A SURVEY OF THE SUBSURFACE SALINE WATER OF TEXAS

VOLUME 1

October 1972
TEXAS WATER DEVELOPMENT BOARD

REPORT 157

A SURVEY OF THE
SUBSURFACE SALINE
WATER OF TEXAS

VOLUME 1

October 1972

Prepared by CORE LABORATORIES, INC.
Consulting & Engineering Department, Dallas, Texas
under contract for the
Texas Water Development Board

Published and distributed
by the
Texas Water Development Board
Post Office Box 13087
Austin, Texas 78711

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FOREWORD

Texas has substantial saline and brackish ground-water resources which are amenable to desalting for the production of additional fresh water supplies. Although desalting is a relatively new technology, desalted water is presently being used, as of early 1972, by three Texas cities for all or part of their water supply, and industrial desalting plants are in operation in at least 25 locations. Additional plants are currently being considered or planned for construction. Also, some additional improvements that are expected in the desalting processes and techniques will allow higher efficiencies at lower operating costs. Desalting, then, has a very significant place in supplying part of Texas' future water needs.

This report provides a basic reference to the occurrence, availability, and quality of saline and brackish ground-water resources as part of the statewide inventory of ground-water resources. The information and data are expected to be particularly useful in future feasibility studies concerning cities and other water users having a potential for meeting their fresh-water requirements through desalting.

The complete report has been prepared in eight volumes. Volume 1 includes a descriptive inventory of the principal saline aquifers and their characteristics, and more than 100 geologic maps and sections which illustrate aquifer location, thickness, structure, and salinity.

Volumes 2 through 8 consist entirely of computer-listed tables of supporting basic data. These will not be needed by most readers, but will be useful to those making detailed studies of local areas. Accordingly, these tabulations have been published in smaller quantity for distribution to parties specifically requesting them after receipt of Volume 1. Contents of the basic-data volumes are as follows:

Volume 2—Chemical Analyses of Saline Water
Volume 3—Aquifer Rock Properties (porosities, permeabilities, ideal specific flow rates)
Volume 4—Geologic Well Data—West Texas (formation depths in wells, thicknesses, lithologies)
Volume 5—Geologic Well Data—Panhandle
Volume 6—Geologic Well Data—Central Texas
Volume 7—Geologic Well Data—East Texas
Volume 8—Geologic Well Data—Gulf Coast

The statewide reconnaissance investigation and preparation of the eight-volume report were accomplished under contract by Core Laboratories, Incorporated. The Water Development Board believes the report to be a major contribution to the body of information required for adequate water development and management in Texas, and expresses its appreciation to Core Laboratories, Incorporated for completion of the project within severe time constraints. Work commenced August 1, 1970, and the report was completed September 1, 1971.

TEXAS WATER DEVELOPMENT BOARD

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Executive Director
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A SURVEY OF THE SUBSURFACE SALINE WATER OF TEXAS

INTRODUCTION

Purpose and Scope

This report presents the results of an investigation of the major saline aquifers of the State of Texas. It was done by Core Laboratories, Inc., for the Texas Water Development Board in fulfillment of a contract dated August 1, 1970.

The purpose of the study was to make a reconnaissance and inventory of the principal saline aquifers of the State. The ultimate use of such an inventory is to serve as a basic reference to the occurrence and availability of large quantities of subsurface saline water that could be utilized in future desalting operations. The study was conducted and has been presented in three basic parts: the salinity of the aquifers, the productivity of the aquifers, and the geology of the aquifers.

The work is intended to provide the Texas Water Development Board with a means of determining which aquifers, if any, are present in all regions of the State that would satisfy the requirements of large-scale desalination. Through the application of the basic data and interpreted geology presented in the three parts of the study, the depth, thickness, and areal extent of aquifers along with their salinity and ideal producing capacities can be determined. From the use of all these data, potentially productive areas can be predicted and more detailed studies can be outlined.

Definitions and Limitations

Saline water, as defined in this report, is water having more than 3,000 parts per million (ppm) of total dissolved solids. In some cases, aquifers were mapped beyond this limit due to lack of control that would allow the establishment of a 3,000-ppm boundary line. The Triassic Santa Rosa Formation of West Texas is known to have in places an average salinity below the 3,000-ppm range, but not enough data exist to delineate fresh water from saline water on a regional scale. Therefore, the aquifer was mapped throughout its entire extent in West Texas.

The productivity limit of aquifers used in the project was a minimum of 100 gallons of water per minute. Again, certain formations were doubtlessly mapped beyond this limit because of lack of data on a regional scale. The maps of the various aquifers presented in this report represent an interpretation of the producing capabilities of the formations based on known reservoir characteristics and extrapolated geology.

No recommendations on the use of water from any aquifer or in specific areas are given in this study. Certain formations that produce large quantities of oil, such as the Woodbine Formation, contain large quantities of saline water. Obviously, formations containing large quantities of oil are not likely to be suggested for use as saline-water sources. All formations in this investigation have been studied in the same manner, regardless of their present or future potential as an oil reservoir. Likewise, no attempt has been made to determine the economic feasibility of utilizing brine from one aquifer in preference to another. In other words, there has been no attempt to rate the aquifers. Tertiary formations in the Gulf Coast have been mapped to the shoreline, even though the sea would provide a more readily available source of brine.

Aquifers in this investigation have been grouped or mapped as larger, more widespread geological units. For example, in central Texas, various smaller aquifers consisting of thin but productive units are found within larger, more widespread geological units. For instance, in the Elderhouse formation, different parts of the state have different aquifer characteristics and extrapolated geology.

The area considered in this investigation was the entire State of Texas. Aquifers were systematically studied and mapped on a regional basis. No single aquifer covers the entire State, but some such as the Elderhouse formation have widespread extent. The data available for use in this study comes from areas heavily drilled by oil wells and oil tests. Drilling is sparse or nonexistent in wide areas of Trans-Pecos Texas and over the Llano uplift and therefore only a minor amount of well control is available there. Figure 1 is a location map showing the major geographical and geological features of the State.

Location

The most comprehensive work concerning saline aquifers of Texas was on a state-wide basis in a "Saline-Water Resources of Texas" by A. S. Wilkinson and L. R. Kaiser. This paper, published as U.S. Geological Survey Water-Supply Paper 955, gives a brief description of the aquifers and includes local maps in the oil-producing areas. The work was not feasible in this study because of the lack of data. The report discusses saline areas extensively and includes small-scale maps on the geographic extent of saline producing formations and tables of basic water data. Lithium, well yields, and water-quality data are discussed.

More publications of the Texas Water Development Board relate to aquifers in the State. These reports are generally on a...
This investigation of the saline aquifers of Texas has been organized into three general or phases of study: the occurrence of the major saline-water sources throughout the State; the depth, thickness, and areal extent of the major saline-water formations; and the salinity inventory of the State. The uses of a compilation of this type are many. Its principal value is in the future production of formation waters within a given rock mass. The result of the tabulation and calculation of water salinity data is the computer output of the salinity inventory of the State as a whole. The result of the tabulation and calculation of water salinity data is the computer output of the salinity inventory of the State as a whole.

**Table 1—Sources of Salinity Data**

<table>
<thead>
<tr>
<th>Source of Data</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water Quality</strong></td>
<td>Assays of waters from the oil-producing formations, all of which were tested in the laboratories of the Texas Water Development Board and the Department of Geology, University of Texas, with the exception of the samples from the Wolfcamp rocks, which were tested in the laboratory of the Petroleum Institute.</td>
</tr>
<tr>
<td><strong>Chemical Analyses of Waters from the Wolfcamp Rocks</strong></td>
<td>Assays of waters from the Wolfcamp rocks, Williamsburg Formation, and Wolfcamp Formation, by R. Kister and W. C. Dietzman, and C. A. Pearson, respectively, in the laboratory of the Petroleum Institute.</td>
</tr>
<tr>
<td><strong>Chemical Analyses of Waters from the Marine Beds</strong></td>
<td>Assays of waters from the Marine beds, by R. Kister and W. C. Dietzman, and C. A. Pearson, respectively, in the laboratory of the Petroleum Institute.</td>
</tr>
</tbody>
</table>

**Personnel**

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Richard H. Snyder</td>
<td>Supervising Geologist</td>
</tr>
<tr>
<td>Paul A. Messinger</td>
<td>Laboratory Analyst</td>
</tr>
<tr>
<td>Will miam D. Dowrey</td>
<td>Engineer</td>
</tr>
<tr>
<td>Frank D. Geisler</td>
<td>Geologist</td>
</tr>
<tr>
<td>Paula A. Messinger</td>
<td>Geologist</td>
</tr>
<tr>
<td>Peter Scott</td>
<td>Geologist</td>
</tr>
</tbody>
</table>

**PRESENTATION OF DATA**

This investigation of the saline aquifers of Texas has been organized into three general or phases of study: the occurrence of the major saline-water sources throughout the State; the depth, thickness, and areal extent of the major saline-water formations; and the salinity inventory of the State. The uses of a compilation of this type are many. Its principal value is in the future production of formation waters within a given rock mass. The result of the tabulation and calculation of water salinity data is the computer output of the salinity inventory of the State as a whole.

**Wells**

In the productivity phase of the study, a large amount of porosity and permeability data were compiled and these data were divided by formation and country (Volume 2). Average flow rate values have been calculated, and the resulting average flow rate values are given in a given country analysis. A monograph is provided in this report from which rock property and salinity data may be compiled.

The geologic portion of the study provides an investigator with maps of the major saline-water-bearing formations throughout the State. The depth, thickness, and areal extent of aquifers are readily determined by the use of these maps. The maps are used in the construction of the maps were taken from 1,000 well logs. A computer listing of geological

**Data Quality, Averaging, and Use**

In conjunction with tabulation of chemical compositions of these saline waters, salinity maps have also been prepared. The hydrologic and chemical properties of these saline water systems were correlated with the computer listing data and are discussed later. These maps illustrate the geographic or salient variation of formation waters within a given rock mass. The result of the tabulation and calculation of water salinity data is the computer output of the salinity inventory of the State as a whole.

**Data Sources**

Investigation of rock properties of subsurface strata that contain saline water is normally limited to oil and gas exploration. Therefore, data available outside oil company files are limited to traditional empirical methods of evaluation. These methods of evaluation were obtained through the Texas Railroad Commission and the Texas Water Development Board. The general data are given in the form of charts, sorted, and grouped into geologic units for water quality data. A total of 2,400 individual saline-water samples are given in the computer listing. Although this is a large number, many aquifers are not adequately represented, and conversely, several of the oil-producing formations have abundant data. The imbalance in the distribution of samples is due to the occurrence of the major saline-water sources in small horizontal and vertical units. When one formation is a prolific producer of oil and gas, there will be a large number of samples. For example, the San Andres of West Texas will have a large concentration of samples in fields, and very few samples outside of producing fields. As a result of the practice of testing formation water in fields in West Texas and in many other areas, the data are very abundant relative to the total wells.

The same situation applies to nonproducing formations as a whole. These formations, which are less prolific, are naturally not so well represented as the major oil-producing formations. There is undoubtedly a great amount of additional salinity data in existence in oil company files that could be made available for study. These files, however, would need substantial time and money, and the expected results would probably not justify the effort. The result of the tabulation and calculation of water salinity data is the computer output of the salinity inventory of the State as a whole.

**Productivity Data**

The permeability and productivity measurements of a reservoir rock is a basic requirement in evaluating its storage and productivity capacities. Therefore, determine these properties for the potential aquifers comprised an integral part of the study, each county was defined as an areal unit. These units were then grouped into geological, series, and group, respectively, which the sample represents. This sampling is expected to reduce these numbers to one meaningful average which can be used to describe the reservoir rock. Both the basic data used and the conclusions drawn are reviewed in order to judge the reliability of the data generated.

**Data Source**

It is a statistical interest to define the scope or “universal” in which data are collected and averaged. For this study, an areal unit is defined as a county or a unique geological unit as defined by a mappable geological unit of similar rock.

The number of data points used to obtain an average within themselves is not dependent according to availability of data. Therefore, the output is designed to show the amount of data used to obtain an average as well as the variation among the data points.

**Sources of Data**

Investigation of rock properties of subsurface strata that contain saline water is normally limited to oil and gas exploration. Therefore, data available outside oil company files are limited to traditional empirical methods of evaluation. These methods of evaluation were obtained through the Texas Railroad Commission and the Texas Water Development Board. The general data are given in the form of charts, sorted, and grouped into geologic units for water quality data. A total of 2,400 individual saline-water samples are given in the computer listing. Although this is a large number, many aquifers are not adequately represented, and conversely, several of the oil-producing formations have abundant data. The imbalance in the distribution of samples is due to the occurrence of the major saline-water sources in small horizontal and vertical units. When one formation is a prolific producer of oil and gas, there will be a large number of samples. For example, the San Andres of West Texas will have a large concentration of samples in fields, and very few samples outside of producing fields. As a result of the practice of testing formation water in fields in West Texas and in many other areas, the data are very abundant relative to the total wells.

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**Data Grouping Technique**

Before statistical averaging can be applied, the data must be grouped so that similar quantities are being compared. For this study, each county was defined as an areal unit. These units were then grouped into geological, series, and group, respectively, which the sample represents. This sampling is expected to reduce these numbers to one meaningful average which can be used to describe the reservoir rock. Both the basic data used and the conclusions drawn are reviewed in order to judge the reliability of the data generated.

**Data Averaging**

To average rock properties of similar type, four basic statistical methods are normally applied. Each method has its own similarity rocks which might be meaningfully averaged. This division becomes the vertical unit of grouping and the second sorting sequence in the program. A total of 2,400 individual saline-water samples are given in the computer listing. Although this is a large number, many aquifers are not adequately represented, and conversely, several of the oil-producing formations have abundant data. The imbalance in the distribution of samples is due to the occurrence of the major saline-water sources in small horizontal and vertical units. When one formation is a prolific producer of oil and gas, there will be a large number of samples. For example, the San Andres of West Texas will have a large concentration of samples in fields, and very few samples outside of producing fields. As a result of the practice of testing formation water in fields in West Texas and in many other areas, the data are very abundant relative to the total wells.

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**Arithmetic Average**

The arithmetic average is commonly called the “average” number. It is defined as the sum of the individual values of a set of numbers divided by the number of such values. The mathematical equation as applied to permeability is
Rock property data are reported completely on each individual sample to give maximum flexibility to the user. Each sample point is listed under the geological unit in which it was grouped. Additionally, all rock groups are tabulated under the appropriate country or state unit which they represent.

The individual sample points give the local geological name, location and depth of the sampling point, and average rock properties. With these data, the user is free to soar and apply only that information most pertinent to the problems at hand.

Idéal Specific Flow Rate

The ideal specific flow rate for each rock group has been included to give the user a reference for comparisons of flow potential of the water aquifer under study. To prevent misunderstanding of terms and subsequent misappropiation of these values, a detailed explanation is required.

Ideal flow for a porous and permeable medium is described in this report as the application of Darcy’s radial flow equation to the rock properties determined in the study. Mathematically, the equation applied to single-phase flow of an incompressible liquid is:

\[ Q_i = 
\frac{27.665Pe}{K_{geo}d_i^2} \]

where \( Q_i \) = ideal flow rate in gallons per minute (gpm); \( P_e \) = pressure or producing bottom hole pressure in psi; \( K_{geo} \) = geometric average permeability; \( d_i \) = bed thickness in feet; \( P_{w} \) = static aquifer pressure in psi; \( P_{w} \) = producing bottom hole pressure of aquifer in psi; \( P_{r} \) = external drainage radius in feet; \( P_{a} \) = static aquifer pressure at a, in pounds per square inch gauge (psig); \( \mu \) = viscosity of water in centipoises (cP); and \( n \) = natural logarithm.

The equation was modified from the above expression by arbitrarily setting the thickness value to unity, thereby making the flow rate expression gpm per square feet per thickness of thickness. The flow described therefore becomes real flow rate one, which allows the user more flexibility in its application. Other terms in the equation are expressed in the following paragraphs.

Permeability

The mode value average of air permeability was considered to be the permeability to water in the calculation of ideal specific flow rates. This assumption is valid when applied regionally to areas where large rock volumes are being described. However, in this application the user should be aware that there is no element of risk in applying such readily available data as air permeability alone in attempting to characterize reservoir flow. Variations in sorting, cementation, and other factors which affect porosity of a rock system also affect the accurate measurement of relative permeability. Therefore, for specific applications where accurate flow calculations are required, the relative permeability must be a laboratory-measured value.

Table 2 - Viscosity of Water as a Function of Temperature

<table>
<thead>
<tr>
<th>Temperature, °F</th>
<th>VISCOSITY, cP</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.79</td>
</tr>
<tr>
<td>50</td>
<td>1.21</td>
</tr>
<tr>
<td>70</td>
<td>1.00</td>
</tr>
<tr>
<td>90</td>
<td>0.80</td>
</tr>
<tr>
<td>110</td>
<td>0.65</td>
</tr>
<tr>
<td>130</td>
<td>0.59</td>
</tr>
<tr>
<td>150</td>
<td>0.57</td>
</tr>
<tr>
<td>170</td>
<td>0.56</td>
</tr>
</tbody>
</table>

In this manner, temperature changes due to heat and elevation were considered. Again it is meant that these temperature calculations are regional in nature and a measured temperature is required for specific application.

Monograph

A monograph of Darcy’s Law as applied in this study has been included to assist the user in changing any variable in the equation (Figure 2). This is necessary due to the regional nature of the assumptions made for calculating the ideal specific flow rate. With more accurate data available in a specific area, accurate calculations can be readily made with this monograph.

To assist the user, an example of an ideal specific flow rate calculation is given at the right of the monograph. The following steps demonstrate this example.

1. Begin Step 1 with depth of the aquifer. These may be actual depths from well data or depths estimated from structural contour maps. For this example, assume an aquifer depth of 52.360 ft.

2. Proceed to Ps, static aquifer pressure through SP, GR. (specific gravity). Static aquifer pressure is in pounds per square inch gauge (psig) + 1.0 x 1000, and specific gravity can be found in the chemical analyses, Volume 2. It can be obtained through outsource sources. For this example, use 1.050.

3. In Step 2, proceed from Ps through Pw (producing bottom hole pressure) to calculate 20 percent of the
Figure 2
Nomograph for Calculating Ideal Specific Flow Rate

For lower permeability calculations, scale A can be reduced by a factor of 10 or 100 if desired. This will reduce answers on scale B and C by an equal factor.

EXAMPLE: Calculation above for V = 35.52 cfs. Scale C = 1.5520 would be reduced to 0.1552 with resulting answers on scale B of 6.66 GPM/FT and 0.066 GPM/FT, respectively. Answer on scale C would be 0.165 and 1.51 GPM, respectively.

For this zone calculations, scale B can be reduced by a factor of 10 or 100 if desired. This will reduce answers on scale C by an equal factor. Conversely, scale B can be increased by a factor of 10 for handling higher zones.

EXAMPLE PROBLEM
WOODBINE FORMATION
ANDERSON CO., TEXAS

GIVEN
1. Darcy's Law
2. SCALE 'A'
3. SCALE 'B'
4. SCALE 'C'

WHERE

D = IDEAL FLOW RATE, GPM
F = EFFECTIVE FLOW RATE TO WATER, GPM
B = IDEAL THICKNESS, FEET
P = IDEAL FLOW RATE, GPM
W = WATER FLOW RATE, GPM
P = MAXIMUM FLOW RATE, GPM
S = WELL BORE RADIUS, FEET
L = NET BORE (CALC.)

OTHER DATA

WELL BORE DIAMETER = 1 FOOT
AVG. BORE HOPE = 5,000 LBS/F
(See literature rock properties)
AVG. BORE VARIOUS HOPE = 4,500 LBS/F
(See literature rock properties)
AVG. BORE PROD. PRESSURE = 4,500 LBS/F
(See literature rock properties)
AVG. BORE PUMP PRESSURE = 4,500 LBS/F
(See literature rock properties)
AVG. BORE TEMPERATURE = 1,250 FT
(See literature data)
AVG. BORE TEMPERATURE = 1,250 FT
(See literature data)

EFFECTIVE ZONE THICKNESS = 500 FEET (See literature data)

REQUIRED: 1. IDEAL SPECIFIC FLOW RATE and 2. IDEAL FLOW RATE

SOLUTION
1. START AT STEP 1 AND PROCEED THROUGH STEP 4
2. DETERMINE V. USE SCALE A AND SCALE B FOR IDEAL FLOW RATE
3. DETERMINE V. USE SCALE B AND SCALE C FOR IDEAL FLOW RATE
4. DETERMINE IDEAL FLOW RATE FROM STEP 5 - 1,000 GPM

- 4 -
5. Averages which have been previously discussed, and are sorted by geological formation, using the county as the areal unit for volume. These data provide a large selection of porosity and too, average rock property data. Lithological changes, faulting, and folding can be drastic in certain regions, thus rendering county-averaged data inaccurate. Then local and regional geology and results should be used in a synthesis of the geology. To conform with the geology as

4. 6. Begin the advantages and disadvantages of these sorting and permeability scale to the pivot isopachous maps or by other sources. For this example, use 8.56.

5. For the ideal flow rate proceeded in Step 6 from ideal flow rate through to the ideal flow rate. Bed thickness can be determined through the use of isopachous maps or by other sources. For this example, use 300 feet.

Results of Productivity Phase of the Study

The results of this phase of the study are given in the computer-calculated summary of aquifer rock properties (Volume 3). The rock properties are presented by the various areas which have been previously discussed, and are sorted by geographic formation, using the county as the areal unit for volume.

The advantages and disadvantages of these sorting techniques have been discussed in the previous section. Some of these factors are also discussed in the results section. The geologist also need some explanation. The most obvious advantage is to be able to compare closely the areal distributions of the producing areas, and to be able to compare the productivity of different areas. One advantage is that the areal production of these rocks on a regional or group basis within the area of one county. As a result, the drawbacks or disadvantages of using average data, one of the neat aspects is that the samples taken from producing zones of a formation may not be representative of that formation as a whole. Only those samples from a single level, lithological changes, faulting, and folding can be drastic in certain regions, thus rendering county-averaged data inaccurate. Then local and regional geology and results should be used in a synthesis of the geology. To conform with the geology as

Geologic Data

Well Data

The basic geologic data used in this investigation have been obtained from electrical and other maps of oil (Figure 5) and from the statistical data of the commercial mapping service used during the project. This data includes the number of wells and the number of acres within each county, the shale is used in the well data, which was provided at the beginning of each well data book. The well data books are separate volumes to this report, as follows:

- **Texas:** (Volume 4)
- **Panhands:** (Volume 6)
- **Central Texas:** (Volume 7)
- **East Texas:** (Volume 8)
- **Gulf Coast:**

Isopachous maps

Isopachous thicknesses were prepared for nearly all major aquifers in the State. These maps are of three types: gross unit thickness maps, net aquifer thickness maps, and net sand thickness maps. Gross and net sand thickness maps in constant-layer intervals (Gulf Coast only).

Net thicknesses of aquifers were mapped for those formations having good quality electric log responses. Most of the principal aquifers in the State, East Texas and the Gulf Coast sands are accurately and easily mapped as net aquifer thickness. Most carbonates, particularly those with varying proportions of evaporites and chert, give poor log response, and are therefore not amenable to net/pes ratio. Most of the carbonate units in West Texas occur in this condition and were consequently mapped as gross unit thickness. The Pennsylvanian of West and central Texas, net aquifer thicknesses were determined from logs but these net values include a variety of lithologies. Pennsylvanian aquifers consist of sandstones, bioclastic and bioturbational, limestones, and occasionally thin dolostones, all of which alternate with shales. The net aquifer thicknesses which is used on the isopachous map is a total of the different lithological members and does not indicate the percent of each lithology relative to another. It only shows how many "clean" rocks or potentially porous aquifer is present in the well.

Salinity Maps

The data for salinity maps were taken from the summaries of chemical analyses of saline water (Volume 2). Data points used to construct the maps are designated different points. Ways for which salinities were obtained from reported data, either from company's analyses or water reservoirs with the aid of references to published data. These maps are shown on the location map, Figure 1. They are diagrammatic, small, and show in categories to construct the maps are designated in different ways. Points for which salinities were obtained from reported data, either from company's analyses or water reservoirs with the aid of references to published data. These maps are shown on the location map, Figure 1.

Structural Maps

With few exceptions, structural contour maps were prepared for all the principal salinae aquifers in the State. These maps depict regional structure on top of the aquifer. The contour interval is 10 feet, and in areas of severe faulting, the contour interval is 20 feet where possible. Some individual structures although poorly controlled areas were mapped with the aid of references to published data. Faults are plotted on the maps, and these were tied into the cross-section data book. The data for salinity maps were taken from the summaries of chemical analyses of saline water (Volume 2). Data points used to construct the maps are designated different points. Ways for which salinities were obtained from reported data, either from company's analyses or water reservoirs with the aid of references to published data. These maps are shown on the location map, Figure 1.

Contour intervals on the salinity maps are variable depending on the availability of data and are shown as red, brown, or pink. This is limited to a single quadrant, it was necessary to construct the maps are designated in different ways. Points for which salinities were obtained from reported data, either from company's analyses or water reservoirs with the aid of references to published data. These maps are shown on the location map, Figure 1.
The West Texas region was subjected to erosion. Yet another shale accumulated in the Delaware and Val Verde basins. Limestones, while the Montoya is a limestone with considerable limestone of the Mississippian have been mapped in this study.

Two upper Ordovician formations. The Simpson is a shale with marine invasion and subsequent deposition of limestone and evaporite deposits in the Arbuckle and Appaloosa basins. This formation is represented by a thin shale and limestone. Another subsidence occurred at this time in the Arkansas basin, represented by a thin shale and limestone. Another subsidence occurred at this time in the Arkansas basin, represented by a thin shale and limestone. Another subsidence occurred at this time in the Arkansas basin, represented by a thin shale and limestone.

The last marine invasion took place in Tertiary time when very shallow water spread over the region. Additional continental deposition occurred during Pliocene and Quaternary times, producing the Pleistocene and continental deposits.

The following chart illustrates the geologic units that have been mapped as aquifers in the West Texas Area. Structure maps have been constructed for all units listed.

The East Texas Area was arbitrarily divided in this study in order to make individual aquifer units present in the East Texas embayment. The area occupies the north central portion of the region and is approximately a line from Dallas to Waco to north Austin. The southern limit is a quite arbitrary, but is drawn south of the course of the Brazos River. Except for the deep Jurassic aquifers (which are limited to the Gulf Coastal Plain) and some contain fresh water, the East Texas area is a Cretaceous province.

The chief structural features are the Sabine uplift and the Edwards aquifer. The area is divided into two main subunits, the Gulf Coastal Plain, and the Edwards aquifer. The Edwards aquifer is the major source of fresh water in the East Texas area.

Little is known of the Paleozoic history in East Texas, especially west of the Ouachita fault belt, since those Paleozoic sediments adjacent to the Ouachita tectonic belt are metamorphosed, and no sediments older than Jurassic have been penetrated in the East Texas embayment. Early Jurassic sea level appears to have been both open marine and restricted. The restricted marine conditions resulted in the deposition of salt and anhydrite. During the Cretaceous, gradual but continuous subsidence occurred. The structure map of the Pennsylvanian in areas C, D, and F coincides with the Pennsylvanian or Mississippian structural features and is grouped in their respective age equivalents. A structure map of the top of the Pennsylvanian Series was also constructed in order to conform to and extend the mapping of the Pennsylvanian in West Texas. Following the Pennsylvanian, Permian rocks were deposited over most of central Texas. Subsequent uplift and erosion removed much of the topography. The last marine invasion was during Tertiary time when shallow marine and coastal marine conditions prevailed. The Cretaceous rocks thinned and southward from the central Texas area.

The following units have been mapped as aquifers in central Texas:

\[
\begin{array}{|c|c|c|c|c|c|}
\hline
\text{GEOLOGICAL \ FORMATION} & \text{TYPE OF AQUIFER} & \text{LITHOLOGY} \\
\hline
\text{Triassic} & \text{NET SAND} & \text{LITHOLOGY} \\
\hline
\text{Permian} & \text{NET SAND} & \text{LITHOLOGY} \\
\hline
\text{Cretaceous} & \text{NET SAND} & \text{LITHOLOGY} \\
\hline
\end{array}
\]

The Gulf Coast area was arbitrarily subdivided to include the Gulf Coastal Plain. To the Gulf Coast, it is divided into two Cretaceous aquifers that each contain the anhydrite and sand/shale intervals. The Gulf Coastal Plain, the Edwards aquifer, and the Cretaceous aquifer, are divided into two main subunits, the Gulf Coastal Plain, and the Edwards aquifer. The Edwards aquifer is the major source of fresh water in the East Texas area, and contains some of the most productive, limestone, and sandstone aquifers. Structure maps are grouped in the separate age equivalents for this aquifer, Figures 13, 14, 15, 16, and 17, respectively.

The Gulf Coast Group is the most widespread of all the aquifers in the State of Texas. The aquifer or one of its age and facies equivalents occurs in wells as far south as Kenedy and Edwards Counties, to as far north as the Oklahoma boundary in the Texas Panhandle. It is also known from as far east as Grasston County, in the subsurface, to its equivalent form occurrence in the Gulf of Mexico. The Gulf Coast aquifer contains the important coastal aquifer at Zavalla, Texas, located at the mouth of the Mississippi River, with a thickness of more than 600 feet. The Edwards and Andrew aquifers are relatively thin and discontinuous, and in smaller uplifts of that region. It is not recognizable south and north of the Edwards aquifer, and is also absent along the continental shelf and over a wide portion of the Panhandle. It is absent due to the relatively shallow water over a wide portion of the continental shelf. As an aquifer containing water of 3,000 ppm total dissolved solids, the Gulf Coast Edwards aquifer is mapped in one of its continental shelf sections for the area of the Gulf of Mexico, where the 3,000 ppm salinity boundary is the upturn.

Several important regional structural trends affect the Edwards aquifer, as well as numerous minor and local structural elements. The most important regional structural trend is the Ouachita fault zone, which extends West from Delwarea-Val Vete, Antiloma, Fort Worth, and Nodle plains. Important regional and local structural elements include the Cretaceous tectonic belt, the Amarillo and Montoya uplifts, the Capitan reef, the Central Texas basin, and the Llano uplifts.
Texas to more than 2,000 feet in the Panhandle. Productivities from both actual and ideal maps, Figures 13 and 14, indicate that porosities and permeabilities average 5 to 10 percent respectively. The Montoya would be expected to have a wide range of regional facies. Surrounding the Central Basin platform is the oldest to youngest, Kinderhook, and the Pre-Cambrian rocks are found at elevations greater than 2,000 feet above sea level in outcrops in the Van Horn and El Paso areas, respectively. The Pennsylvanian rocks are found at elevations ranging from 2,000 to 3,000 feet subsea in the Delaware basin. It is now suggested that the influent of meteoric waters from outcrops of that region.

Rocks of the Bend aquifer cover most of the study area and are comprised of shale with minor sandstones. The Pre-Silurian rocks are absent in the southern part of the study area, which includes the Oxfordian, Mississippian, and Pennsylvanian rocks, and consists of dolomite, limestone, and chert. The Montoya is primarily of shale with thin but widespread beds of sandstone and limestones. The porous members are oil productive in West Texas, and the Panhandle and consists of dolomite, limestone, and chert. The structure map, Figure 26, is contoured on top of the Mississippian regardless of age or lithology.

Mississippian rocks are divided into four series which are, oldest to youngest: Flemish, Blackwelder, and the lowest part of West Texas, the upper part of the section consists of the Bonfire formation which is subdivided into the lower and upper parts. The Bonfire formation is commonly called the "Silurian shale," but over large areas the series is non-continuous and is overlain by the Fusselman formation. The Fusselman formation is the upper part of the Siluro-Devonian system and is separated from its equivalent in the Panhandle and north central Texas by the Arbuckle Formation. The Arbuckle Formation attains a thickness of more than 3,000 feet subsea along the flank of the Central Basin platform.

The Siluro-Devonian aquifer is divided into sections as the Texas Panhandle and central Texas, and the Bliss and Wilberns Formations of central Texas and the Arbuckle Formation attains a thickness of more than 3,000 feet subsea in the Delaware basin. It is now suggested that the influent of meteoric waters from outcrops of that region.

The Siluro-Devonian formation contains a large volume of water. However, productivities from both actual and ideal maps, Figures 13 and 14, indicate that porosities and permeabilities average 5 to 10 percent respectively. The Montoya would be expected to have a wide range of regional facies. Surrounding the Central Basin platform is the oldest to youngest, Kinderhook, and the Pre-Cambrian rocks are found at elevations greater than 2,000 feet above sea level in outcrops in the Van Horn and El Paso areas, respectively. The Pennsylvanian rocks are found at elevations ranging from 2,000 to 3,000 feet subsea in the Delaware basin. It is now suggested that the influent of meteoric waters from outcrops of that region.

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Salinities in the bend vary from 50 to 200,000 ppm. Several specific water sources in the area, especially the San Andres Aquifer, have no detectable fluoride. Average porosity for Bend rocks ranges from 5 percent to slightly greater than 20 percent. Permeabilities can vary from 5 to 100 millidarcies in the upper-exploitation range. Typical porosities and permeabilities are shown on Figures 46 and 47. Rock properties such as porosity and permeability have been measured and are shown on the isopach map of the Wolfcamp.
sands to one, and anhydrite in this section.

Consists of dolomite, anhydrite, shale, and sandstone. A structure map has been prepared for this aquifer, Figure 61.

End of Permian time.

Deposits which are

Formation outcrops in the Rustler long ridge and trough features which are aligned north-south. The structure map was also used to extend stratigraphic information to poorly defined localities, Precambrian igneous and metamorphic rocks are present over the Diablo platform in

wells. Thus these rocks are missing over local structures on the Diablo platform, and then gradations to zero thickness to

Pennsylvanian and from Permian through Quaternary, the gross aquifer produces fresh or slightly brackish water to wells both private and public sources in West Texas. In West County, where the east-west structural axes on the

are prominent, the individual sands must be identified, and occasional conglomerates are present. No salinity map has been prepared for this aquifer, but salinity of individual strata is present and it is possible to increase from the outcrop westward toward the Midland basin.

Rustler Aquifer

The Rustler aquifer of Permian age located in West Texas consists of dolomite, ashphalt, shale, and sandstone. A structure map has been prepared for this aquifer, Figure 61.

The Rustler aquifer occurs mostly in the Delaware basin and Certain structural highs in the panhandle areas of West Texas. The Rustler Formation outcrops in the Rustler hills of eastern Culberson County, where the outcrop is nearly continuous over a thick area which fitted the Delaware basin and covered the platform near the edges of the Delaware basin.

The Rustler aquifer consists of an almost uniformly thick deposit of dolomite and sandstone. The porous beds in the Rustler are from 50 to 100 feet below the actual top of the formation, and are from 100 to 300 feet thick through the Delaware basin and then to less than 50 feet over the platform. The porous beds thin to a feather edge to the south and east.

Structure on top of the Rustler ashphalt consists of several long ridge and trough features which are parallel with the Permian Section throughout its thickness in the eastern part of the Delaware basin. Thus the isopachous map along its eastern margin from southeast of Andrews to southeast of Big Spring.

Trans-Pecos Aquifer

The Trans-Pecos aquifer located in West Texas consists of sandstone and shale. Structure and isopachous maps have been prepared for this aquifer, Figures 62 and 63, respectively.

Trans-Pecos rocks occur in a portion of the Permian basin and western Panhandle areas of Texas. They are exposed as far north as near the eastern border of Amboy and as far south as a narrow exposure in the Poiso River valley in Wand and Culberson Counties. Within the Delaware basin, the Permian ashphalt outcrops along its eastern margin from southeast of Andrews to southeast of Big Spring.

The thickness of the Trans-Pecos ashphalt in the Delaware basin is variable, and occasional red shales and gray, generally thin dark limestone beds of marine origin to the south. Both units are related in that they are back-reef deposits, and the Permian (Mauo and Leonard), Cretaceous (undersaturated), and Quaternary. Generalized stratigraphy for the pre-Pennsylvanian are as follows:

Age | Lithology
--- | ---
Pennsylvanian | Limestone, shale, sandstone
Mississippian | Limestone, shale, sandstone
Devonian | Limestone, shale
Ordovician | Limestone

These units have been mapped on the geologic map of the pre-Pennsylvanian, Figure 67. The units on top of the Ordovician Permian, Cretaceous, and Quaternary. Using the U.S. Geological Survey map of the 3 gpm per liter, the total thickness of about 100 feet was used. The structure map was also used to extend stratigraphic information to poorly defined areas. For additional information on the Delaware basin was correlated. Using a combination of seismic and well structure data, the subsurface geology of the entire region was interpreted.

It became apparent that due to the paucity of data, detailed maps of the geologic geology must be less meaningful. It was decided to map the region by designating two gross units: a) the pre-Pennsylvanian and b) the Permian through Quaternary. Using the combined data, a subsurface structure map of the pre-Pennsylvanian was prepared, and a structure contour map of the Permian through Quaternary. A few deep oil
drillers in the Hueco bolson.

The Smackover aquifer of Jurassic age located in the East Texas basin itself, the Ouachita tectonic belt. These units were deposited in the Ouachita basin due to space well controlled and lack of productivity information.

From the standpoint of geologic age, the Smackover Formation in West Texas may be divided into two units. However, the boundary between the Jurassic Cotton Valley and the Mississippian Smackover is difficult to map, even though there is an unconformity between these two units. Therefore, mapping the Permian is of considerable interest to the Smackover aquifer, west of the Permian-Trias- Cretaceous-Texas region, and the Smackover-Cotton Valley as a datum change. Within the Smackover basin, the Buckner formation is present and readily definable, and the basement unit, the Smackover-Cotton Valley from the Smackover Formation and is thus grouped together in a gross thickness map, Figure 30.

No salinity map was prepared for this aquifer due to lack of data. The salinity in the Buckner cannot be recognized, and the Cotton Valley formation is in direct contact with overlying Cenozoic basinal deposits, and then to zero thickness over the Diablo platform.

The Smackover Formation includes Saltwater in the east, and South, Permian in the west, and the Blue and Van Hirsch Sandstone.

Safavieh and productivity values are not well known; however, the aquifer group would have to be readily from moderate to terms of estimated quality and yield.

The second group of aquifers is the post-Pennsylvanian undifferentiated, and the Permian (Mauo and Leonard), Cretaceous (undersaturated), and Quaternary. Generalized stratigraphy for the post-Pennsylvanian are as follows:

<table>
<thead>
<tr>
<th>Age</th>
<th>Lithology</th>
<th>Aquifer Formation Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pennsylvanian</td>
<td>Limestone, shale, sandstone</td>
<td>Pennsylvanian Sandstone Aquifer</td>
</tr>
<tr>
<td>Mississippian</td>
<td>Limestone, shale, sandstone</td>
<td>Mississippian Limestone Aquifer</td>
</tr>
<tr>
<td>Devonian</td>
<td>Limestone</td>
<td>Devonian Limestone Aquifer</td>
</tr>
<tr>
<td>Ordovician</td>
<td>Limestone</td>
<td>Ordovician Limestone Aquifer</td>
</tr>
</tbody>
</table>

The upper member of the Smackover aquifer is a porous oil-saturated limestone which is well developed and appears to be confined to the margins of the East Texas basin. This member is about 10 feet thick. The basal unit of the Smackover basin is about 5 feet in thickness. The Smackover-Cotton Valley as a datum change. Within the Smackover basin, the Buckner Formation is present and readily definable, and the basal unit of the Smackover-Cotton Valley from the Smackover Formation and is thus grouped together in a gross thickness map, Figure 30.

The Edwards and Glen Rose aquifers of Cretaceous age located in South west and eastern Texas, and South Texas, respectively, are the upper Edwards and the lowermost Glen Rose aquifers.

The Edwards and Glen Rose Formation are in direct contact, They form a single hydrologic system, extending from the Llano Uplift to the Rio Grande. One structure map continued on top of the Edwards Formation, Figure 74, is sufficient to pick the isopachous thickness by the east and south. Approximately 30 percent of the reefs are present.

The most important sand body in the Edwards Group is the Edwards sandstone. It is composed of a red shaly sandstone and sandstones up to nearly 2,000 feet thick in Cochran, Yoakum, and Frio counties, and thins to the east and south. Approxinately 20 percent of the reefs are present.

The Edwards and Glen Rose aquifers of Cretaceous age located in South west and eastern Texas, and South Texas, respectively. These aquifers are divided into two units.
Shale. In areas that salinities increase constant ly from the outcrop southward. Salinities in the lower Glen Rose aquifer of East Texas, grading into sandy limestones and Lake Anhydrite, and the lower Glen Rose which is synonymous with the Glen Rose Formation.

The Edwards Formation is an important source of fresh water in south and south-central Texas, and is the primary ground-water resource for many municipalities, including San Antonio. Large volumes and rates of saline water can be expected from the Edwards and Glen Rose aquifers.

The Paluxy Aquifer of Cretaceous age located in East Texas consists of sandstone, limestone, and marl. Structure, isopachous and salinity maps have been prepared for this aquifer, Figures 83, 85, and 90 respectively.

For this investigation, the Paluxy aquifer includes a portion of the upper Glen Rose Formation. The Paluxy aquifer is a nonporous, dense crystalline shale with fossiliferous and glauconitic sandstone lenses while the Dock is unporous and of non-marine (fluvial and ephemeral) origin. The Glen Rose Formation contains the majority of the sands in the northern Edwards Aquifer System. The production of these sands is especially in the northern portion of north-central Texas, suggests the distribution of valuable aquifers in the Texas Panhandle, Sweetwater and Lipscomb Counties, and the southeastern part of the Edwards Aquifer.

South of this area the sands are more evenly distributed between both formations and are a result of a highly destructive delta action as evidenced by the channel-mouth sand bars, coastal barrier sands, and prodeltaic shales. The thickness and areal extent of these sediments in this area become more prominent as one moves south. Here the northern boundary of the Dock is well developed and the Glen Rose Formation is found to the south.

Near the end of Woodbine deposition, the Sabine area was uplifted resulting in removal of Woodbine sediments in this area. The presence of Woodbine sands has an extreme range of porosity and permeability from less than 1 millidarcy to several millidarcies.

The Woodbine aquifer of Tertiary (Eocene) age located throughout the Gulf Coast region of Texas consists of sands and shale. Dissolved solids in the Woodbine aquifer range from 2,000 ppm to about 60,000 ppm in the Gulf Coast area. The Woodbine is considered to be a minor source of saline water.

The site of this investigation is in northern Titus County near the Mexia-Talco fault zone. This small area is characterized by a generally non-porous, dense crystalline shale with fossiliferous and glauconitic sandstone lenses while the Dock is unporous and of non-marine (fluvial and ephemeral) origin. The Glen Rose Formation contains the majority of the sands in the northern Edwards Aquifer System. The production of these sands is especially in the northern portion of north-central Texas, suggests the distribution of valuable aquifers in the Texas Panhandle, Sweetwater and Lipscomb Counties, and the southeastern part of the Edwards Aquifer.

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Near the end of Woodbine deposition, the Sabine area was uplifted resulting in removal of Woodbine sediments in this area. The presence of Woodbine sands has an extreme range of porosity and permeability from less than 1 millidarcy to several millidarcies.
aquifers have been mapped as stratigraphic units, whether or not these units represented true time-stratigraphic boundaries or only control. While rock boundaries. Isopachous maps of the respective stratigraphic units have been gross thickness maps or a type of net curve, making it possible to obtain an accurate description from the map. It was decided to use the maximum benefit of electric logs, because there is a high potential difference on the spontaneous potential curve, and the methods used in constructing the zone net sand thickness increases markedly in Zone 3, compared to the overlying Zone 2. Several areas contain more than 900 feet of net sand, while a few trends of less than 10 feet also occur. Figure 96. In the salinity map, Figure 97. Several very high salinities are present in areas of otherwise lower salinities. These anomalies occur in the upper Gulf Coast and are thought to be near salt domes.

Zone 4 (4,000 Feet Subsea to 6,000 Feet Subsea)

Several thick areas net sands occur in Zone 4. Figure 98. The thickest accumulations occur along the coast line where the thickness averages more than 1,000 feet and attains nearly 1,200 feet. Salinity of more than 100,000 ppm are common on the salinity map. Figure 99. Anomalous salinity values of over 250,000 ppm occur over salt domes.

Zone 5 (9,000 Feet Subsea to 8,000 Feet Subsea)
The net sand isopach map of Zone 5, Figure 100, shows a long, thin “thread” of sand which parallels the coast line. Sands totaling 100 feet extend the entire length of the Gulf Coast in Zone 5 and attain 1,000 feet in portions of the area. The map shows a few trends of less than 100 feet in a narrow strip from Corpus Christi to the Louisiana breaker line. The areas are interpreted due to the erosion of gradient depth. The salinity map, Figure 101, is typical of the previous zones. There are several anomalies where total dissolved solids reach 200,000 ppm.

Zone 6 (10,000 Feet Subsea to 10,000 Feet Subsea)
The net thickness map of Zone 6, Figure 102, appears to result from the intersection of the horizontal zones with a zone with a single, thick sand body overlain and underlain by shale. The sand attains 900 feet in the lower Gulf Coast and thin to less than 100 feet in a narrow strip from Corpus Christi to the Louisiana Breaker line. The areas are interpreted due to the thinning of the sand thickness map beginning on the inner or seaward side, as a long “thread,” a “thin” thread, or another “thread” as depicted by the contours. Although there is no age correlation to the regional sand distribution there is a possible trend, and if the zone is given, the sands become younger moving from the land toward the coast.

Since the methods used in constructing the zone net sand isopachous and salinity maps were somewhat mechanistic, only a brief description of each of the maps in this section has been presented. The maps are not complete, and the reader is referred to the separate listing of these data which are sorted by depth and area as the final report.

Zone 1 (1,200 Feet to Sea Level)
No maps have been included for Zone 1 since practically no saline water occurs above sea level.

Zone 2 (Sea Level to 2,000 Feet Subsea)
Sand containing saline water in Zone 2 occur mainly in two areas. One area is located adjacent to the coast line, extending nearly the entire length of the coast. Another area of sand development occurs along a trend from Webco County to Deafened County. Isopachous and salinity maps. Figure 94 and 95, have been constructed. Salinities very close to fresh water on the inland side to over 600,000 ppm. No particular pattern is discernable from the map.

Zone 3 (2,000 Feet Subsea to 4,000 Feet Subsea)
Net sand thickness increases markedly in Zone 3 compared to the overlying Zone 2. Several areas contain more than 900 feet of net sand, while a few trends of less than 100 feet also occur. Figure 96. In the salinity map, Figure 97, several very high salinities are present in areas of otherwise lower salinities. These anomalies occur in the upper Gulf Coast and are thought to be near salt domes.

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- Van Horn-El Paso sheet, March 1968
- Amarillo sheet, February 1969
- Waco sheet, June 1970
- Perryton sheet, March 1968
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- West-East Cross Section, North Texas Geological Society, Paul E. M. Purcell, President, March 1954.
- North-South Cross Section, Panhandle Geological Society, Robert B. Totten, Chairman, May 1966.
- North-South Cross Section, Panhandle Geological Society, Graydon L. Mehlen, Chairman, February 1962.
Figure 3
A-A', West Texas, Culberson to Scurry Counties
Figure 4
B-B', North Central Texas, Scurry to Collin Counties
Figure 5
C-C', East Texas, Denton to Shelby Counties
Figure 6
D-D', (Diagrammatic), Western Trans-Pecos,
El Paso to Culberson Counties
Figure 7
L-L', Panhandle and West Texas, Sherman to Terrell Counties
Figure 8

M-M', Central Texas, Montague to Blanco Counties
Figure 9
N-N', East Texas, Red River to Trinity Counties
O-O', Central Texas and Gulf Coast, Lampasas to Matagorda Counties
Figure 11
P-P', South Central Texas, Guadalupe to Bee Counties
Figure 12
R-R', South Texas and Gulf Coast, Maverick to Cameron Counties
Figure 13
Ellenburger Structure, West Texas-Panhandle
Figure 14
Ellenburger Structure, Central Texas
EXPLANATION

Line showing gross thickness of Ellenburger aquifer. Includes Arbuckle and Cambrian sands. Interval is variable.

Northeast to south Normal fault patterns indicate downthrown side.

Figure 15
Ellenburger Gross Thickness, West Texas-Panhandle
EXPLANATION

Lines showing gross thickness of Ellenburger aquifer
Includes Arbuckle and Cottons sands
Well used for control
Normal fault, wave indicates downthrown side

Figure 16
Ellenburger Gross Thickness, Central Texas
Figure 17
Ellenburger Water Salinity, West Texas
Figure 18
Ellenburger Water Salinity, Central Texas
Figure 20
Simpson Gross Thickness, West Texas
Figure 22
Montoya Gross Thickness, West Texas-Panhandle
Figure 23
Siluro-Devonian Structure, West Texas
Figure 24
Siluro-Devonian Gross Limestone Thickness, West Texas-Panhandle
EXPLANATION

---

Low-shading concentration of dissolved solids, in parts per million of water in the Siluro-Devonian aquifer. Intervals are variable.

Data point used for control.

Normal fault, western indicates downthrown side.

---

Figure 25
Siluro-Devonian Water Salinity, West Texas
EXPLANATION

Lee showing altitude of top of Mississippian aquifer
Dashed is subaqueous
Datum is mean sea level
Well used for control
Normal fault, northeasterly throw Southwest side

Figure 26
Mississippian Structure, West Texas-Panhandle
EXPLANATION

---

Line showing concentration of dissolved solids, in parts per million, of water in the Mississippian aquifer.

Data point used for control

Normal fault, seawater indicated

Location of Area

---

Figure 28
Mississippian Water Salinity, West Texas
Figure 29
Pennsylvanian Structure, West Texas-Panhandle

EXPLANATION

- Line showing altitude of top of Pennsylvanian aquifer
- Interval is variable
- Datum is mean sea level
- Well used for control
- Normal fault; sawteeth indicate downthrown side
EXPLANATION

Line showing net thickness of limestone and minor detritals in the Pennsylvanian aquifer area.

Well used for control.

Normal fault/slicken indicates downthrown side.

Figure 30
Pennsylvanian Net Thickness, Limestone and Minor Detritals, West Texas-Panhandle
Figure 31
Pennsylvania Water Salinity,
West Texas Panhandle

EXPLANATION

- 50,000-

Line showing concentration of dissolved solids, in parts per million, of water in the Pennsylvania aquifer.

Data point used for control.

Normal fault; southwest slope downthrown side.
Figure 32
Pennsylvanian (Undifferentiated) Structure, Central Texas
EXPLANATION

Line showing altitude of top of Bend aquifer
Datum is mean sea level

Well used for control

Normal fault, southerly indicates downthrown side

Figure 33
Bend Structure, Central Texas
Figure 34
Bend Net Thickness, Limestone and Sand, Central Texas
Figure 37
Strawn Net Thickness, Limestone and Sand, Central Texas
Figure 38
Strawn Water Salinity, Central Texas
Figure 39
Canyon Structure, Central Texas
EXPLANATION

- Line showing net thickness, limestone and sand of the Canyon aquifer
- Mf: used for control

Figure 40
Canyon Net Thickness, Limestone and Sand, Central Texas
Figure 41
Canyon Water Salinity, Central Texas
EXPLANATION

68
Line showing net thickness, limestone and sand, of the Cisco outlier. Areas of zero net thickness within the outlier are not shown.

795
Well used for control

Figure 43
Cisco Net Thickness, Limestone and Sand, Central Texas
Line showing concentration of dissolved solids, in parts per million, of water in the Cisco aquifer

Data point used for control

Figure 44
Cisco Water Salinity, Central Texas
Line showing attitude of top of Wolfcamp aquifer.
Datum is mean sea level.
Well used for control.

Wolfcamp Structure, West Texas-Panhandle
Figure 46
Wolfcamp Structure, Central Texas
Figure 48
Wolfcamp Net Thickness, Limestone and Sand, Central Texas
Figure 49
Wolfcamp Water Salinity, West Texas-Panhandle
Figure 50
Wolfcamp Water Salinity, Central Texas
EXPLANATION

Line showing altitude of top of Leonard aquifer follows base. contour lines show top of Bone Spring. Platform and shelf areas: contour lines show top of Clear Fork. Midland and Vol Verde basins: contour lines show top of Leonard Undifferentiated. Datum is mean sea level. Well used for control. Normal fault symbols indicate downthrown side.

Figure 51
Leonard Structure, West Texas
EXPLANATION

Lake showing gross thickness of Leonard aquifer
Subarea basic lines show thickness of Bone Spring
Platform and shelf areas lines show thickness of Clear Fork and Middle
Missed and Missed lines new area thickness of Leonard and/or
In Midland area: Includes Tampak and

Figure 52
Leonard Gross Thickness, West Texas
Figure 53
Leonard Water Salinity, West Texas
Figure 55
San Andres Gross Thickness, West Texas
Figure 56
San Andres Water Salinity, West Texas
EXPLANATION

100
Line showing altitude of top of upper Guadalupe aquifer.

Black isos - contour lines show top of Delaware Mountain Group.

Light blue isos - contour lines show top of Whitehorse Group.

Red isos - contour lines show top of upper Guadalupe undifferentiated.

Reef complex contour lines show top of Captain Reef.

Datum is mean sea level.

Figure 57
Upper Guadalupe Structure, West Texas
Figure 58
Upper Guadalupe Gross Thickness, West Texas

EXPLANATION

Lines showing gross thickness of upper Guadalupe aquifer.
- Dark lines show thickness of Delaware Mountain Group.
- Medium lines show thickness of Modoc Group.
- Light lines show thickness of Whitehorn Group.
- Cross-hatched lines show thickness of upper Guadalupe undifferentiated.

Interval is variable: 500 feet in Delaware and Vol Verde basins, 200 feet elsewhere.

"t" Well used for control.
Figure 59
Upper Guadalupe Water Salinity, West Texas
Figure 60
Upper Permian (Undifferentiated) Gross Thickness, Central Texas

EXPLANATION
Line showing gross thickness of upper Permian (undifferentiated) aquifer includes all rocks above the Wolfcamp and below the T. R. Wolfcamp, Mississippi.

Well used for control.
Figure 61
Rustler Structure, West Texas
Figure 62
Santa Rosa Structure, West Texas-Panhandle
Figure 63
Triassic Net Sand Thickness, West Texas-Panhandle
Figure 64
Subcrops of Pre-Permian Aquifers, Trans-Pecos
EXPLANATION
---2000---
Line showing altitude of top of the pre-Permian group of aquifers
Interval is variable
Datum is mean sea level
Log is
Well used for control
---ilen---
Normal fault, saw teeth indicate downthrown side

Figure 65
Pre-Permian Structure, Trans-Pecos
Figure 66
Pre-Permian Net Permeable Thickness, Trans-Pecos
The above symbols show the approximate extent of the post-Pennsylvanian saline aquifers. Rocks containing water with less than 3,000 ppm dissolved solids are excluded.

Figure 67
Extent of Post-Pennsylvanian Aquifers, Western Trans-Pecos
Figure 68
Post-Pennsylvanian Gross Thickness, Western Trans-Pecos

EXPLANATION

Line showing gross thickness of the post-Pennsylvanian group of saline aquifers. Rocks containing water with less than 3,000 ppm dissolved solids are excluded.

Interval is variable

TG30
Well used for control

Normal fault; downward indicates downthrown side

Location of Area

10 20 Miles

Figure 68
Post-Pennsylvanian Gross Thickness, Western Trans-Pecos
EXPLANATION

-1200

Lime showing attitude of top of the Smackover, or the Cotton Valley Limestone. See relationship of these formations in the Smackover interval, see cross sections, Figures 68 and 69.

-000
0

Well used for control

Norrot fault, southern indicates downthrown side

Figure 69
Smackover Formation and Cotton Valley Limestone Structure, East Texas
EXPLANATION

- Line showing gross thickness of the Smackover Formation, or the Smackover and Cotton Valley Limestone
- Well used for control

Figure 70
Smackover Formation and Cotton Valley Limestone Gross Thickness, East Texas
EXPLANATION

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Line showing altitude of top of Pettet-Travis Peak aquifer.

Datum is mean sea level.

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Well used for control.

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Normal fault; arrows indicate downthrown side.

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Figure 71

Pettet-Travis Peak Structure, East Texas
Figure 72
Pettet-Travis Peak Net Sand Thickness,
East Texas

EXPLANATION

Line showing net sand thickness of Pettet-Travis Peak aquifer.
Includes sands of the Cotton Valley Group.

Well used for control.
**EXPLANATION**

Line showing concentration of dissolved solids, in parts per million, of water in the Pettet-Travis Peak aquifer. Interval is variable.

Data points used for control.

\*Dissolved solids calculated from spontaneous potential log.

\(\text{Dissolved solids from reported data.}\)

Figure 73

Pettet-Travis Peak Water Salinity, East Texas
EXPLANATION

Line showing altitude of top of Edwards aquifer. North of the aquifer limit, loss show altitude of top of the equivalent Fredericksburg Group.

Datum is mean sea level

Well used for control

Normal fault, seaward indicates downthrown side

Figure 74
Edwards Structure, Gulf Coast
Figure 75
Edwards Net Thickness, Gulf Coast
Figure 77
Lower Glen Rose Net Thickness, Limestone and Sand, East Texas
EXPLANATION

- Line showing concentration of dissolved solids, in parts per million, of water in the Lower Glen Rose aquifer.
- Interval is variable.
- Data points used for control:
  - Dissolved solids calculated from spontaneous potential log.
  - Dissolved solids from reported data.

Figure 78
Lower Glen Rose Water Salinity, East Texas
Figure 79
Paluxy Structure, East Texas
Figure 80
Paluxy Net Sand Thickness, East Texas
Location Of Area TARRANT

Line showing concentration of dissolved solids, in parts per million, of water in the Paluxy aquifer. Interval is variable.

Data points used for control:
× Dissolved solids calculated from spontaneous potential log
# Dissolved solids from reported data

Figure 81
Paluxy Water Salinity, East Texas
EXPLANATION

Line showing depth of top of Woodbine aquifer in southern and northeastern parts, lines show depth of top of undifferentiated Woodbine- Eagle Ford. Datum is mean sea level.

'W' Well used for control

Narrow foot, southwest, indicates downthrown side

Figure 82
Woodbine Structure, East Texas
EXPLANATION

Lines showing net thickness of sand in the Woodbine aquifer. In southern and northeastern parts, lines show net thickness of sand in the undifferentiated Woodbine-Eagle Ford. Interval is variable.

Figure 83
Woodbine Net Sand Thickness, East Texas
Figure 84
Woodbine Water Salinity, East Texas
EXPLANATION

- Line showing net thickness of sand in the Eagle Ford aquifer.
- Well used for control

Figure 85
Eagle Ford Net Sand Thickness, East Texas
Figure 86
Eagle Ford Water Salinity, East Texas

EXPLANATION
60,000
Line showing concentration of dissolved solids, in parts per million, of water in the Eagle Ford aquifer.

- Interval is variable

Data points used for contour:
- Dissolved solids calculated from semi-empirical potential log.
- Dissolved solids from reported data.
EXPLANATION
- 50
Line showing net thickness of sand in the Nacatoch aquifer.

Symbol
Well used for control

Normal fault, southerly indicates downthrown side

Figure 88
Nacatoch Net Sand Thickness, East Texas
Figure 89
Olmos Structure, South Texas

EXPLANATION
—1000—

Line showing altitude of top of Olmos Formation which is within the Olmos aquifer.

Datum is mean sea level

63A04
Well used for control
EXPLANATION

Line showing net thickness of sand in the Olmos aquifer. Includes San Miguel, Olmos, and Escondido Formations.

Well used for control

Figure 90
Olmos Net Sand Thickness, South Texas
Figure 91
Carrizo-Wilcox Structure, Gulf Coast
Figure 92
Carrizo-Wilcox Net Sand Thickness, Gulf Coast
Figure 93
Carrizo-Wilcox Water Salinity, Gulf Coast
Figure 94
Zone 2 Net Sand Thickness, Gulf Coast

EXPLANATION

Line showing net thickness of sand containing saline water in Zone 2 (sea level to 2,000 feet subsea). Areas of zero net thickness within the zone are not shown.

Interval in variable

Well used for control
Figure 95
Zone 2 Water Salinity, Gulf Coast

EXPLANATION

Line showing average concentration of dissolved solids in parts per million of salted water in Zone 2 (dead level to 2,000 feet subsea). Interval is variable.

Data point used for control.
Figure 96
Zone 3 Net Sand Thickness, Gulf Coast

EXPLANATION

Lines showing net thickness of sand containing saline water in Zone 3 (2,000 to 4,000 feet subsea). Areas of zero net thickness within the zone are not shown.

Well used for control.
Figure 97
Zone 3 Water Salinity, Gulf Coast

EXPLANATION

Line showing average concentration of dissolved solids in parts per million of saline water in Zone 3 (2,000 to 4,000 feet subsea). Interval is variable.

Data points used for control:
Dissolved solids calculated from spontaneous potential log. Dissolved solids from reported data.
Figure 98
Zone 4 Net Sand Thickness, Gulf Coast

EXPLANATION
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Line showing net thickness of sand containing saline water in Zone A. 10,000 to 20,000 feet subsurface. Areas of zero net thickness within the zone are not shown. Interbedding is considerable.

Note: Well used for control.
Line showing net thickness of sand containing saline water in Zone 5 (6,000 to 8,000 feet subsea). Areas of zero net thickness within the zone are not shown. Interval is variable.

Well used for control.

Figure 100
Zone 5 Net Sand Thickness, Gulf Coast
Figure 101
Zone 5 Water Salinity, Gulf Coast
Figure 102
Zone 6 Net Sand Thickness, Gulf Coast

EXPLANATION

Line showing net thickness of sand containing saline water in Zone 6 (6,000 to 10,000 feet subsea). Areas of zero net thickness within the zone are not shown. Interval is variable.

Well used for control.
Figure 103
Zone 6 Water Salinity, Gulf Coast

EXPLANATION

Line showing average concentration of dissolved solids in parts per million of saline water in Zone 6 (15,200 ft-20,000 ft below mean sea level) is variable.

Data points used for control:

Dissolved solids calculated from spontaneous potential log

Dissolved solids from reported data.