TEXAS WATER COMMISSION

Report LD-0265

INVESTIGATION OF GROUND-WATER CONTAMINATION IN THE VEALMOOR OIL FIELD, HOWARD AND BORDEN COUNTIES, TEXAS

By

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with a
Design Criterion for Lined Surface
Evaporation Pits, High Plains Region of Texas

by

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January 1965

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VEALMOOR OIL FIELD
HOWARD AND BORDEN COUNTIES, TEXAS

INTRODUCTION

This investigation was conducted as the result of a letter dated September 28, 1963 from Mr. Carl Lockhart, acting as spokesman for a group of landowners in the area of the Vealmoor Oil Field, Borden and Howard Counties, Texas. The letter, signed by five of the landowners, stated that they were of the opinion that their fresh water supply was being polluted by the disposal of oil-field brines into unlined surface pits.

Field investigations of the complaint were conducted during the periods January 20 to January 25, 1964 and April 20 to April 25, 1964. During the initial investigation, water samples were obtained for chemical analysis from water wells and springs throughout the oil field area. The second part of the field study consisted of measuring water levels and collecting of additional samples for chemical analysis. All producing oil wells, tank batteries, and brine-disposal facilities in the Vealmoor oil field were located and inspected.

Location and Extent

The Vealmoor oil field is a multiple-county field encompassing parts of Howard and Borden Counties. It is located approximately 20 miles north-northeast of Big Spring (See Figure 1). Vealmoor, a small community dependent primarily on oil production and agriculture for its economy, is located in the western part of the area.

The extent of this investigation covered an area of approximately 19 square miles. Although limited ground-water data were developed in the area of the Oceanic oil field, located west of the Vealmoor field, ground-water conditions as related to oil development and the production and disposition of oil-field brine were not investigated in detail in the Oceanic field.

Previous Investigations

No previous detailed ground-water investigations have been made in the area of the Vealmoor oil field. Samuell (1937) compiled records, logs, and analyses of a number of water wells and test holes in Howard County, and Ellis (1949) investigated ground-water resources in Borden County; these reports include several wells in the Vealmoor field area. Ground-water conditions in the Big Spring area of Howard County were studied by Livingston and Bennett (1944), although the extent of their study did not include the area of the Vealmoor field. A recon-

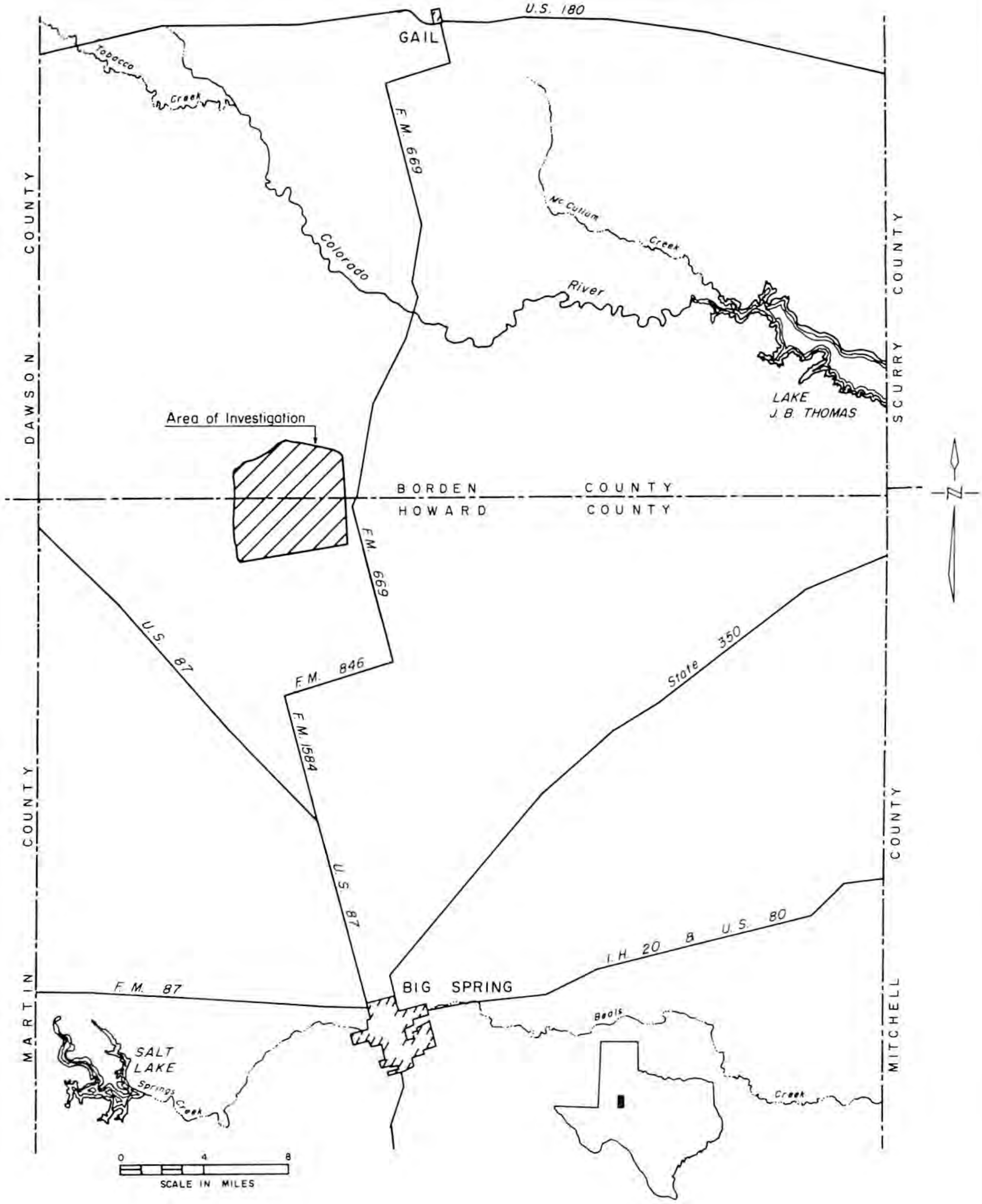

Figure 1

Index Map Showing Location of Area of Investigation

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naissance investigation of the ground-water resources of this part of the Colorado River Basin was made by Shamburger (Mount, and others, 1964). Partial chemical analyses have been performed on samples obtained by local landowners from several wells and springs in the area in recent years.

Well-Numbering System

The wells and springs located and sampled during this investigation are identified by means of consecutive numbers beginning with 1. In order to facilitate identification, the consecutively-numbered wells are also each assigned a suffix based on the location of the well in a legal subdivision shown on Plate 1. For example, well 27-32, as given in Tables 1 and 2, is located in Section 32. Wells included in this report which were assigned numbers in previous reports are identified in Table 1.

Acknowledgements

The collection of much of the basic data would not have been possible without the cooperation of the landowners, particularly Mr. Carl Lockhart, and personnel of the various oil companies active in the area, notably Texaco Inc.

This investigation was conducted under the supervision of L. G. McMillion, Director, Ground Water Division.

GEOGRAPHY

The physiography of the area is characterized by a rolling, moderately rugged surface modified locally by distinct and prominent escarpments and incised stream channels. Surface drainage-ways trend northeast and form part of the drainage system of the Colorado River. The principal drainage ways, German and Plum Creeks, are intermittent streams characterized by ground-water spring flow locally, and both creeks are confluent with the Colorado River approximately ten miles upstream from Lake J. B. Thomas, which lies in Borden and Scurry Counties (Figure 1).

The natural vegetation of the area is predominantly mesquite. Cotton and various feed crops are grown by dry-farming methods. Vegetable crops grown on several truck farms in the area are irrigated by ground water.

The climate of this region is semiarid with an average annual rainfall of approximately 18 inches. The average, annual, net evaporation from a fresh, free-water surface for the period 1940 to 1957 was 6.04 inches per year.

GENERAL GEOLOGY

The principal geologic units exposed at the surface and the major structural features in this region of Texas are indicated in the generalized geologic map shown in Figure 2. The sequence of sedimentary rocks comprising the geologic section in the Vealmoor field form part of the Midland Basin, a subordinate structural feature of the vast Permian Basin or West Texas geosyncline.

A composite well log illustrating the stratigraphic sequence down to rocks of Ordovician Age is shown in Figure 3. This log illustrates the sedimentary units penetrated by wells in the nearby Good oil field, Borden County, and therefore is not indicative of the true depths and thicknesses of the same units in the Vealmoor field. However, the thicknesses of the various rock units do not vary significantly between the two areas.

The geologic units which are pertinent to a study of ground water in the area are of Triassic and Tertiary Age; consequently, discussion of the older horizons is omitted.

Triassic System

Rocks of Triassic Age belonging to the Dockum Group crop out at the surface in the northern part of the Vealmoor area and unconformably underlie deposits of Tertiary Age in the southern and western parts of the area. The beds of the Dockum Group consist of alternating layers and lenses of predominantly red and blue clay, shale, silt, and relatively fine-grained, cross-bedded sandstone and gravel, all of continental origin. The Dockum Group in the Vealmoor area is approximately 1,250 feet thick. The beds dip gently westward into the Midland Basin.

The middle part of the Dockum Group is characterized by several massive beds of sandstone and gravel, commonly termed the Santa Rosa Sandstone. The upper part of the Triassic sequence in the area is defined as the Chinle Formation, and it consists predominantly of shale and clay with subordinate sandstone lenses. A distinct blue-green reduction halo is characteristic of the uppermost clay beds of the Chinle Formation where they are in contact with overlying younger rocks.

Tertiary System

A relatively thin mantle of deposits of Tertiary Age overlies the Triassic rocks over a large part of the area. In the north-central and northeastern parts of the Vealmoor field, the Tertiary deposits feather out against the older Triassic rocks. The contact between the Tertiary and Triassic rocks is not readily evident in many places, and it was not mapped in detail during this investigation due to the limited time available for field work. Field observations and ground-water data collected during this study indicate, however, that currently available published geologic maps (Figure 2) are inaccurate with respect to the position of the Tertiary-Triassic contact in the Vealmoor area. The mantle of Tertiary deposits extends farther northward than indicated in Figure 2.

The Tertiary sediments present in Howard and southwestern Borden Counties are generally considered to belong to the Ogallala Formation of Pliocene Age, although it is possible that some of these deposits may be of Pleistocene Age and thus younger than the Ogallala. Fossil seeds identified as Pliocene in age

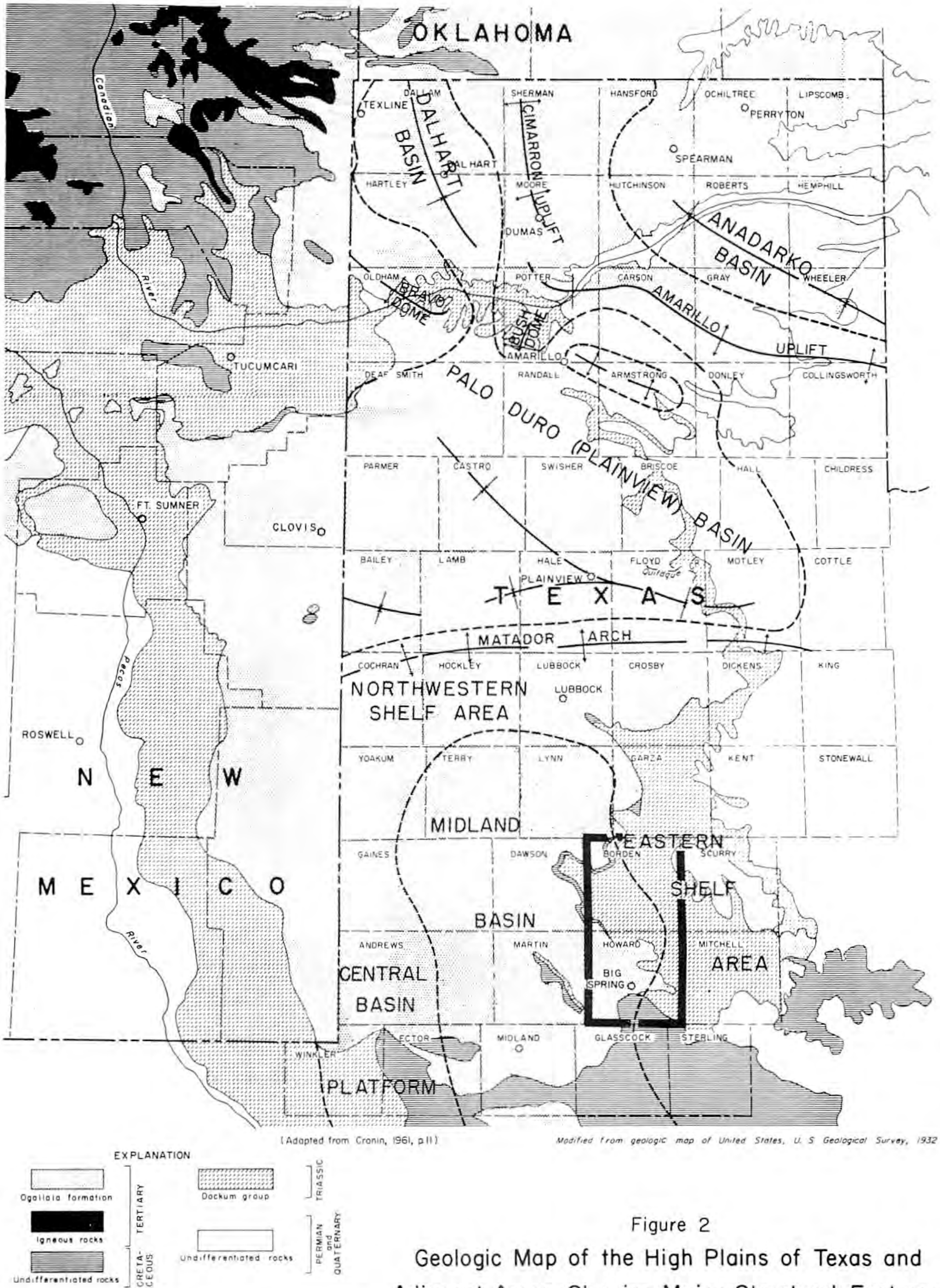

Figure 2

Geologic Map of the High Plains of Texas and Adjacent Areas Showing Major Structural Features

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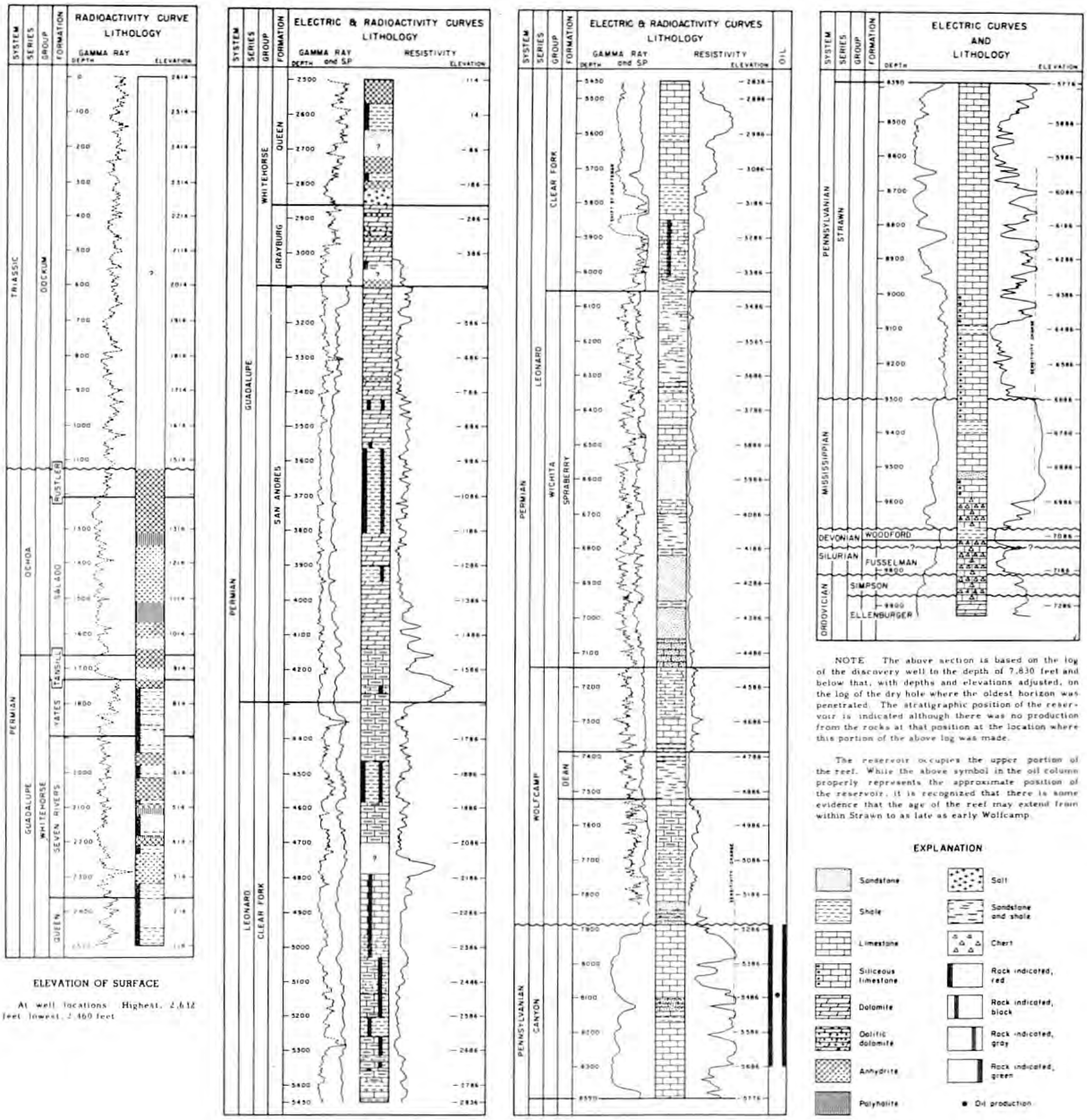
GOOD FIELD, Borden County, Texas



(After Schreiner, 1953)

Figure 3

Composite Well Log Showing Typical Section of Rocks Penetrated

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have been collected from these deposits at several localities in northern Howard County (Frye and Leonard, 1957). For purposes of this report, the alluvial sedimentary deposits in the Vealmoor field area are considered as a part of the Ogallala Formation, which is the principal source of water in the High Plains of Texas (Figure 2).

The Ogallala Formation in the area consists principally of sandy conglomerate containing abundant abraded fossil shells, many of which are of Cretaceous Age. Pebbles and cobbles of chert and limestone are abundant locally. The conglomerate is commonly loosely cemented with calcium carbonate and locally interbedded with beds of fine-to medium-grained quartz sandstone (Figure 4 and 5).

Massive beds of caliche directly overlie the conglomerate at some exposures, although in the thicker parts of the sequence, silt and sand overlie the conglomerate.

The thickness of the Ogallala Formation, where present in the area, ranges from no more than a few feet to a possible maximum of approximately 200 feet in the topographically high area just east of Vealmoor.

Sandy soils characterized by caliche subsoils overlie the Ogallala Formation locally.

Figure 4.-- Outcrop of Ogallala Formation along German Creek in $NW\frac{1}{4}$ of Section 34, Block 32, T-3-N, T & P RR Survey, Howard County. Chert-bearing, sandy conglomerate overlies medium-grained, moderately well-sorted, chert-bearing sandstone. Conglomerate consists of well-rounded quartz pebbles, chert pebbles, and calcareous fossils of Cretaceous (?) Age in carbonate-cemented sandstone matrix. View is south.

Figure 5.-- Conglomerate of Ogallala Formation unconformably overlying red and gray clay of the Dockum Group at sample locality 2-34 in Section 34, Block 32, T-3-N, T & P RR Survey, Howard County. Calcareous subsoil with interspersed caliche nodules overlies conglomerate. Spring flow is contaminated. View is south.

OIL PRODUCTION

Development

The extent of current oil development in the Vealmoor field and in the nearby Oceanic field is indicated on Plate 1. The discovery well in the Vealmoor field was drilled in 1948 to rocks of Pennsylvanian Age. Most of the development of the field took place during the period 1950-1952.

Oil is produced in the Vealmoor field from the "Canyon Reef" of Pennsylvanian Age at an average depth of about 7,900 feet. Current annual and cumulative oil production as of January 1, 1963 was 692,622 and 17,736,528 barrels respectively.

Reservoir energy in the "Canyon Reef" is the result of a water drive mechanism.

Methods of Well Completion and Abandonment

In order to determine the adequacy of well-completion practices with respect to the protection of ground water in the area, all available well records were obtained from the Texas Railroad Commission. The length of surface casing set in wells for which records are available is indicated beside each well on Plate 1.

According to completion reports submitted to the Railroad Commission by operators, surface casing in most wells was set generally at subsurface depths between 300 and 400 feet and cemented to the surface. A string of intermediate casing, commonly 8-5/8 inches in diameter, was set at a depth of about 3,000 feet or greater and cemented from the casing shoe with several hundred sacks of cement. The purpose of this intermediate casing string was apparently to control high-pressure conditions and to shut off highly corrosive brines present in the upper part of the Permian section.

The production casing or "long string," commonly 5-1/2 inches in diameter, was set at or near the total depth of the well and cemented with sufficient cement to fill several hundred feet of the well bore-casing annulus.

Exceptions to the above-described program included such procedures as setting a greater length of surface casing in lieu of an intermediate casing string.

Abandonment practices, as reflected by data submitted by operators to the Railroad Commission, are illustrated by the compilation given in Table 3. Surface casing was reportedly left cemented in place in all abandoned holes. The intermediate string of casing was left in some holes but was removed from many. Mud and cement plugs were used to confine reservoir fluids in the lower part of the bore hole, and cement plugs, generally 25 sacks, were reportedly set in the bottom of the surface casing. The competency of these plugs to remain at their original depths of emplacement in the presence of highly mineralized brines and possible high-pressure conditions cannot be evaluated without a re-drilling program.

BRINE PRODUCTION AND DISPOSAL

During the very early stages of oil production in the Vealmoor field, the produced salt water was placed in unlined surface pits or else allowed to flow into surface drainage-ways. As the production of brine increased, other means of disposal were sought in order to minimize contamination. The first abandoned well to be converted into a brine-disposal well was the M. M. Jones "A" Well 1 in 1950. Since then, the steady increase in brine production has necessitated the conversion of additional wells for disposal purposes, so that presently there are 6 injection systems in operation in the field. The locations of these wells are shown on Plate 1 and completion data, as reported by operators to the Railroad Commission, are given in Table 4.

A statewide inventory of brine production and disposition for the year 1956, as reported by operators to the Texas Railroad Commission, indicated a daily brine production of 3,735 barrels, of which all but 269 barrels produced daily was re-injected into disposal wells. A similar but more comprehensive inventory conducted for the year 1961 indicated daily and yearly brine production of 6,582 and 2,171,265 barrels respectively, of which 99.9 percent was reportedly re-injected by disposal wells.

Except for large volumes of brine produced on leases formerly operated by Seaboard Oil Company (now operated by Texaco, Inc.) and injected into the Jones disposal well, unlined surface pits constituted the principal method of brine disposal on many leases in the Vealmoor field prior to 1956. However, even since 1956, a number of pits have been continuously or else intermittently in operation in the field. The location of pits presently in use as well as the site of former pits now abandoned are indicated on Plate 1.

The chemical character of brine produced in the Vealmoor field is indicated by a tabulation of chemical analyses in Table 2. A sample taken from a surface pit during this investigation showed concentrations of 46,150 ppm chloride, 840 ppm sulfate, and 76,228 ppm total dissolved solids. The ratio of chloride to sulfate, based on equivalents per million, was approximately 74:1.

In the Oceanic oil field, the eastern periphery of which lies just 1 mile west of the Vealmoor field, the daily and annual brine production in 1961 was 1,162 and 412,817 barrels respectively. Of this total, 98.6 percent was discharged into unlined surface pits. However, several disposal wells have been put into operation in the field in recent years.

The brine produced with the oil in the Oceanic field is more highly mineralized than that produced in the Vealmoor field (see Table 2).

PHYSICAL MECHANICS OF GROUND-WATER CONTAMINATION RESULTING FROM DISPOSITION OF OIL-FIELD BRINES

Unlined Surface Pits

A common misconception is that highly mineralized brines disposed of into unlined surface pits are evaporated. Under favorable climatic conditions, a properly constructed pit of adequate surface area and lined with an impermeable material may effectively evaporate the water content of a brine solution, assuming the brine surface is free of evaporation retardants, such as oil films, or stagnation due to microorganisms. The dissolved minerals in the brine cannot be evaporated, however, and any precipitants which might form may subsequently be carried into the ground water or surface drainage-ways by rainfall.

A design criterion illustrating the minimum sizes necessary for lined surface evaporation pits in the High Plains of Texas is included in the Appendix of this report.

The permeable nature of such aquifers as the Ogallala Formation, the small effective surface area of typical-sized pits which have been used in the area, and the usual oil film present on the brine surface indicates that probably most of the brine which has been disposed of by means of unlined pits in the Vealmoor field, as well as other fields located on the Ogallala Formation in this region, has been lost by seepage. The comparatively shallow depth of the water table in the area makes it a further probability that most of this brine has entered the ground water.

Figure 6 schematically illustrates seepage loss from an unlined surface pit near an area of natural ground-water discharge in the Vealmoor field. The ground water "mound" illustrated in Figure 6, which experimental studies indicate may develop on the water table beneath a pit, obviously could modify the normal direction of ground-water movement and its associated contaminants in the area of the pit. It is further apparent that in areas of no natural or artificial ground-water discharge, contamination resulting from brines which have entered the ground water may not become apparent for many years because of the inherent slow rate of movement of ground water.

Subsurface Injection

Other than surface discharge, subsurface injection is generally the most effective and economical method of disposing of oil-field brines, provided the disposal well is adequately constructed, the formation used for disposal is capable of receiving the brines and is not hydrologically connected with the fresh water aquifer, and other wells or bore holes which have penetrated the disposal formation in the area are adequately cased, cemented, and/or plugged.

Table 4 gives methods of completion and operating conditions of the disposal wells in operation in the Vealmoor field as indicated by observation during this investigation and as reported by operators in the permit application to the Texas Railroad Commission and in the 1961 salt-water inventory. These data indicate that 2 different stratigraphic horizons are currently being utilized for

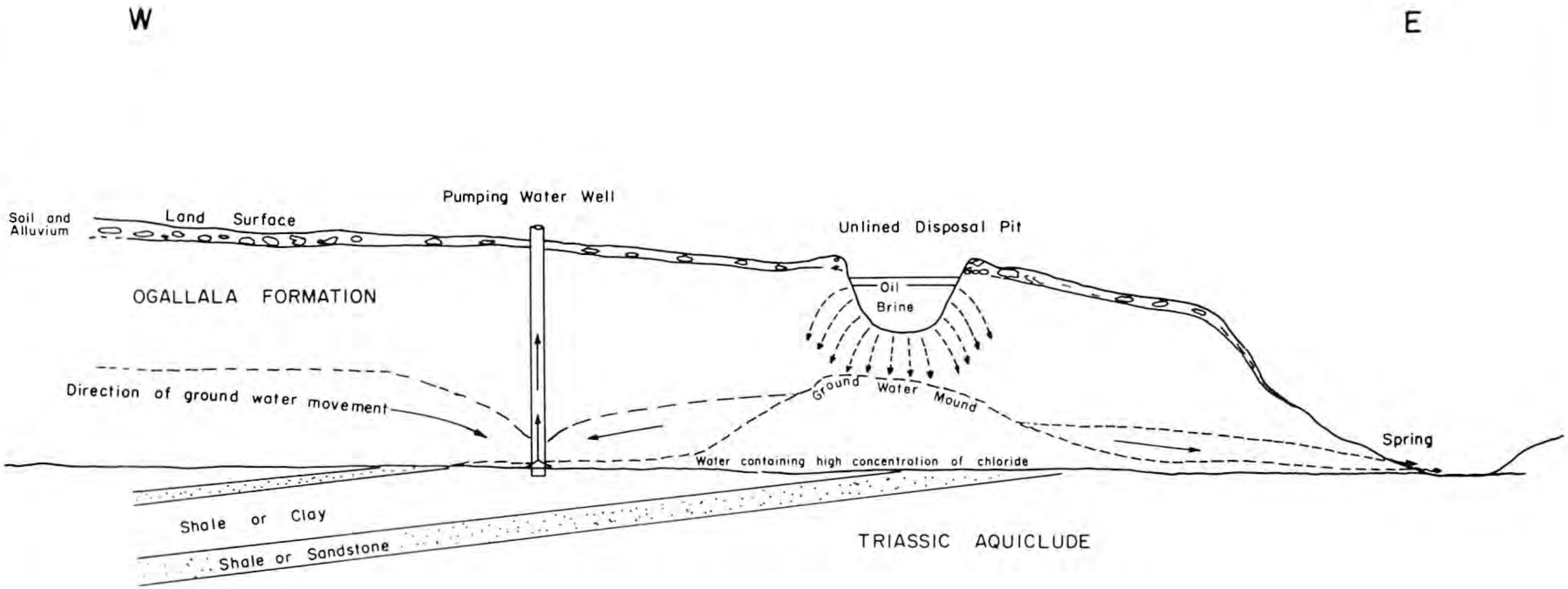

Figure 6

Schematic Diagram Showing Mechanics of Ground-Water Contamination Resulting from Discharge of Oil-Field Brine into Unlined Surface Pits, Vealmoor Oil-Field Area

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brine disposal in the Vealmoor field. The San Andreas Limestone is being used in 5 wells, and the Canyon Reef is being utilized in the remaining well (Figure 3). The reported methods of completion of several representative injection wells are schematically illustrated in Figure 7.

Leakage of the injected brines through corroded casing and/or the development of abnormal pressures in the disposal reservoirs as a result of the injection operations is a possibility. In the presence of inadequately plugged or cased bore holes (either oil tests or stratigraphic tests) penetrating the disposal formation, the latter could be a major contributor to the contamination problem in the Vealmoor area.

Buried salt water flow lines serving injection wells in the area also constitute potential sources of contamination should leakage develop as a result of corrosion.

OCCURRENCE OF GROUND WATER

During this investigation, a total of 50 wells and 5 springs were located and most were sampled for chemical analysis. These wells are located on Plate 1; pertinent data, where available, are given in Table 1; and chemical analyses are compiled in Table 2.

The salinity of water is a measure of the concentration of dissolved minerals. It commonly determines the suitability of the water for various uses. A general classification of water based on the concentration of dissolved mineral solids in ppm (parts per million) is as follows (Winslow and Kister, 1956):

Description	Dissolved solids (ppm)
Fresh	Less than 1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	More than 35,000

Dockum Group

The Dockum Group is not a source of domestic water supply in the Vealmoor area, although ground water occurring in some of the shallow sandstone beds of the Dockum has been used for stock-watering, oil-well drilling, and garden irrigation. Well 21-25, located at Vealmoor, was recently drilled into the Dockum beneath the overlying Tertiary rocks in an attempt to obtain larger volumes of water for the community of Vealmoor; however, residents complain the water is too saline for general domestic use. A sample of the water showed a total dissolved solids concentration of 3,323 ppm, sodium and sulfate being the principal constituents. The deeper sandstone lenses of the Dockum Group, exclusive of the massive Santa Rosa beds, produce water used for stock-watering in several areas of southern Borden County just north of the Vealmoor field, although the water

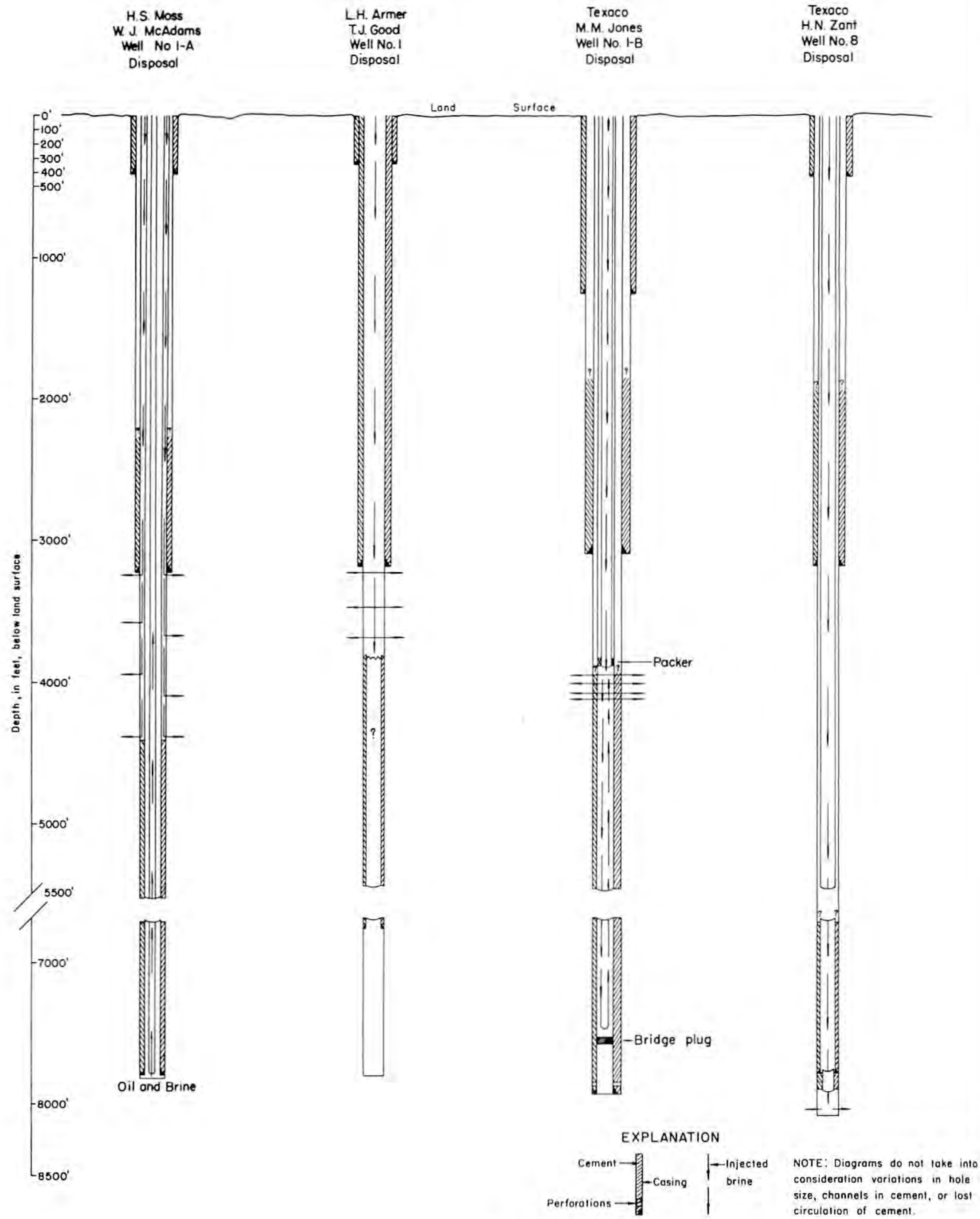

Figure 7

Schematic Diagrams Showing Reported Methods of Completion of Typical Brine-Disposal Wells in the Vealmoor Oil Field

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is generally moderately saline. For example, a sample from well 46-22, which produces from zones of the Dockum penetrated to a depth of 440 feet, had a dissolved solids concentration of 5,780 ppm when sampled in 1948. Sodium, sulfate, and chloride were the primary constituents, the ratio of chloride to sulfate, in equivalents per million, being approximately 1.7 to 1.

The chemical character of ground water in the deeper Santa Rosa Sandstone in the Vealmoor area is presently undetermined but is probably highly saline as indicated by regional studies (Mount, and others, 1964).

The relatively impermeable clay beds of the uppermost part of the Dockum Group apparently form an effective aquiclude for the overlying Tertiary aquifer. However, in some places, permeable sandstone beds of the Dockum may be in contact with overlying Tertiary rocks and therefore may locally form part of the hydrologic system which furnishes usable domestic water supplies in the area.

Ogallala Formation

The Ogallala Formation is the principal fresh-water aquifer in the area of investigation and throughout northern Howard County. The ground water in the formation occurs under unconfined or water table conditions, although the presence of lenticular clay beds in the formation may result in slight artesian pressure locally. The source of water in the formation is precipitation which falls on the land surface and ground water which moves into the area as underflow.

During the present investigation, water levels were measured in 28 wells. The depth to water in these wells ranged from 9 to 152.6 feet below land surface. A comparison of current water-level measurements with previous measurements in 1936 and 1948 indicate water levels have declined only a few feet in the western part of the area; however, in the area east of German Creek, data indicate that the decline in water levels has been much greater.

The thickness of the zone of saturation in producing wells ranged from approximately 4 to 38 feet, the average being approximately 15 feet. The extent of saturation of the formation is highly variable in the area. An evaluation of the areal pattern of ground-water saturation and development, and discussions with water well drillers active in the area, indicate that the zones of significant ground-water saturation trend in northeasterly directions and are therefore perhaps coincidental with courses of ancient stream-channel deposits of the Ogallala Formation.

The wells producing from the formation in the Vealmoor area are generally powered by windmills, small (3-5 horsepower) submersible electric pumps, or are equipped with jet pumps. Several irrigation wells are equipped with pump jacks. The capacity of the wells range from about 1 to 35 gallons per minute, the average being about 8 gallons per minute.

Ground water in the formation moves by gravity in the direction of the slope of the water table or hydraulic gradient toward points of natural or artificial discharge. The slope of the water table is dependent upon several factors, such as variations in permeability of the aquifer material, the topography of the land surface, and the configuration of the aquiclude or bedrock surface underlying the aquifer. The direction and velocity of ground-water movement is rarely uniform; generally the water will follow devious paths through deposits of sediment affording the least resistance to flow, such as uncemented sand and gravel. Where an intermittent surface drainage-way has become incised below the water table, the water table slopes toward the stream-incised channel and the ground water will generally be discharged at the surface.

When a well is pumped, a sphere of influence, commonly termed the cone of depression, is created around the well which results in the movement of ground water toward the well. The lateral extent or radius of this cone of depression is dependent upon several hydrologic characteristics of the aquifer, but in a homogeneous aquifer it is due primarily to the operating capacity of the well. Thus, a high capacity well or a closely spaced group of low capacity pumping wells may cause a significantly large cone of depression and therefore a reversal in the normal hydraulic gradient in the aquifer.

Detailed topographic maps have not yet been prepared in the study area. During this investigation, an attempt was made to establish surface elevations, with a Paulin altimeter, at the sites of wells in which water levels had been measured. Atmospheric conditions at the time prevented the development of reliable data; consequently, the altitudes of the land surface and the water table in the area could not be mapped with accuracy. Such a map would prove extremely useful in interpreting the source and direction of movement of contaminants in the area. However, the data available are sufficient to allow some generalizations regarding the movement of ground water in the Ogallala Formation of the Vealmoor area.

The general direction of ground-water movement in the aquifer is apparently toward the southeast, although numerous exceptions to this general direction of movement are present. In the south-central part of the area, the ground water in the Ogallala Formation has a northward component of movement toward the periphery of the aquifer. Likewise, in the northeast corner of Section 34 in the east-central part of the area, incision of surface drainage through the aquifer and into the underlying Triassic rocks has resulted in a northerly movement of ground water, where it is discharged by several seeps and springs onto the Triassic land surface (Figure 5, Plate 1).

The velocity of ground-water movement depends upon the prevailing hydraulic gradient, the porosity, and the coefficient of permeability of the aquifer at any locality. The coefficient of permeability of the aquifer in the Vealmoor area has not been determined, although an average value of between 300 to 400 gallons per day/ft^2 is generally accepted for the coefficient of permeability of the Ogallala Formation in the Southern High Plains. Assuming that the average coefficient of permeability of the aquifer in the Vealmoor area is somewhere near 400 gallons per day/ft^2 (which may be considerably too low), and assuming an average effective porosity of 30 percent, the comparatively steep hydraulic gradient indicated by water-level data in parts of the area (near German Creek) suggests that the ground water may move as much as 1.5 to 3 feet or more per day in places, although the overall average velocity of ground-water movement in the Ogallala Formation in this region is probably less than 1 foot per day.

In an effort to determine the chemical characteristics of the natural ground water in the area, 39 wells and 5 springs were sampled for chemical analysis (Table 2). A number of these wells were sampled twice to insure that a representative analysis of the water was obtained. Analyses from several wells in the area, sampled in 1936 and 1948 during the Howard and Borden County well inventories, also provide historical data for comparison with the current analyses.

The chemical character of the ground water in the area is somewhat variable from place to place. The dissolved solids content or salinity of water from the wells and springs recently sampled ranged from 310 to 21,481 ppm. In 28 of the samples, the dissolved solids content exceeded 800 ppm. The concentration of chloride ions among the samples ranged from 22 to 12,900 ppm and the ratio of chloride to sulfate, based on equivalents per million, ranged from about 1:1 to more than 90:1. These data include, of course, samples of ground water affected by contamination as well as those believed to represent natural waters in the area. The normal temperature of the ground water in the area is about 68 F.

The nitrate (NO_3) content of the samples ranged from less than 0.4 to 179 ppm; 12 of the samples had 40 ppm or more of nitrate. Nitrate is considered the final oxidation product of nitrogenous matter, and its presence in significant concentrations may indicate contamination by domestic sewage or decayed organic matter. However, in many shallow ground waters of west-central Texas, relatively high nitrate concentrations are common and apparently are naturally-occurring phenomena. Concentrations of nitrate in excess of 45 ppm in water used for infant feeding have been related to the incidence of infant cyanosis (Methemoglobinemia or "blue baby" disease).

Hardness is caused by the presence of calcium and magnesium. All but 3 of the samples contained more than 180 ppm total hardness; therefore the water must be classified as very hard according to commonly accepted standards.

In order to better illustrate these variations in the chemical nature of the water, the concentrations of the principal chemical constituents, in equivalents per million, were plotted on radial coordinates and the resulting patterns are shown on Plate 1. Thus, similarities in the shape of the patterns reflect similarities in the relative proportions of dissolved ions at different localities; likewise, variations in the percentages of the principal ions present in the ground water are also reflected by dissimilarities in the shapes of the patterns.

In a further effort to present a coherent picture of the diagnostic chemical characteristics of the natural ground water in the area and the changes in these characteristics caused by the addition of chemical contaminants, the use of trilinear diagrams (Piper, 1944) and the concept of hydrochemical facies (Back, 1961; Morgan and Winner, 1962) as illustrated in Figure 8 were applied to a number of representative analyses (Figure 9).

In the basic trilinear diagram in Figure 9, each analysis is represented by three plotted points. The proportions of cations and anions, in percent of half the total equivalents per million, are represented by single points in the lower triangles. The points plotted in the center parallelogram represent the intersection of a projection of each of these points along a line parallel to the upper margin of the field and indicates the character of the water as represented by the relationship among the Na+K, Ca+Mg, CO_3+HCO_3, and Cl+SO_4 ions. The classification of hydrochemical facies (both cation and anion facies) is superimposed on the central parallelogram. It should be pointed out that the trilinear plotting system only differentiates types of waters and does not involve absolute concentrations.

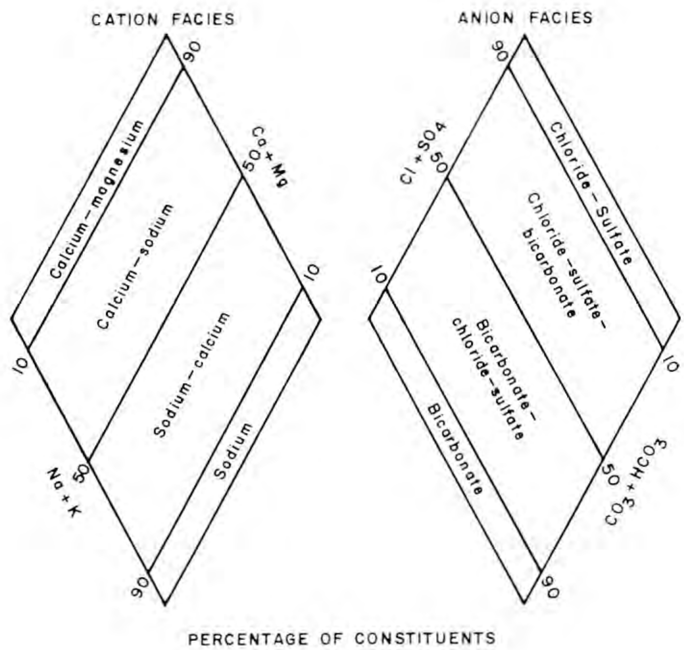

Figure 8
Nomenclature for Hydrochemical Facies
(Modified after Back, 1961)

The majority of the analyses of ground water samples apparently reflecting natural waters in the Vealmoor area plot within the Ca, Na cation facies, although several fall within the Na, Ca facies. The anion facies are predominantly Cl + SO_4, HCO_3 and HCO_3, Cl + SO_4.

Two samples of water from the shallow Triassic rocks belong to the Na, Ca and Na cation facies and the Cl + SO_4 anion facies, clearly demonstrating the dissimilarity of waters in the two hydrologic systems. Furthermore, although the shallow Triassic waters plot near the analyses of Canyon Reef brine in the central field of Figure 9, the ratio of chloride to sulfate in the Triassic waters is much lower than in the Canyon Reef brine.

Further discussion of the significance of the analyses shown in Figure 9 is given in the section of this report titled RESULTS OF INVESTIGATION.

RESULTS OF INVESTIGATION

The most obvious sources of contamination in the area are unlined pits used for disposal of the produced brine. During the first part of this investigation in January, 1964, nine pits were in use in the Vealmoor field (See Plate 1). Eight of these pits were unlined excavations; the ninth is a large asbestos-cement lined pit on the W. F. Long lease (Figure 10) which is utilized as a central collection point for brine to be injected into disposal wells. Most of the pits in the western part of the field apparently are periodically receiving only small amounts of brine and tank-bottom wastes.

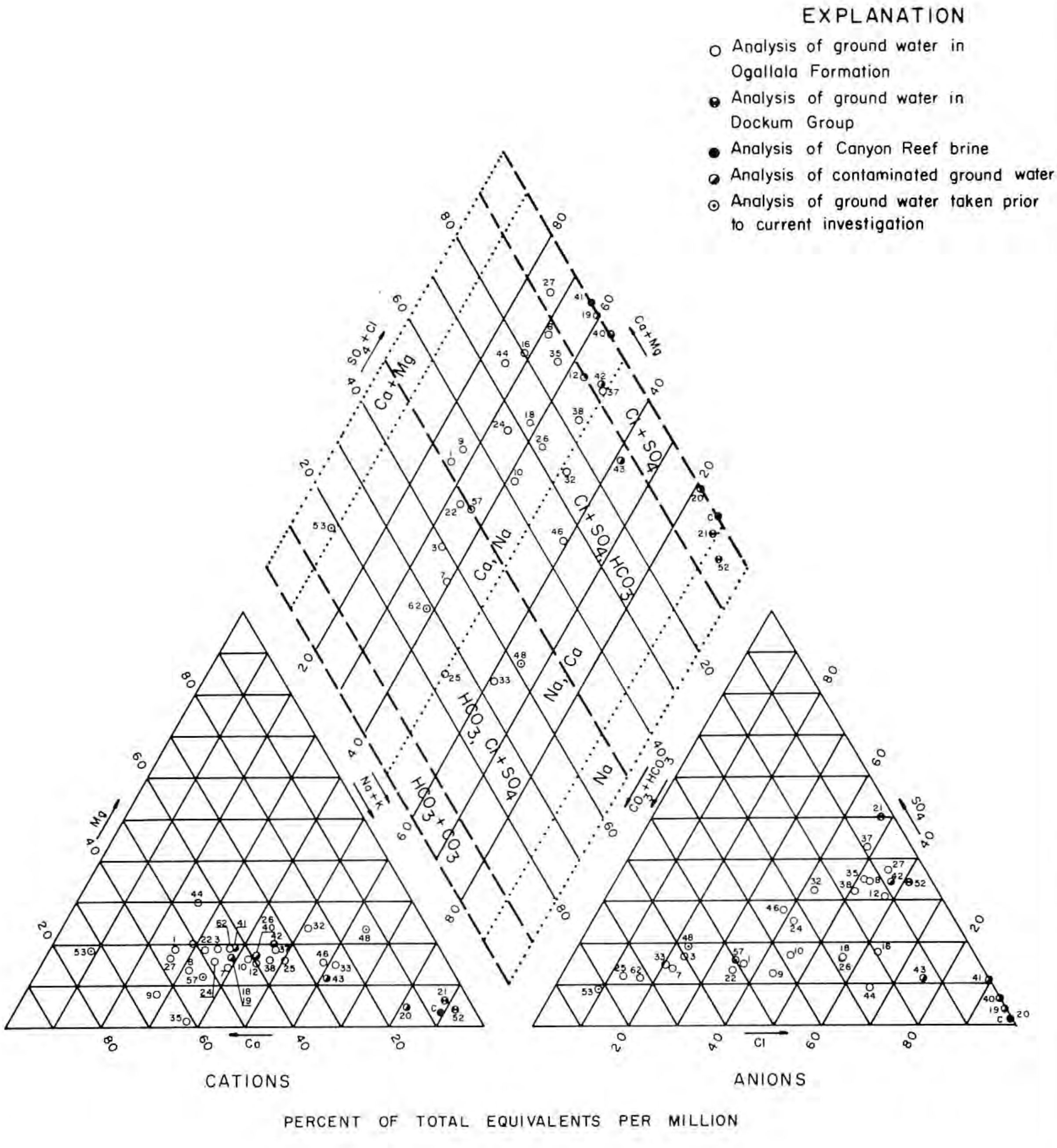

Figure 9

Analyses of Water Samples from the Vealmoor Oil-Field Area Represented by Three Points Plotted in Trilinear Diagrams

(After Piper, 1944; Back, 1961; and Morgan and Winner, 1962)

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The most distinguishing chemical characteristics of the brine produced in the Vealmoor field, as well as most oil-field brines, are the high sodium chloride content and the high ratio of chloride to sulfate (approximately 75:1). Conversely, natural ground waters in the Ogallala aquifer in most parts of the area are characterized by subequal proportions of chloride and sulfate. Consequently, a mixture of the produced brine and natural ground water would be expected to produce a water high in sodium chloride and with a high ratio of chloride to sulfate.

However, as a water solution percolates through an aquifer in which the dissolved ions in solution and the material comprising the aquifer are not in chemical equilibrium, the character of the solution may be significantly altered, particularly with respect to the relative proportions of the major cations calcium, magnesium, and sodium. A water with a high percentage of sodium relative to other cations may exchange much of its sodium for calcium and magnesium present in the aquifer material after only a short distance of travel. Consequently, in aquifers containing abundant calcium and magnesium, a contaminated water affected by such base exchange may contain a significantly higher percentage of calcium and magnesium and a much lower percentage of sodium than would be expected from the relative proportions of these cations in the contaminant source.

Likewise, sulfate, present as calcium sulfate (gypsum) or sodium sulfate, in an aquifer is very soluble in the presence of sodium chloride solutions (Herman, 1955); hence, the sulfate concentration of a contaminated ground water may sometimes appear abnormal with respect to the amount of sulfate available in the contaminant.

After chemical equilibrium is established as a result of continuous influxes of contaminants, the relative proportions of the ions will more closely approach the theoretical mixture.

The presence of ground-water contamination in the Vealmoor area was actually first noticed after the impoundment of spring flow in German Creek in a newly completed earthen reservoir on the Carl Lockhart farm (Section 34, Plate 1). After a fish-kill and the reported death of livestock which had watered from the reservoir, the reservoir was drained. Subsequently, livestock refused to drink from the springs, suggesting that contaminated spring flow was responsible for pollution of the reservoir. The springs were reportedly sampled for partial analyses and found to have very high chloride concentrations. Following these events, well 19-34, located east of German Creek and used for domestic water supply, became contaminated and had to be abandoned and well 59-34, a stock-watering well, also had to be abandoned because of the high salinity of the water.

The unlined surface pits located on the Lockhart and Love leases in the eastern half of Section 34 have apparently been used more or less continuously for brine disposition since the development of these leases. The unlined pit on the Lockhart lease (Figure 11) reportedly received 9 barrels of brine per day in 1956 and 13 barrels per day (4,745 barrels per year) in 1961. During the period 1956 through 1961 alone, apparently more than 28,000 barrels of highly mineralized brine was discharged on the surface of this lease, which could have percolated to the ground water because of the permeable nature of the formation.

The typical sodium chloride pattern of the brine analyses is illustrated by the coordinate pattern diagrams on Plate 1 ($NW\frac{1}{4}$, Section 40). The development of the characteristic sodium chloride pattern and the abnormally high chloride

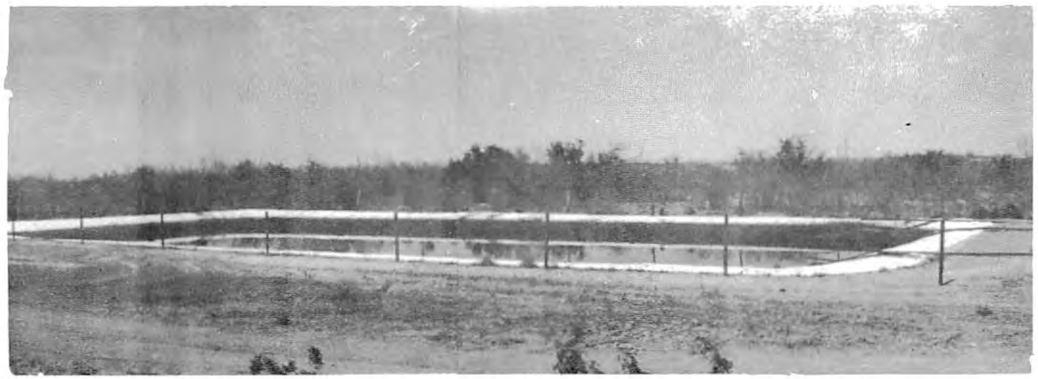

Figure 10. -- Brine-collection pits at Texaco Pipeline Station, $NE\frac{1}{4}$, $NW\frac{1}{4}$ Section 33, Block 32, T-3-N, T & P RR Survey, Howard County. Pit on left is asbestos-cement lined to prevent seepage. Brine is pumped from pits to disposal well. View is east.

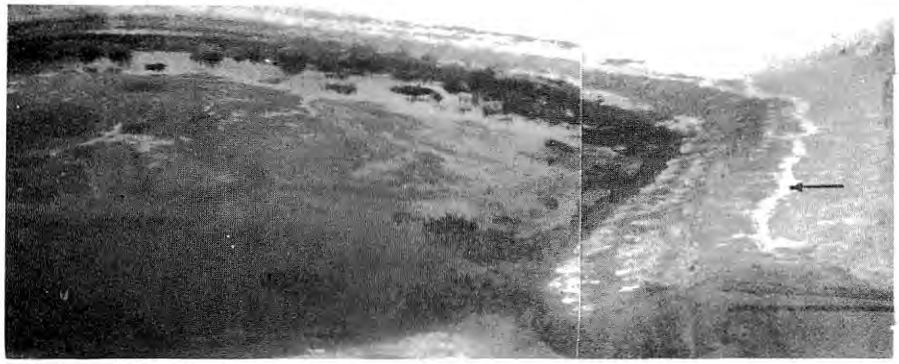

Figure 11.--Unlined surface disposal pit on Carl Lockhart lease, NW$\frac{1}{4}$ Section 34, Block 32, T-3-N, T & P RR Survey, Howard County. Pit is constructed in permeable conglomerate shown in Figure 4 and 5. Former level of brine is indicated by salt precipitate (arrow). Waste crude oil and tank bottom residue remain in pit. View is northeast. Picture taken 4-22-64.

Figure 12.--Abandoned unlined surface-disposal pit constructed in Ogallala Formation in Section 24, Block 33, T-3-N, T & P RR Survey, Borden County (Oceanic Oil Field). Thick oil film covers surface. View is east. Picture taken 4-22-64.

concentrations (up to 12,900 ppm in well 20-34) of the wells and springs in the northeast part of Section 34 illustrates the contamination of the ground water in this area by a source containing principally sodium chloride.

In the central hydrochemical facies diagram of Figure 9, the analysis of Canyon Reef brine plots in the Na, Ca and Cl + SO_4 facies. Assuming that the original character of the ground water in the area of Section 34 was similar to the analyses of wells 7-39, 9-34, or 10-35, which fall in the Ca, Na and Cl + SO_4 facies, and assuming the Canyon Reef brine was responsible for the contamination, a theoretical mixture should plot in the vicinity of a line connecting the analyses of brine and natural ground water in all of the trilinear fields, the relative position of the point along the line depending on the relative concentrations of the two sources.

The position of the analyses of the contaminated wells and springs (19-34, 20-34, 34-35, and 40-34 through 43-34) in Figure 9 indicate a sharp anion change to the Cl + SO_4 facies; however, the cation facies of several of the analyses is Ca, Na rather than Na, Ca which would be expected. This phenomenon can be attributed to base exchange occurring as the contaminant or contaminated solution moves through the Ogallala Formation.

The concentration of sulfate in the contaminated wells and springs 39-34, and 40-34 through 42-34 appears abnormally high with respect to the sulfate concentration in other wells in the area and the chloride-sulfate ratio of the brine. This could be attributed either to solution of sulfate by the brine or more likely reflects a comparatively high sulfate concentration (low chloride-sulfate ratio) of the natural ground water in this locality (as suggested by sample 42-34 which showed a comparatively low degree of contamination at the time of sampling). This postulated natural mineralization may possibly be due to processes of evapotranspiration because of the shallow depth of the water table in this area.

Analyses of samples from the group of wells located south and southeast of the contaminated wells and springs (wells 8-34, 9-34, 34-35, and 10-35 through 18-35) suggest that the quality of the ground water in this area may also be changing. In this area, the salinity and character of the ground water changes rather significantly from south to north (see Plate 1). The anion facies changes from HCO_3, Cl + SO_4 to Cl + SO_4, HCO_3 and, in most samples, the ratio of chloride to sulfate increases from less than 2:1 to more than 3:1 in some samples. Wells 11-35 through 17-35 are used for irrigation of a small vegetable farm and are pumped rather heavily during growing seasons. This comparatively heavy pumpage may have steepened the hydraulic gradient, significantly increased the rate of ground-water movement, and brought about an influx of contaminated ground water from the surrounding area. However, it is also possible that the analyses reflect only the character of the natural water in this area. For example, sample 46-35 (Plate 1) is from a now-abandoned windmill well which was sampled in 1936, prior to any oil development in the area. This analysis is comparable to analyses of nearby wells sampled during the present investigation, although the ratio of chloride to sulfate in the sample from well 46-34 was only slightly more than 1:1 as compared to the recent analyses of wells in the area which show chloride-sulfate ratios of approximately 3:1 or greater.

This group of irrigation wells (12-34 through 17-34) was sampled during the first part of this investigation when most of the wells had been pumping steadily for several days, whereas the second group of samples, with the exception of well 17-35, was taken after the wells had been idle for several weeks. Generally, the salinity of the water appeared slightly higher in the first group of analyses than in the second, although the relative proportions of the constituents did not change significantly. It is not uncommon that the salinity of ground water in a homogeneous aquifer increases with depth, which is usually due to the tendency of heavier ions, which contribute to the salinity, to concentrate near the bottom of the aquifer. When wells are pumped and the water table lowered, mixing occurs which is reflected by the increased mineralization of the sample from the discharging well.

Much of the water being used for irrigation in the area of these wells presently has a high salinity hazard, indicating that non salt-tolerant crops may be adversely affected with continued use of the water. The sodium (alkali) hazard of the water is still comparatively low, however, indicating that no severe danger of the development of harmful levels of sodium in the soils as a result of the use of this water for irrigation.

Analyses of samples from other wells in the Vealmoor field area suggest either early stages of contamination or a general deterioration of the quality of the ground water in the area due to the entrance of brines into the ground water from now-abandoned surface pits, or other sources. Samples from wells 24-33 and 26-33 (Plate 1) contain relatively high concentrations of chloride and plot in the Cl + SO_4, HCO_3 anion facies as compared with samples from nearby wells 25-40, 36-41, and 48-40 (1936 analysis) which plot in the HCO_3, Cl + SO_4 facies. Similarly, well 27-32 produces comparatively highly mineralized water although the relatively low ratio of chloride to sulfate suggests this might reflect natural mineralization. The lack of appreciable development of the ground water in the area of these wells, apparently due primarily to the insufficient saturation of the deposits, precludes any reliable conclusions at present concerning the natural chemical character of the water.

The group of wells producing from the Ogallala aquifer in Borden County in the northern part of the area also poses a problem in attempting to interpret the character of the natural ground water in that area. Wells 37-29 and 38-20 have comparatively high chloride concentrations, falling respectively within the Cl + SO_4 and Cl + SO_4, HCO_3 anion facies. However, the chloride-sulfate ratio, based on equivalents per million, is approximately 1:1. The thinning of the aquifer in this area and the shallow depth of the water table may contribute to a natural increase in salinity of the ground water through processes of evapotranspiration.

Wells 35-20, 53-20, and spring 44-20 in this area also yield comparatively saline ground water which reportedly has deteriorated in quality in recent years. Evapotranspiration resulting from the shallow depth of the water table at this locality of ground-water discharge probably has an effect on the degree of mineralization of the ground water. The high nitrate content (148 ppm) also suggests that organic pollution may have affected the ground water. However, the marked increase in mineralization of the ground water near well 53-20, as reflected by an analysis of the nearby spring 44-20 sampled during the current investigation, cannot be attributed to organic pollution. As this may be an area of discharge for ground water in transit from other areas of oil and brine production to the west and southwest, additional investigation is required to determine reasons for these changes.

An incident of contamination was investigated by personnel of the Colorado River Municipal Water District in October, 1963 in the Oceanic oil field. A sample of ground-water seepage (sample 60-24) in Plum Creek, which drains the Oceanic field, showed a chloride concentration of 44,600 ppm. This area was not investigated in detail during the current study.

SUMMARY OF CONCLUSIONS

The principal fresh-water bearing unit in the area of the Vealmoor oil field is the Ogallala Formation of Pliocene Age. Currently, the formation supplies all of the water used for domestic and irrigation purposes in the area.

In the north-central and northeastern part of the area of investigation, the Ogallala Formation is not present and rocks belonging to the Dockum Group of Triassic Age are exposed at the surface. The upper part of the Dockum Group contains slightly to moderately saline water which is used locally for stock-watering.

The Vealmoor field was developed principally during the years 1950-1952. Throughout much of the Vealmoor field, the largest part of the brine which has been produced from the Pennsylvanian reservoir has been re-injected into the subsurface, although significant amounts of brine and tank-bottom wastes have been intermittently discharged into unlined pits in the past. However, on several leases in the eastern part of the field, unlined surface pits have constituted the principal method of brine disposition since development in these areas.

Correlation of the data collected during this investigation and previous investigations indicates that a number of wells and springs which yield water from the Ogallala Formation in the eastern part of the Vealmoor field are contaminated from sources high in sodium chloride. The principal source of contamination is apparently seepage of oil-field brine discharged into unlined surface pits in the area of contamination. However, leakage of natural brines from deeper horizons through possible inadequately cased, cemented, or plugged oil or stratigraphic tests could also constitute a potential source of contamination. The development of abnormal pressures in some of the formations being used for brine disposal might also contribute to the ground-water contamination problem.

Current analyses of the ground water in the Ogallala Formation in other parts of the Vealmoor field area also suggest that changes have occurred or are presently occurring in the salinity and character of the water; however, further investigation, including test-drilling and water sampling, is considered necessary to conclusively determine the causes for these apparent changes. In the northeastern part of the area of investigation, changes in the character of the ground water, as indicated by comparison of current and historical data, may be related to oil production and brine disposition in the nearby Oceanic oil field; however, this area was not investigated in detail during the current study. At least one instance of ground-water contamination in the Oceanic field was established by a previous investigation.

RECOMMENDATIONS

1. In order to prevent further contamination of ground water in the Vealmoor oil field, the use of unlined surface pits for the disposal of produced brines and other fluid wastes should be prohibited on those leases located on the Ogallala Formation. Because streams draining the area ultimately contribute to the storage of Lake J. B. Thomas, it is further recommended that all surface discharges of oil-field wastes in the field, inclusive of those leases located in areas of Triassic exposures, be prohibited.

2. Injection of brine into the shallow Triassic aquifers in the Vealmoor field should be prohibited.

3. A general clean-up program is needed on many producing leases in the Vealmoor oil field. Leaking pipes, unions, packing, and connections should be replaced. Buried salt-water transportation lines should also be checked for possible leaks.

4. Continuing observation of the quality of the ground water in the area should be maintained, particularly in the area of irrigation where the salinity of the ground water is approaching a point where continued use of the water may prove injurious to soils and crops.

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* Name of agency changed to Texas Water Commission January 30, 1962.

Table 1.--Records of wells in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas

Method of lift and type of power: C, cylinder; E, electric; J, jet; N, none; S, submersible; W, windmill.
Water-bearing unit: T, rocks of Tertiary age; Tr, rocks of Triassic age.
Use of water: D, domestic; Irr, irrigation; S, stock; N, none.

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water bearing unit	Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)		Below land-surface datum (ft)	Date of measurement			
1-38	S. L. Lockhart	-- Murdock	1927	100	8 6	0- 20 80-100	T	82.4	4-22-64	C,W	S	Formerly used for domestic supply. Temp. 67°F.
2-38	do	O. Williams	1961	105	10	105	T	79.5 75.5	1-20-64 4-22-64	S,E	Irr	Well acidized in 1961. Temp. 70°F.
3-38	do	do	1962	105	10	105	T	75.4 77.2	1-21-64 4-22-64	S,E	Irr	Temp. 68°F.
4-38	do	-- Roberson	1963	105	8	105	T	76.7 79.2	do	J	D	Do.
5-39	J. O. Haney	--	--	75	--	--	T	62.0	4-22-64	C,W	S	Do.
6-38	S. L. Lockhart	--	1949	72	8	72	T	55.9 56.8	1-21-64 4-22-64	J	D	Do.
7-39	B. W. Jackson	--	--	45	8	--	T	39.3 39.5	do	J	D	
8-34	E. W. Love	L. Murdock	--	--	--	--	T	28.6 30.9	do	C,W	S	
9-34	A. M. Anderson	B. Baker	1961	40	6	40	T	29.5	4-22-64	J	D	
10-35	Hassie Clanton	--	1924	70	6	--	T	55.0	4-23-64	C,W	S	
11-35	J. C. Clanton	J. A. Clanton	1928	45	--	--	T	37.1	1-21-64	C,W	D	Temp. 68°F.
12-35	do	do	1928	60	N	--	T	50.2	4-22-64	C,E	Irr	Do.
13-35	do	-- Jackson	1927	60	--	--	T	52.4	do	C,E	Irr	Temp. 66°F.
14-35	do	B. Baker	1954	60	--	--	T	53.9	do	C,E	Irr	
15-35	do	do	1954	60	--	--	T	52.3	do	C,E	Irr	Temp. 68°F.
16-35	do	do	1954	60	--	--	T	--	--	C,E	Irr	Do.
17-35	do	do	1954	--	--	--	T	54.2	4-22-64	C,E	Irr	Temp. 64°F.

Table 1.--Records of wells in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water bearing unit	Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)		Below land-surface datum (ft)	Date of measurement			
18-35	W. J. McAdams	--	--	75	--	--	T	--	--	C,W	D,S	Temp. 68°F.
19-34	Carl Lockhart	--	1952	30	8	30	T	--	--	--	N	Abandoned approximately 2 years ago because of contamination. Thick oil film on water in well.
20-34	do	--	--	15	--	--	T	9.0	1-23-64	--	N	Dug well. Reported to be over 100 years old.
21-25	Bert Massingill	J. B. Hodges	1963	254	4 8	0-222 222-254	Tr	--	--	S,E	N	Acidized in May 1963. Water too saline for general domestic use.
22-38	S. L. Lockhart	--	1950	58	6	58	T	45.0	4-24-64	C,E	D	Temp. 68°F.
23-38	do	--	1927	65	8	65	T	52.0 52.6	1-23-64 4-22-64	C,W	S	Do.
24-33	E. L. Clanton	B. Baker	1951	68	7	68	T	44.7	4-24-64	C,E	D	Do.
25-40	do	--	--	75	6	75	T	60.0	do	C,W	D	Do.
26-33	W. F. Long J. S. Jackson	--	1946	30	8	30	T	--	--	J	S	
27-32	M. M. Jones	--	1948	65	8	--	T	35.8	4-25-64	C,W	S	Temp. 68°F.
28-31	C. Peterson	--	1959	110	8	--	T	101.8	4-24-64	C,W	D	Do.
29-30	E. E. Gill	--	1955	200	7-5/8	200	T	--	--	J	D	Do.
30-30	-- Brummett	B. Kincaid	1925	102	10	--	T	95.0 97.8	9-1-36 4-24-64	C,W	D	Well No. 841 in Samuell, 1937. Temp. 68°F.
31-19	O. McBride	--	--	60	--	--	T	33.0	4-25-64	J	D	Temp. 68°F.
32-20	M. Clanton	--	1925	65	--	--	T	27.2	do	C,W	D	Do.
33-30	J. Jackson	--	1954	110	8	110	T	60.3	do	S,E	D	
34-35	W. J. McAdams	--	1952	32	8	--	T	23.7	4-21-64	C,E	S	Temp. 68°F.
35-20	D. Williams	--	--	20	8	--	T	12.2	4-22-62	J	S	
36-41	Mrs. R. Simpson	--	64	118	8	--	T	85.6	4-25-64	N	N	
37-29	H. N. Zant	--	--	--	6	--	T	21.0	do	C,W	Irr	
38-20	W. E. Plunkett	--	--	--	--	--	T	23.2	4-24-64	J	D	

Table 1.--Records of wells in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing: Diameter (in.)	Casing: Depth (ft)	Water bearing unit	Water level: Below land-surface datum (ft)	Water level: Date of measurement	Method of lift	Use of water	Remarks
39-34	Carl Lockhart	--	--	Spring	--	--	T	Flows	1-23-64 4-21-64	N	N	Formerly used as stock water and source for surface reservoir.
40-34	do	--	--	Spring	--	--	T	Flows	do	N	N	Do.
41-34	do	--	--	Spring	--	--	T	Flows	do	N	N	Do.
42-34	do	--	--	Spring	--	--	T	Flows	do	N	N	Do.
43-34	do	--	--	Spring	--	--	T	Flows	do	N	N	Do.
44-20	J. M. Harris	--	--	Spring	--	--	T	Flows	1-23-64 4-22-64	N	S	Water reportedly has become increasingly. mineralized in recent years.
45-20	D. Hanks	--	1944	22	--	--	T	10.0	6-15-48	N	N	Formerly used for stock-watering. Well No. G-22 in Ellis, 1949.
46-35	H. H. Harland	--	--	50	--	--	T	33.2	6- 9-36	N	N	Abandoned. Well No. 811 in Samuell, 1937.
47-46	E. Simpson	R. Davidson	1934	171	--	--	T	146.4	6- 5-36	--	--	Well No. 807 in Samuell, 1937.
48-40	A. Simpson	--	--	159	--	--	T	152.6	6- 9-36	--	--	Well No. 812 in Samuell, 1937.
49-42	Lone Star Land Co.	--	--	159	--	--	T	100.8	9- 1-36	--	--	Well No. 839 in Samuell, 1937.
50-31	H. A. Pace	--	--	175	--	--	T	145.2	do	--	--	Well No. 840 in Samuell, 1937.
51-25	J. F. Winnan	--	--	99	--	--	T	91.7	do	--	--	Well No. 842 in Samuell, 1937.
52-22	T. J. Good	--	1944	440	--	--	Tr	200.0	--	C,W	S	Well No. G-21 in Ellis, 1949.
53-20	D. Hanks	--	1944	22	--	--	T	10.0	6-15-48	N	S	Well No. G-22 in Ellis, 1949.
54-23	C. H. Zant	--	1946	63	--	--	T	65.0	6-16-48	C,W	D,S	Well No. G-23 in Ellis, 1949.
55-48	Mrs. L. Simpson	--	--	149	--	--	T	143.1	6- 5-36	C,W	S	Well No. 805 in Samuell, 1937.
56-47	M. C. Hayden	--	--	160	--	--	T	136.3	do	C,W	D,S, Irr	Well No. 806 in Samuell, 1937.
57-38	S. L. Lockhart	Murdock Bros.	1927	68	--	--	T	54.7	6- 9-36	N	N	Abandoned. Well No. 810 in Samuell, 1937.
58-39	-- Clanton	--	--	68	--	--	T	58.4	do	N	N	Abandoned. Well No. 809 in Samuell, 1937.
59-34	E. W. Love	--	--	--	--	--	T	--	--	N	N	Formerly used for stock watering. Reportedly abandoned because of high salinity of water.

Table 1.--Records of wells in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Casing		Water bearing unit	Water level		Method of lift	Use of water	Remarks
					Diameter (in.)	Depth (ft)		Below land-surface datum (ft)	Date of measurement			
60-24	-- Simpson	--	--	Spring	--	--	T	--	--	N	N	Brine seepage along creek. Sampled by personnel of Colorado River Municipal Water District in 1963.
61-25	--	--	--	50	--	--	T	--	--	--	--	Inventoried and sampled by personnel of U. G. Geological Survey in 1941.
62-47	C. H. Hyden	--	--	160	--	--	T	--	--	--	--	State well no. 28-37-101.
63-23	T. J. Good	--	--	--	--	--	--	--	--	--	--	Surface tank used for stock watering.

Table 2.--Chemical analyses of samples from wells and springs in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas

(Analyses given are in parts per million except specific conductance and pH)

Samples analyzed by Texas State Department of Health unless indicated otherwise by footnote.

Well or spring no.	Owner	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
1-38	S. L. Lockhart	100	1-20-64	47	--	93	19	51	260	60	107	2.0	3.5	507	311	860	7.9
2-38	do	100	1-21-64	40	--	81	11	51	298	54	47	1.3	10.0	438	249	730	7.7
		100	4-22-64	40	--	69	16	51	262	52	50	1.1	9.0	417	237	699	7.6
3-38	do	100	1-21-64	33	--	64	15	53	245	53	54	1.1	10.5	405	222	686	7.9
		100	4-22-64	38	--	74	17	53	228	72	70	1.1	19.0	456	252	752	7.6
4-38	do	100	1-21-64	42	--	65	16	32	214	37	52	2.2	13.0	364	229	620	7.7
		100	4-22-64	38	--	67	15	43	211	40	51	2.1	21.0	381	228	619	7.6
5-39	J. O. Haney	75	1-21-64	42	--	87	28	50	272	60	97	1.3	21.0	521	333	899	7.6
		75	4-22-64	44	--	100	26	61	285	67	114	1.4	27.0	580	356	989	7.5
6-38	S. L. Lockhart	72	1-21-64	44	--	204	49	106	207	192	373	1.9	52.0	1,124	710	1,940	7.3
		72	4-22-64	40	--	183	45	94	207	179	329	1.0	42.0	1,020	640	1,750	7.3
7-39	B. W. Jackson	45	1-21-64	40	--	61	12	59	261	37	53	1.3	4.0	397	201	676	7.5
		45	4-22-64	38	--	59	13	61	261	35	58	1.1	5.5	399	208	678	7.5
8-34	E. W. Love	40	1-21-64	40	--	317	45	202	228	446	510	1.0	60.0	1,734	980	2,810	7.2
		40	4-22-64	38	--	333	48	221	223	495	550	1.0	65.0	1,860	1,030	2,890	7.2
9-34	A. M. Anderson	40	1-21-64	44	--	147	11	71	299	61	169	.6	45.0	697	411	1,200	7.4
		40	4-22-64	33	--	219	17	92	349	120	285	.6	38.0	980	620	1,650	7.2
10-35	Hassie Clanton	--	1-21-64	44	--	86	20	98	234	81	160	1.3	10.0	611	298	1,092	7.6
11-35	J. C. Clanton	45	1-22-64	49	--	91	28	131	275	106	201	2.4	7.0	750	340	1,290	7.3
12-35	do	60	do	47	--	252	61	309	205	439	640	1.8	32.0	1,885	880	3,050	7.3
		60	4-22-64	51	--	140	38	261	253	258	409	2.4	15.0	1,300	500	2,160	7.5
13-35	do	65	1-22-64	44	--	152	37	122	193	154	335	1.7	21.0	982	530	1,720	7.5
		65	4-22-64	33	--	158	40	138	188	167	360	1.7	24.0	1,010	560	1,800	7.3
14-35	do	60	1-22-64	47	--	169	40	104	182	142	367	2.0	14.0	977	590	1,740	7.2
		60	4-23-64	26	--	154	37	101	165	130	338	2.0	9.0	880	530	1,640	7.2
15-35	do	60	1-22-64	44	--	150	36	117	189	163	317	1.6	17.5	944	520	1,630	7.3
		60	4-23-64	4	--	139	33	107	82	108	390	1.8	.4	820	483	1,600	7.1

See footnotes at end of table.

Table 2.--Chemical analyses of samples from wells and springs in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well or spring no.	Owner	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
16-35	J. C. Clanton	60	1-22-64	49	--	163	37	102	190	130	341	2.0	16.0	933	560	1,650	7.4
		60	4-23-64	30	--	150	38	96	181	117	320	2.1	18.0	860	530	1,590	7.4
17-35	do	60	1-22-64	47	--	161	38	98	189	131	339	2.1	13.0	924	560	1,690	7.3
		60	4-23-64	14	--	216	52	173	133	246	560	2.0	.4	1,330	750	2,400	7.1
18-35	W. J. McAdams	75	1-23-64	42	--	129	27	122	232	110	273	1.5	8.0	832	435	1,480	7.6
19-34	Carl Lockhart	30	do	7	--	920	207	920	85	206	3,480	1.1	<.4	5,787	3,150	>12,000	7.2
		30	4-21-64	10	--	840	175	810	85	230	3,100	1.5	<.4	5,210	2,820	8,760	7.1
20-34	do	15	1-23-64	42	--	1,110	194	6,900	233	197	12,900	1.3	10.0	21,481	3,570	>12,000	6.9
		15	4-21-64	35	--	930	182	5,700	243	187	11,100	1.2	15.0	18,300	3,070	>12,000	7.2
21-25a/	Bert Massingill	254	1-23-64	7	--	66	31	1,050	132	1,320	780	1.8	5.0	3,323	294	4,800	7.9
22-38	S. L. Lockhart	58	do	44	--	70	16	54	220	42	87	1.4	11.0	438	240	720	7.5
		58	4-23-64	40	--	70	16	52	217	43	85	1.3	14.0	428	239	741	7.6
23-38	do	65	1-23-64	54	--	71	16	36	240	36	55	.9	9.0	390	243	653	7.5
24-33	E. L. Clanton	68	do	65	--	151	31	120	317	175	219	3.4	6.0	928	500	1,510	7.4
25-40	do	75	do	47	--	36	9	58	232	28	22	3.5	3.0	321	128	505	7.8
26-33	J. S. Jackson	30	do	38	--	166	45	201	340	165	406	3.5	<.4	1,197	600	2,060	7.5
27-32	M. Jones	65	do	49	--	420	72	212	171	660	710	2.3	25.0	2,240	1,350	3,380	7.4
28-31	C. Peterson	110	do	30	--	38	14	102	305	53	46	2.9	5.0	444	152	742	7.5
29-30	E. E. Gill	200	do	40	--	37	16	54	254	29	28	2.3	2.0	332	160	546	7.6
30-30	P. H. McKee	102	9- 1-36	--	--	15	14	125b/	329	35	42	--	--	393	93	--	--
	-- Brummett	102	1-23-64	28	--	25	10	107	296	43	37	2.6	4.0	399	106	672	7.8
31-19	O. McBride	60	do	35	--	129	50	224	325	313	289	2.3	40.0	1,244	530	2,000	7.8
32-20	M. Clanton	65	1-24-64	42	--	104	56	232	305	294	295	3.2	40.0	1,214	491	1,950	7.9
33-30	J. S. Jackson	110	do	33	--	36	14	105	299	47	54	2.7	9.0	398	147	742	7.6
34-35	W. J. McAdams	32	4-21-64	42	--	130	43	152	279	174	279	1.6	55.0	1,010	500	1,710	7.4
35-20	D. Williams	20	4-22-64	28	--	263	57	243	262	415	490	2.0	148.0	1,780	890	2,780	7.3

See footnotes at end of table.

Table 2.--Chemical analyses of samples from wells and springs in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well or spring no.	Owner	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
36-41	R. Simpson	118	4-25-64	28	--	43	8	55	215	29	33	3.5	3.5	310	140	542	7.7
37-29	H. N. Zant	42	do	42	--	284	94	483	229	820	690	4.2	179.0	2,710	1,100	4,020	7.4
38-20	W. E. Plunkett	--	4-24-64	26	--	265	68	391	312	550	630	2.9	69.0	2,160	940	3,440	7.3
39-34[d]	Carl Lockhart	--	5-14-63	--	--	--	--	--	--	910	2,050	--	--	--	--	--	--
40-34	do	Spring	1-24-64	10	--	1,800	500	2,200	89	595	7,460	2.0	<.4	12,000	6,550	>12,000	7.2
41-34	do	Spring	do	47	--	1,350	384	1,400	170	820	5,000	2.8	29.0	9,114	4,960	>12,000	7.0
		Spring	4-21-64	40	--	750	201	890	192	710	2,720	2.9	56.0	5,500	2,700	8,680	7.1
42-34	do	Spring	1-24-64	23	--	302	95	475	222	710	900	1.7	19.0	2,637	1,150	4,200	7.6
43-34	do	Spring	4-22-64	16	--	132	33	313	183	122	610	2.0	<.4	1,320	466	2,440	7.3
44-20	J. M. Harris	Spring	do	16	--	264	105	171	475	129	690	2.8	<.4	1,610	1,090	2,940	7.6
45-20[f]	D. Hanks	22	6-15-48	25	--	69	10	9[b]	184	18	12	--	18.0	273	212	--	--
46-35[c]	H. H. Harland	50	6- 9-36	--	--	81	28	215[b]	342	204	210	--	--	906	319	--	--
47-46[c]	E. Simpson	171	6- 5-36	--	--	22	17	69[b]	256	23	30	--	--	287	127	--	--
48-40[c]	A. Simpson	159	6- 9-36	--	--	14	15	79[b]	195	50	40	--	--	294	97	--	--
49-42[c]	Lone Star Land Co.	159	9- 1-36	--	--	230	76	35[b]	171	154	470	--	--	1,049	887	--	--
50-31[c]	H. A. Pace	175	do	--	--	--	--	--	244	15	40	--	--	285	--	--	--
51-25[c]	J. F. Winnan	99	do	--	--	--	--	--	360	27	28	--	--	377	--	--	--
52-22[a] [f]	T. J. Good	440	6-15-48	10	--	80	36	1,980[b]	278	1,560	1,980	--	1.5	5,780	348	--	--
53-20[f]	D. Hanks	22	do	25	--	69	10	9[b]	184	18	12	--	18.0	273	212	--	--
54-23[f]	C. H. Zant	63	6-16-48	56	--	103	62	211[b]	330	239	312	--	14.0	1,160	512	--	--
55-48[c]	Mrs. L. Simpson	149	6- 5-36	--	--	--	--	--	238	96	42	--	--	394	--	--	--
56-47[c]	M. C. Hayden	160	do	--	--	38	10	71[b]	256	27		--	--	310	137	--	--
57-38[c]	S. L. Lockhart	68	6- 9-36	--	--	102	14	78[b]	268	65	102	--	--	493	312	--	--

See footnotes at end of table.

Table 2.--Chemical analyses of samples from wells and springs in the area of the Vealmoor and Oceanic oil fields, Howard and Borden Counties, Texas--Continued

Well or spring no.	Owner	Depth of well (ft)	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
58-39	-- Clanton	68	6- 9-36	--	--	--	--	--	244	61	114	--	--	465	--	--	--
60-24	-- Simpson	Spring	10-29-63	--	0.14	2,660	580	25,100	220	510	44,600	2.2	<0.4	73,700	9,050	161,586	6.7
61-25f/	--	50	5- 1-41	--	--	54	22	140	476	62	52	--	--	564	225	--	--
62-47g/	C. H. Hyden	160	7-31-61	34	--	48	13	50b/	245	30	31	1.5	4.3	332	174	534	7.1
63-23	T. J. Good	Stock Tank	4-23-64	2	--	55	11	153	61	64	284	.5	<.4	600	182	1,177	7.8
64-34	Carl Lockhart	German Creek	4-21-64	2	--	1,700	462	1,960	121	1,150	6,600	2.0	<.4	11,900	6,150	27,234	7.2

Analyses of oil-field brine produced from Canyon Reef, Vealmoor oil field

Current operator	Lease	Point of collection	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
Texaco	V. Owens	Pit	1-23-64	20	--	2,300	520	26,220	338	840	46,150	2.7	<0.4	76,228	7,900	--	7.2
Do.e/	S. L. Lockhart	Well no. 2	6-15-54	--	228	4,050	1,010	36,300	232	774	65,500	--	--	--	--	--	6.8
Do.e/	M. M. Jones	Well no. 3	7-19-54	--	8	3,030	680	31,800	0	869	56,200	--	--	--	--	--	3.6
Do.e/	D. C. Zant	Well no. 1	7-17-54	--	17	2,810	725	33,000	286	963	57,200	--	--	--	--	--	6.8
Do.e/	J. O. Haney	Well no. 2	do	--	6	2,810	820	31,400	0	1,000	55,000	--	--	--	--	--	3.5

Analyses of oil-field brine produced from Pennsylvanian rocks, Oceanic oil field

Current operator	Lease	Point of collection	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids	Total hardness as $CaCO_3$	Specific conductance (micromhos at 25°C.)	pH
Pan American	M. M. Jones	Well no. 4	3-20-58	--	3.0	4,589	876	41,531	268	1,018	73,757	--	--	122,039	--	--	6.9

a/ Sample from Triassic aquifer.
b/ Sodium (Na) + Potassium (K).
c/ Sample analyzed by Bureau of Industrial Chemistry, The University of Texas.
d/ Sample analyzed by Southwestern Laboratories, Midland, Texas.
e/ Sample analyzed by Dowell Inc., Midland, Texas.
f/ Sample analyzed by U. S. Geological Survey.
g/ Well 62-47: Sodium adsorption ratio is 1.6; percent sodium is 39.

Table 3.-- Records of methods of plugging of various abandoned oil wells and commercially unproductive exploratory tests, Vealmoor oil field area, Howard and Borden Counties, Texas.

(All Data From Files of Texas Railroad Commission, Austin)

Lease	Well No.	Operating Company Drilling Well	Location: Survey	Location: Section	Surface Size (in.)	Casing Length (ft.)	Date Well Plugged	Total Depth of Well	Plugging Record
Hassie Clanton	1	Monterey Exploration Co. Newman Brothers Drlg. Co.	T&P RR Blk.32 T-3-N	NE$\frac{1}{4}$, SE$\frac{1}{4}$ 35	11-3/4	356	7-30-60	8003	"Heavy mud & cement plugs, fully cemented surface casing, capped at top."
Do.	2	do	do	NW$\frac{1}{4}$, SE$\frac{1}{4}$ 35	11-3/4	367	8- 3-60	7923	"Heavy mud & cement plugs, fully cemented surface casing, capped at top."
Mayme Clanton	1	Seaboard Oil Co.	do	NW$\frac{1}{4}$, SW$\frac{1}{4}$ 20	10-3/4	1253	12-12-48	8340	Plugged w/50 sx. cement @8080-8200'; plug in bottom 7-5/8 casing w/30 sx.
T. J. Good	1	Cosden Petroleum Corp.	do	SE$\frac{1}{4}$, SW$\frac{1}{4}$ 21	13-3/8 8-5/8	416 3167	1-25-50	7941	Left 3167' 8-5/8 inch casing (cemented 300 sacks); pumped 50 sacks cement to bottom hole.
Do.	2	Cosden Petroleum Corp.	do	SW$\frac{1}{4}$, SW$\frac{1}{4}$ 21	13	347	3-20-51	8038	100 sacks of cement were pumped as plug at bottom of hole. 100 sacks of cement were pumped at 3150'. Top of hole bridged, cemented and welded.
Do.	1*	Ray Oil Co.	do	SW$\frac{1}{4}$, SE$\frac{1}{4}$ 22	11-3/4 7-5/8	359 3080	5-28-52	7815	"No plugs used. Hole filled with mud-laden fluid."
Archie Hodnett	1	Spartan Drilling Co.	do	NE$\frac{1}{4}$, NE$\frac{1}{4}$ 29	13-5/8 9-5/8	511 3257	3-10-56	7876	Bridge plug set @ 6500'; McCullough aluminum permanent bridge plug set at 1250'; 5' plug cement at surface; 3/8" plate welded in top.
Do.	2	Seaboard Oil Co.	do	SW$\frac{1}{4}$, NE$\frac{1}{4}$ 29	10-3/4	1287	8-31-51	7906	Hamilton bridge plug set @ 7745'. Calseal on top of plug from 7745-7727'. Top of 10 3/4" OD casing plugged with 10 sxs. cement. Valve screwed in top collar of surface casing.
Mildred Jones	1	White Eagle Oil Co.	do	NW$\frac{1}{4}$, NE$\frac{1}{4}$ 32	13-3/8 9-5/8	432 3239	3- 2-55	7976	50 sack cement plug @ 7976-7556'; 25 sack cement plug from 3250 to 3040'.
Mildred M. Jones	A-1	Seaboard Oil Co.	do	NE$\frac{1}{4}$, NW$\frac{1}{4}$ 32	10-3/4 7-5/8	1283 3202	7-19-49	4160	Cement plug from 2600-2723' plus mud-laden fluid.
Do.	A-2*	do	do	do	10-3/4	385	3- 8-54	7988	50 sack plug from 7731-7988' and 25 sack plug from 4087-4190' in 7-5/8" casing. 15 foot plug in top of 10-3/4" casing.
Do.	B-1*	do	do	NW$\frac{1}{4}$, NE$\frac{1}{4}$ 32	13-3/8 9-5/8	1248 3087	5-12-51	7974	13-3/8 casing set with 100 sx., 9-5/8" casing set with 300 sx., 7" casing set at 7974' with 500 sx. Set bridge plug at 7507' in 7" casing and filled to 7526' with plastic plus mud-laden fluid.
Carl Lockhart	2-c	L. H. Armer	do	NW$\frac{1}{4}$, NE$\frac{1}{4}$ 34	8-5/8	90	7-15-55	4660	5-1/2" casing set @ 4526' & cemented with 125 sx. 346 feet recovered. Spotted 25 sx. cement plug in bottom 5-1/2" casing. Filled with 10# mud to 90'. Spotted cement plug from 90' to surface. Welded cap on surface.

Table 3.-- Records of methods of plugging of various abandoned oil wells and commercially unproductive exploratory tests, Vealmoor oil field area, Howard and Borden Counties, Texas. (Cont'd)

Lease	Well No.	Operating Company Drilling Well	Location: Survey	Location: Section	Surface Size (in.)	Casing Length (ft.)	Date Well Plugged	Total Depth of Well	Plugging Record
S. L. Lockhart	1	Magnolia Petroleum Co.	T & P RR Blk. 32, T-3-N	NE¼, NW¼ 38	10-3/4 7-5/8	465 3225	12- 2-57	7994	7994-7800' w/455 sx. cement. 7800-7336' w/heavy mud; 7336-7203 w/30 sx. cement; 7203-6074' w/heavy mud; 6074-5964' w/25 sx; 5964-3284 w/heavy mud; 3284-3174'w/25 sx; 3174-15' w/heavy mud; 15'-surface w/5 sx; Bull plug in top of 10-3/4" casing.
Lockhart-Good	1	Trice Production Co.	do	SW¼, SW¼ 22	12-3/4 8-5/8	156 2450	6-20-55		50 sacks 7463'-7625'; 50 sacks 2941-3102'; 25 sacks at surface
E. W. Love	2*	Magnolia Petroleum Co.	do	SW¼, SE¼ 34	10-3/4 7-5/8	452 3215	6-29-52	7962	7962'-7762' w/46 sx. cement; 7762'-3315' w/heavy mud; 3315'-3115' w/47 sx. cement; 3115'-50' w/heavy mud; 50' to surface with/20 sx. cement
W. J. McAdams	1	L. H. Armer & W. H. Peckham	do	SW¼, SW¼ 26	11	523	7- 1-50	7944	Plug 50 sx. on bottom 7944'-7619'; 8" casing from 600'-3025'; 11' casing surface to 583'; Cement plug of 50 sx at 100'
Do.	2	do	do	do	None		12-26-51	4595	7-5/8 casing at 3033 w/150 sx. 5 1/2 at 4563 w/100 sx. 50 sx cement plug. 4500'-4586'; 59 sx plug 90' to surface.
Do.	1	Oceanic Oil Co.	do	NE¼, NW¼ 26	13-3/8 8-5/8	406 3025	6-23-54	7935	Cement plug placed at 7724-7811' with 25 sacks cement. Cement plug placed in intermediate at 2733'-2820' with 25 sx. cement.
Do.	1	H. S. Moss	do	NW¼, SW¼ 27	10-3/4	405	9-30-56	7833	125 sack plug squeezed into formation; 25 sx. plug in 5-1/2" casing @ 560; 25 sx @ 3100'; 15 sx. @ 400'; 10 sx. in top.
Do.	4	do	do	SW¼, SW¼ 27	13-3/8	415	12- 5-56	7853	50 sx. plug @ 7853'; 25 sx. plug in 5-1/2" @ 6206'; 25 sx. plug @ 3100'; 10 sx. plug 400'; 10 sx. plug in top.
Muse & Newsom	1	Earle M. Craig, Jr.	do	NW¼, SE¼ 31	13-3/8 8-5/8	382 3142	3-14-54	8380	50 sx. cement at T.D., 50 sx. at 4450', 25 sx. @ 3850', 10 sx. @ top of 8-5/8" casing. Cement circulated on surface casing & intermediate casing.
Dean Self	1	Texas Pacific Coal & Oil Co.	do	NW¼, NE¼ 39	13-3/8 8-5/8	234 3195	11-21-54	7968	29 sx. cement plug 7968'-7900'; 25 sx. cement plug 3170'-95' steel cap on top.
Akin Simpson	1	Trans-Tex Drilling Co.	do	NE¼, NE¼ 41	13-3/8	431	10-29-53	8039	Cement plug from 481' to 381' and plugged top w/20 sacks cement.
Do.	1	Goldston Oil Corp.	do	NW¼, NW¼ 46	13-3/8 9-7/8	420 3203	9-20-50	8100	Cement plug was placed by the circulation method from 8100'-7700'; 5900-6200'; 3100'-3250'; 20 sacks cement was poured in top with plate welded over 9-5/8" casing head.

Table 3.-- Records of methods of plugging of various abandoned oil wells and commercially unproductive exploratory tests, Vealmoor oil field area, Howard and Borden Counties, Texas. (Cont'd.)

Lease	Well No.	Operating Company Drilling Well	Location		Surface Size (in.)	Casing Length (ft.)	Date Well Plugged	Total Depth of Well	Plugging Record
			Survey	Section					
Akin Simpson	1	D. E. Vasser & A. W. Howard	T & P RR Blk. 32, T-3-N	NW$\frac{1}{4}$, NE$\frac{1}{4}$ 45	13-3/8	420	9- 3-53	8145	25' plug at top of cement 7 rock, cement plug at bottom of casing.
M. S. Veal	4	Seaboard Oil Co.	do	SW$\frac{1}{4}$, NE$\frac{1}{4}$ 40	10-3/4 7-5/8	401 3183	7-28-52	8092	25 sacks cement plug from 7970'-8092'; 10 sx. plug in top of surface casing. Steel plate on top collar.
Mae Zant	1	do	do	NE$\frac{1}{4}$, SW$\frac{1}{4}$ 29	10-3/4 7-5/8 5-1/2	1259 3186 7892	2- 6-52	7940	1259'-10-3/4" casing cemented w/800 sx.; 3186'-7-5/8" casing cemented w/500 sx.; 7892'-5-1/2" casing cemented w/200 sx. Model "K" Baker Plug @ 7647'; Hydromite from 7647'-7621'.
H. N. Zant	"A"-3	do	do	SW$\frac{1}{4}$, SW$\frac{1}{4}$ 19	10-3/4	389 3192	1-16-55	8253	25 sack plug @ 8145'-8253'; 15 sack plug 2421' to 2500'.

* Presently being used as salt water disposal wells.

Table 4.--Reported methods of completion of brine-disposal wells in the Vealmoor oil field, Howard and Borden Counties, Texas

(All data from files of Texas Railroad Commission, Austin)

Lease	Well no.	Current operating company	Date permit granted by Railroad Comm.	Survey	Section	Injection zone (in feet below land surface)	Surface casing: Size (in.)	Surface casing: Length (ft)	Surface casing: Cement (no. of sacks)	Intermediate casing: Size (in.)	Intermediate casing: Length (ft)	Intermediate casing: Cement (no. of sacks)	Long string casing: Size (in.)	Long string casing: Length (ft)	Long string casing: Cement (no. of sacks)	Type injection	Current daily volume of brine injected (bbls)	Surface injection pressure (psi)
W. J. McAdams	1-A	H. S. Moss	10-27-60	T&P RR BLK. 32 T-3-N	NW 1/4, SW 1/4, 27	3,075 - 4,300	13-3/8	391	400	8-5/8	3,197	?	5-1/2	7,797	250	Annulus	150	0-50
M. M. Jones "A"	1	Texaco	5-22-50	do	NE 1/4, NW 1/4, 32	3,199 - 4,150	10-3/4	1,295	800	--	--	--	7-5/8	3,199	500	Tubing	1,000	Pump pressure
M. M. Jones	1-B	do	12- 2-63	do	NW 1/4, NE 1/4, 32	3,930[a] - 4,100	13-3/8	1,248	700	9-5/8	3,087	300	7	7,958	500	Tubing with packer	4,500	Do.
T. J. Good	1-SWD	L. H. Armer	8- 7-61	do	SW 1/4, SE 1/4, 22	3,027 - 3,800	10-3/4	359	350	--	--	--	7-5/8	3,027	2,100	Long String	500	Do.
H. N. Zant	8	Texaco	5-21-56	do	NW 1/4, NW 1/4, 28	7,910 - 8,100	10-3/4	421	325	7-5/8	3,180	--	5-1/2 4" Liner[b]	7,801 140	200 ?	do	2,200	465-930
E. W. Love	2	L. H. Armer	5-16-57	do	SW 1/4, SE 1/4, 34	3,215 - 5,500	10-3/4	444	325	--	--	--	7-5/8	3,209	2,100	do	150	200-500

[a] Undetermined as to whether or not cement behind 7-5/8 inch casing is above 3,199 feet; therefore interval 3,087-4,100 feet may be open for injected salt water.
[b] Liner set from 7,770-7,910 feet with cement squeezed at top.

APPENDIX

A DESIGN CRITERION FOR LINED SURFACE EVAPORATION PITS, HIGH PLAINS REGION OF TEXAS

A Design Criterion for Lined Surface Evaporation Pits, High Plains Region of Texas

By

H. H. Porterfield, Hydrologist

To determine the approximate minimum size of a lined surface evaporation pit necessary for complete evaporation of the water content of brine, a number of factors must be considered. Figures of average values for long periods of time cannot be used in this determination because of the large variations in the rates of rainfall and evaporation, and also because the distribution of the gross amounts of rainfall and evaporation vary greatly in respect to time and area. Another factor of importance is that water must be available at all times to utilize the potential evaporation. The effect of salinity is to reduce evaporation, but because of the many variables, some of which are interrelated, it is not possible to define a simple relationship between increase in salinity and decrease in rate of evaporation. Reduction in evaporation because of salinity, however, can be expressed as a function of the freshwater evaporation rate, and therefore it is essential that as small an increment of time as practical should be used in determining the effective evaporation.

Because there are many combinations of input rates and mineral concentrations as well as variations in evaporation rates and rainfall, it is not practical to specify one minimum evaporation-pit size for the entire High Plains. In order to simplify the determinations of the approximately minimum-size evaporation pit for various locations within the High Plains, several graphs were prepared. These graphs are based on studies made by the Texas Water Commission and historical records for the period 1940-62.

Steps for the determination of approximate minimum evaporation-pit size are as follows:

1. Choose an appropriate base area from the graphs shown on Figure A1 through A4, for a corresponding salinity and desired input rate, at an assumed pit depth. Example: For an input of 100 barrels per day, with a salinity of 50,000 parts per million, and a pit depth of 6 feet, the corresponding base area is about 1.22 acres.

2. Choose a distribution coefficient from the isograms of distribution coefficients map shown in Figures A5 through A8, for the corresponding salinity and desired location, and multiply the base area by this coefficient to determine the approximate minimum area. Example: If the desired area is in the southwest part of Gaines County, for a salinity of 50,000 parts per million the coefficient is 0.85. The approximate minimum area is 0.85 x 1.22 = 1.04 acres.

3. Determine from Figure A9 the depth of precipitate resulting from the evaporation of one foot depth of saline water, for the input salinity. Example: For an input salinity of 50,000 parts per million the resulting depth of precipitate per foot of solution evaporated is 0.0235 feet.

4. Find the cumulative annual input depth from Figure A10, in feet, for the corresponding input rate, in barrels per day, for the determined pit area. Multiply this value by the depth of precipitate per foot of solution to find the total depth of precipitate deposited in one year for the determined pit area. Example: For an input of 100 barrels per day on a pit area of 1.04 acres, find the annual input depth of 4.5 feet. The precipitate deposited in 1 year is 4.5 x 0.0235 = 0.11 feet. If the pit life is expected to be 10 years, then 10 x 0.11 = 1.1 feet depth required to store the deposited precipitate.

5. From Figure A11, determine the 24-hour average maximum point rainfall depth for the desired recurrence interval. Example: For a recurrence interval of 50 years the rainfall depth is 6 inches (0.5 feet).

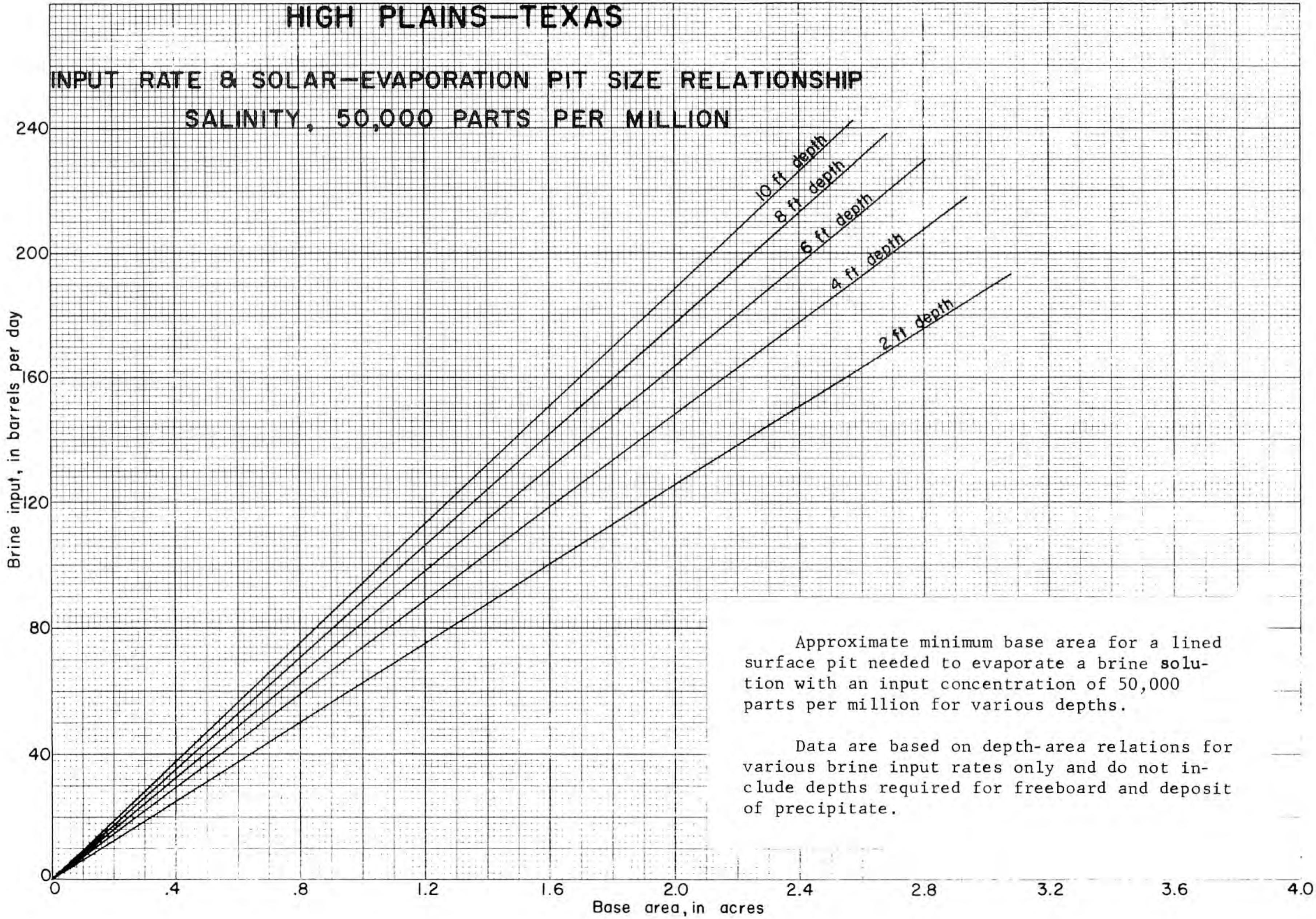
6. Total the various increments of depth to find the total pit depth necessary. Example:

Assumed pit depth	6.0 feet
Depth necessary for deposit of precipitate........	1.1 feet
Freeboard to accomodate rainfall..................	.5 feet
Total pit depth necessary for 10-year life........	7.6 feet

These examples indicate that to store and dissipate brine with a saline concentration of 50,000 parts per million at the rate of 100 barrels per day in southwestern Gaines County, the approximate minimum size of a lined evaporation pit (with design pit life of 10 years) would have an area of 1.04 acres (45,302 square feet) and a depth of 7.6 feet.

It must be remembered that these figures are based on idealized conditions, and if the situation varies from the foregoing assumptions the evaporation-pit sizes determined by this method would be erroneous.

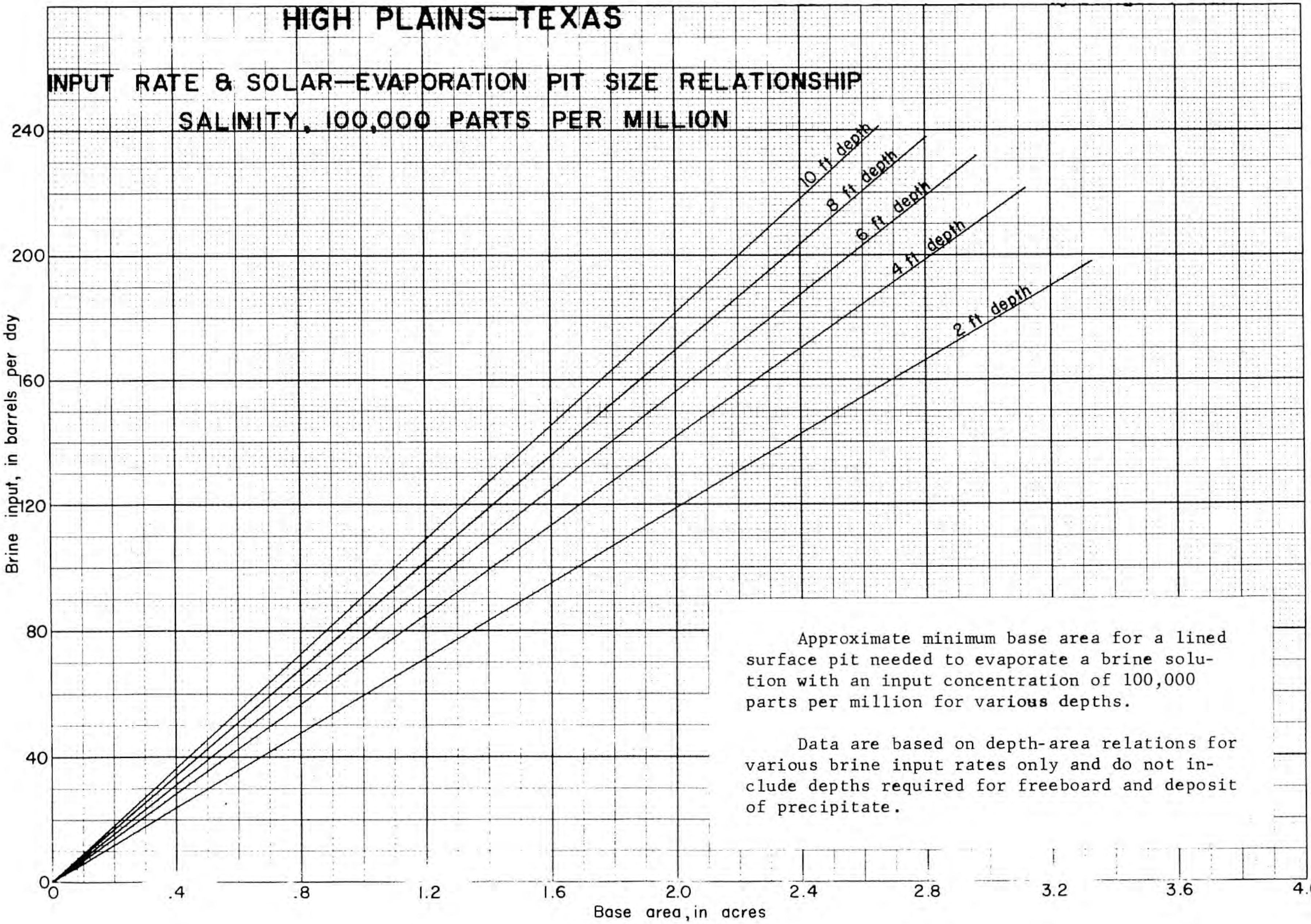
Figure A1



Approximate minimum base area for a lined surface pit needed to evaporate a brine solution with an input concentration of 50,000 parts per million for various depths.

Data are based on depth-area relations for various brine input rates only and do not include depths required for freeboard and deposit of precipitate.

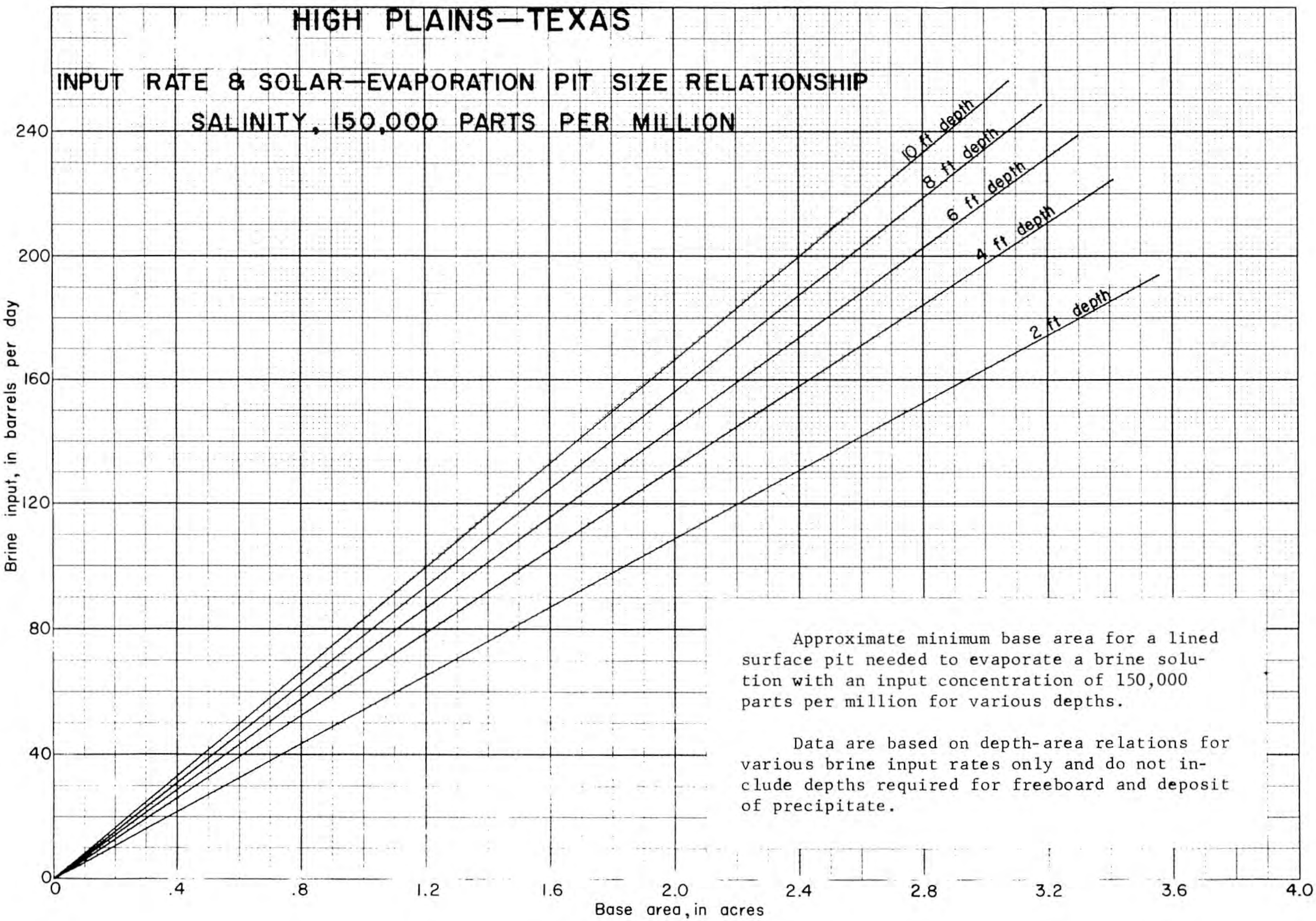
Figure A2



Approximate minimum base area for a lined surface pit needed to evaporate a brine solution with an input concentration of 100,000 parts per million for various depths.

Data are based on depth-area relations for various brine input rates only and do not include depths required for freeboard and deposit of precipitate.

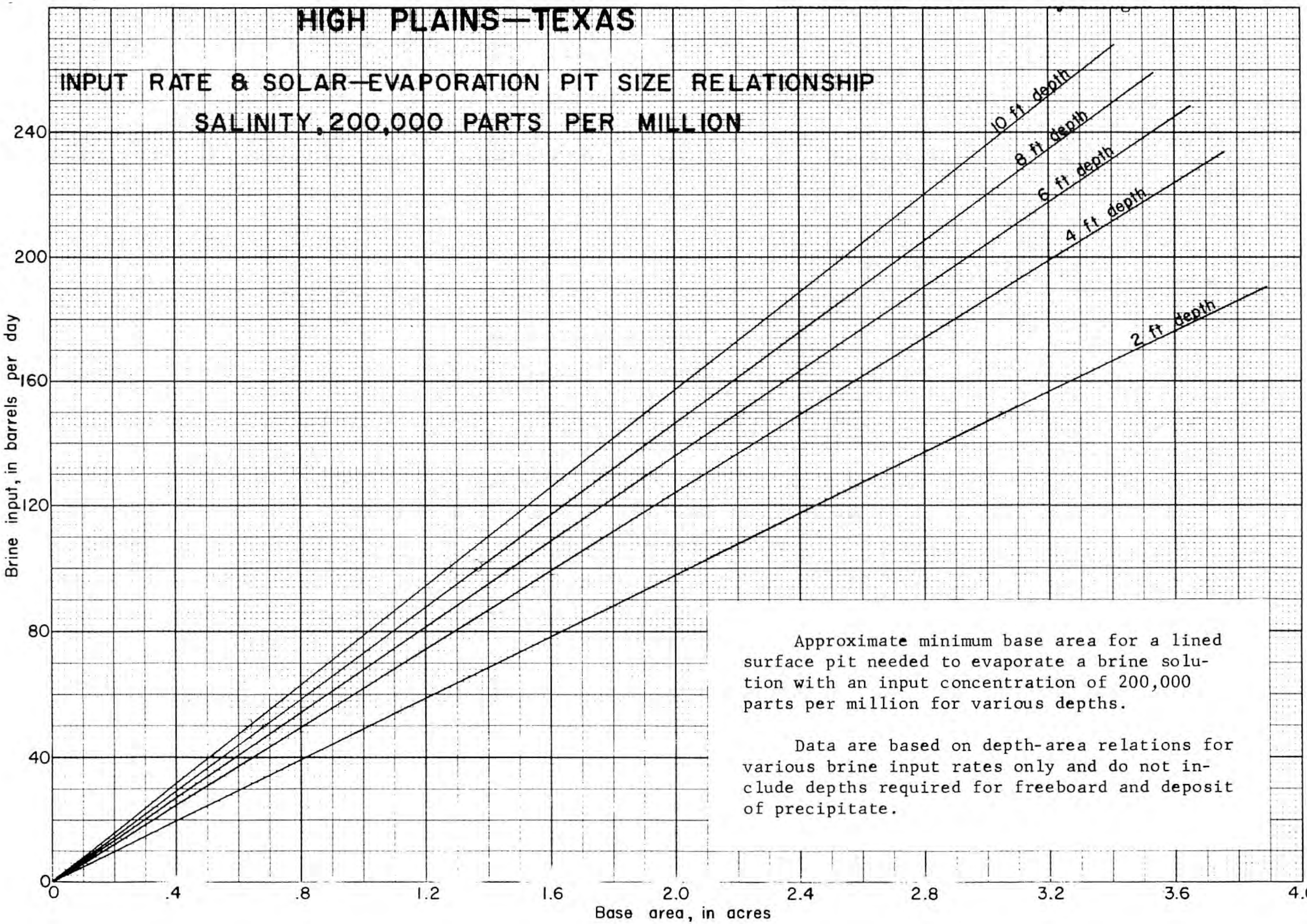
Figure A3



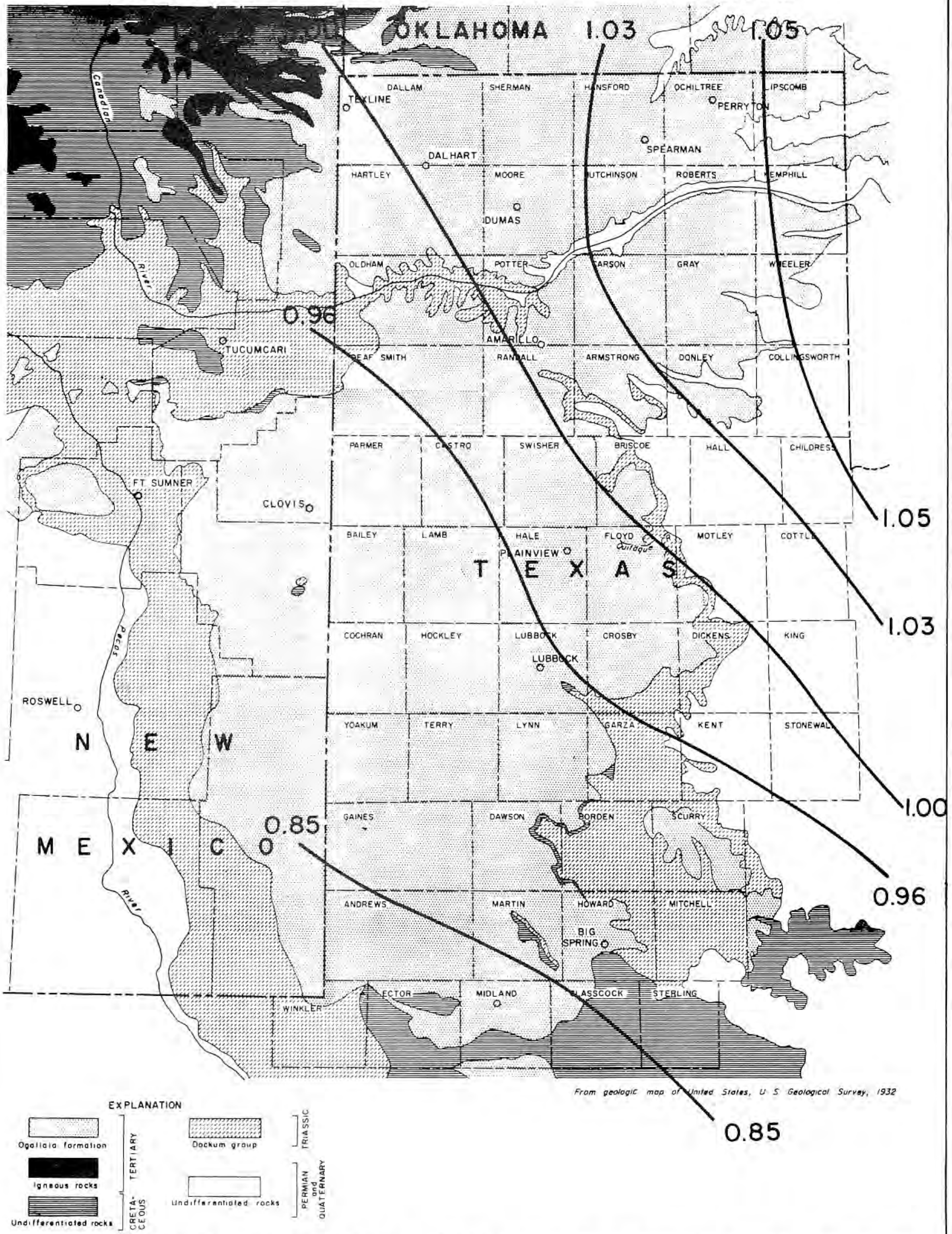
Approximate minimum base area for a lined surface pit needed to evaporate a brine solution with an input concentration of 150,000 parts per million for various depths.

Data are based on depth-area relations for various brine input rates only and do not include depths required for freeboard and deposit of precipitate.

Figure A4


HIGH PLAINS—TEXAS
INPUT RATE & SOLAR—EVAPORATION PIT SIZE RELATIONSHIP
SALINITY, 200,000 PARTS PER MILLION
10 ft depth
8 ft depth
6 ft depth
4 ft depth
2 ft depth
Brine input, in barrels per day
Base area, in acres
0
40
80
120
160
200
240
0
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6
4.0
Approximate minimum base area for a lined surface pit needed to evaporate a brine solution with an input concentration of 200,000 parts per million for various depths.
Data are based on depth-area relations for various brine input rates only and do not include depths required for freeboard and deposit of precipitate.

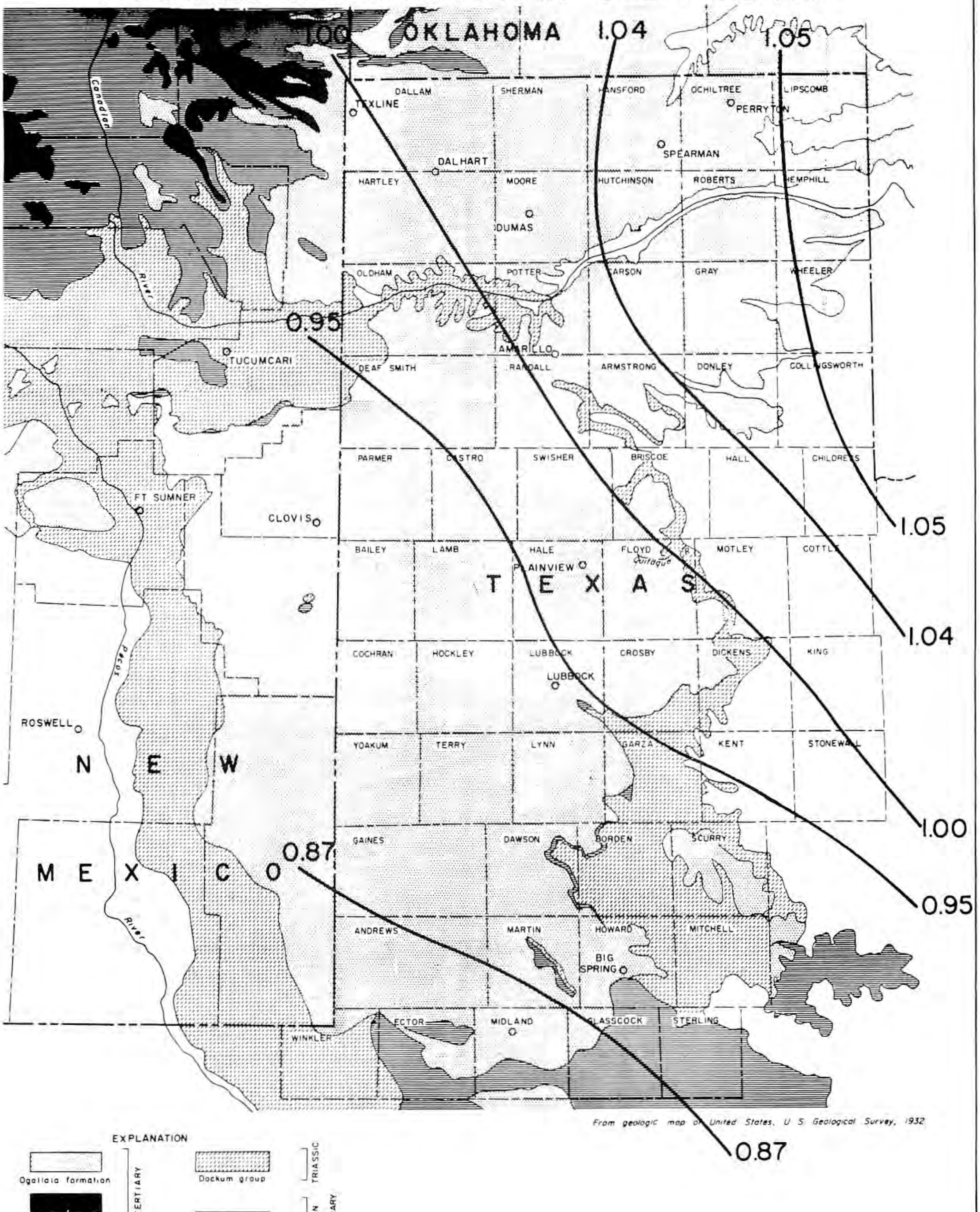
ISOGRAMS OF DISTRIBUTION COEFFICIENTS



Coefficients for extrapolation of <u>base</u> evaporation-pit areas for brine inputs of 50,000 parts per million within the High Plains.

Figure A6

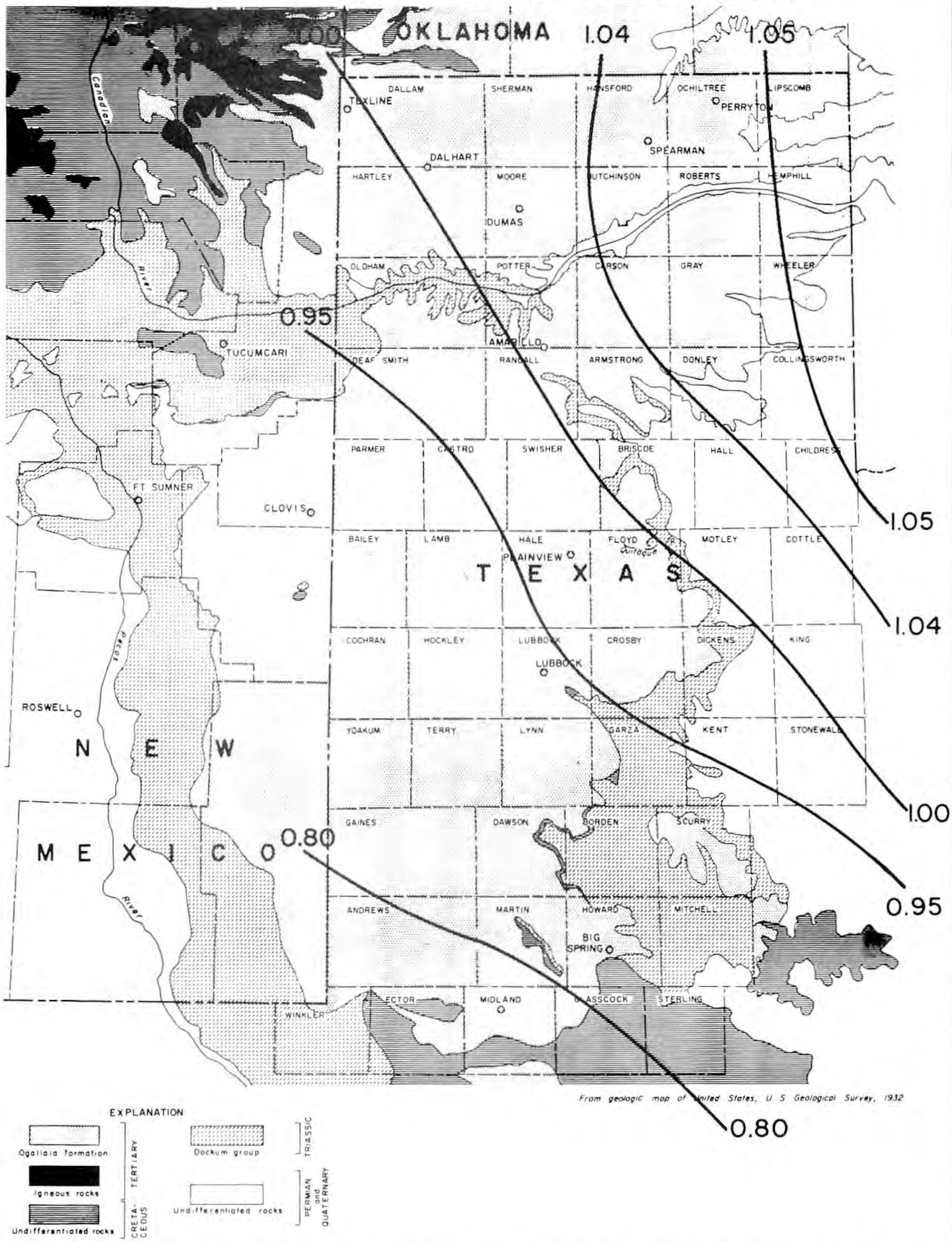
ISOGRAMS OF DISTRIBUTION COEFFICIENTS



Coefficients for extrapolation of base evaporation-pit areas for brine inputs of 100,000 parts per million within the High Plains.

Figure A7

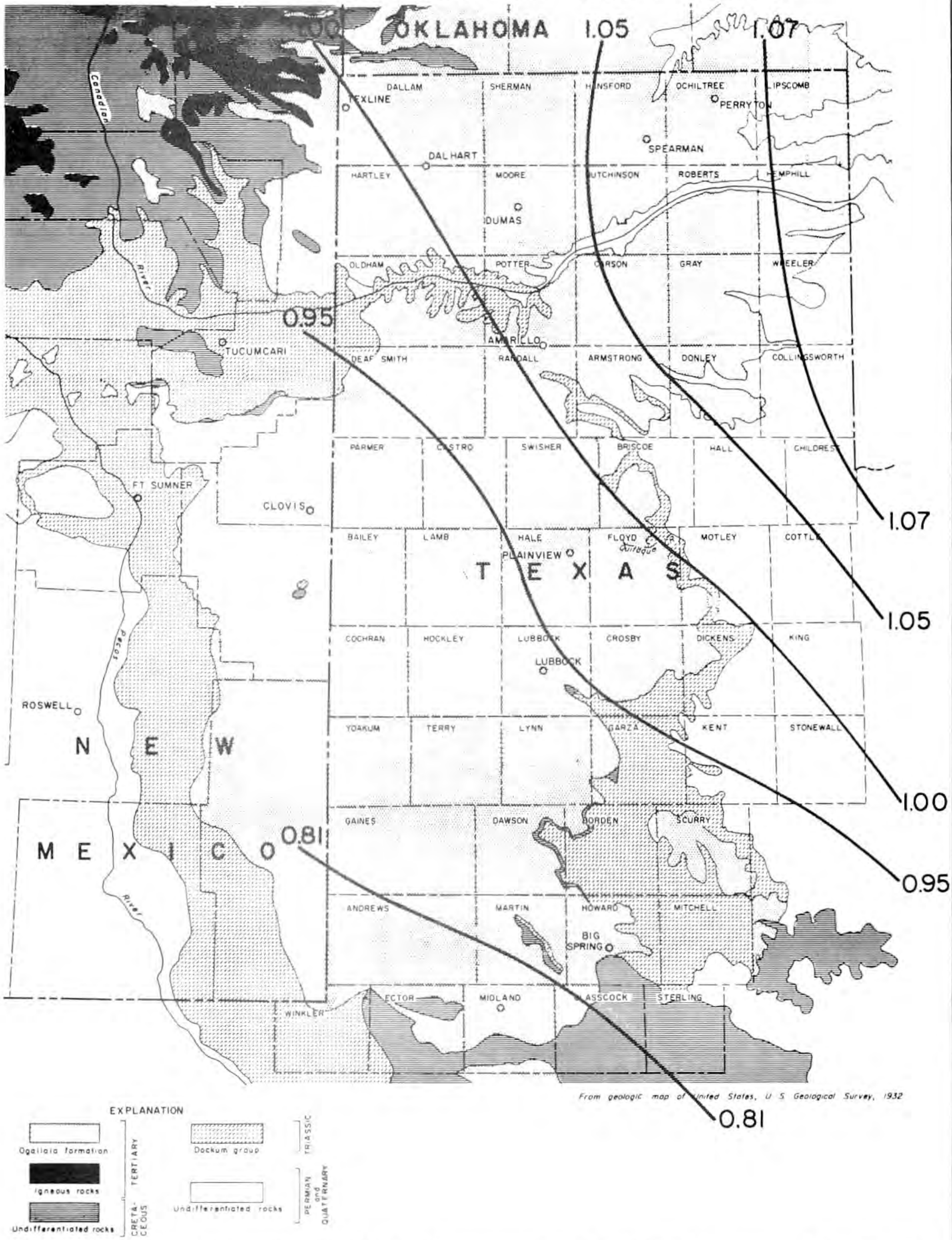
ISOGRAMS OF DISTRIBUTION COEFFICIENTS



Coefficients for extrapolation of base evaporation-pit areas for brine inputs of 150,000 parts per million within the High Plains.

Figure A8

ISOGRAMS OF DISTRIBUTION COEFFICIENTS



Coefficients for extrapolation of base evaporation-pit areas for brine inputs of 200,000 parts per million within the High Plains.

Figure A9

Depth of precipitate resulting from the evaporation of one foot depth of saline water for various concentrations of solutions.

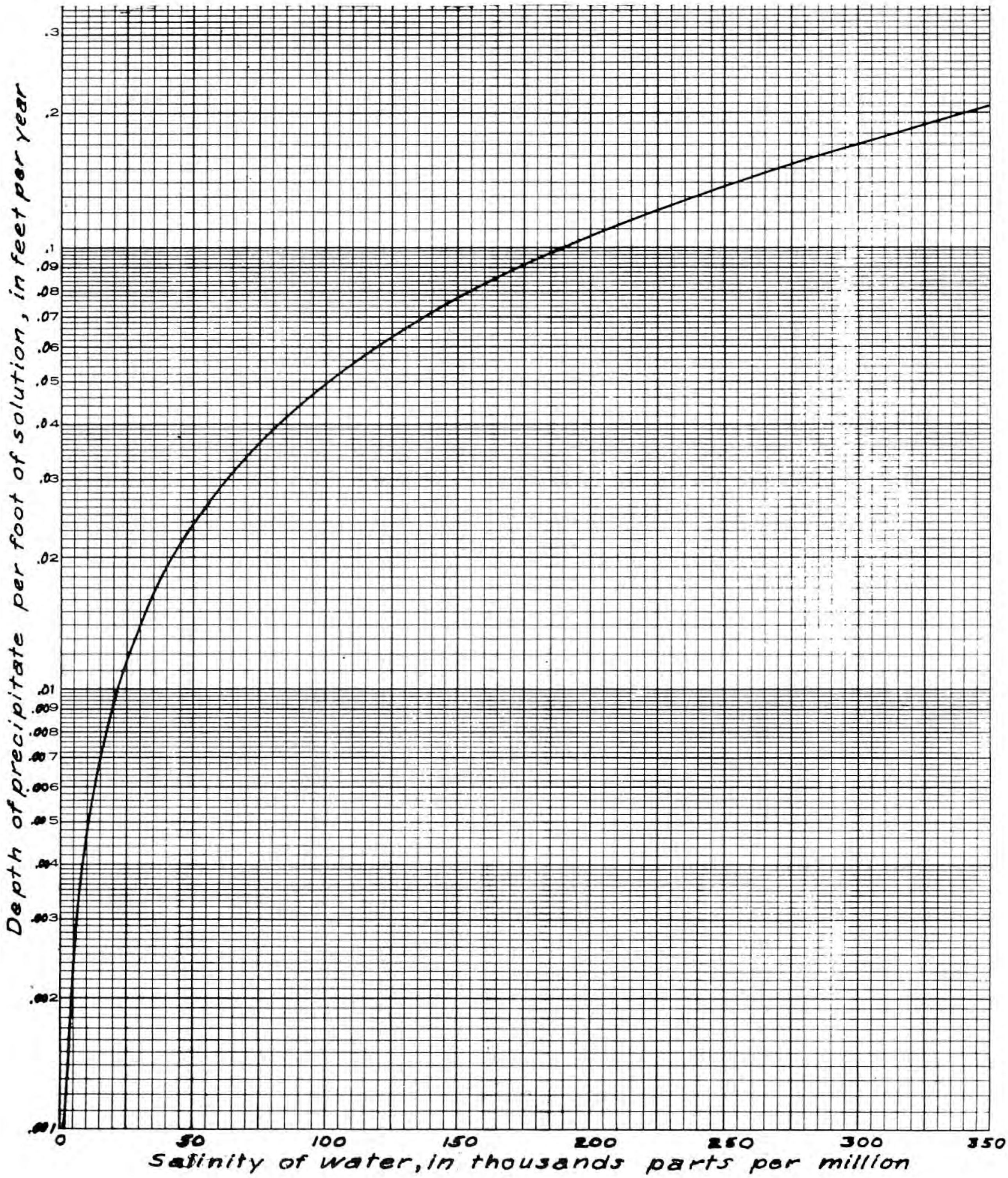
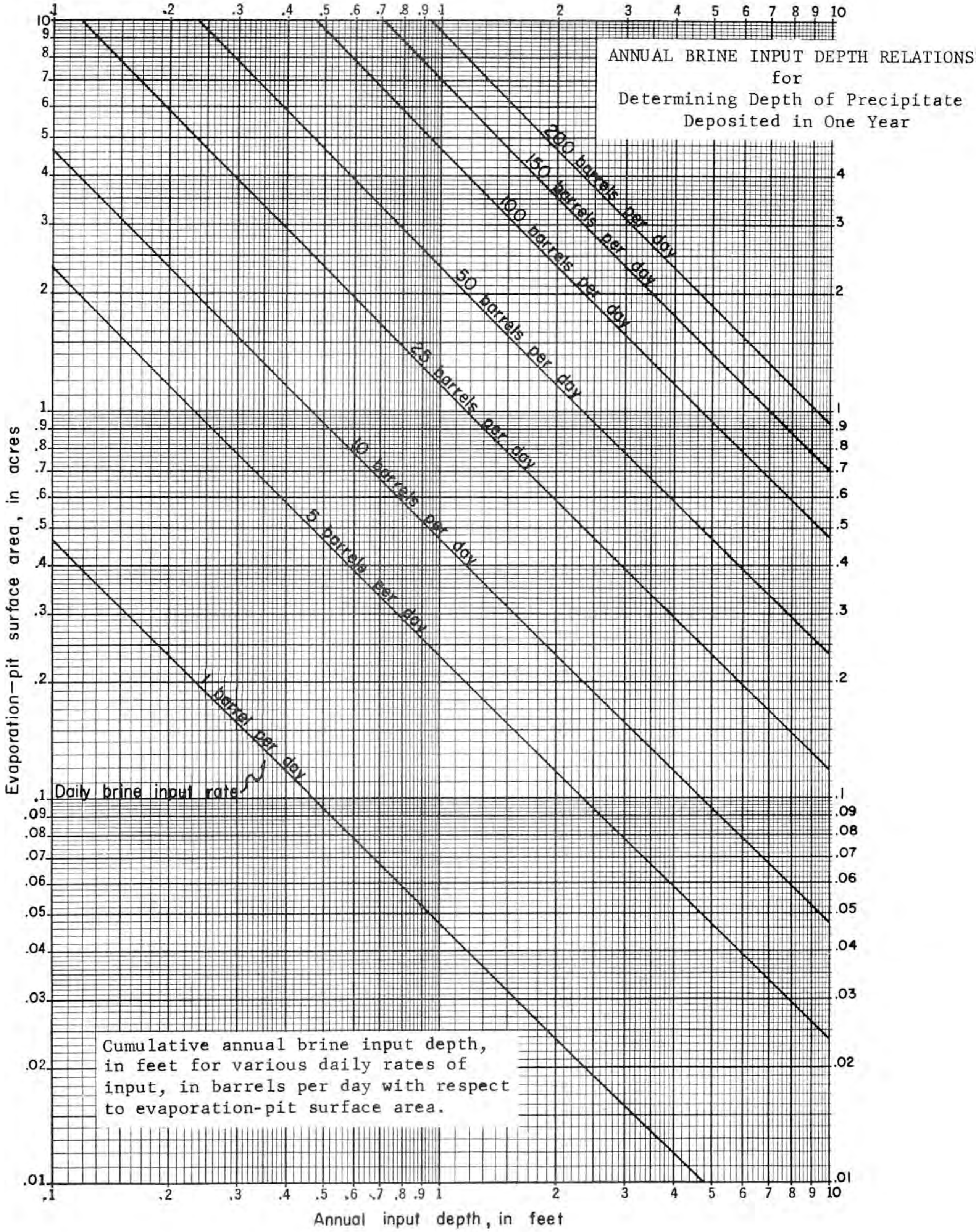
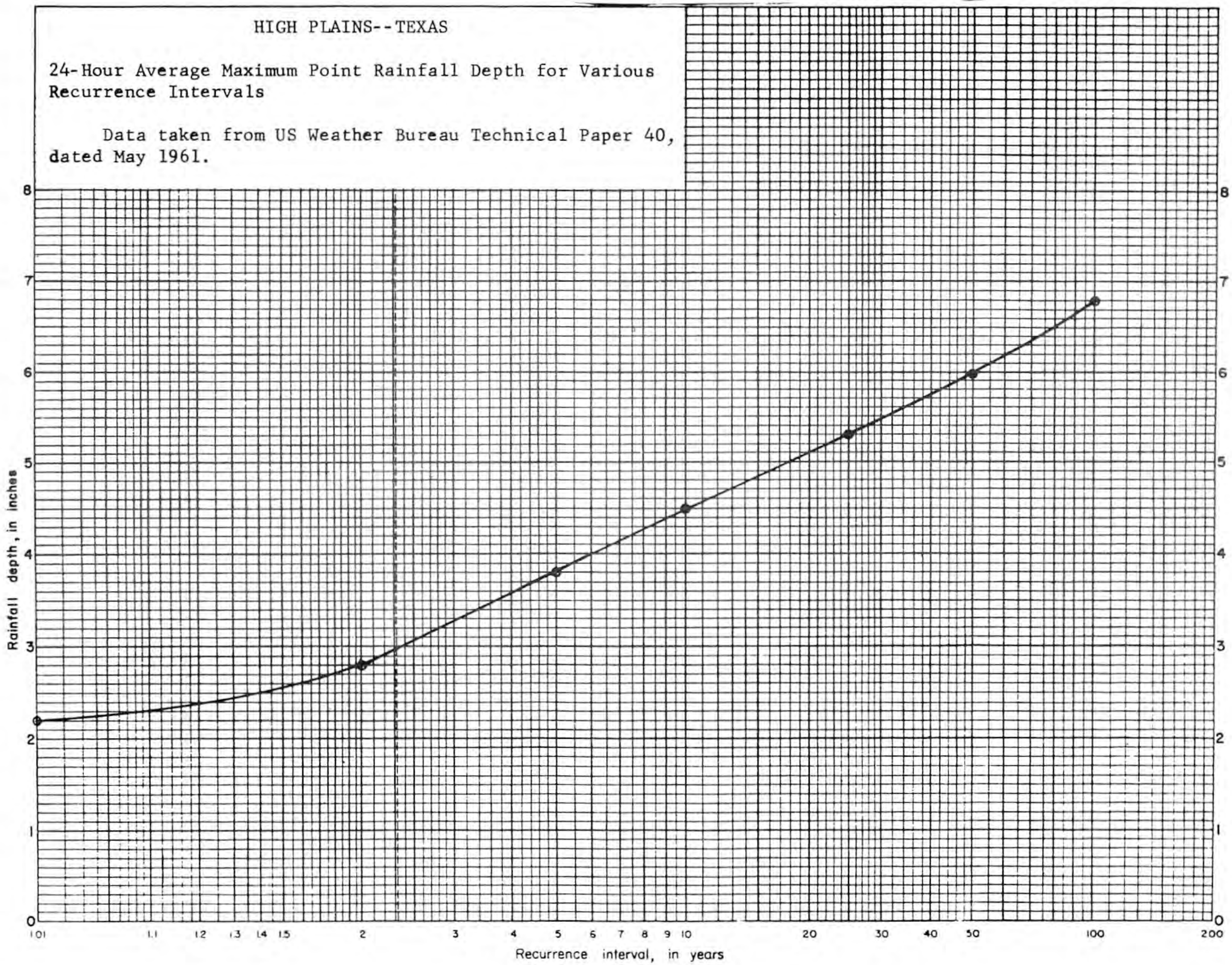


Figure A10



ANNUAL BRINE INPUT DEPTH RELATIONS
for
Determining Depth of Precipitate
Deposited in One Year
200 barrels per day
150 barrels per day
100 barrels per day
50 barrels per day
25 barrels per day
10 barrels per day
5 barrels per day
1 barrel per day
Daily brine input rate
Cumulative annual brine input depth, in feet for various daily rates of input, in barrels per day with respect to evaporation-pit surface area.
Evaporation—pit surface area, in acres
Annual input depth, in feet
.1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 3 4 5 6 7 8 9 10
.01 .02 .03 .04 .05 .06 .07 .08 .09 .1 .2 .3 .4 .5 .6 .7 .8 .9 1 2 3 4 5 6 7 8 9 10

Figure A11


HIGH PLAINS--TEXAS
24-Hour Average Maximum Point Rainfall Depth for Various Recurrence Intervals
Data taken from US Weather Bureau Technical Paper 40, dated May 1961.
Rainfall depth, in inches
0
1
2
3
4
5
6
7
8
1.01
1.1
1.2
1.3
1.4
1.5
2
3
4
5
6
7
8
9
10
20
30
40
50
100
200
Recurrence interval, in years

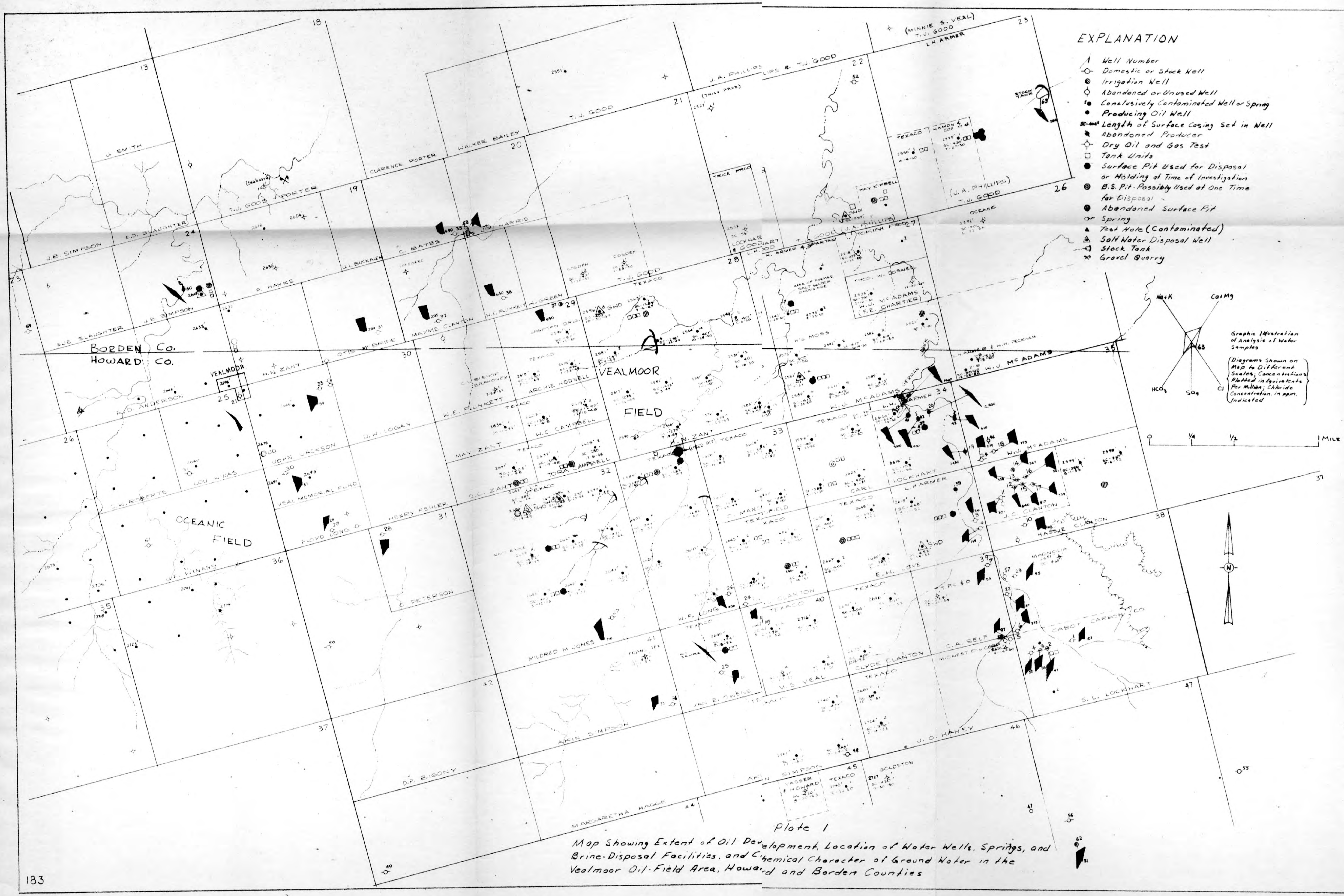


Plate 1

Map Showing Extent of Oil Development, Location of Water Wells, Springs, and Brine-Disposal Facilities, and Chemical Character of Ground Water in the Vealmoor Oil-Field Area, Howard and Borden Counties