent of the saline aquifers are determined for each area in the State.

This study showed that geothermal desalination is a feasible concept, but for the specific conditions in New Mexico, it is presently uneconomical. This does not indicate that other geothermal applications are necessarily also uneconomical. For this study, the information on geothermal temperatures and aquifer characteristics was extremely limited. Therefore, a more comprehensive study of the geothermal resources in the State, including the hydraulic characteristics and aquifer extent, should be conducted.

APPENDICES

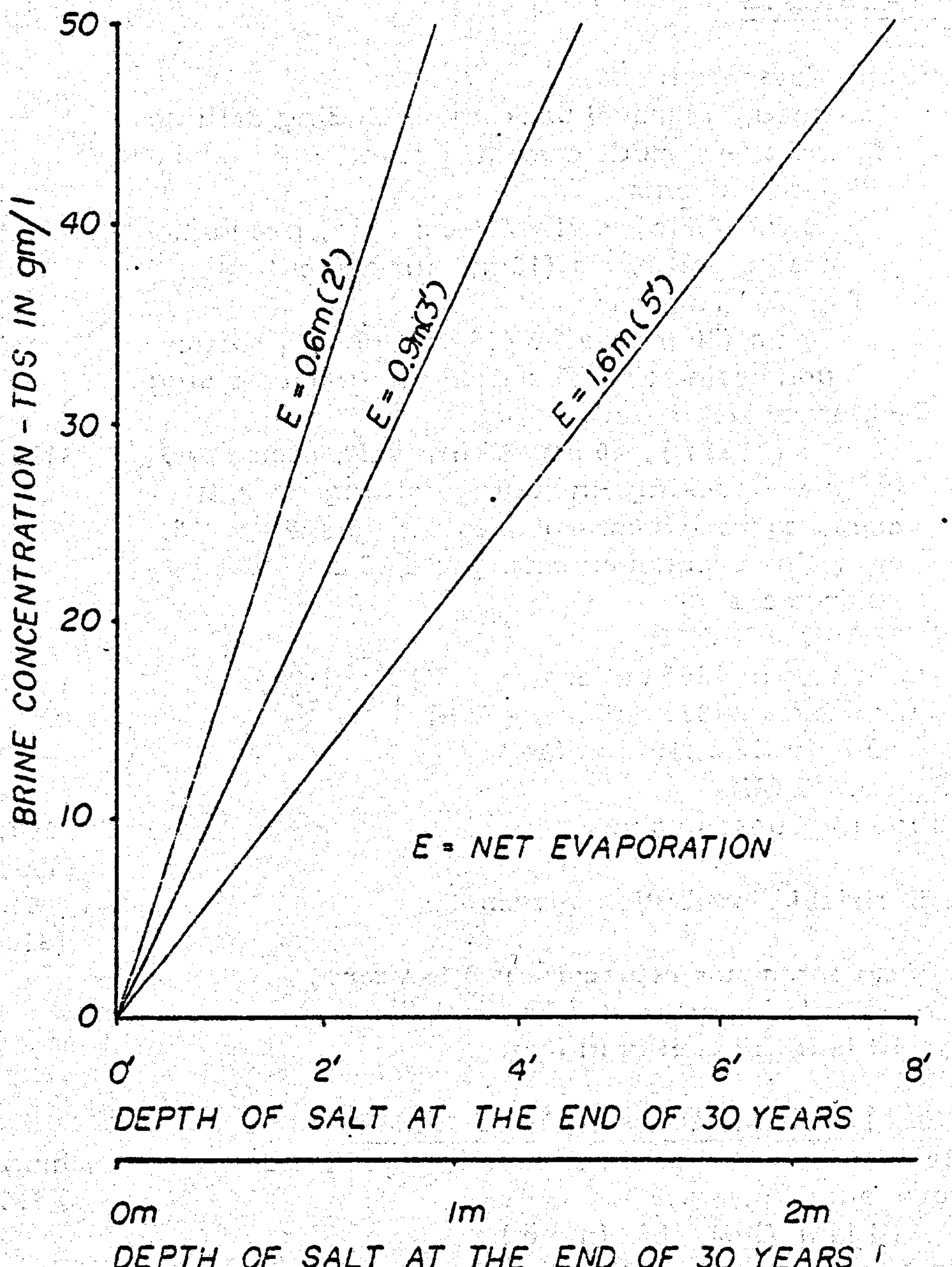


Figure 1 Salt accumulation in brine disposal evaporation ponds for varying brine concentrations at the end of 30 years. (Source: Day, 1970)

TABLE 1. Capital, operating, and maintenance costs for geothermal and saline process water wells.

CAPITAL COSTS	UNIT COST
[a]WELLS	
Saline Water Wells	
Cemented, w/gravel packing, including drilling rig and crew, mud, cement, gravel	
Gallup - Grants	$70/m
40 cm (16 in) well w/18 cm (7 in) production casing and 25 cm (10 in) surface casing	($21/ft)
T or C - Tularosa	$86/m
50 cm (20 in) well w/25 cm (10 in) production casing and 40 cm (16 in) surface casing	($26/ft)
Geothermal Water Wells	
1000 m (3300 ft), 40 cm (16 in) well, cemented, w/gravel packing, including drilling rig and crew, corrosion control, cement, gravel, w/18 cm (7 in) production casing and 25 cm (10 in) surface casing	$130,000/well
[b]PUMPS AND MOTORS	
Pump cost in 1966 dollars = $7.3Q^{.453}H^{.642}$	
Pump cost in 1977 dollars = $19Q^{.453}H^{.642}$	
(Q is in GPM, H is in feet)	
[b]MISCELLANEOUS	
Pipeline construction	$80,000/km ($130,000/mile)
Electrical distribution system	$1800/km ($3000/mile)
Pump and motor replacement @ 15 years w/6% inflation/year = $45Q^{.453}H^{.642}$ (Q is in GPM, H is in feet)	
[b]OPERATING AND MAINTENANCE COSTS	
Electrical costs w/pump efficiency = 60% and motor efficiency = 90% (Q is in GPM, H is in feet)	kw hr/yr/well=3QH @ $.03/kw hr
Maintenance = 4% Capital Costs	

[a]Based on personal communications with Clyde Wilson, USGS, New Mexico Water Resources Research Institute, Las Cruces, New Mexico, July 1977.
[b]Reference: Lansford, 1976.

TABLE 2. Capital, operating, and maintenance costs for brine disposal evaporation ponds and injection wells.

CAPITAL COSTS	UNIT COST
EVAPORATION PONDS - 20 hectare (50 acre) ponds	
[a]Land - $125/hectare ($50/acre)	$2500/pond
[a]Dike - Earth work, moving and compaction	$360/m^3 ($.10/ft^3)
[b]Lining - 30 mil thick	$3.25/m^2 ($.30/ft^2)
[c]DISPOSAL WELLS	
40 cm (16 in) wells, cemented, w/gravel packing, including drilling rig and crew, mud, cement, gravel, w/18 cm (7 in) PVC coated production tubing and 25 cm (10 in) surface casing	$100/m ($30/ft)
[a]PUMPS AND MOTORS	
Same as saline process water wells (Q is in GPM, H is in feet)	$19Q^{.453}H^{.642}$/well
[a]MISCELLANEOUS	
Pipeline construction (same as saline process water wells)	$80,000/km ($130,000/mile)
Electrical distribution system (same as saline process water wells)	$1800/km ($3000/mile)
Pump and motor replacement @ 15 years w/6% inflation/yr (same as saline process water wells) (Q is in GPM, H is in feet)	$45Q^{.453}H^{.642}$/well
[a]OPERATING AND MAINTENANCE COSTS	
Electrical costs (same as saline process water wells)	kw hr/yr/well=3QH @ $.03/kw hr
Maintenance = 10% of Capital Costs	

[a]Reference: Lansford, 1976.
[b]Reference: Le Gros, 1969.
[c]Based on personal communications with Clyde Wilson, USGS, New Mexico Water Resources Research Institute, Las Cruces, New Mexico, July 1977.

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