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PROPOSED WATER-RESOURCES STUDY OF SEARLES VALLEY, CALIFORNIA

By

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INTRODUCTION

This is a planning report, designed to outline the scope and time required to complete a study of the hydrology of the Searles Valley area, San Bernardino, and Inyo Counties, Calif. A preliminary conceptual model of the geohydrology is presented as an aid in better understanding the objectives of the proposed work.

Searles Valley is a structural basin in the Mojave Desert region, about 130 miles northeast of Los Angeles (fig. 1). The valley is about 25 miles long and 10 miles wide, and the lowest part is occupied by Searles Lake. The lake has a surface area of about 40 square miles at the elevation of 1,616 to 1,621 feet above mean sea level. Most of the lake surface is moist during most of the year, but standing water is usually absent except following infrequent periods of precipitation on the lake or surface runoff from the surrounding mountains. Some water usually stands in ponds in local depressions, however.

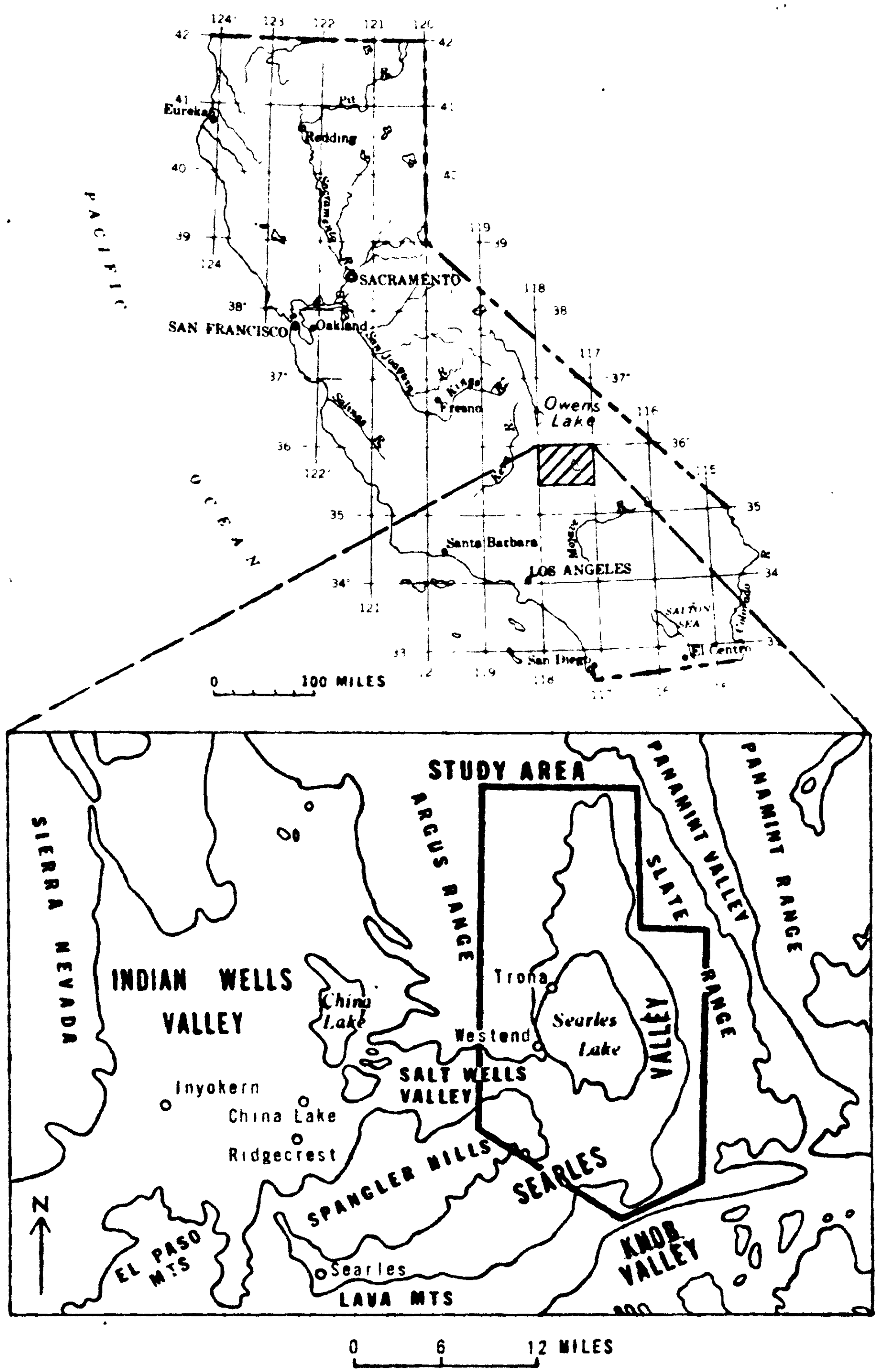
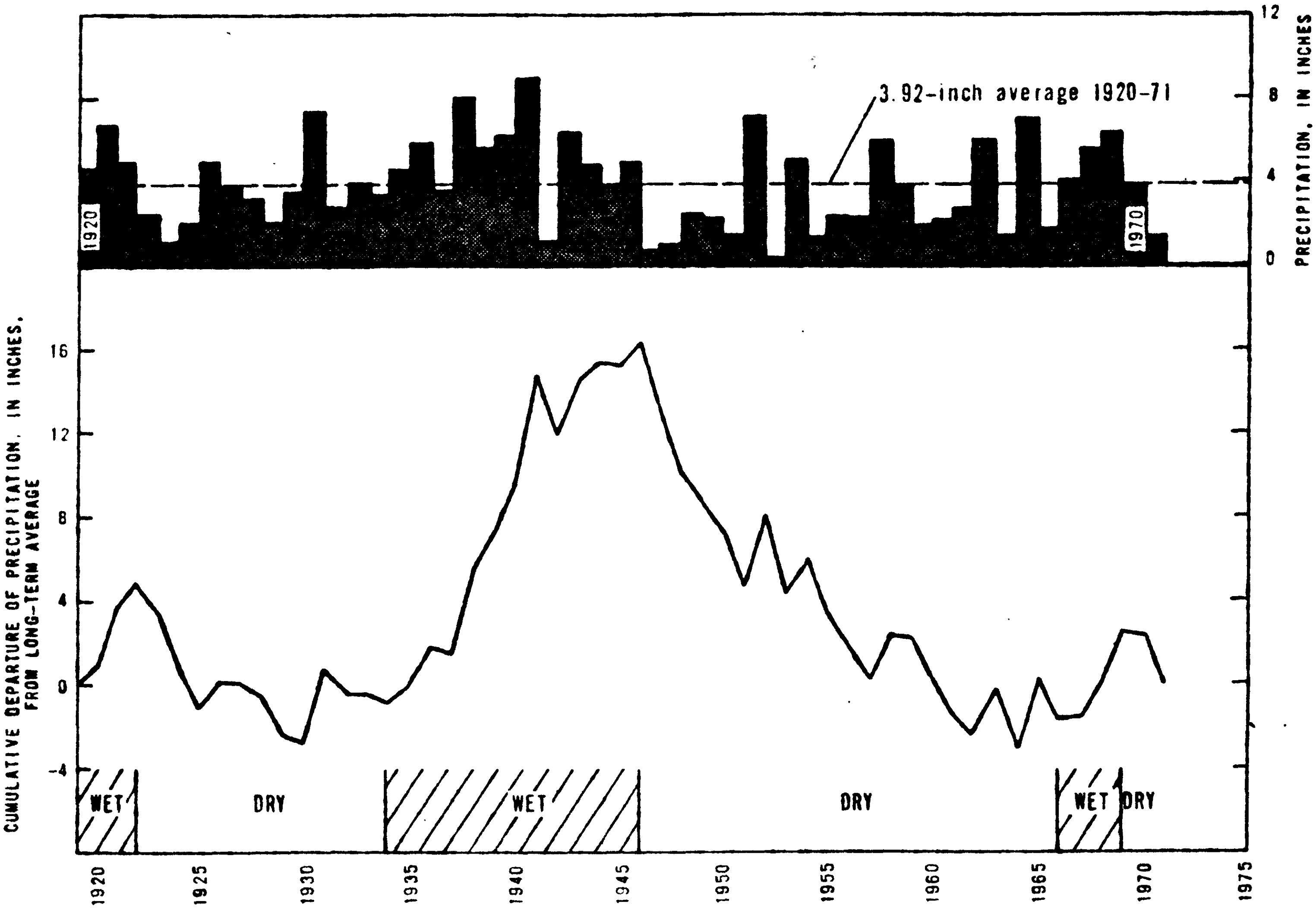


FIGURE 1.--Index map.

The climate in Searles Valley is hot and arid. Precipitation occurs mostly in the winter and at Trona averaged 3.92 inches per year from 1920 to 1971, with extremes of 9.01 inches in 1941 and 0.42 inch in 1953 (U.S. Weather Bureau). On the higher mountain slopes, about 3,000-4,000 feet above the lake, the maximum average precipitation is estimated at 10 inches per year (written commun., S. E. Rantz, 1972).

The precipitation data from 1920 to 1971 at Trona, together with the cumulative departure from the long-term average (fig. 2), shows the wet and dry climatic periods on the lake. An extended dry period, 1923-34, was followed by an equally long wet period, 1935-46. Since 1947, Trona has been in a dry period except for 1967-69.

Since the early 1900's Searles Lake has been an important source of concentrated brines from which chemicals are extracted in large quantities. Prior to 1971 the cumulative value of brine production was about $1 billion (oral commun., D. F. Ziehl, 1972). The brine is withdrawn by pumping wells.



Data from National Weather Service
(U.S. Weather Bureau)

FIGURE 2.--Precipitation data at Trona, 1920-71.

Generalized Geologic and Hydrologic Setting

Searles Valley is a north-trending closed basin underlain by unconsolidated sediments of Quaternary age. Geophysical evidence indicates the fill is about 3,300 feet thick in the center of the basin (Mabey, 1956, p. 849). Surrounding the basin and beneath the unconsolidated deposits are the consolidated basement rocks of the Slate and Argus Ranges, Spangler Hills, and other hills (fig. 1).

In Pleistocene time Searles Lake was usually the third in a chain of lakes. Owens Lake (fig. 1), the first in this chain, received most of its water from the Owens River, which drained part of the east side of the Sierra Nevada. When Owens Lake filled, it overflowed into Indian Wells Valley to form China Lake, which in turn overflowed into Searles Valley to form Searles Lake. At its highest level, Searles Lake was 640 feet above the present valley floor and coalesced with China Lake to form one body of water. This large lake overflowed around the south end of the Slate Range into Panamint Valley and possibly into Death Valley.

Although Searles Lake overflowed during several intervals, much of the time it was the terminus of the chain and salines concentrated in the lake. When the upstream supply of water to the lake was reduced by increased aridity, the evaporation exceeded the inflow and salines were further concentrated. Eventually the lake water evaporated, leaving behind the salts.

A geologic map of the Searles Valley area was prepared as part of an earlier study by the U.S. Geological Survey (Moyle, 1969). The water-bearing deposits consist mainly of moderately well-sorted sand, gravel, silt, and clay. The alluvium is porous and permeable, extends below the water table, yields water freely to wells, and is the principal unit bearing fresh or brackish water.

Natural recharge to Searles Lake is presumably from three sources: (1) percolation of the infrequent runoff which occurs as flash floods from the surrounding mountains; (2) subsurface flow in unconsolidated sediments; and (3) infrequently, direct infiltration of rain. Under undeveloped conditions, all water movement within the Searles Valley alluvial deposits was toward Searles Lake. Presumably no water can escape from the basin except by evaporation.

Only small quantities of potable water have been found in Searles Valley. In the northern part of the basin on the east side of the Argus Range, springs supply local domestic needs and originally supplied about 100 acre-feet of water per year for use in the Trona area (U.S. Bureau of Reclamation, 1967). On the south side of the basin, the water is generally too brackish for domestic use, but can be used for cooling and other industrial purposes.

Analyses of ground water from the basin indicate that dissolved solids range from about 5,000 mg/l (milligrams per liter) on the edge of the lake to more than 350,000 mg/l in the center (Moyle, 1969). North of Searles Lake, near Valley Wells, fresh to brackish ground water has been obtained for many years; however, the water from some of the wells has become more saline during recent years.

Most of the domestic water and some of the water used in the chemical plants in Searles Valley is piped from wells in Indian Wells Valley. These wells and the 8- and 12-inch pipelines are owned, operated, and maintained by the Kerr-McGee Chemical Corp. and Stauffer Chemical Co., respectively. These companies utilize part of the water at chemical plants and sell the remainder to the Searles Domestic Water Co. for domestic use.

Previous Work and Reports

Searles Lake was explored in 1862 when J. W. Searles discovered extensive deposits of borax when crossing the playa.

Searles Lake was mentioned very briefly in two early publications: one by De Groot (1890) described the physiography; the other by Anderson (1892 described some mineral springs. The need for potash during World War I resulted in publication of the classic paper by Gale (1914) describing the hydrology, geology, and mineralogy of Searles Valley. Other early studies include a paper on brine evaporation (Hicks, 1917), ground-water inventory (Thompson, 1929), geochemical classification and origin of brines (Clarke, 1924), geology and equilibrium of brines (Teeple, 1929), and geology (Blackwelder, 1931, 1941).

During the last 20 years, information has been accumulated and published on the mineralogy and stratigraphy of Searles Lake Valley by Smith (1958, 1960, 1962, 1965, 1966, 1967, 1968); Smith and Pratt (1957); Haines (1959); and Smith and Haines (1964). Blanc and Cleveland (1961) described a regional overview of lake geology in southeastern California. Scholl (1960) studied the pinnacles south of Searles Lake; Flint and Gale (1958) studied lake stratigraphy including radiocarbon dating; Smith, Troxel, Gray, and Von Huene (1968) studied the geology of the Slate Range, which included a gravity map of a part of Searles Lake; Stuiver (1964) studied carbon isotopic distribution and chronology of Searles Lake sediments; and Mabey (1956) made a geophysical study of a part of the basin.

Mineralogical studies include reports by Pabst and Sawyer (1948); Pabst, Sawyer, and Switzer (1955); Hay and Moiola (1963); Hemley and Jones (1964); and Eugster and Smith (1965).

Published hydrologic studies of Searles Valley are few. Moyle (1969) made a well and spring inventory of the basin, and the U.S. Bureau of Reclamation (1967) briefly described water conditions in a general planning report. White, Hem, and Waring (1963) briefly described the brines, and Ver Planck (1958) described salt recovery from the lake.

Accordingly, hydrologic reports from several other saline-water areas were examined. Of particular interest were reports on effects of salinity on rate of water evaporation (Harbeck, 1955); evaporation at Salton Sea (Blaney, 1955), and Silver Lake (Blaney, 1957); salt-crust accumulation as an index of leakage from artesian aquifers (Feth and Brown, 1962); salinity and hydrology of closed lakes (Langbein, 1961); hydrology of Deep Springs Lake (Jones, 1965); hydrology of Death Valley (Hunt, Robinson, Bowles, and Washburn, 1966); and hydrogeology of the Bonneville Salt Flats, Utah (Turk, 1969).

Management Objectives and Purpose and Scope

The primary purpose of this study was to design an investigation needed to define the water resources of Searles Valley to the extent necessary for achieving established water-basin management objectives. The occurrence, movement, recharge to, and discharge from both the brine and brackish water aquifers are important to an understanding of the hydrology. Pumping of wells owned by a third chemical company just beginning operations on the lake has recently caused changes in the hydrologic system. Neither complete hydrologic analysis, nor even a water budget of the valley, is available; thus, it is not now possible to forecast the consequences of pumping during future years. The hydrology, as it is presently understood, and the problems faced by management, together form the basis for the program of studies outlined herein.

The objective of the water-resources study proposed would be to provide information needed by the U.S. Geological Survey for administering the mineral leases in Searles Valley. Royalties paid to the U.S. Government by the mineral producers have amounted to about $1.5 million annually during recent years. A study and report such as proposed could form the basis for management decisions needed to insure the continuation of this income and to insure that the brine resource is utilized without waste and in accordance with existing laws and regulations.

Achievement of the desired management goals rests on four important factors:

1. The volume and grade of the mineral resources available for extraction.

2. The water resources available for use in both extracting and processing the minerals.

3. Achieving an understanding of the hydrologic system, including the effects of brine withdrawal and artificial recharge on the distribution and quality of the brine.

4. Achieving a workable water-basin-management program whereby the Geological Survey and the chemical companies can insure that sufficient water will be available for all necessary and justifiable purposes at equitable and economic costs.

On the basis of our present concept of the hydrologic system as outlined in this report, we believe that there are several alternative management plans from which a best plan might be eventually selected. Each alternative may have some economic benefits, as well as some associated penalties. For example, if it is decided that the brine level should be lowered beneath the surface of the lake in order to conserve water and presumably reduce the costs of pumping other water needed to recharge and keep the system full, because more surface-water inflow would become usable and evaporation would be reduced, a significant economic benefit might result. On the other hand, if the lowered brine levels cause land subsidence, surface-solution channels, or severe dilution of brines, substantial correctional costs might be incurred.

The proposed program of studies outlined in this report is designed to develop the information base for selecting the best system for managing the brine and peripheral aquifers conjunctively, rather than describing the system itself. All questions related specifically to management of the brine aquifers must be based on a more complete knowledge of the hydrology of the system, which would result from the program of future studies proposed herein, and additional studies of the brine system not outlined in this report.

In order to define the program of studies proposed herein, it was first necessary to make several broad assumptions about the future operation and management of the Searles Valley hydrologic system. These assumptions are as follows:

1. The resource to be conserved for use consists of (a) mineral-bearing brine, and (b) minerals in the solid state that can be best extracted by a solution-mining process.

2. The brine aquifers beneath the lake must be maintained full or nearly full throughout the period of mineral extraction, by some means of recharging.

3. The chemical quality of the brines must be maintained at commercial grade throughout the period under consideration, but not necessarily at the same grade.

4. Water needed for recharging the brine aquifer will be found and made available throughout the period under management consideration.

Plans consistent with the above assumptions should be developed to meet the management goals about how the system will be operated. The program of studies outlined in this report was designed to provide the hydrologic data and information needed for choosing among several possible alternative management plans that might be formulated, and to provide data needed to confirm that item 4, above, can in fact be achieved.

The principal questions which must be answered, then, are as follows:

1. How much supplemental water from the peripheral aquifer will be required to maintain the brine system full or nearly full, under various schedules of extraction?

2. Where can such water be pumped?

3. How large is the recoverable supply of supplemental water from the peripheral aquifer that is needed for plant cooling, chemical processing, and brine aquifer recharge?

4. Under various patterns of pumping and rates of pumping, what will be the outflow of brine from the central lake area to the peripheral aquifer?

5. Can large-yielding wells be drilled in the peripheral aquifer between the basin margins and the lake for providing supplemental water and brine-aquifer recharge, and, if so, where.

The proposed program of studies was designed to provide data needed to answer the five questions listed above.

Therefore, the scope of the preliminary study includes:

1. Compiling an inventory of pertinent geohydrologic information for the valley, including aerial photographs; geologic, geophysical, and hydrologic data; water-quality data; drillers' logs of wells; brine-recharge records, including quantity, quality and location of recharge; pump tests at wells; well-production records; imported-water records; and lake evaporation.

2. Preparing a bibliography of geohydrologic reports for Searles Lake and other areas pertinent to this study.

3. Collecting and examining enough geohydrologic data to formulate a conceptual model of the hydrology of the basin. This phase of the investigation consisted of collating or constructing geologic and stratigraphi sections; compiling historic records of standing water on the lake; and formulating hypothetical circulation patterns of ground water from density distribution, ground-water contour maps, recharge and pumping patterns, and hydrographs of selected wells.

4. Designing a program of study, data collection, interpretation, test drilling, and model building to meet the objectives.

The work was done during May-July 1972 under the general direction of Lee R. Peterson, district chief in charge of water-resources investigations in California, and the immediate supervision of R. E. Miller, chief of the Garden Grove subdistrict.

Acknowledgments

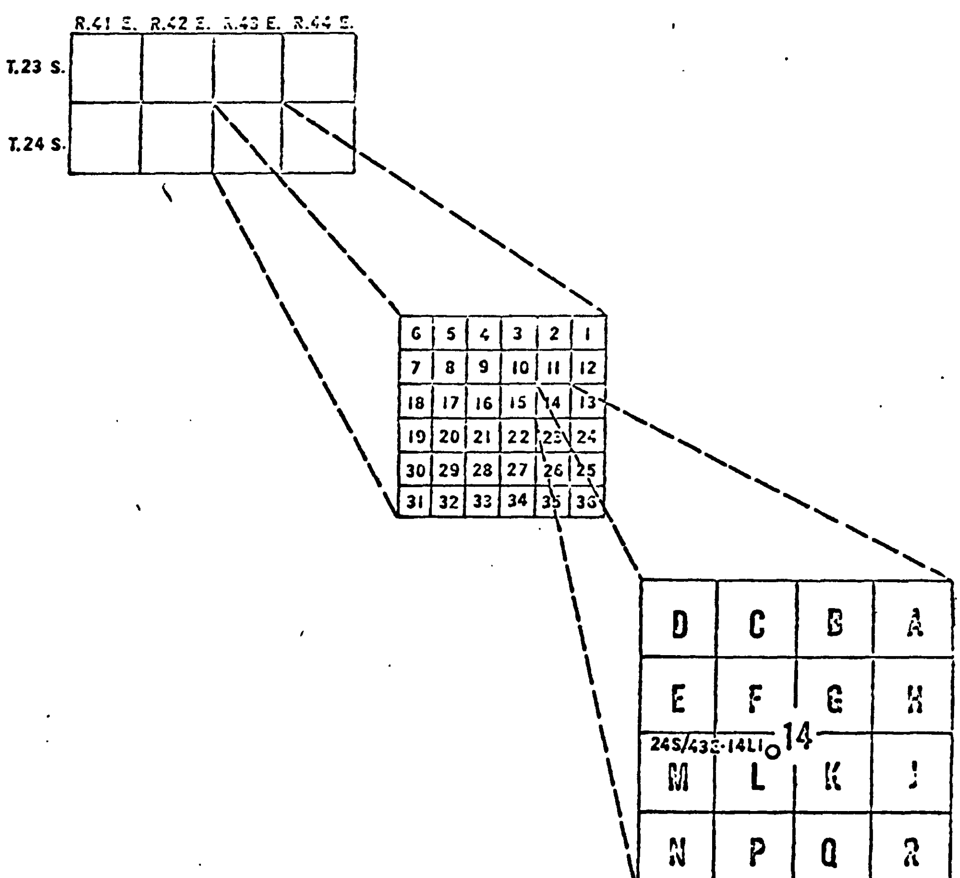
We are greatly indebted for discussions and consultations with many individuals and colleagues during this planning study. Of particular benefit were the discussions with our Geological Survey colleagues: Alfred Clebsch, Jr., Jacob Rubin, J. H. Feth, Donal Ziehl, and L. H. Saarela; special thanks are accorded G. I. Smith for the benefit of his discussions and unpublished data--based on more than 15 years of work and experience in the valley.

Geohydrologic data were collected through the cooperation of the chemical companies at Searles Lake. We are especially grateful for the help from Kerr-McGee Chemical Corp. (formerly American Potash and Chemical Co.): F. C. Hohne, manager, Non-Fuel Minerals, Oklahoma City, Okla.; J. A. Sonia, manager, Lake Resources, and D. L. Cramer Bornemann, senior geologist, Trona, Calif.; from Stauffer Chemical Co.: Dr. L. E. Mannion, chief geologist, Richmond, Calif.; Peter G. Cortessis, plant superintendent, Industrial Chemical Division, and Charles Cowie, engineer, Westend, Calif.; and from subsidiaries of Occidental Petroleum Corp.: Dr. H. E. McCarthy, vice president and laboratory director, and James Slayden, engineer, Garrett Research and Development, Inc., La Verne, Calif.; and Tony Regone, assistant works manager, Hooker Chemical Corp., Ridgecrest, Calif.

The help, assistance, and data supplied by these individuals and others is gratefully acknowledged. These acknowledgments, of course, do not commit any of the above individuals to views and interpretations expressed herein.

Well-Numbering System

Wells are numbered according to their location in the rectangular system for the subdivision of public land. For example, in the number 24S/43E-14L1, the part of the number preceding the slash indicates the township (T. 24 S.), the part between the slash and the hyphen indicates the range (R. 43 E.), the number between the hyphen and the letter indicates the section (sec. 14), and the letter indicates the 40-acre subdivision of the section. Those wells with the letter U do not yet have an assigned State well number. Within the 40-acre tract wells are numbered serially, as indicated by the final digit. Thus, well 24S/43E-14L1 is the first well to be listed in the NE¼SW¼ sec. 14, T. 24 S., R. 43 E., Mount Diablo base line and meridian as shown in the diagram below:



GENERAL MINING TECHNIQUES

The salt body in the center of the lake has been mined continually since the early 1900's and is divided into two zones. The upper zone or salt body, including overburden mud, extends downward from the lake surface a maximum thickness of about 90 feet (Haines, 1959, pl. 5). Below this zone is a layer of fine mud, clay, and less-soluble salts about 12 feet thick, called the parting mud. Beneath the parting mud is a second salt zone which has a maximum thickness of about 50 feet (Haines, 1959, pl. 6). The brine level in both bodies is approximately at land surface, although the salts in the two zones differ in concentration. The upper-zone brine is high in potash and sulfate and less rich in borax and sodium carbonate, and concentrations of these salts in the lower-zone brine are reversed.

Pre-1972

In the development of Searles Lake, prior to 1916, many operators attempted to produce borax, soda ash, potash, and sulfate of soda by concentrating brine pumped from wells through solar evaporation. The operations failed for at least two reasons, (1) the evaporation ponds leaked; and (2) complex rather than simple salts were formed during the crystallization process resulting from evaporation, and processing these salts for market was too costly at the processing plants then used. Many operators either relinquished or cancelled their leases as a result of these difficulties.

In 1918, F. M. (Borax) Smith formed the Westend Chemical Co. and after years of experimental work selected a plant process now in use. In 1968, two operators remained: Kerr-McGee Chemical Corp. (formerly American Potash and Chemical Corp.) and the Westend Chemical Division of Stauffer Chemical Co. The Kerr-McGee plant was built at Trona and began commercial operations in September 1916.

The mining techniques of the Kerr-McGee and Stauffer Companies are now similar. Brine is pumped from wells and is processed to recover the valuable minerals. If upper-zone brine is used, wells 8-10 inches in diameter are drilled to a depth of 50-75 feet to the parting mud dividing the two zones, and the holes are cased to within 10 feet of bottom. In general, the pump intake is placed near the top of the hole and brine enters the uncased part of the hole. If lower-zone brine is used, holes are drilled to a depth of 80-125 feet through the upper and lower zones into the bottom mud. The wells are cased except for the lower 10 feet, and the upper salt body is completely sealed from the lower body.

Brine is pumped from about 60 to 100 wells spaced at least 500 feet apart; pumping is usually at a rate of 50-100 gpm (gallons per minute) per well. Each well is connected to a pipeline and the brine is transported 2-5 miles to the processing plants west of Searles Lake.

Pumping brine from many widely spaced low-discharge wells spreads the pumping depression over a large area; it also causes a shallow depression instead of a deep pumping cone in a localized area as would be caused by using a few high-yielding wells. The purpose of this skimming from the brine system is to minimize fluid flow across property boundaries, to allow for more precise chemical-quality control of fluids pumped from the individual wells, and to reduce land subsidence which causes cracking of roads, pipelines, and dikes and ponds. Chemical-quality control can be attained, allowing water rich in minerals having high current prices to be pumped from wells, when pumping operations are closely controlled.

Two processes are used for extraction of the various salts from the brine. These processes are called the carbonation process and the evaporation and crystallization process. The mineral recovery processes used are important to this study only as they influence rates of brine withdrawal or consumptive use of water, but the interested reader is referred to Hellmers (1938), Dyer (1950), and Ryan (1951) for more detailed descriptions of the two processes.

The processing procedures require that large quantities of water be used, but most of the water is not consumed. Supplemental sources of water must be used, and these include brackish water pumped from wells along the north and west side of the lake and fresh water piped 20 miles from wells in Indian Wells Valley (fig. 1). After processing, most of the remaining brine and brackish and fresh water is returned to the lake. Part of this water recharges the salt body to maintain high brine levels in the lake and possibly redissolves a part of the ore body, and part is evaporated by the sun. The quantity of water returned to the brine area of the lake is in excess of that originally pumped.

Post-1972

During 1969, a third company, Occidental Petroleum Corp., and its subsidiaries, obtained leases and prospecting permits on the edge of Searles Lake, primarily in the southern part. As of spring 1972, most of the lake is leased or owned by Kerr-McGee, Stauffer, and Occidental (fig. 3).

The mining of brines through wells by Occidental may differ from the technique used by the other two companies. The salt extraction process developed by Occidental (Garrett Research) will use solar energy to crystallize salts from the somewhat more dilute brines pumped from near the lake edge. Garrett (1961) described the process expected to be used by Occidental. As the Occidental Petroleum Corp. process relies mainly on solar energy to remove water from the brine, large quantities of water may be used. The general mining procedure may be to pump in the spring about 16 wells at an individual rate of about 1,000 gpm. The water will be used to fill a large pond, which may be kept full by intermittent pumping, until the brine is sufficiently concentrated by evaporation. Then the brine may be pumped to several nearby harvest ponds and allowed to evaporate to dryness. During the summer, all the ponds will be filled with brine. Pumping may continue for 8 months during the hot season but be stopped in the winter when the salts are harvested and processed through the plant.

Occidental Petroleum Corp. started pumping in 1968 for development purposes. By January 1972 the proposed mining program was started and continued by pumping 16 wells at a rate of 800-1,000 gpm per well into a solar pond. On March 29 the pumping rate was reduced to about 100 gpm per well when the regional lowering of brine levels was attributed to this pumping program.

Occidental proposes to obtain some fresh water (treated sewage effluent) for use in mineral processing; this water will be imported by pipeline from Indian Wells Valley.

It may be possible to maintain the lake-brine level by pumping brackish water from deep wells drilled along the edge of the lake; this water could be piped to the lake for recharging the ore body to help maintain brine levels. In addition, precipitation on the lake surface and surface-water runoff to the lake might become sources of usable water if evaporation were reduced by lowering the brine levels to create additional storage space in the shallowest lake deposits.

CONCEPTUAL MODEL OF THE BASIN

A conceptual model, or hydrologic working hypothesis, of the Searles Lake basin was formulated even though the information available was deficient and time was short. The lack of either hydrologic data or previous hydrologic analysis hindered the evaluation, and therefore the conclusions reached about the hydrologic system are tentative and subject to revision. Only a schematic framework is presented in this section of the report, primarily by diagrams and figures; descriptive material previously published was used whenever possible.

Geologic and Chemical Framework

The general configuration of the bedrock under the basin fill is shown by two sections (fig. 4). The interpretation is based primarily on geophysical work by Mabey (1956) and Smith, Troxel, Gray, and Von Huene (1968); on unpublished work by Kerr-McGee Chemical Corp.; and on a few well logs from Searles Valley. Additional data on the depth to bedrock will be needed for the area south of Searles Lake, between the lake and the Garlock fault. The geologic sections show that practically all the lake is underlain by interbedded salines and lake marls, with only a thin veneer of presently exploited ore in the center of the basin.

The east and north edges of the playa are bordered by a feature known as the trona reef. This reef, which rises a few inches above the playa surface, is a saline efflorescence composed mostly of the mineral trona and apparently results from trona-bearing water rising to evaporate at the land surface. The Wilson Canyon fault apparently forms a poorly permeable zone that to some degree acts as a barrier to ground-water movement. The position of the fault may control the linear area along which ground water rises to the surface to form the reef.

Earlier studies (Smith and Pratt, 1957; Haines, 1959; Smith, 1962; and Eugster and Smith, 1965) showed the stratigraphy beneath the lake (fig. 5). From the top downward, the deposits consist of: (1) the overburden mud, (2) the upper salt body, (3) the parting mud, (4) the lower salt body, (5) the bottom mud, and (6) the mixed layer.

The overburden mud underlies the surface of Searles Lake within the area underlain by the upper salt body (Haines, 1959, pl. 5) and generally extends about 1 mile beyond the outer boundary of the upper salt body (fig. 6). The average thickness of the mud is about 23 feet, on the basis of 88 cores. It is from 5 to 15 feet thick along the northwest edge of the lake, and more than 30 feet thick near the north, south, and southwest edges (written commun., G. I. Smith, 1972). On the periphery of the salt body, the base of the overburden mud is in contact with a sand layer that is the lateral equivalent of the upper salt body. This contact is hydrologically significant.

The upper salt body is the largest of the commercially mined saline deposits and was the first to be exploited. The upper salt body is lens shaped, has a maximum thickness of about 90 feet, and underlies about 42 square miles. The top 10-15 feet of the deposit consists primarily of halite (NaCl) (Teeple, 1929), and the more valuable minerals trona ($Na_2CO_3 \cdot Na\ HCO_3 \cdot 2H_2O$) and hanksite ($9Na_2SO_4 \cdot 2Na_2CO_3 \cdot KCl$) are beneath. The volume of the upper salt body is estimated to be 850,000 acre-feet (written commun., G. I. Smith, 1972).

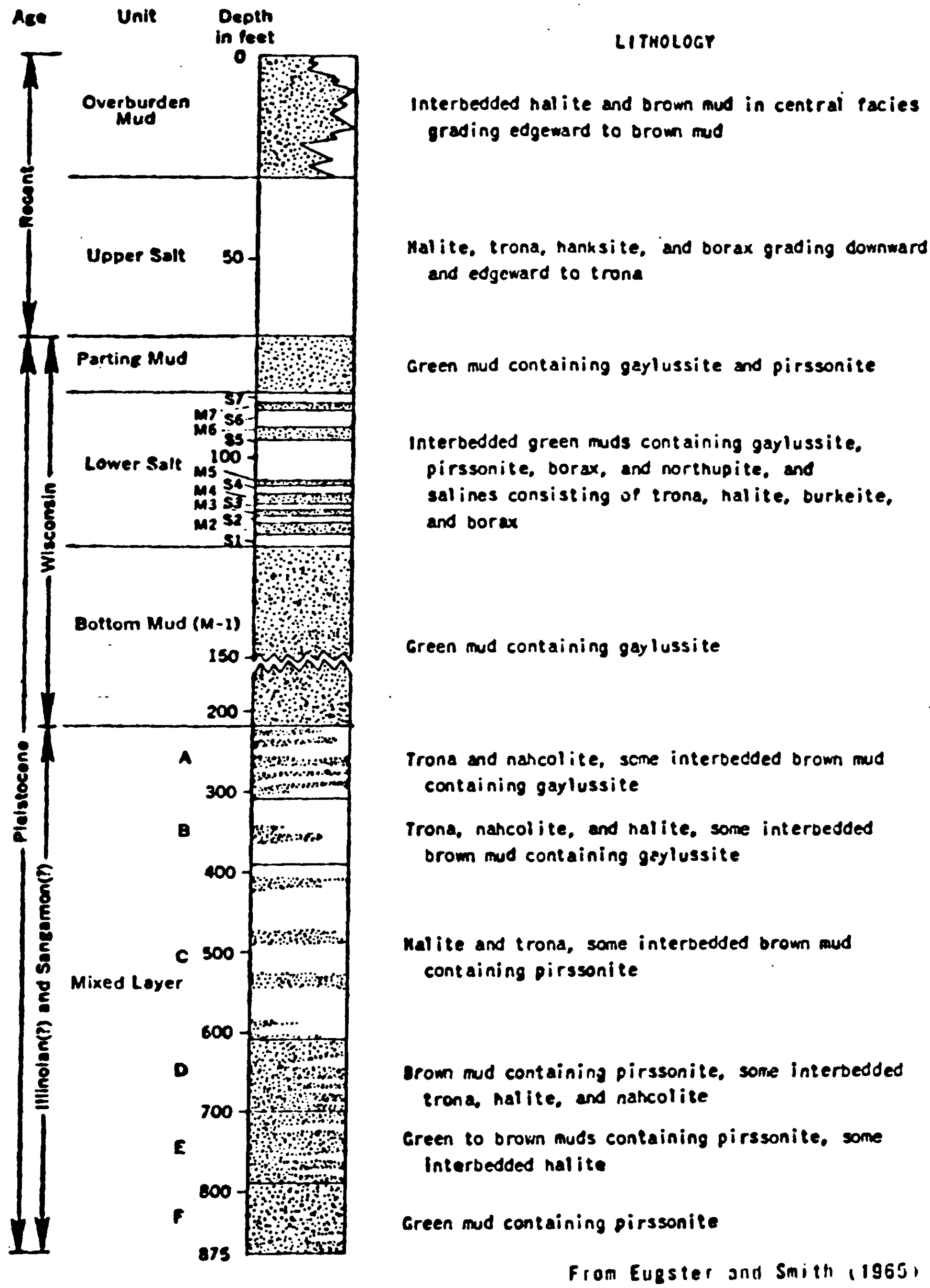


FIGURE 5.--Stratigraphic section.

Underlying the upper salt body is a layer about 12 feet thick of laminated, dense, generally black clay and mud. It is called the parting mud (Haines, 1959, p. 144) because it separates the upper and lower salt bodies into two separate geologic and chemical bodies. The parting mud has been previously considered an impermeable layer which would prevent hydrologic connection between the two separately mined salt bodies.

The lower salt body has about the same surface area as the upper salt body (fig. 6) and has a maximum thickness of about 50 feet (Haines, 1959, pl. 6). The lower salt body differs from the upper layer in that it contains more clay and marl seams. The unit has been divided into seven saline layers (S1-S7) separated by six mud layers (M2-M7) (fig. 5). The volume of the saline layers is about 440,000 acre-feet and that of the mud layers is about 347,000 acre-feet (written commun., G. I. Smith, 1972). Thus, the total volume of the interbedded muds and salts in the lower salt structure is about 787,000 acre-feet, with the predominant minerals being trona, halite, burkeite ($2Na_2SO_4 \cdot Na_2CO_3$) and borax ($Na_2B_4O_7 \cdot 10H_2O$).

The bottom mud and the mixed layer lie beneath the lower salt body. The mixed layer has been divided into six stratigraphic units (fig. 5), characterized by different suites of evaporite minerals (Smith, 1962). Mud layers predominate, although many saline layers are present. More detailed exploration of these deeper saline layers in the mixed layer will be required to determine their potential as ore. The bottom mud and mixed layer combined may be as much as 3,175 feet thick, computed as the difference between basement at 3,300 feet beneath the lake (Mabey, 1956) and the bottom of the lower salt body at a depth of 125 feet. The mixed layer grades laterally into the alluvial deposits that extend laterally to the valley sides and are important hydrologically.

Our concept of the chemical framework of the water and brines of the basin was based on published water-quality analyses (Moyle, 1969) and unpublished data on brackish water and brine density obtained from the chemical companies. No attempt was made to describe any long-term change in concentration of specific minerals in the brines.

Fluid density was used an an indicator of brine concentrations. The Geological Survey for practical purposes considers water of less than 7,000 mg/l dissolved solids to have a density of 1.000 g/ml (gram per milliliter) (Rainwater and Thatcher, 1960, p. 161). Brine having a density of 1.301 g/ml from Searles Lake has been analyzed and contains about 350,000 mg/l dissolved solids (written commun., G. I. Smith, 1972). On the basis of a few data points, a correlation was made of the fluid density and dissolved solids in Searles Lake (fig. 7). This graph was used in formulating our concept of the flow system, as the distribution of fluid densities measured must have a profound effect on the movement of ground water.

The brines within the area of the upper and lower salt bodies range in fluid density from 1.250 along the edges to more than 1.300 at the center. The density of brackish water near the edge of the lake is about 1.050 g/ml, as shown by water from the chemical company wells at Trona and West End. Water at Valley Wells, north of the lake, ranged in density from 1.000 to 1.006 g/ml in 1963 (3,000-12,000 mg/l dissolved solids) (Moyle, 1969, p. 67-68). In 1972 the dissolved solids ranged from 3,000 to 15,000 mg/l (written commun., D. L. Bornemann, 1972). Spring water in the Argus Range, northwest of the lake, is generally low in dissolved solids with a density of 1.000 g/ml. South of the lake to the Garlock fault, the water is of somewhat variable quality but has a density of about 1.000 g/ml.

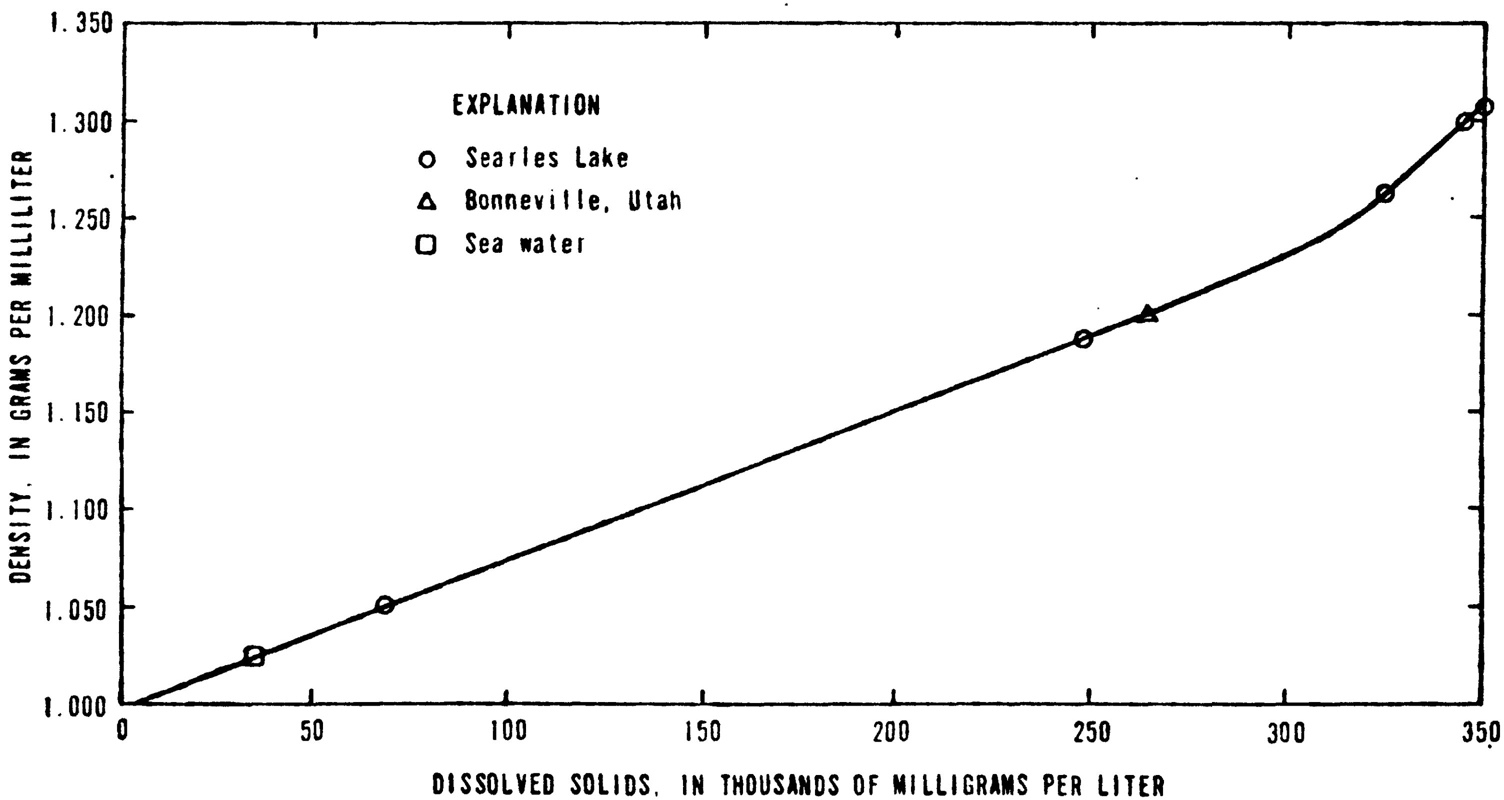


FIGURE 7.--Fluid density versus dissolved solids.

Hydrologic System

For purposes of this study, the aquifers of the Searles Valley were separated into two general systems: those containing brine and those containing fresh-to-brackish water, called, respectively, the brine and peripheral aquifers. Water in each aquifer has a different mode of occurrence, different recharge, virtually independent movement, and distinct chemical composition. The brine aquifer is in the center, beneath the lake, and the peripheral aquifer (fresh-to-brackish water) surrounds the brine area and extends laterally to the basin margin.

Natural Recharge

Searles Valley has a drainage area of about 725 square miles. The primary source of natural recharge to the basin is surface-water runoff from the surrounding mountains. An unknown quantity of the runoff percolates into the ground and recharges the peripheral aquifer, and some runoff reaches the lake surface where it ponds; most of it eventually evaporates. A small quantity of recharge to the brine system presumably occurs from precipitation on the lake surface. Average runoff and recharge are difficult to estimate because there are no gaging stations in the basin, and the only precipitation station is at Trona.

By indirect methods, an engineering consultant for Occidental Petroleum Corp. (written commun., 1972) estimated that 30,000 acre-feet of runoff per year reaches the lake or infiltrates the ground-water system. No estimates were made of distribution. Because the estimate was based on gaged runoff from a small watershed in the Sierra Nevada adjacent to nearby Indian Wells Valley and the data adjusted for Searles Valley, it is our opinion that this estimate of runoff may be greater than the actual runoff.

According to Kunkel and Chase (1969, p. 70), about 20 acre-feet of ground water enters Searles Valley per year through Salt Wells Valley from Indian Wells Valley. Apparently, no other ground water flows into Searles Valley from adjacent basins.

The Dynamic Flow System

In deducing the natural-flow conditions prior to man's development in the basin we considered the following: (1) the areal extents and relative positions of fresh-brackish water and brine, (2) position of the Wilson Creek fault and Trona Reef, (3) distribution of standing water on the lake, and (4) fluid-density differences between waters. Our concept of the flow system under native hydrologic conditions is shown schematically in figure 8. Under native conditions the hydrologic system was in balance; recharge was equal to evaporation over a period of several decades.

Surface-water runoff from the mountains moved overland and discharged onto the lake surface. The water that percolated into the peripheral aquifers flowed toward the lake, but discharged by evaporation at the edge of the brine area because it could not displace the high-density fluid. The brine remained virtually static except for minor local circulation due to evaporation and surface-water recharge whenever space was available. Both aquifers were filled with fluids and were essentially in equilibrium. The upper and lower salt bodies in the brine probably had similar hydraulic heads, indicating either no hydrologic continuity between the bodies, or hydrologic continuity, but no flow from deep to shallow zones of water with equal density.

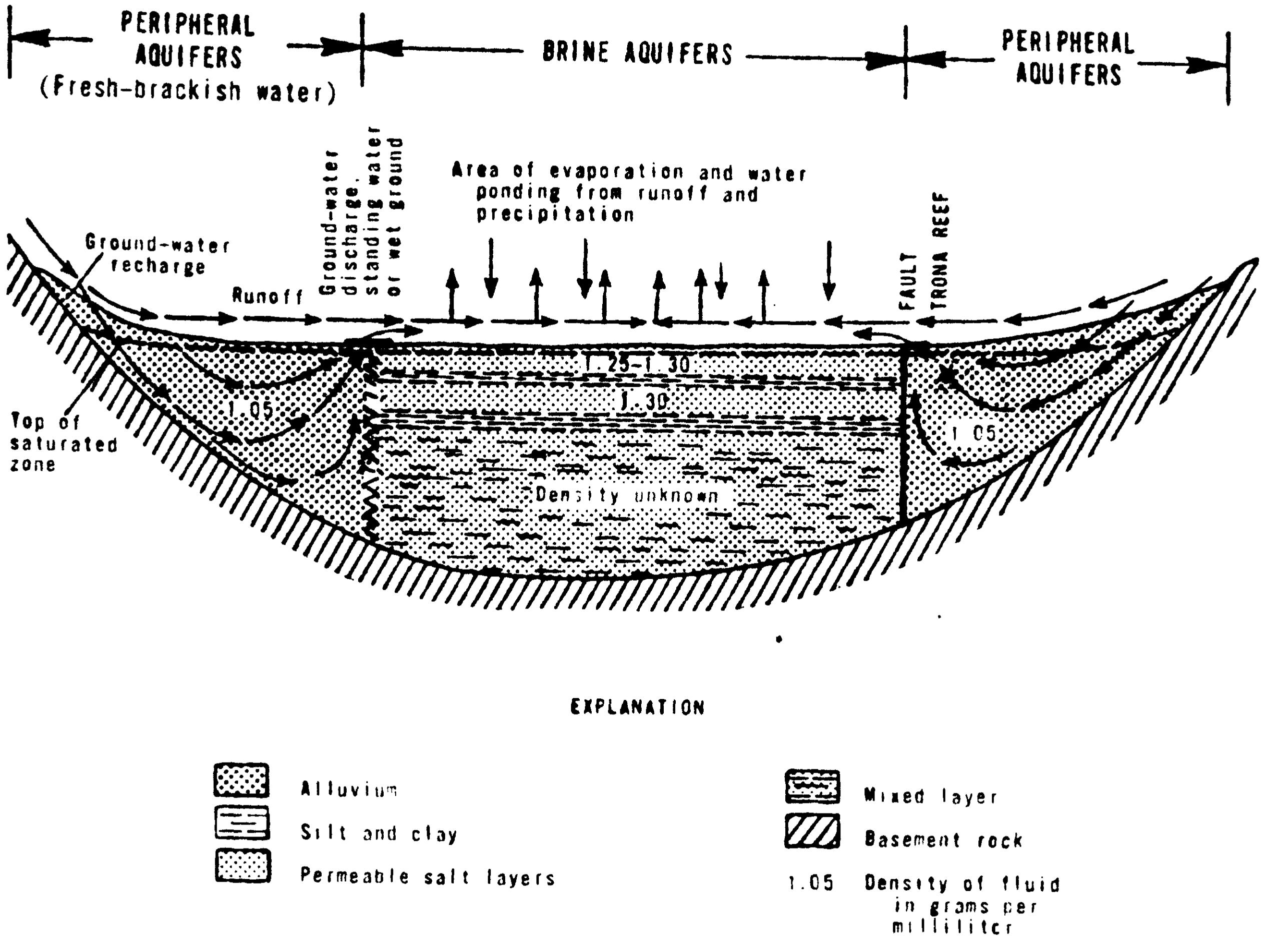


FIGURE 8.--Schematic section showing hypothetical circulation of water under native conditions.

Pumping from an aquifer changes the flow system. The flow system under pumping conditions depends on the quantity and distribution of pumping, especially in relation to the location and rate of natural discharge and recharge, on the hydrologic characteristics (transmissivity, hydraulic conductivity (permeability), storage coefficient, and the specific yield) of the peripheral and brine aquifers. Figure 9 shows schematically our concept of the flow system under pumping conditions (pre-1972). Originally, all the brine was pumped from the upper salt body. Withdrawals from the lower salt body gradually increased to about 30-40 percent of the total pumping. However, a changing economic market for various salts can alter these percentages; valuable salines are pumped from some wells while other wells producing lower-value salts are shut down.

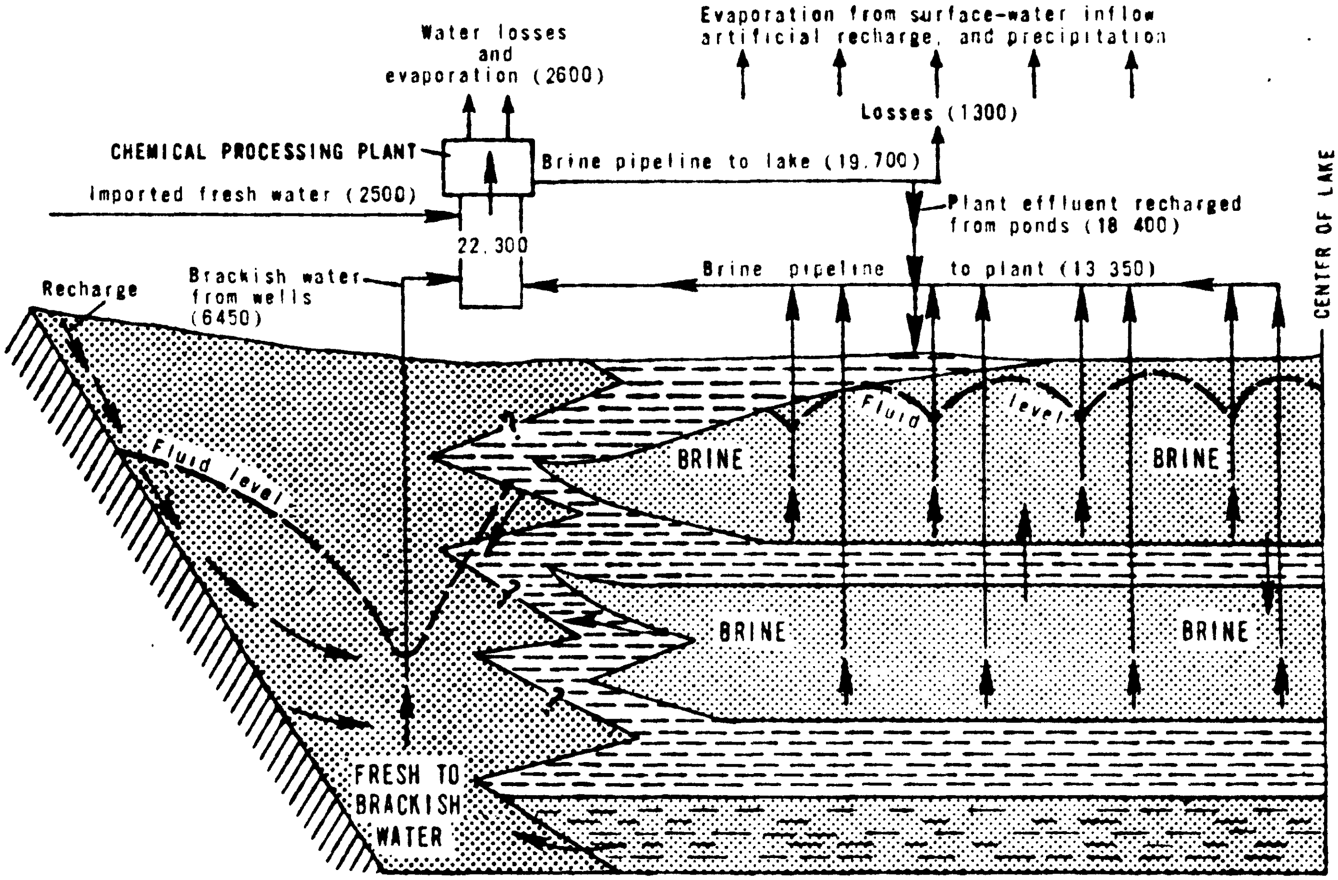
The problems which must be solved quantitatively require data not presently available. The general hydrologic system, and our concept of a practical modeling approach, are shown diagrammatically in figure 10. The data needed are:

1. The quantity of brine that may migrate to the peripheral aquifers under various pumping regimes.

2. Quantity and position of recoverable water in storage in the peripheral aquifers.

3. Yields of wells in the peripheral aquifers.

4. The rate of head change in the peripheral aquifers under various pumping regimes.



Note: Values are in acre-feet per year based on three-year average (1969-71)

EXPLANATION

FIGURE 9.--Schematic diagram of the flow system under developed conditions.

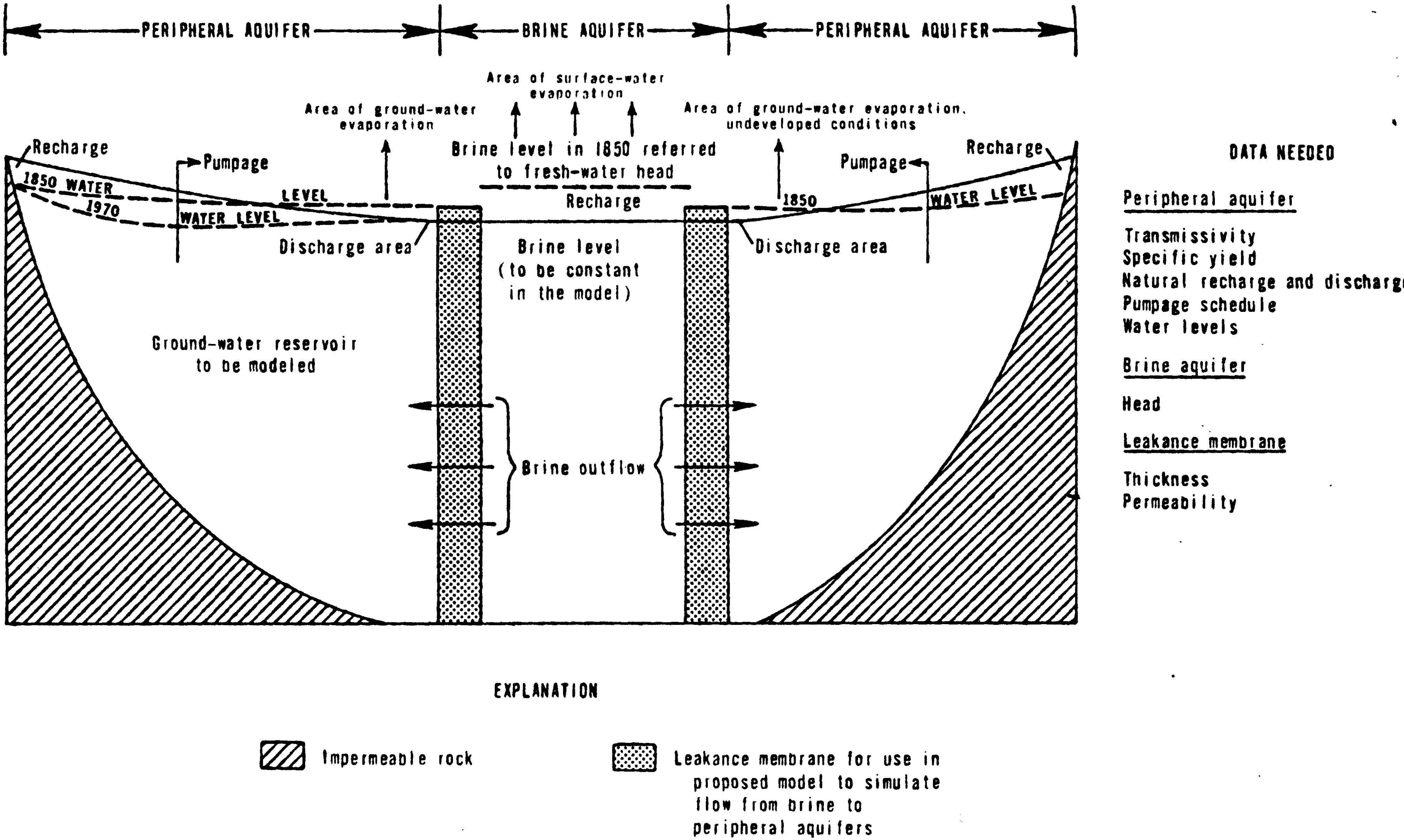


FIGURE 10.--Schematic of the hydrologic system and a generalization of the modeling approach proposed.

Effects of Mining by Wells

A map showing fluid-level contours based on numerous measurements made in wells (Moyle, 1969) is shown in figure 11. The measurements have not been corrected for different fluid densities. The location of standing water on the lake, determined from October 1966 aerial photographs, is superimposed on this map.

The contours show the moderate fluid decline in the peripheral aquifer near Westend, Trona, and Valley Wells; the higher fluid mound at the recharge ponds; and the relative flatness of the fluid surface in the brine. The fluid contours between the Garlock fault and the lake indicate a gradient of 5-10 feet per mile, in an area uninfluenced by pumping.

In the center of the lake, the equivalent hydraulic head of the brine (converted to brackish-water head of 1.050 g/ml density) is higher than the head in the adjacent peripheral aquifers. For example, the thickness of the upper and lower salt bodies is about 125 feet; it is saturated with fluid having a density of 1.300 g/ml. Assuming the water in the peripheral aquifer at Westend and Trona has a fluid density of 1.050 g/ml (fig. 11), it would take a column of that water 155 feet high to balance the column of brine in the center of the lake (125 feet x 1.3). Thus, the 1,615 brine-level contour (center of fig. 11) would need to be about 30 feet higher (elevation 1,645) if it represented a water-level contour for a fluid at the same density as that of the adjacent water in the peripheral aquifer.

On the basis of records supplied by the operating companies for the years 1969-71 and our engineering judgment, a schematic (pipe) diagram (fig. 9) was constructed. The diagram represents only an approximation of the flow system because firm estimates of natural recharge or discharge are not available. Figure 9 shows that Kerr-McGee and Stauffer Chemical Companies for 1969-71 have nearly maintained the overall water balance in the basin on the basis of their pumping only. However, this may not be significant because an imbalance appears to exist between the extractions from the peripheral aquifers and recharge to the brine aquifers. These two companies added to the brine aquifers about 5,000 acre-feet of fluid per year in excess of withdrawals. Fluid levels are at or near land surface in the brine area, and further studies would be required to determine the flow path of this fluid. Possibly some of the fluid migrates to the peripheral aquifers or to the brine wells, but much more is probably eventually lost by solar evaporation. If this is the case, and if the flow from the brine to the peripheral aquifers is small, there is a net annual depletion of ground water in storage in the basin with all the deficit being mined from the peripheral aquifers. During the period 1969-71 the annual deficit may have exceeded 6,000 acre-feet. The developable supply from the peripheral aquifers, therefore, may constitute the limiting quantity of water that can be pumped from the basin for use. This quantity is of critical importance to any future basin-management programs to be undertaken.

Natural runoff to the lake from precipitation in the mountains has little opportunity to recharge the brine system because the aquifer is full. Much of this water is now lost through solar evaporation, but it might be possible to better utilize such water. If recharge to the dewatered peripheral aquifers could be induced by building artificial spreading basins, the deficit might be reduced. In this arid climate, however such a program of artificially recharging the peripheral aquifers would be expensive and might not be economically feasible.

In summary, prior to 1972, the fluid levels remained near land surface in the brine aquifer and continued to decline in the aquifers at Westend, Trona, and Valley Wells. For example, the depth to water below land surface in well 26S/43E-6F3 at Westend was 112 feet on May 25, 1972; the water level at well 25S/43E-17D5 at Trona was 171 feet below the surface on June 22; and at well 24S/43E-22N2 at Valley Wells the water level was 199 feet below the surface on June 28. These were measurements of the nonpumping water level. The water-level decline in these wells was 12 feet (1967-72), 12 feet (1964-72), and 16 feet (1962-72), respectively. Pumping levels, of course, during that time interval were much deeper.

On January 15, 1972, Occidental Petroleum Corp. started large-scale pumping of brine from 16 wells about 50 feet deep finished in the upper salt body at the southern edge of the lake in secs. 13 and 14, T. 26 S., R. 43 E. (fig. 12). The other two companies continued their pumping operations of about 7,500 gpm at a rate of 50-100 gpm per well. The average pumping rate at Occidental's site ranged from 9,000 to 12,000 gpm in January and from 10,000 to 13,000 gpm in February; the rate was about 12,500 gpm in March. Due to regional lowering of brine levels in the ore body, on March 28, 1972, the Geological Survey requested Occidental to reduce the rate of withdrawals from the brine system. In early April, the rate was 1,000-1,300 gpm but had increased to 2,500-3,000 gpm by late April; it was 4,000 gpm in May and continued at the rate of about 4,000-4,500 gpm until about the middle of June.

Prior to pumping by Occidental Petroleum Corp. the static brine level on the lake ranged from 3 to 8 feet below land surface. The pumping of 9,000-12,000 gpm from the upper salt body in the southern edge of the lake caused fluid levels to decline in both the upper and lower salt bodies. Fluid-level declines at 26 selected wells in the upper salt body in the southern half of the lake ranged from 5 to 11 feet; the decline was 5 to 9 feet in wells in the lower salt body. This decline in both salt bodies is of hydrologic significance and indicates that hydraulic continuity exists between the salt bodies in the area. Hydrographs of six selected observation wells, three in the upper and three in the lower salt body, show the fluid-level response due to Occidental's pumping (fig. 13). Observation wells LS-23, LS-27, and GS-8 (fig. 12) are 3/4, 1-1/2, and 3-1/4 miles, respectively, from the Occidental well field. When pumping was reduced to about 1,100 gpm on March 29, the fluid levels recovered in the 26 observation wells. On May 25, fluid levels averaged about 5 feet lower than the levels observed prior to the pumping described.

The rapid response and widespread lowering of fluid level in the brine aquifer stimulated considerable interest in whether or not existing estimates of porosity and specific yield of the deposits and of coefficients of storage for the brine aquifer were accurate or in need of reevaluation. According to Flint and Gale (1958, p. 689) and Haines (1959, p. 146), the porosity of the upper and lower salt bodies is about 40 percent. Preliminary data from all three companies (pumping tests of early 1972 and other data) indicate coefficients of storage of about 10-20 percent for the salt bodies.

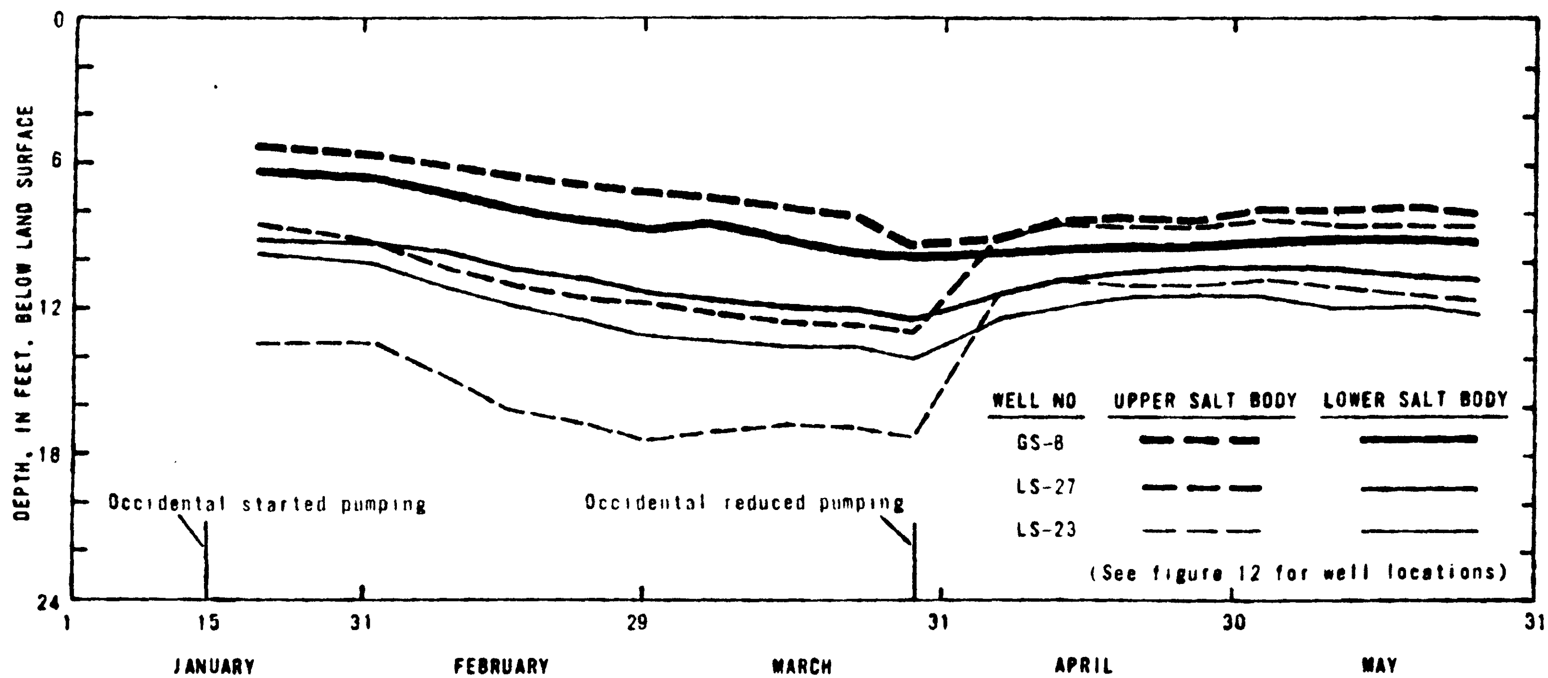


FIGURE 13 --Hydrographs of selected brine wells, January - May, 1972.

The porosity of the shallow-brine aquifer in the Bonneville Salt Flats, Utah, was determined to be 45 percent, and the specific yield was estimated to be 10-12 percent (Turk, 1969, p. 104). These values may be similar to those of the Searles Lake deposits.

However, if the brine aquifer is maintained full by recharging, the actual specific yield and porosity are of little practical significance; therefore, determinations of the true values are not planned as part of the studies proposed.

The rapid fluid response in the brine area due to Occidental's pumping suggests a high transmissivity and a range in aquifer storage coefficient corresponding to the values for semiconfined aquifers. Selective aquifer tests could be made to determine these coefficients at Searles Lake, but here again a determination of the true values would presumably be of little practical use and thus such tests are not planned for the reasons outlined above.

Fossil and Reconstituted Brine

The total estimated volume of the permeable sediments in the Searles Lake ore body is 1,290,000 acre-feet. This includes 850,000 acre-feet of sediments in the upper salt body and 440,000 acre-feet of sediments in the lower salt body. The clay and marl layers (M2-M7) were not included in the calculations. Assuming a porosity of 40 percent for the salt deposits based on preliminary company analysis, the original volume of recoverable brine in storage may have been about 520,000 acre-feet.

On the basis of 1969-71 records supplied by the two established operating companies, brine pumping averaged about 12,000 acre-feet per year during that period. Thus, if recharge and recirculation of fluids were negligible, the recoverable brine would be depleted in 40-50 years, at the current pumping rates. Because brine has been pumped and recharged for more than 50 years, it is currently believed by many that some reconstituted brine is being pumped from wells and circulated to the processing plants. Nevertheless, it is probable that near the base of both salt bodies or away from major producing wells there may be fossil brine of virtually the original composition. Because of the recharge and discharge relations, and due to hydrodynamic dispersion, there has probably been much mixing of the original and recharged brines.

Records of the total pumpage from the brine aquifers were not available for use during this study. However, the total extraction (market) of salt from the ore body in 50 years is estimated at 22,000 acre-feet (oral commun., J. A. Sonia, 1972). If this salt had a porosity of about 40 percent, and thus a density of about 1.26, the volume of original brine which it would be necessary to pump and process to obtain the volume of minerals marketed would be about 250,000 acre-feet, assuming 65 percent efficiency in recovering the desired minerals and that 50 percent of the salt in the brine was sodium chloride that was not marketed. This estimate agrees closely with crude estimates of cumulative pumpage compiled by interpolating between pumpage estimates for the years 1940, 1950, and 1970.

Therefore, pumping from the ore body during 50 years has probably removed about 250,000 acre-feet of brine, a volume equal to about half the original volume of brine stored in the upper and lower salt bodies. Because of dispersion and possibly channelized flow in the system, however, some of the brine pumped may have come from the water recharged to the system. Thus, the remaining "fossil" brine in the upper and lower salt bodies may exceed 50 percent of the original volume.

The water for recharging the system can have three possible sources: (1) surface inflow to the lake or effluent from the chemical processing plants; (2) upward flow from a deep source, if the hydraulic gradient (density corrected) between deep and overlying brine becomes favorable; or (3) inward flow from the peripheral area, if the hydraulic gradient becomes favorable. This recharged water probably takes into solution the solid salts, possibly in concentrations such that it can be pumped for processing.

The circulation pattern established for years between sites of recharge (plant effluent discharge to the lake) and brine-production wells may not be the most efficient or economical way to carry out solution mining. Development of an optimum brine-aquifer management program will require data and studies beyond those contemplated as part of the studies proposed in this report.

Solution mining may cause land-surface subsidence or local collapse of the surface. If the total mineral production has been about 22,000 acre-feet, or about 1.7 percent of the original volume of the salt deposits, the removal of these salts from the brine area of about 25,000 acres would account for an average lowering of less than 1 foot in the lake surface during 50 years. The actual subsidence would be less if more recirculated brine can now be stored in the aquifer wherever increased porosity has been caused by solution of the salts.

PROJECT DESIGN FOR THE BASIN

The comprehensive water-resources study of Searles Valley proposed herein has been designed in two major parts: (1) a geohydrologic and geochemical analysis of the valley, and (2) model studies needed to confirm quantitative estimates of hydrologic data and for use as a basin-management tool. Each part consists of some aspects that can be quickly completed, depending on urgency and need for solving some current problems.

The geohydrologic analysis of the basin is required first. Then, a numerical modeling program can be developed. However, modeling techniques must be considered in the initial study.

Available Data Needed for the Proposed Studies

Needed data available from previous studies include:

Moyle (1969)

1. Geologic map, showing location of selected wells.
2. Tables describing selected wells and springs, and water-level records, drillers' logs, chemical analyses of water, and pumping tests.

Haines (1959)

1. Core logs from drill holes GS1-GS41.

Smith and Pratt (1957)

1. Core logs from selected drill holes.

Mabey (1956)

Smith, Troxel, Gray, and Von Huene (1968)

1. Gravity map of part of the basin.

Successful analysis of the Searles Valley water resources will depend on obtaining a high degree of cooperation and exchange of information among all the operating chemical companies and the Geological Survey. A successful comprehensive study cannot be completed without access to the lake area and to company wells. The company data will be vital, but the Geological Survey must collect new data as needed.

Needed data unpublished but available for the study are described below.

Natural boundary conditions of the aquifers.--Drillers' logs of existing company wells.

The only precipitation station in the basin is at Trona (1920-present). There are no surface-water gaging stations. Chemical companies have some records of lake evaporation.

The brine ore body has been intensively drilled to shallow depths and infrequently to deeper depths. Data for a few wells in the peripheral aquifers are available.

Pattern and rate of ground-water withdrawals.--Company records are available and are the only source of pumping data (distribution pattern, rate, and quantity) for both the brine and peripheral aquifers.

Pattern and rate of artificial recharge.--Company records are available for the amounts of imported water and effluent from the processing plants that is used for artificial recharge of the brine aquifers.

Water-level trends.--Numerous long-term well records show that the brine level has always been maintained at or near the lake surface. Along the west side of the lake and at Valley Wells, wells in the peripheral aquifers are monitored; elsewhere, water-level records are sparse or absent.

Fluid chemistry.--The chemical companies and the U.S. Geological Survey have voluminous chemical analyses, and fluid densities have been measured since the early 1900's. These data are for water from many depth intervals and cover the full areal extent of the brine. Analyses of the peripheral water are comparatively few, and these represent the well discharge that may be pumped from several zones of different quality.

Some additional data are available, if needed, but these data presumably will be of minor use during the proposed investigation. These data are described below.

Aquifer coefficients.--Porosity and specific-yield data for the brine aquifers are available from preliminary company records, but for the planned investigation these data will be of little or no use, because we assume that the fluid levels in the brine aquifers will be maintained at or near the lake surface, in accordance with management policy.

Aerial photographs.--Complete coverage of the basin is available for 1946, 1960, and 1966.

Land subsidence.--Chemical companies have leveling data on the lake surface for 1956 and 1972. Land-surface elevations at section corners determined by Mabey (1956) for the gravity survey, and bench marks leveled in about 1912 could be evaluated and rechecked if necessary, but such work is not planned as a part of the proposed study.

Additional Data to be Collected

As previously shown, many pertinent data required for the proposed study can be compiled from the previous studies and collected from the files of the chemical companies. In addition, the following are needed:

1. Water-level contour maps based on measurements of water level in wells throughout the peripheral aquifer. These data must be corrected for different water densities and then be related to the head in the brine aquifer, which also must be computed from water-level and density data. Contour maps must be prepared for at least two periods for use in verifying the basin model.

2. Long-term average annual ground-water recharge to the basin, and the distribution of the recharge, must be compiled. Few or no data are now available on which such estimates can be based. Measurements of channel geometry will be made at several sites to determine average-annual runoff (Hedman, 1970). Because data will undoubtedly be incomplete or unobtainable, the recharge estimates developed must be checked for consistency with other data by a trial-and-error procedure during model verification.

3. Water samples from selected wells for chemical analysis, including determination of stable isotopes of hydrogen needed to trace the source and flow of water in the system.

4. Estimate of the average annual surface-water runoff to the lake. This estimate is needed because one management alternative may be to permit the brine aquifer water level to be lowered below lake level and thereby make space available for storing surface water. Some recharge that otherwise would have to be pumped from the peripheral aquifers could be conserved in that case.

5. Pumping tests to determine aquifer transmissivity and coefficients of storage in the peripheral aquifers. These and other data are needed for compiling maps of aquifer parameters needed for modeling the basin.

6. Hydraulic conductivity between the peripheral and brine aquifers. These data are needed in order to simulate lateral ground-water flow in the model between the brine and peripheral aquifers, under assumed and observed pumping regimes.

7. Distribution of relative hydraulic head between the brine and peripheral aquifers. This information is needed for modeling the basin.

8. Test wells along the east and south sides of the lake in the peripheral aquifer. These wells are needed to determine the transmissivity, storage coefficients, and water-yielding characteristics of aquifers that might supply supplemental water needed if some alternative management programs are selected.

9. Geophysical logs, including formation density, neutron porosity, gamma ray-neutron, and electric.

10. Processing of selected data for computer manipulation.

Proposed Scope and Method of Investigation

Geohydrologic and Geochemical Analyses

The completion of this phase of the study would require 1½ years. The components of study include: (1) developing a water budget for the basin; (2) geohydrologic evaluation of the interrelations between the brine aquifers and the peripheral aquifers; (3) test-drilling program; and (4) hydrologic analysis and compilation of basin boundary conditions, aquifer parameters, recharge, and pumpage.

Analysis of the basin water budget includes (1) watershed rainfall-runoff correlations, (2) estimate of surface-water runoff to the valley floor and lake, (3) pattern and rate of pumping, (4) characteristics and rates of fresh-brackish water and brine evaporation from the lake surface and surrounding area, (5) subsurface inflow-outflow relations between the brine and peripheral aquifers, (6) patterns and rates of artificial recharge, and (7) fluid-level changes in the aquifers.

The analysis of the interrelations between the brine and peripheral aquifers would also include (1) geology along the common boundary; (2) characteristics such as thickness, hydraulic conductivity (permeability), and storage coefficient of the boundary zone area between the brine and peripheral aquifers; and (3) flow-pattern analysis, with fluids converted to a standard fresh-water head of density 1.000 g/ml.

A separate part of this phase of the study is an extensive test-drilling program intended for completion by a private contractor. Five test holes are proposed and tentatively located along the south and east sides of Searles Lake in the peripheral aquifers (fig. 11).

Well No.	Location	Estimated depth, in feet
1	Sec. 35, T. 26 S., R. 43 E.	1,000
2	Sec. 16, T. 27 S., R. 43 E.	1,000
3	Sec. 6, T. 25 S., R. 44 E.	500
4	Sec. 20, T. 25 S., R. 44 E.	500
5	Sec. 15, T. 26 S., R. 44 E.1/	500

1. Located on U.S. Navy property; permission to drill is required.

The purpose of the wells is to determine the areal extent, thickness, and water-yielding characteristics of the peripheral aquifers in the area of testing. The availability of sufficient water from the peripheral aquifers is fundamental to the continued mining of brine from the lake. The test-drilling program includes:

1. Drilling with rotary rig an 8-inch diameter pilot hole to the desired depth.

2. Running geophysical logs, including electric, gamma-gamma, neutron, and others, to determine aquifer geohydrologic characteristics and aid in proper design of the proposed production wells.

3. Reaming out pilot hole to 22-inch diameter and setting 14-inch diameter steel casing, perforating selected intervals.

4. Gravel packing well between 14- and 22-inch diameter annulus.
5. Installing large-capacity pump.
6. Test pumping for 48 hours.
7. Collecting water samples.
8. Analyzing drill and pump-test data.

Model Studies

A review of the water-management problems and hydrologic data available in Searles Valley indicates that the objectives of water users and managers probably cannot be achieved unless a model of the ground-water basin is developed as a tool for testing the feasibility of alternative management programs.

The basic approach proposed is the simulation of ground-water flow utilizing mathematical flow equations and a data base to be generated when completing the proposed geohydrologic and geochemical study. In Searles Valley the peripheral and brine aquifers are largely independent of each other because of geologic boundaries and fluid density. The purpose of modeling the peripheral aquifer is to predict the basin-wide water-level response in the aquifer and the extent of continued water-level declines, particularly at Valley Wells and along the west side of the lake, and elsewhere, under proposed future pumping. Modeling the brine is not considered because the system is maintained nearly full and only local circulation occurs.

The second stage of model development, water-quality modeling, might eventually be needed but is not considered to be needed now and is not considered in this report.

For the studies proposed, and to meet the previously stated management objectives for the basin, a two-dimensional flow model of the Searles Lake area will be needed. The model will consist of data and elements about as illustrated in the schematic shown in figure 10. Fundamentally, the brine aquifer will be held at a constant head, water flow between the brine and peripheral aquifers will be simulated by an appropriate leakance network, and water-level changes in the peripheral aquifer will be simulated in the model. As stated earlier, the water supply from the peripheral aquifer is of primary concern.

This phase of the study will require 1 year after the initial analysis is completed.

Work Schedule of the Study

The work schedule is divided into two major divisions. Phase I is the geohydrologic and geochemical analysis of Searles Valley, subdivided into two parts--appraisal and test drilling. A professional hydrologist would be assigned full time to the geohydrologic and geochemical appraisal, supplemented by technicians for specific short-term assignments. This work will require about 1½ years.

The test-drilling program would be supervised by a well-drilling specialist of the Geological Survey; this will require about 6 months.

Phase II involves completing the mathematical flow model of the Searles Lake basin and will require 1 year. All proposed studies are contingent on availability of trained personnel.

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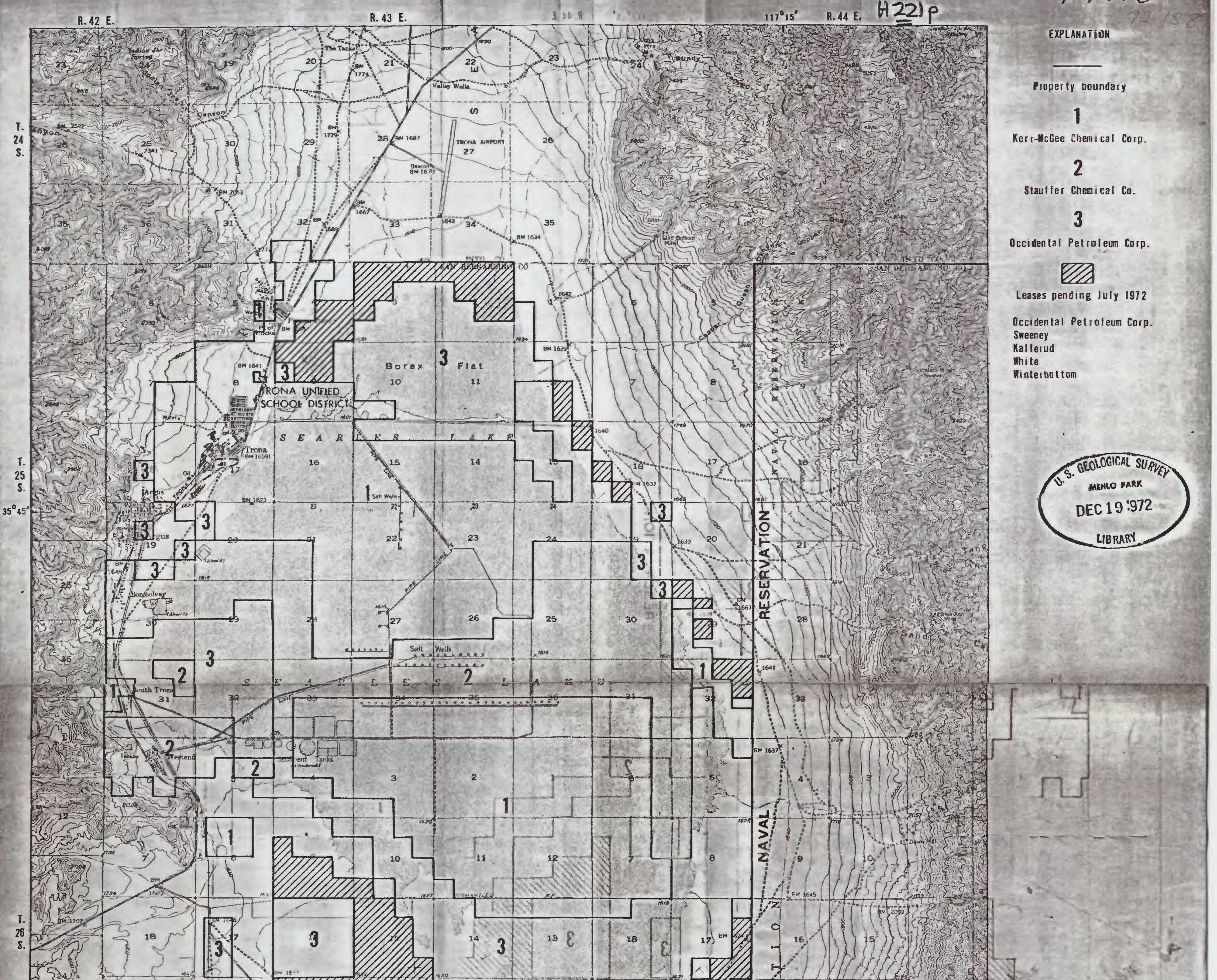
(200)
H221p

FIG. 3



Base from U.S. Geological Survey Searles Lake 1:62,500, 1949; Trona 1:62,500, 1949; Manly Peak 1:62,500, 1950; and Wingate Pass 1:62,500, 1950

Unpublished data from U.S. Geological Survey and U.S. Bureau of Land Management

FIGURE 3.--Property location.

(200)
H221p

FIG. 4
SHEET 1

FIGURE 4.—Geologic section.

(200)
H221p

FIG. 4
(CONT'D)
SHEET 2

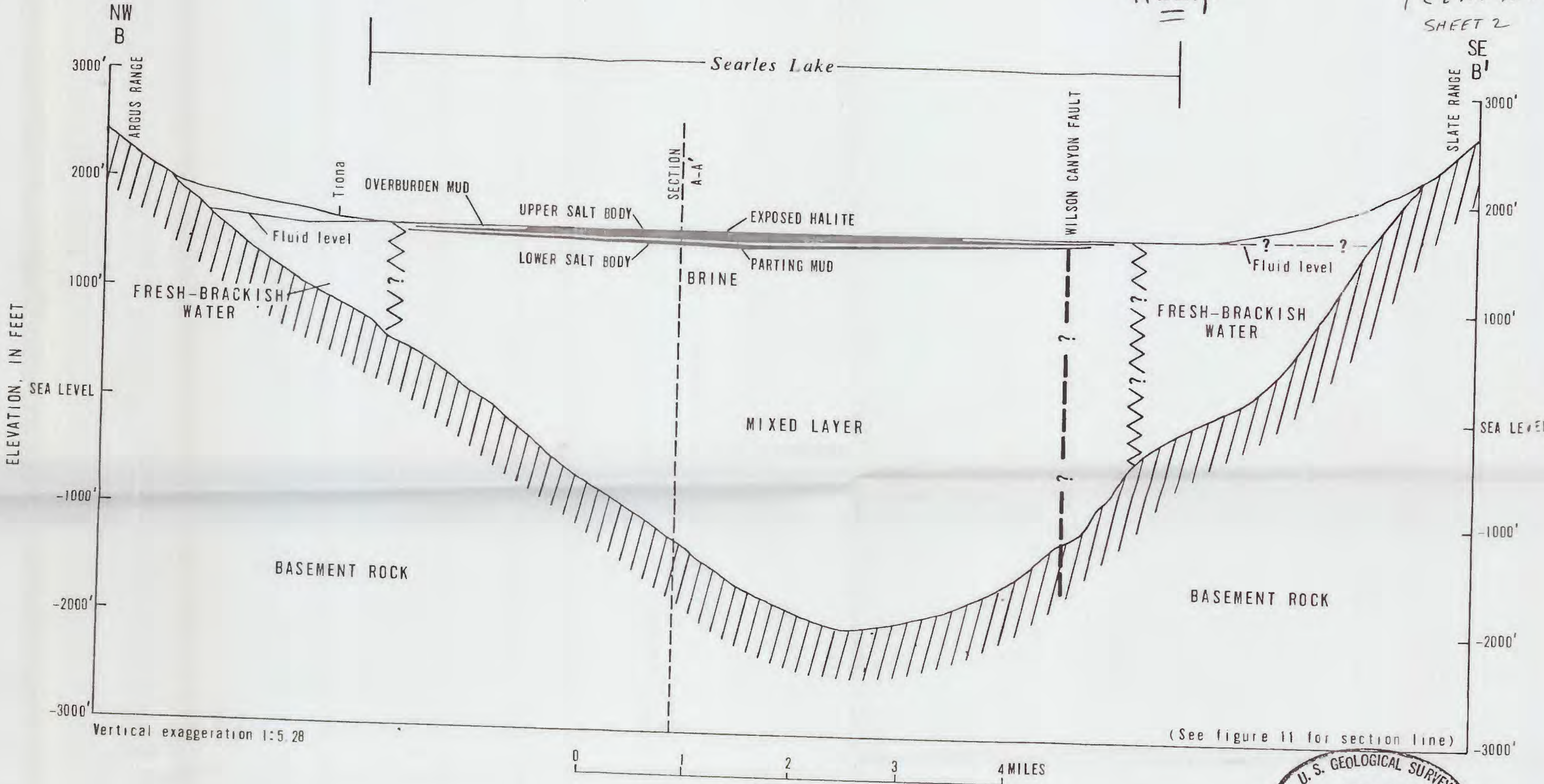
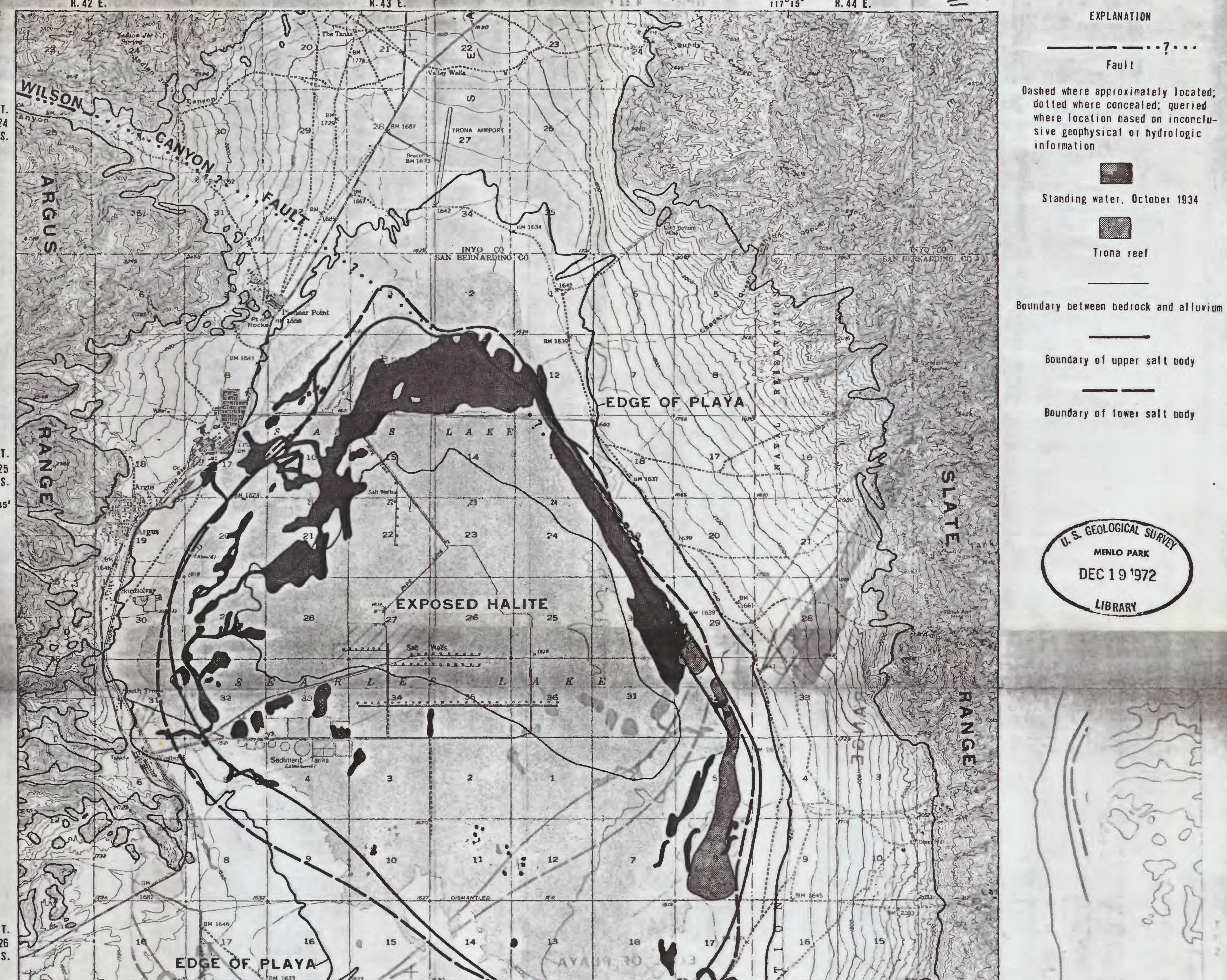


FIGURE 4.--Continued

(200)
H221p

FIG. 6



Base from U.S. Geological Survey Searles Lake 1:62,500, 1949; Trona 1:62,500, 1949; Manly Peak 1:62,500, 1950; and Wingate Pass 1:62,500, 1950

Geology from W.R. Moyle, Jr., (1969); salt boundaries from D.V. Haines (1959, pls. 5 and 6). Unpublished data from U.S. Geological Survey and Kerr-McGee Chemical Corp.

FIGURE 6.--Geohydrologic conditions, 1934.