TEXAS WATER DEVELOPMENT BOARD

REPORT 1

GROUND-WATER RESOURCES OF JACKSON COUNTY, TEXAS

By

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FOREWORD

On September 1, 1965 the Texas Water Commission (formerly, before February 1962, the State Board of Water Engineers) experienced a far reaching realignment of functions and personnel, directed toward the increased emphasis needed for planning and developing Texas' water resources and for administering water-rights.

Realigned and concentrated in the Texas Water Development Board were the investigative, planning, development, research, financing, and supporting functions, including the reports review and publication functions. The name Texas Water Commission was changed to Texas Water Rights Commission, and responsibility for functions relating to water-rights administration was vested therein.

For the reader's convenience, references in this report have been altered, where necessary, to reflect the current (post September 1, 1965) assignment of responsibility for the function mentioned. In other words credit for a function performed by the Texas Water Commission before the September 1, 1965 realignment generally will be given in this report either to the Water Development Board or to the Water Rights Commission, depending on which agency now has responsibility for that function.

Texas Water Development Board

John J. Vandertulip

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GROUND-WATER RESOURCES OF JACKSON COUNTY, TEXAS

ABSTRACT

Jackson County, an area of 854 square miles, is in the Gulf Coastal region of South Texas and is about midway between Houston and Corpus Christi. Fresh ground water, used extensively for rice irrigation, public supply, and industry, is basic to the present and future welfare and economy of the county.

The ground water occurs in thick sequences of sand and gravel, the dominant sediments forming the ground-water reservoir. Included in the reservoir are various rock formations of different ages, but all consist of similar water-bearing sediments. The entire sequence of sediments functions as a single aquifer called the Gulf Coast aquifer. The water in the aquifer, continually being replenished by rainfall, is moving toward the Gulf of Mexico at a rate of about 20 feet per year.

The use of ground water has increased significantly over the past quarter-century. In 1940, the total pumpage was almost 10,000,000 gpd (gallons per day). By 1964, the pumpage increased more than 8 times to 82,000,000 gpd. Of this amount, 96 percent was used for irrigation, 2 percent for industry, 1.5 percent for public supply, and less than 1 percent for rural domestic and livestock needs.

Ground-water levels are declining at an average rate of about 1.5 feet per year. In some areas, however, where heavy pumpage is concentrated, declines are as much as 6 feet per year. Water levels will continue to decline as more ground water is pumped and additional wells installed, but the relatively large amount of rainfall in the area probably is adequate to effectively provide the aquifer with sufficient water to offset the present rate of pumpage and eventually stabilize the declines. As a consequence of ground-water pumpage and declining water levels, land-surface subsidence is occurring in most places in Jackson County. The subsidence, probably not exceeding 6 inches in most places, is not yet considered a problem because of its fairly uniform regional effect.

Fresh ground water containing less than 1,000 ppm (parts per million) dissolved solids is available everywhere in Jackson County except in a 25-square-mile area along the Lavaca River from Lavaca Bay northward to the confluence of the Lavaca and Navidad Rivers. About 95 million acre-feet of fresh water is in storage in the county. Underlying the fresh water is about 35 million acre-feet of slightly saline water containing from 1,000 to 3,000 ppm dissolved solids; it is available everywhere in the county.

The quality of the fresh ground water is suitable for irrigation, public supply, and many industrial purposes. Most of the water does not exceed the maximum concentrations of chemical substances recommended by the U.S. Public Health Service. Some of the fresh water is being contaminated locally by salt water, although regionally contamination is not a serious problem.

The 1963 pumping rate of 82 mgd (million gallons per day) probably could be continued indefinitely without serious consequences. By taking advantage of part of the tremendous quantity of water in storage, the rate of pumping could be increased to 300 mgd or more. However, at this rate of pumping, the rate of replenishment probably would be exceeded, and the water levels would decline continuously.

GROUND-WATER RESOURCES OF

JACKSON COUNTY, TEXAS

INTRODUCTION

Fresh ground water is the most important natural resource in Jackson County, and it is being used extensively for rice irrigation and for public supply and industrial needs. The increasing economic development of the county makes it essential that adequate data regarding the ground-water resources be available.

The purpose of the Jackson County study was to describe the occurrence, quality, quantity, availability, and dependability of the ground-water supply, particularly with reference to the sources of water suitable for additional irrigation, public supply, and industrial needs. The scope of the study included a determination of the location and extent of fresh water-bearing sands, the chemical quality of the water they contain, the chemical quality of ground water being pumped and the effects this pumpage has had on water levels and water quality, the productive characteristics of the important water-bearing sands, and an estimate of the quantity of ground water available for future development.

The study which began in 1963 was a cooperative project of the Jackson County Commissioners' Court, the then Texas Water Commission, and the U.S. Geological Survey. The study was made under the immediate supervision of A. G. Winslow, district geologist of the U.S. Geological Survey in charge of ground-water investigations in Texas.

Prior to this study, little detailed information was available regarding Jackson County's vital ground-water resources. Taylor (1907, p. 16-18) briefly noted the occurrence of flowing wells in the county; Follett and Cumley (1943) collected records of 210 wells and included drillers' logs and chemical analyses in their report; Sundstrom, Hastings, and Broadhurst (1948, p. 176-177) collected basic data on the public-supply wells at Edna and Ganado; Wood (1956) discussed the availability of ground water in the Gulf Coast region of Texas which includes Jackson County; Rayner (1958) compiled records of water-level measurements in wells in Jackson County; and Wood, Gabrysch, and Marvin (1963) discussed the ground-water potential of the principal water-bearing formations in the Gulf Coast region.

Appreciation is expressed to the following individuals and firms for their assistance during the investigation: Crowell Bros., Ganado, Texas; Leonard Mickelson, El Campo, Texas; Katy Drilling Co., Katy, Texas; Layne-Texas Co., Inc., Houston, Texas; Henry Cleveland, Dallas, Texas; John Dittrich, Mauritz Farms, Ganado, Texas; C. R. Elrod, senior civil engineer, Aluminum Co. of America, Point Comfort, Texas; W. R. Fuge, Humble Oil and Refining Co., Houston,

Texas; S. F. Bird, producing superintendent, and C. E. Chandler, geologist, Mobil Oil Co., Victoria, Texas; R. J. LeBlanc, staff geologist, Shell Oil Co., Houston, Texas; Dr. H. A. Bernard, research associate, Shell Development Co., Houston, Texas; Byron Wiess, division superintendent, Sun Oil Co., Beaumont, Texas; and W. F. Hughes, agricultural economist, Economic Research Service, U.S. Department of Agriculture, College Station, Texas. The cooperation of these individuals and firms and of many irrigators and industrial and city officials in Jackson County facilitated the preparation of this report and is hereby gratefully acknowledged.

The well-numbering system used in this report is one accepted by the Texas Water Development Board for use throughout the State and is based on latitude and longitude. Under this system, each 1-degree quadrangle in the State is given a number consisting of two digits. These are the first two digits appearing in the well number. Each 1-degree quadrangle is divided into $7\frac{1}{2}$-minute quadrangles which are also given two digit numbers from 01 to 64. These are the third and fourth digits of the well number. Each $7\frac{1}{2}$-minute quadrangle is subdivided into $2\frac{1}{2}$-minute quadrangles and given a single digit number from 1 to 9. This is the fifth digit of the well number. Finally, each well within a $2\frac{1}{2}$-minute quadrangle is given a 2-digit number in the order in which it is inventoried, starting with 01. These are the last two digits of the well number. Only the last three digits of the well numbers are shown beside the well symbols on the well-location map (Plate 1); the first four digits are shown in the northwest corner of each $7\frac{1}{2}$-minute quadrangle. In addition to the 7-digit well number, a 2-letter prefix is used to identify the county. The prefixes for Jackson County and adjacent counties are as follows: Jackson, PP; Lavaca, RY; Victoria, YT; Calhoun, BW; Matagorda, TA; Wharton, ZA; and Colorado, DW.

Jackson County, an area of 854 square miles, is in the Gulf Coastal region of South Texas between about latitudes 28°40' and 29°20' N and longitudes 96°10' and 96°50' W. Edna, the county seat, is about midway between Houston and Corpus Christi (Figure 1).

OCCURRENCE AND DISTRIBUTION OF THE GROUND WATER

The Ground-Water Reservoir--The Gulf Coast Aquifer

Ground water in Jackson County occurs in thick sequences of sand and gravel, the dominant type of sediments forming the ground-water reservoir. Included in the reservoir are various rock formations of different ages, but all consist of similar water-bearing sediments. The entire sequence of sediments and rock formations that contain fresh and slightly saline water in Jackson County may be treated as a single aquifer, and the term, "Gulf Coast aquifer" is hereby applied.

Geologic Description of the Stratigraphic Units Forming the Gulf Coast Aquifer

The stratigraphic units that contain fresh and slightly saline water in Jackson County are, from oldest to youngest, the Oakville Sandstone of Miocene age, the Lagarto Clay of Miocene(?) age, the Goliad Sand of Pliocene age, the Lissie Formation and Beaumont Clay of Pleistocene age, and the alluvium of

Figure 1

Map of Texas Showing Location of Jackson County

U.S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

Recent age (Table 1). All units are exposed in Jackson County except the Oakville Sandstone and Lagarto Clay which appear north of the county (Figure 2).

The units are exposed in belts that are nearly parallel to the Gulf Coast. The younger units crop out close to the coast and successively older ones farther inland; thus, the older units are exposed at successively higher elevations. Because of the different ages of the units, the surfaces are progressively more eroded and dissected inland. Conversely, the surfaces of the younger units are comparatively uneroded and are relatively level.

The units are inclined or dip toward the Gulf at an angle greater than the land surface; therefore, they are found at progressively greater depths in a Gulfward direction. For instance, a particular sand bed that is at the surface in Lavaca County may be several hundred feet deep in southern Jackson County. The units in Jackson County dip from about 70 feet per mile to less than 15 feet per mile, the steepest dips being associated with the older formations.

The units are not uniform in composition or thickness. Sand and gravel beds commonly grade laterally into clay, and clay beds may grade into silt or sand in very short distances. Thin beds may pinch out and change composition within a few hundred feet. This explains why some wells in Jackson County tap much greater thicknesses of sand than nearby wells. Individual beds of sand and clay interfingering with other similar beds generally are connected laterally and vertically so that the ground water can move from one bed to another and from one formation to another. The entire sequence of sediments thus functions as a single aquifer. For the purposes of this investigation, the thicknesses of the individual units are not significant and they were not determined. The thicknesses shown in Table 1 are approximate and are based on determinations made in nearby parts of the Gulf Coast region.

The water in the Gulf Coast aquifer in Jackson County occurs under artesian and water-table conditions. Water under artesian conditions has a pressure greater than atmospheric pressure, and a well tapping a sand under artesian conditions becomes filled with water to a level above the point where the water was first found. Water under water-table conditions is under atmospheric pressure, and a well penetrating a sand under such conditions becomes filled with water to a level no higher than the level where the water was first found. In Jackson County, water-table conditions prevail in relatively shallow sands--less than about 100 feet in depth; artesian conditions become more prevalent with increasing depth.

The Heavily Pumped Zone

Only a part of the Gulf Coast aquifer that contains fresh and slightly saline water is heavily pumped. Although many rural domestic and stock wells produce water from the very shallow parts of the aquifer and several public supply and industrial wells produce from the deep parts, the greater part of the ground water pumped in the county, mostly by irrigation wells, is from an intermediate zone in the aquifer. This zone of large withdrawals of water from the aquifer is termed the heavily pumped zone.

The heavily pumped zone varies in thickness and position within the aquifer, depending upon the location in the county. In the Ganado area, the heavily pumped zone is commonly 150 to 250 feet thick and occupies the interval from about 100 to 350 feet below the surface. In the Cordele and Morales areas,

Table 1.--Geologic description and water-bearing properties of stratigraphic units forming the Gulf Coast aquifer in Jackson County

System	Series	Stratigraphic unit	Estimated thickness (feet)	Composition	Water-bearing properties and distribution of supply
Quaternary	Recent	Alluvium	0- 125?	Fine sand, silt, and clay, and basal coarse sand and gravel chiefly in Navidad and Lavaca River valleys.	Not capable of yielding significant amounts of fresh water. Water is mostly highly mineralized in lower Lavaca and Navidad River valleys.
	Pleistocene	Beaumont Clay	0- 250?	Limy clay, sandy clay, clayey sand, and fine to medium sand. In many places thick lenses of sand occur in the clay.	Capable of yielding small to moderate amounts of fresh water in the southern part of the county where the formation is thickest. Highly mineralized water underlies fresher water in places near the coast.
		Lissie Formation	0- 400?	Thick beds of fine to very coarse sand and gravel interbedded with thin beds of clay. Gravelly sand most abundant in the Ganado area east of Sandy Creek and Navidad River.	Capable of yielding large amounts of fresh water in most of the county, except in southwestern part and near lower Lavaca and Navidad River valleys. Supplies most of the water to shallow irrigation wells in the Ganado area.
Tertiary	Pliocene	Goliad Sand	500-1,200?	Fine to coarse limy sand interbedded with clay and some gravel. Beds of caliche and sand and gravel impregnated with caliche are common on the outcrop. Formation is predominantly sandy.	Capable of yielding large amounts of fresh water in most of the county except in southern part where formation contains mostly highly mineralized water. Supplies most of the water to deep irrigation wells in northern part of county.
	Miocene(?)	Lagarto Clay	700-1,500	Fine to coarse limy sand, silt, and limy clay. Some hard layers of sandstone and conglomerate. Zones of clay and sandy clay are commonly from 100 to 200 feet thick. Individual sand beds are as much as 50 feet thick in places.	Not capable of yielding significant amounts of fresh water. Water is mostly slightly saline in northern part of county and becomes increasingly saline southward.
	Miocene	Oakville Sandstone	500- 700	Chiefly medium, limy sand and thin interbedded limy clay. Some hard layers of sandstone. Thick sand beds near base are traceable for many miles downdip.	Not capable of yielding fresh water. Water is mostly highly mineralized throughout county except in extreme northern part.

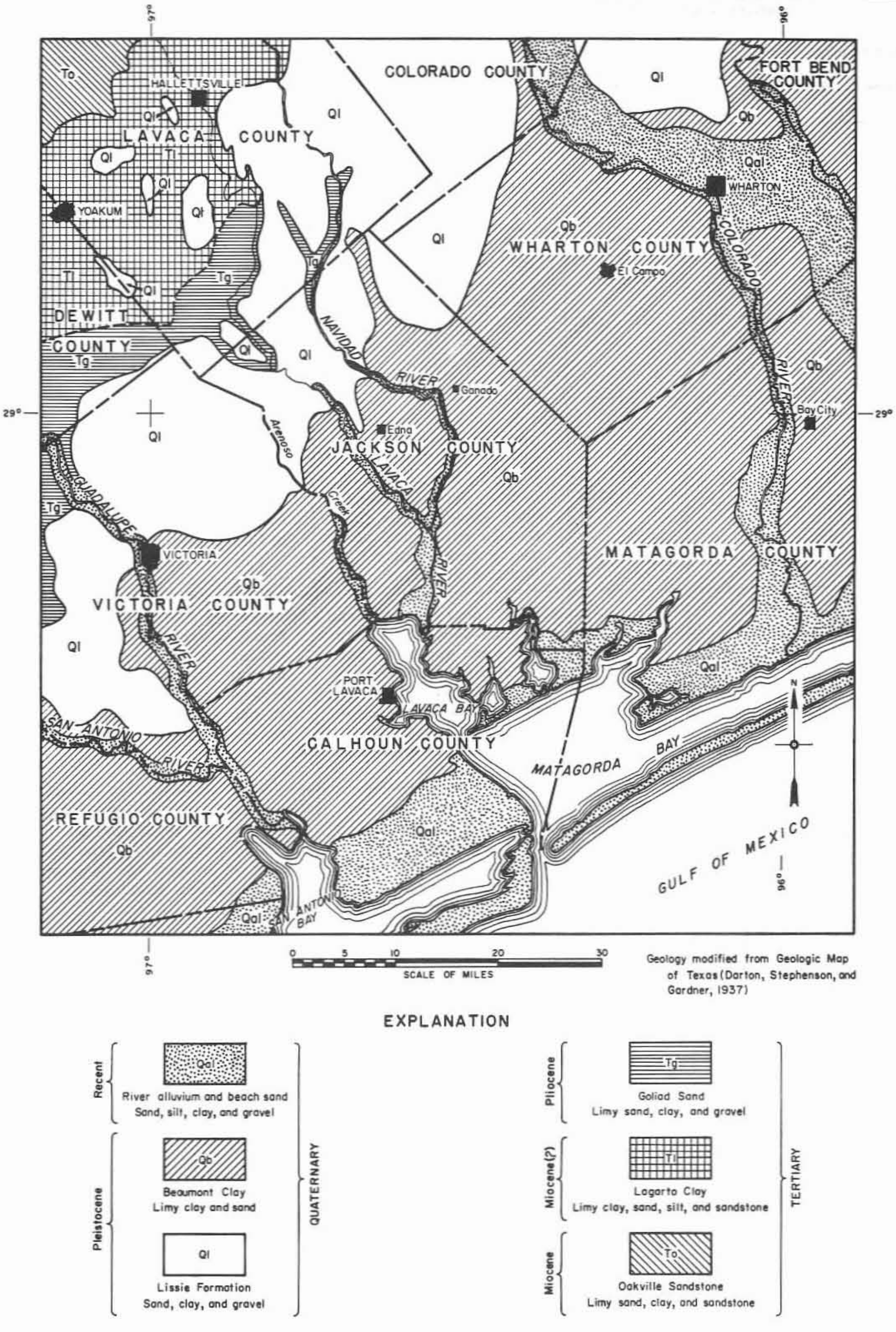

Figure 2

Geologic Map of Jackson County and Adjacent Areas

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

the zone is commonly 600 feet thick and occupies the interval from about 200 to 800 feet below the surface. The variations in thickness of the zone are determined largely by the amount of sand required in any one area to produce the needed quantity of water.

SOURCE AND REPLENISHMENT OF THE GROUND WATER

The principal source of ground water in Jackson County is rainfall on the land surface in the county and in adjacent areas which drain into the county. Of the approximately 38 inches of rainfall that is received annually in Jackson County (Figure 3), only a small amount ever reaches the water table. It is this small amount of fresh water that replenishes the aquifer and replaces the water that is removed by pumping and by natural discharge. The amount of water reaching the water table is difficult to determine, but if it is as much as 10 percent of the rainfall (3.8 inches per year) it would provide more than enough water to replace that pumped for all uses in the county in 1963.

The principal areas of replenishment to sands supplying water to wells in Jackson County depend upon the location and depth of the wells. For instance, a sandy zone 1,000 feet deep in a well in the northeastern part of the county would reach the land surface in central Lavaca County where it would be replenished by rainfall. In this instance, the sandy zone is assumed to be dipping about 50 feet per mile. On the other hand, a sandy zone 200 feet deep in a well at Ganado would be replenished by rainfall a few miles north of Cordele, assuming a dip of 20 to 25 feet per mile for this younger and less steeply dipping sandy zone.

Parts of the aquifer that are lightly pumped supply large quantities of water to the heavily pumped zone. Ground water moves vertically across beds as well as horizontally along the beds; therefore, water is contributed to the heavily pumped zone from parts of the aquifer overlying and underlying the zone of heavy pumpage. The transfer of water to the heavily pumped zone from shallow overlying sands was observed in Well PP-80-05-401, 7 miles south of Ganado (Figure 4). Near the end of the irrigation season when water levels were lowest, a spinner survey to measure vertical movement of water in the well, showed that 42 gpm (gallons per minute) was moving from the shallow sands to several deeper sands within the zone of heavy pumpage. In March 1964 after the irrigation wells had been shut down for several months, the movement of water to the heavily pumped zone had diminished to 14 gpm. The surveys indicate that the heavily pumped zone was being replenished from the shallow zone with water between as well as during the irrigation seasons. Well casings that are perforated in more than one zone are known to be effective means of transferring water; however, the transfer of water in Jackson County is also occurring without the aid of well casings wherever the heavily pumped zone is adjacent to zones that are under higher pressure.

RATE AND DIRECTION OF MOVEMENT OF THE GROUND WATER

The ground water underlying Jackson County is moving constantly. The water moving out of the county beneath the surface or being discharged within the county is replenished by water moving into the county from updip areas in the adjacent counties to the north. The general direction of movement of the ground water is southeastward toward the Gulf of Mexico. Locally, however, in areas of continuous pumping, the direction of movement is toward these areas

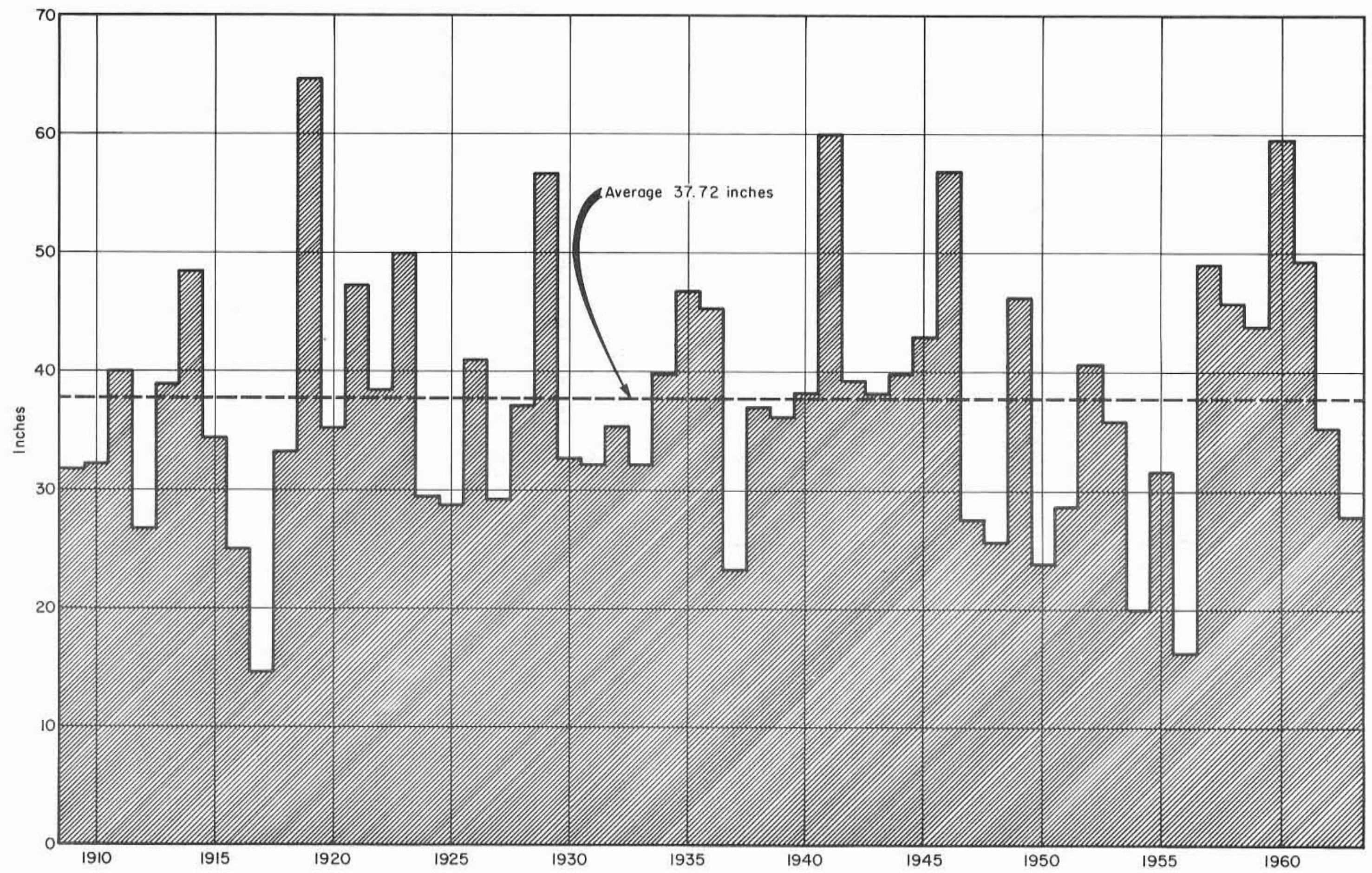

Figure 3

Annual Precipitation at Edna, Jackson County, 1909-63

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

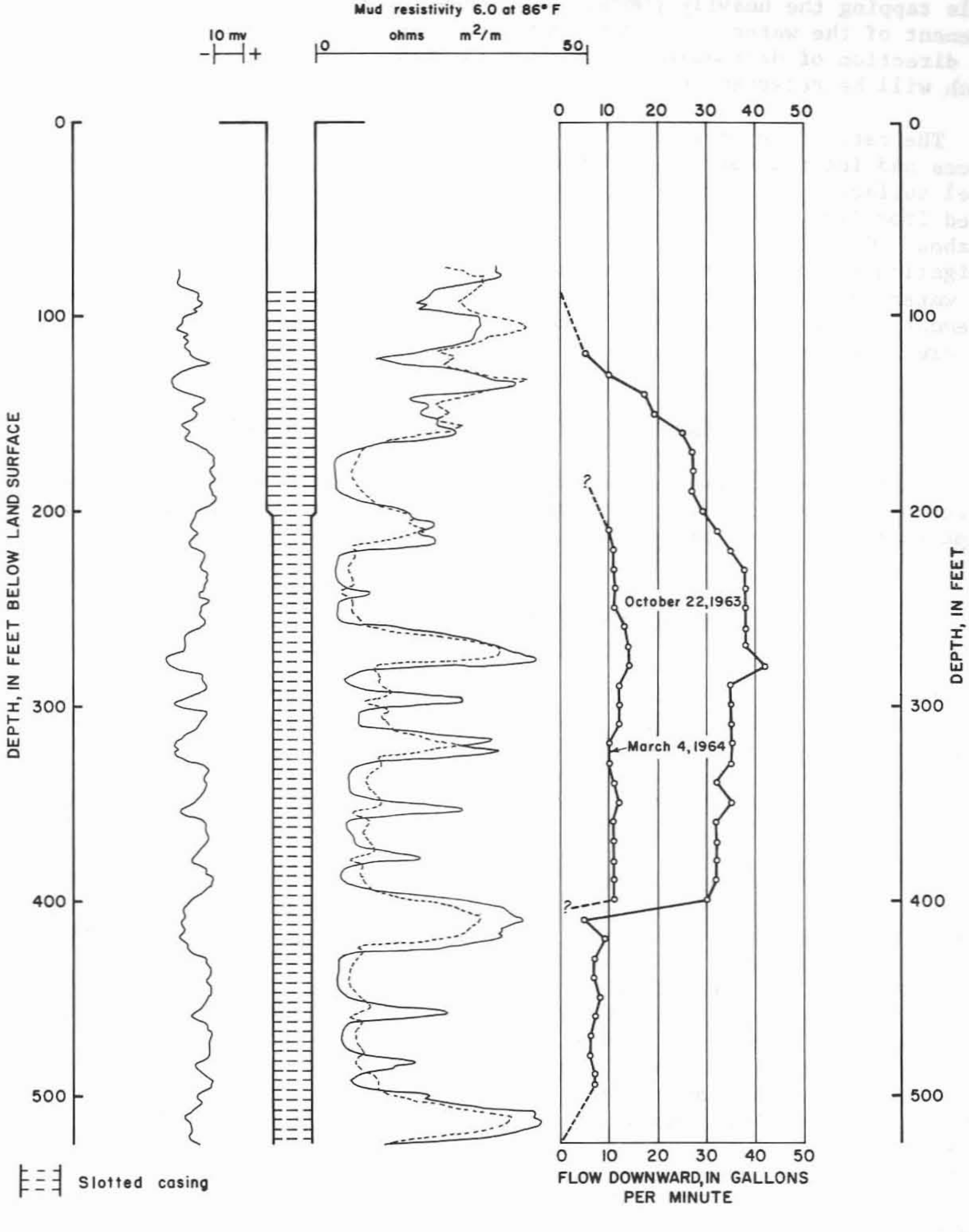

Figure 4

Spinner Survey in Well PP-80-05-401 Showing Transfer of Water From Shallow Sands to the Deeper Heavily Pumped Sands, Jackson County

U.S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

from all directions. Figure 5, which shows the altitude of water levels in wells tapping the heavily pumped zone, shows in a general way the direction of movement of the water. The water moves at right angles to the contours and in the direction of decreasing altitude. The map represents a pressure surface which will be referred to in this report as the water-level surface.

The rate of movement of the ground water depends upon the size of the open spaces and interconnecting passages in the aquifer and the slope of the water-level surface. Based on an average slope of the water-level surface as determined from Figure 5, the average velocity of the ground water in Jackson County is about 20 feet per year. However, velocities toward pumping wells during the irrigation season are much greater. When the wells are pumped, the slope of the water surface toward the wells is steepened, thereby increasing the rate of movement and causing greater volumes of water to be directed to the wells from the areas of recharge or replenishment.

DISCHARGE OF GROUND WATER FROM THE AQUIFER

The Gulf Coast aquifer in Jackson County discharges water by natural processes and through wells. The more important methods of natural discharge are seepage into streams, evaporation, and consumption by vegetation.

Seepage into Streams, Evaporation, and Consumption by Vegetation

Seepage of ground water into streams in the outcrop area of the aquifer represents a significant loss of ground water in Jackson County. This loss can be considered rejected recharge--that is, water that enters in the areas of replenishment but cannot move downward into the main body of the aquifer under the present slope of the water table; the water moves toward stream valleys where it is discharged and runs off.

Seepage is common along the Lavaca and Navidad Rivers and their tributaries in Jackson County, thereby sustaining their flow even during most periods of below-normal rainfall. The Lavaca River north of the gaging station near Edna drains 887 square miles in Jackson and adjacent counties and has an average base flow (the total flow of the stream that is contributed entirely by springs or seepage of ground water from the aquifer with no direct runoff from recent storms) of about 22,000 acre-feet per year. The Navidad River north of the gaging station near Ganado drains 1,116 square miles in Jackson and adjacent counties and has an average base flow of about 17,000 acre-feet per year. Assuming that an equal amount of ground water is lost per square mile above and below both gaging stations and throughout the remainder of Jackson County not drained by these rivers, then the average base flow (rejected recharge) for the 854 square miles in Jackson County is about 17,000 acre-feet per year. This is about one-sixth as much ground water as was pumped for all purposes in the county in 1963. The base flow of about 17,000 acre-feet per year represents less than $\frac{1}{2}$ inch of rainfall that enters the aquifer as replenishment but is rejected and lost to the streams. This compares favorably with other calculations of rejected recharge in different rainfall belts in the Gulf Coast region of Texas (Wood, 1956, p. 30-33).

A low-flow investigation was made in 1947 to show gains or losses of flow in a selected reach of the Lavaca River during a period of base flow revealed that the river from 3.5 miles northwest of Edna to 6.5 miles south of Edna gained 2,558 gpm, equivalent to about 4,000 acre-feet per year (Texas Board Water Engineers, 1960, p. 60). It is not known whether the continuing withdrawal of ground water and the consequent lowering of water levels has materially reduced the flow of the streams by decreasing the rejected recharge in the outcrop of the aquifer. It is possible, however, that the aquifer could eventually capture the base flow of the streams by reducing the level of the water table in the outcrop below the level of the stream channels.

Evaporation in Jackson County uses a significant amount of ground water. The average annual evaporation of 60.97 inches (determined at Beeville but approximately the same as that in Jackson County) is more than $1\frac{1}{2}$ times the average annual precipitation. It is greatest during the summer when the soil moisture demand to sustain plant life also is large (Figure 6). However, evaporation from soil is less than that from a free water surface, but the amount of evaporation increases as the soil becomes drier (Rich, 1951, p. 6). Thus, the 60.97 inches of annual evaporation determined from a free-water surface is considerably greater than the actual evaporation from the soil. Nevertheless, the moisture evaporated from the soil decreases the potential replenishment of ground water to the aquifer.

Large quantities of ground water pumped on rice fields are evaporated. Assuming that the fields remain flooded 3 months during the growing season, almost 50,000 acre-feet of water was evaporated from nearly 29,000 acres irrigated in 1963.

Consumption of water by vegetation in Jackson County represents a decrease in the potential recharge to the aquifer. Woodlands, consisting chiefly of varieties of hardwood such as oak, cover almost 8,000 acres of the county. As reported by Raber (1937, p. 81-82), the maximum seasonal water consumption of hardwoods such as oak is about 10 inches per acre based on 60-year old, even-aged, full-stocked stands. Assuming these figures apply to the woodlands and climatic conditions in Jackson County, about 7,000 acre-feet of water per year, or about 6 mgd (million gallons per day), is consumed by the woodlands in the county. If the root systems of varieties of hardwood extend from 10 to 20 feet below land surface, as reported by Raber (1937, p. 3-4), then much of the woodlands are taking ground water from the zone of saturation. This represents a direct loss of water from storage in the outcrop area of the aquifer and a decrease in the potential amount of replenishment.

In summary, the 17,000 acre-feet of ground water per year that is discharged to the streams as rejected recharge and the 7,000 acre-feet of ground water per year that is consumed by woodlands represents a total of 24,000 acre-feet per year that could be considered as potential replenishment to the aquifer in Jackson County, if the water table was at a level below the stream channels and below the reach of trees. The transfer of ground water from the shallow part of the aquifer to the underlying heavily pumped zone is lowering the water levels in parts of the outcrop area and will gradually salvage some of the ground water used by vegetation and discharged into streams.

Withdrawal by Wells

The withdrawal of ground water by wells represents the largest quantity of water discharged from the aquifer. In 1963, about 82 mgd or 92,000 acre-feet was withdrawn by wells in Jackson County.

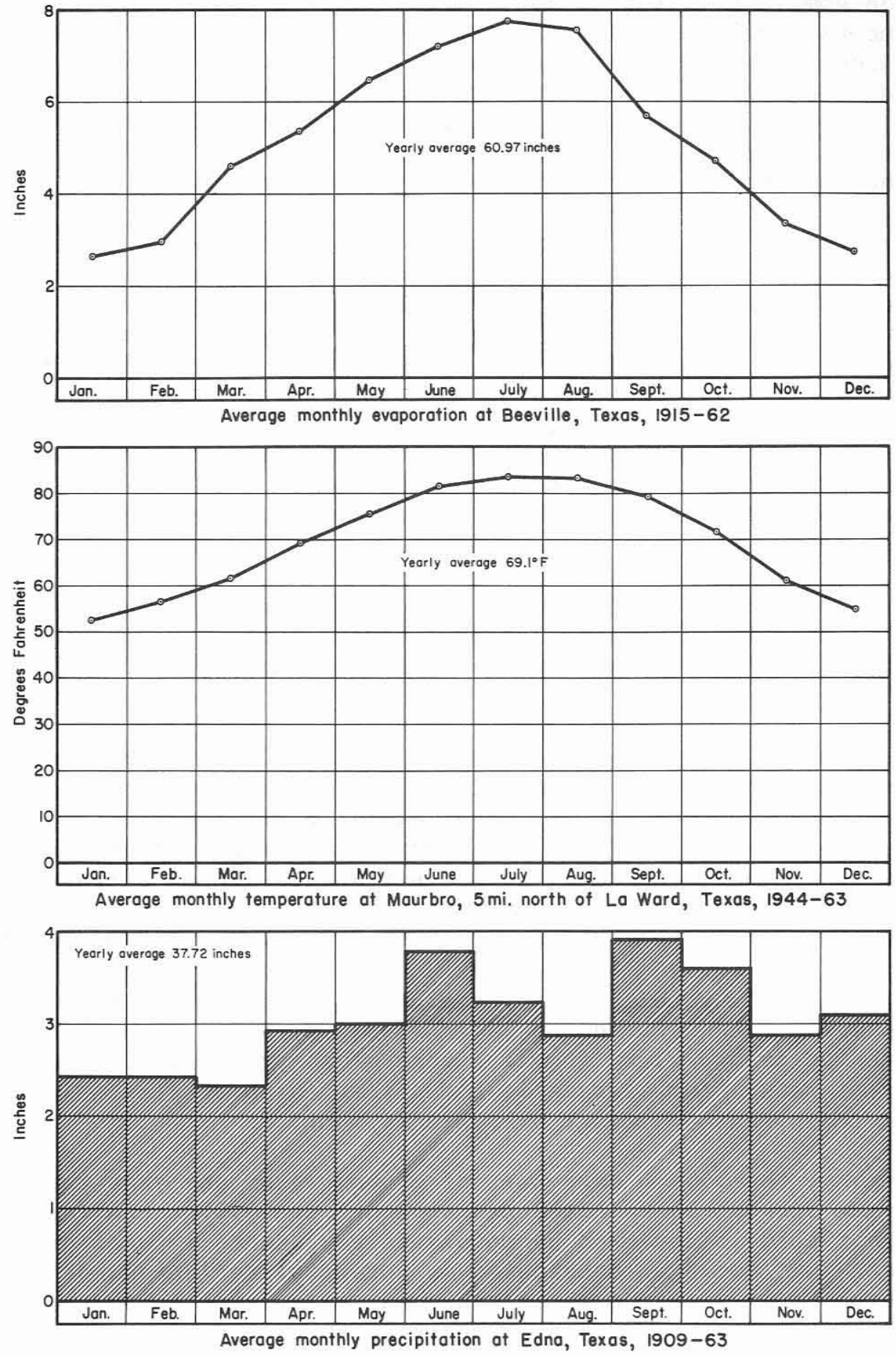

Figure 6

Monthly Evaporation at Beeville, Temperature at Maurbro, 5 Miles North of La Ward, and Precipitation at Edna

(From records of U.S. Weather Bureau and Bloodgood, Patterson, and Smith, 1954)

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

CAPACITY OF THE AQUIFER TO YIELD WATER

The capacity of the Gulf Coast aquifer to yield water to wells depends largely upon its composition, such as gravel, sand, silt, or clay, the uniformity of the grain size, and the amount and distribution of openings between the grains. These factors vary from place to place; consequently, the aquifer in some parts of Jackson County is more productive than in other parts. The water-yielding capacity of the Gulf Coast aquifer is discussed in terms of the permeability of the sand, the transmissibility and storage capacity of the aquifer, and the specific capacities and yields of wells.

Permeability of the Sand

The permeability of the sand is its property of transmitting water through the openings between the grains. The degree of ease or difficulty by which this is accomplished is expressed by the term "field coefficient of permeability." It is the rate of flow of water in gallons per day under prevailing conditions of temperature through each foot of thickness of the aquifer in a width of 1 mile, for each foot per mile slope of the static level of water in the aquifer.

Pumping tests were made on 64 wells tapping the Gulf Coast aquifer in Jackson County and adjacent areas to determine the permeability of the sand (Table 2). The permeabilities (field coefficients of permeability) ranged from 59 to 885 gpd (gallons per day) per square foot and averaged about 300.

The permeability of the sand in the heavily pumped zone varies widely throughout Jackson County (Figure 7). In general, the most permeable sand is east of Sandy Creek and east of the Navidad River below its junction with Sandy Creek. This includes the areas of Lolita, La Ward, Francitas, and especially the Ganado area where the highest field coefficients of permeability were recorded. West of this general area in roughly the western half of the county, the sands have average field coefficients of permeability considerably smaller than the average in the eastern half of the county.

The differences in permeability reflect differences in the composition and compaction of the aquifer and the depth and thickness of the heavily pumped zone. The gravel and very coarse sand in the Ganado area, which transmit water more easily than fine to medium sand, largely account for the high permeabilities in that area. Coarse sand and gravel are lacking in most places elsewhere in the county. The fine to medium sand recorded in the western part of the county largely account for the lower permeabilities. Also the thicker zone of heavy pumping commonly includes more beds of silt and clay giving lower permeabilities for the entire pumped zone. As a rule, the deeper sands are more compact and tight because of the weight of overlying sediments.

Transmissibility and Storage Capability of the Aquifer

The "coefficient of transmissibility" is another way of expressing the capacity of the aquifer to transmit water. It is the number of gallons of water which will move in 1 day through a section of the aquifer 1 mile wide and a height equal to the saturated part of the aquifer for each foot per mile slope of the water-level surface. Permeability denotes a characteristic of a unit of the water-bearing material, whereas transmissibility denotes a similar characteristic of the aquifer as a whole.

The storage capability or water-yielding capacity of the aquifer can be expressed in terms of its storage coefficient. It is the volume of water, in cubic feet, either yielded from or taken into storage by a vertical column of the aquifer 1 foot square and extending through the aquifer when the water level declines or rises 1 foot. Where the aquifer is under artesian pressure generally in relatively deep sands, the storage coefficient is much smaller than where water-table conditions prevail generally in relatively shallow sands. Pumping tests in Jackson County revealed storage coefficients ranging from a low of 1.8×10^{-5} in sands 1,185 to 1,291 feet deep in Well PP-66-60-902 at Ganado to a high of 4.2×10^{-3} in sands 42 to 180 feet deep in Well PP-66-60-609 3 miles north of Ganado. The average coefficient of storage from seven determinations in Jackson and Calhoun Counties was 1.3×10^{-3} (Table 2).

Pumping tests were made on 69 wells tapping the Gulf Coast aquifer in Jackson County and adjacent areas to determine the coefficients of transmissibility (Table 2). The results of the tests were analyzed either by the basic nonequilibrium formula or the recovery formula (Theis, 1935). The coefficients of transmissibility determined ranged from a low of 8,700 gpd per foot in a section of the aquifer screened from 1,185 to 1,291 feet in Well PP-66-60-902 at Ganado to 232,000 gpd per foot at Well PP-80-05-301, 8 miles southeast of Ganado where the well is screened from 40 to 292 feet. The average coefficient of transmissibility in Jackson County and adjacent areas is almost 70,000 gpd per foot. Transmissibilities of 75,000 gpd per foot are common where irrigation wells screen relatively thick sections of the aquifer. The industrial or public supply wells, which screen only selected sands and, consequently, produce from a relatively thin section of the aquifer, have transmissibilities ranging from about 10,000 to 30,000 gpd per foot.

The approximate transmissibility of the entire fresh-water-bearing (less than 1,000 parts per million dissolved solids) part of the Gulf Coast aquifer in Jackson County and adjacent areas is shown on the map in Figure 31. The approximate transmissibility shown is based on data obtained from more than 70 pumping tests throughout the county and adjoining areas where the transmissibility of a section of the aquifer was determined. These data were used to determine average permeabilities for various vertical sections of the aquifer. The permeability figures were used to estimate the transmissibility of the aquifer by referring them to many correlated logs of wells which penetrated the full thickness of the fresh-water-bearing section and to known thicknesses of fresh-water-bearing sand. The map outlines areas of similar water-bearing properties and is used in estimating the relative availability of ground water, a subject discussed in a later section of this report.

Specific Capacities and Yields of Wells

The specific capacity of a well is the yield in gallons per minute per foot of drawdown, the drawdown being the difference in the water level in a well when it is pumping and when it is idle. As a rule, the yield of a well varies directly with the drawdown--that is, doubling the drawdown of a well will double or nearly double its yield. Thus, the specific capacity is an aid in estimating the probable yield of a well, the drawdown, and the pumping level.

Table 2.--Coefficients of permeability, transmissibility, and storage of the Gulf Coast aquifer, and specific capacities and yields of wells in Jackson County and adjacent areas

Well number	Date	Screened interval (feet)	Field coefficient of permeability (gpd per ft^2)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Yield (gpm)	Drawdown or recovery (feet)	1-hour specific capacity (gpm per ft)	Remarks
PP-66-50-801	8-22-63	229- 886	116	45,000	--	1,040	42.3	25	Recovery test
51-202	8-23-63	100- 720	169	60,900	--	1,230	--	--	Do.
305	8-28-63	225-1,010	59	24,200	--	1,650	50	31	Do.
505	7- 6-55	300- 627	200	42,000	--	1,200	69	17	Do.
509	8-21-63	268- 729	210	65,400	--	2,380	65	37	Do.
604	8-17-63	240- 663	110	34,700	--	1,380	75	18	Do.
808	9- -63	200- 973	--	--	--	2,146	88	24	Do.
903	8- 7-63	100- 618	--	16,200	--	600	50.2	12	Drawdown test
904	do	110- 592	238	58,000	--	847	28.7	28	Recovery test
52-407	8-17-63	280- 960	173	58,700	--	1,800	40.1	45	Do.
704	9-27-63	218- 745	150	59,900	--	1,190	30.1	40	Do.
705	9-25-63	300- 812	--	67,600	2.6×10^{-3}	--	--	--	Interference test; Well PP-66-52-706 pumping
706	do	180- 743	227	68,600	--	1,770	42.9	41	Recovery test
907	8- 8-63	130- 490	178	46,300	--	1,475	46.9	32	Drawdown test
58-801	8-30-63	133- 663	122	46,800	--	1,250	40.2	31	Recovery test
903	7- 7-55	205- 695	121	47,000	--	1,400	50.5	28	Do.
59-303	9- 4-63	70- 575	403	141,000	--	1,427	18.6	77	Do.
308	8-14-63	221- 755	228	53,500	--	1,490	--	--	Do.
501	8-20-63	153- 666	125	36,200	--	1,800	39.5	46	Drawdown test
601	do	250- 843	149	47,800	--	1,528	33.1	46	Recovery test
901	10- 4-63	183- 630	183	58,700	--	1,395	32.9	42	Do.
60-106	8-13-63	210- 570	268	55,800	--	950	38.6	25	Drawdown test
201	8-16-63	154- 671	243	81,200	--	2,320	32.1	72	Recovery test

(Continued on next page)

Table 2.--Coefficients of permeability, transmissibility, and storage of the Gulf Coast aquifer, and specific capacities and yields of wells in Jackson County and adjacent areas--Continued

Well number	Date	Screened interval (feet)	Field coefficient of permeability (gpd per ft^2)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Yield (gpm)	Drawdown of recovery (feet)	1-hour specific capacity (gpm per ft)	Remarks
PP-66-60-205	8-22-63	97- 224	734	93,900	--	2,080	30.7	68	Drawdown test
505	8- 1-63	135- 316	457	116,300	--	1,560	34.7	45	Do.
603	7-31-63	64- 274	401	65,200	--	791	40.7	19	Do.
608	9-27-63	112- 234	475	53,100	--	985	44.4	22	Recovery test
609	9-18-63	42- 180	--	140,000	4.2×10^{-3}	--	--	--	Interference test; Well PP-66-60-608 pumping
703	8-21-63	132- 513	180	57,500	--	1,590	66.5	24	Drawdown test
703	do	132- 513	182	58,300	--	1,590	62.6	25	Recovery test
902	10-19-55	1,185-1,291	107	8,700	1.8×10^{-5}	--	--	--	Interference test; Well PP-66-60-903 pumping
61-702	8-30-63	127- 315	885	133,300	--	1,561	34.2	46	Recovery test
803	7- 8-55	67- 317	610	85,000	--	930	--	--	Do.
80-02-601	9-24-63	165- 849	232	64,400	--	1,000	37.3	27	Drawdown test
03-202	9-13-63	194- 880	282	135,000	--	1,205	10.8	108	Recovery test
301	10-20-55	970-1,195	169	27,000	--	1,000	80.3	12	Do.
04-403	9-13-63	222- 679	140	38,000	--	1,530	37.6	41	Do.
05-301	9- 9-63	40- 292	--	232,000	5.9×10^{-4}	--	--	--	Interference test; Well PP-80-05-310 pumping
310	8- 9-63	115- 210	835	69,300	--	945	27.7	34	Drawdown test
507	9-19-63	178- 795	366	103,200	--	2,270	36.9	62	Recovery test
701	9- 6-63	120- 429	313	43,900	--	1,230	44.7	28	Do.
06-101	7- 8-55	85- 550	727	189,000	--	1,620	--	--	Do.
102	9- 9-63	104- 364	790	124,000	--	1,690	29.9	58	Drawdown test
104	do	50- 215	--	119,000	1.4×10^{-3}	--	--	--	Interference test; Well PP-80-06-102 pumping
703	7- 8-55	154- 590	359	79,000	--	1,450	36.1	40	Recovery test
704	8-21-63	146- 430	616	104,800	--	1,500	19.4	78	Do.
11-201	7- 7-55	108- 572	180	53,000	--	1,070	--	--	Do.

(Continued on next page)

Table 2.--Coefficients of permeability, transmissibility, and storage of the Gulf Coast aquifer, and specific capacities and yields of wells in Jackson County and adjacent areas--Continued

Well number	Date	Screened interval (feet)	Field coefficient of permeability (gpd per ft^2)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Yield (gpm)	Drawdown or recovery (feet)	1-hour specific capacity (gpm per ft)	Remarks
PP-80-12-502	10-17-63	90- 330	476	69,000	--	1,545	30.5	51	Recovery test
13-404	9-10-63	150- 510	258	72,300	--	1,340	33.0	41	Do.
901	9-11-63	140- 775	166	43,200	--	1,571	--	--	Do.
14-103	9-12-63	200- 752	306	73,400	--	1,855	--	--	Do.
401	do	150- 710	467	131,000	--	1,951	--	--	Do.
21-201	9-21-49	412- 467	455	19,100	--	250	--	--	Do.
201	3- 5-64	412- 467	--	--	--	250	21.1	12	Do.
202	3- 4-64	411- 461	--	--	--	246	27.2	9	Do.
203	3- 6-64	409- 469	--	--	--	489	54.9	9	Do.
204	3- 9-64	428- 578	--	--	--	635	90.8	7	Do.
601	9-19-63	317- 635	320	61,000	--	1,245	35.8	35	Do.
22-501	9- 5-63	288- 370	361	20,600	--	540	33.2	16	Do.
RY-66-35-902	7-20-55	172- 559	100	22,000	--	950	59.5	16	Do.
57-301	6-12-64	234- 584	193	44,500	--	1,020	28.1	36	Do.
YT-66-58-702	7-11-55	140- 600	177	38,500	--	1,570	34.4	46	Do.
80-10-101	4-30-59	270- 880	226	83,000	--	2,300	36.0	64	Do.
701	5- 5-59	160- 450	276	47,000	--	1,170	--	--	Do.
19-501	do	158- 324	230	21,000	--	330	--	--	Do.
BW-80-19-801	10-12-55	173- 233	267	15,500	--	440	43.1	10	Do.
20-801	12- 1-48	254- 365	352	19,400	3.1×10^{-4}	--	--	--	Interference test; Well BW-80-20-803 pumping
801	do	254- 365	340	18,700	1.3×10^{-4}	--	--	--	Interference test; Well BW-80-20-802 pumping
802	4-17-49	254- 369	338	25,000	--	602	54	11	Recovery test
802	2-20-64	254- 369	--	--	--	614	54.4	11	Do.
803	12- 1-48	250- 359	240	15,600	--	372	27	14	Do.

(Continued on next page)

Table 2.--Coefficients of permeability, transmissibility, and storage of the Gulf Coast aquifer, and specific capacities and yields of wells in Jackson County and adjacent areas--Continued

Well number	Date	Screened interval (feet)	Field coefficient of permeability (gpd per ft^2)	Coefficient of transmissibility (gpd per ft)	Coefficient of storage	Yield (gpm)	Drawdown or recovery (feet)	1-hour specific capacity (gpm per ft)	Remarks
BW-80-20-803	2-20-64	250- 359	--	--	--	697	50.2	14	Recovery test
TA-80-07-501	7-13-55	220- 820	403	120,000	--	1,680	21.3	83	Do.
15-401	do	225-1,044	188	63,000	--	2,000	47.4	42	Do.
23-101	7-19-55	190- 776	344	82,500	--	1,560	34.3	45	Do.
ZA-66-45-804	7-11-55	110- 388	577	127,000	--	1,675	36.1	46	Do.
61-305	7-14-55	134- 599	460	115,000	--	2,100	25.3	83	Do.
62-904	7-18-55	162- 573	382	102,000	--	1,430	21.0	68	Do.
		Average..	300	70,000	1.3×10^{-3}	1,330	41	38	

Figure 8 outlines areas of similar specific capacities that may be expected from wells screening the heavily pumped zone in Jackson County and adjacent areas. The variations in specific capacities in the county are due chiefly to the position and thickness of the screened interval in the well and to the permeability of the sand, and to a lesser extent, on the construction of the wells. Generally, a relatively deep well that screens a large part of the aquifer has a greater specific capacity than a relatively shallow well that screens less of the aquifer. However, differences in permeability from place to place could reverse the normal situation. As an example, Well PP-66-60-205 near Ganado, screened from 97 to 224 feet, has more than twice the specific capacity than Well PP-66-51-305 in the northeastern corner of the county screened from 225 to 1,010 feet. This difference in specific capacity and reversal of the normal situation is due mainly to the high permeability (734 gpd per square foot) in the shallow well which produces from gravel and coarse sand compared to the low permeability (59 gpd per square foot) in the deep well which produces from finer material.

Abnormal specific capacities can be the result of well construction and development. Some wells have smaller specific capacities than expected because of failure by the driller to remove completely the drilling mud from the formation when test pumping or failure to obtain a good gravel pack around the screen. Conversely, some wells actually have larger specific capacities than expected because the sands are cleaned and developed so that the effective diameter of the well is larger than the original drilled hole.

The specific capacities and yields of about 70 wells determined from pumping tests on wells tapping the Gulf Coast aquifer in Jackson County and adjacent areas are listed in Table 2. The yields of 58 irrigation wells ranged from 330 to 2,380 gpm, averaging about 1,450 gpm; the 1-hour specific capacities of 49 of these wells ranged from 12 to 108 gpm per foot, averaging about 45 gpm per foot.

The yields of most of the irrigation wells were measured near the peak of the irrigation period when water levels were low; consequently, most of the yields were less than they would have been at the beginning of the irrigation period when water levels were considerably higher. The yields and 1-hour specific capacities of the public supply and industrial wells tested were much smaller than those of the irrigation wells; the yields of these wells ranged from 150 to 1,000 gpm and the specific capacities ranged from 7 to 14 gpm per foot. Very few wells in Jackson County are screened through the entire thickness of the water-bearing sands; therefore, the yields and specific capacities of the wells in general are less than the maximum that could be developed if the wells penetrated to the bottom of the aquifer and were screened opposite all water-bearing sands.

DEVELOPMENT OF THE AQUIFER

Prior to the 20th century, Jackson County had not begun to develop its vast underground water supply. The Gulf Coast aquifer was essentially in a state of equilibrium--that is, the amount of replenishment or recharge from rainfall equaled the amount of natural discharge of ground water. Water levels would rise or fall primarily in response to the amount of rainfall.

At the beginning of the 20th century, the drilling of irrigation wells and the pumpage of ground water were artificial conditions imposed on the previously nearly stable conditions in the aquifer. The aquifer reacted to the pumpage by losing water from storage and possibly by decreasing the amount of natural discharge or increasing the amount of recharge from streams. Reaction and adjustment in the aquifer to increasing withdrawals of water by an increasing number of wells is still continuing.

Records of 405 water wells in Jackson County were obtained during the ground-water study (Table 6), including drillers' logs of 138 wells (Table 7). Of the wells inventoried, 246 were used for irrigation, 20 for industrial purposes, and 12 for public supply. The remainder of the water wells inventoried included wells used for rural domestic and stock needs and various types of abandoned water wells. The well inventory included only a part of the total number of wells in the county; however, records of all the public supply, industrial, and most of the irrigation wells were obtained. Locations of the wells are shown in Plate 1.

Pumpage of Ground Water

Table 3 shows the quantity of ground water pumped for irrigation, industry, public supply, and rural domestic and livestock needs in Jackson County in 1963. In that year, about 82 mgd, or about 92,000 acre-feet, of ground water was pumped.

Table 3.--Pumpage of ground water in Jackson County, 1963

Use	Million gallons per day	Acre-feet per year
Irrigation	78.6	88,100
Industry	1.73	1,940
Public supply	1.23	1,380
Rural domestic and livestock needs	.65	729
Totals*	82	92,000

* Figures are approximate because some of the pumpage is estimated. Totals are rounded to two significant figures.

Irrigation

Pumpage of ground water for irrigation in Jackson County in 1963 was 78.6 mgd, or 88,100 acre-feet. This was 96 percent of the ground water pumped for all purposes in the county in that year. Rice, the principal irrigated crop, accounts for nearly all the ground water withdrawn for irrigation.

The irrigation of rice, begun in 1901 near Ganado, is now widespread throughout most of Jackson County; however, rice is not grown in the extreme southwestern part of the county because of a lack of adequate ground water of suitable quality. After 1901, rice acreage gradually increased, and in 1909 about 11,000 acres was irrigated. After 1918, rice acreage decreased, reaching a low of 485 acres in 1933. In the 30-year period from 1934 to 1964, land in rice production increased from 2,100 to nearly 29,000 acres, and the amount of ground water pumped increased from about 6,000 to about 88,000 acre-feet during the same period. From 1942 to 1963, the number of irrigation wells in use increased from 23 (Follett and Cumley, 1943, p. 1) to 246. A relatively small acreage was irrigated with surface water, and in 1963 about 95 percent of the rice was irrigated with ground water.

Table 4 shows the source and amount of water applied to rice acreage in Jackson County from 1934 through 1963. The amount pumped for irrigation usually varies inversely with the amount of rainfall during the rice growing season; the sum of these two amounts, that is, the total water received on the land, remains fairly constant. The total amount of water received on rice land in Jackson County was estimated to be 4.2 acre-feet per acre, on the basis of a measured average of 3.6 acre-feet per acre over a 14-year span in the Katy rice-growing area (Lang and Winslow, 1950, p. 25) plus 0.6 acre-foot per acre increase in evaporation in Jackson County over that in the Katy area. Pumpage measurements in 1963 from Wells PP-66-52-407 and PP-80-13-901 based on fuel consumption, pumping time, well capacity, and acres irrigated were 3.1 and 2.9 acre-feet per acre, respectively; this closely approximates the estimated average of 3.2 acre-feet per acre pumped in 1963 throughout the county and substantiates the average 4.2 acre-feet per acre from rainfall and irrigation given in Table 4. The peak year of ground-water pumpage was 1954 when almost 133,000 acre-feet of ground water was used. This abnormally large pumpage was due to a record number of acres under irrigation in 1954 and an abnormally small amount of rainfall during the growing season that year. Figure 9 shows graphically the pumpage of ground water for irrigation in Jackson County from 1934 through 1963.

Industrial Use

Pumpage of ground water for industry in Jackson County in 1963 was 1.73 mgd, or 1,940 acre-feet. This was only 2 percent of the ground water pumped for all purposes in the county in that year.

The use of ground water for industrial purposes in Jackson County has increased significantly in the past quarter century. From 1940 to 1964, it increased from 0.04 mgd, or 46 acre-feet, to 1.73 mgd, or 1,940 acre-feet, by far the largest percentage increase by class of use in the county (Figure 10). Most of the increase was due to the beginning of operations in 1950 of the Aluminum Co. of America at Point Comfort.

The Aluminum Co. of America is the largest single user of ground water for industrial purposes. The plant site at Point Comfort in Calhoun County has no fresh ground water; consequently, the ground water for the plant is obtained from a well field in southern Jackson County. Four wells about 500 to 600 feet deep furnish water for the plant and for the city of Point Comfort. About 90 percent of the fresh water pumped from the wells is used industrially, mainly for cooling and sanitary purposes. Two brackish water wells at the plant site and a surface-water supply supplement the plant's industrial usage. In 1963, 1,523 acre-feet, or 78.5 percent, of the total ground water pumped for industry in Jackson County was used at the Aluminum Co. of America plant.

Table 4.--Source and amount of water applied to rice acreage in Jackson County, 1934-63

Year	Acres irrigated[a]	Rainfall, in feet, May through September[b]	Amount of irrigation water pumped, in acre-feet per acre	Total amount of irrigation water pumped, in acre-feet	Amount of surface water pumped, in acre-feet[c]	Amount of ground water pumped, in acre-feet
1934	2,100	1.3	2.9	6,090	0	6,090
1935	2,410	1.9	2.3	5,543	1,045	4,498
1936	2,900	2.5	1.7	4,930	1,277	3,653
1937	3,900	.8	3.4	13,260	5,950	7,310
1938	3,800	1.5	2.7	10,260	8,934	1,326
1939	4,000	2.0	3.2	12,800	8,457	4,343
1940	4,300	1.2	3.0	12,906	2,450	10,450
1941	5,725	2.1	2.1	12,023	6,578	5,445
1942	8,000	1.9	2.3	18,400	9,469	8,931
1943	8,000	1.5	2.7	21,600	9,874	11,726
1944	9,000	1.5	2.7	24,300	8,920	15,380
1945	11,000	1.5	2.7	29,700	8,689	21,011
1946	13,500	2.7	1.5	20,250	10,613	9,637
1947	17,000	1.0	3.2	54,400	11,435	42,965
1948	24,380	1.0	3.2	78,016	12,200	65,816
1949	23,700	1.4	2.8	66,360	11,121	55,239
1950	20,800	1.0	3.2	66,560	12,310	54,250
1951	27,000	1.2	3.0	81,000	9,236	71,764
1952	28,500	1.6	2.6	74,100	11,188	62,912
1953	30,700	2.0	2.2	67,540	5,592	61,948
1954	37,000	.5	3.7	136,900	4,094	132,806
1955	29,255	1.7	2.5	73,138	4,771	68,367
1956	27,100	.4	3.8	102,980	5,151	97,829
1957	17,150	1.5	2.7	46,305	1,463	44,842
1958	26,290	1.6	2.6	68,354	5,739	62,615
1959	26,295	1.5	2.7	70,997	6,196	64,801
1960	26,262	2.5	1.7	44,645	634	44,011
1961	26,286	3.0	1.2	31,543	2,209	29,334
1962	28,920	1.3	2.9	83,868	3,614	80,254
1963	28,920	1.0	3.2	92,544	4,440	88,104

a/ Records of U.S. Department of Agriculture
b/ At Edna, Texas
c/ Records of Texas Water Development Board

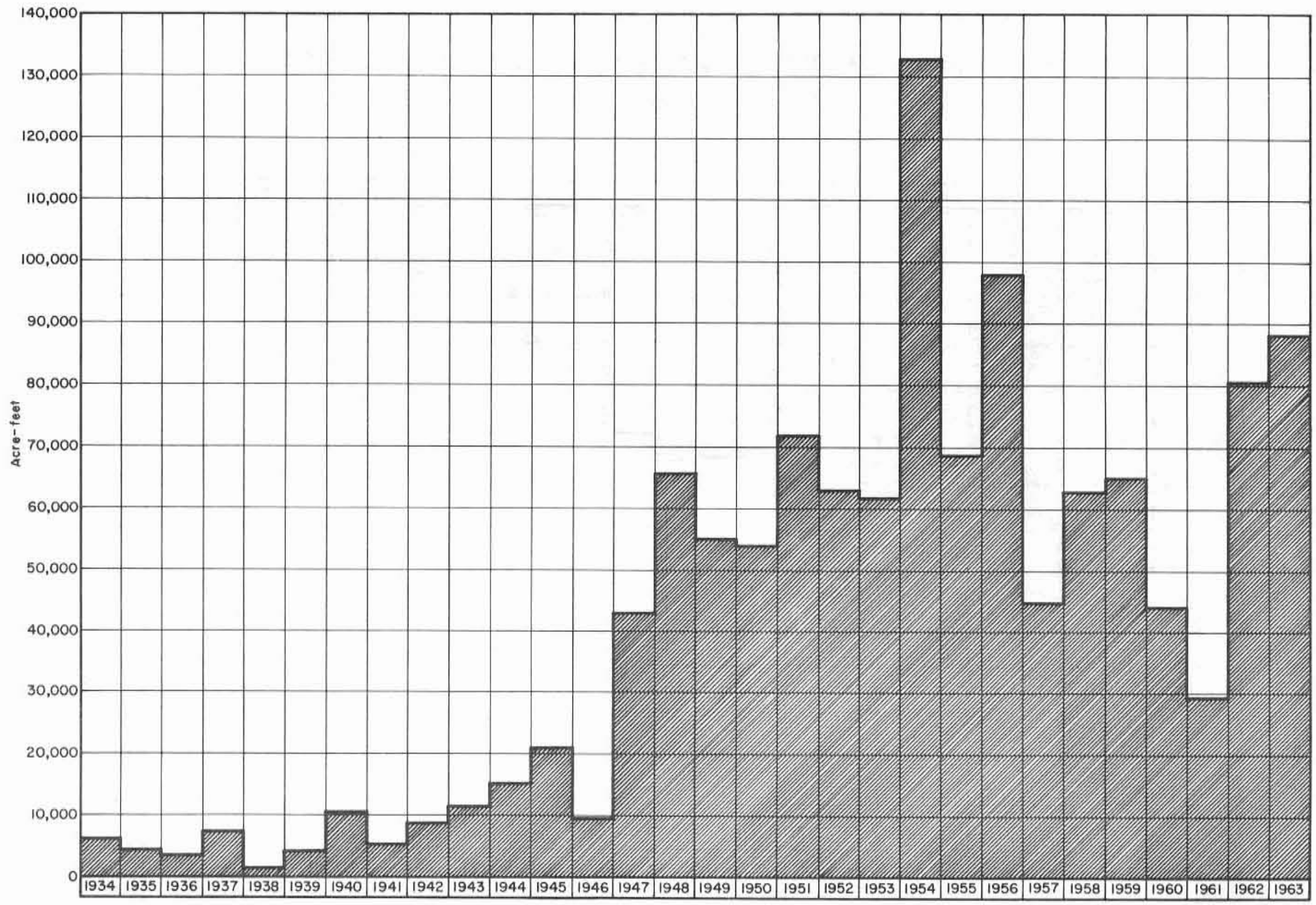

Figure 9

Pumpage of Ground Water for Irrigation in Jackson County, 1934-63

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

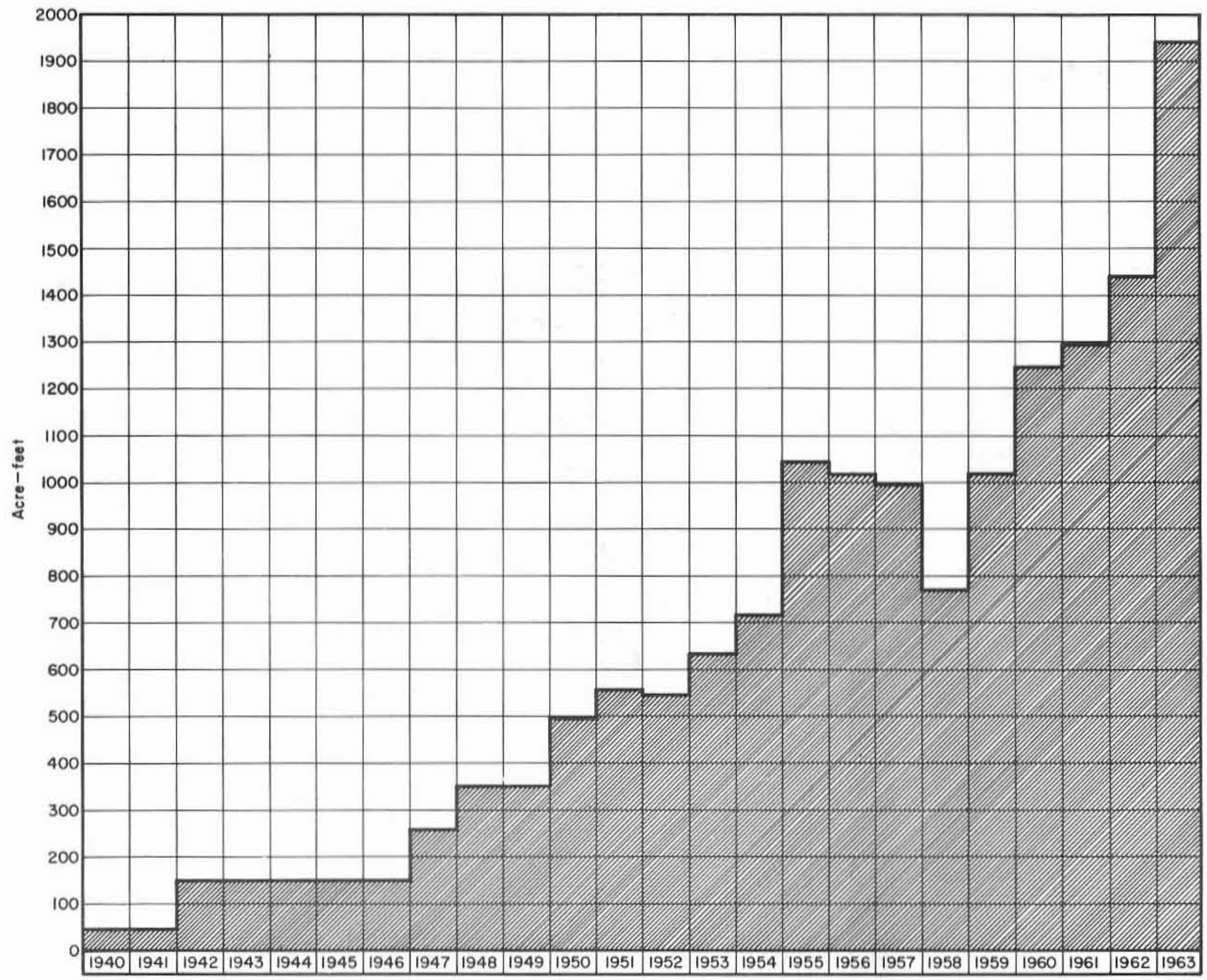

Figure 10

Pumpage of Ground Water for Industry in Jackson County, 1940-63

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

The oil and gas industry in Jackson County uses the rest of the water pumped for industrial purposes. Lavaca Producing Co., Mobil-Lolita compressor station, Texaco compressor station, Trunkline Gas Co., United Gas Pipeline Co., and the Mobile gasoline plant pumped a total of 417 acre-feet in 1963.

Public Supply

Pumpage of ground water for public supply in Jackson County in 1963 was 1.23 mgd, or 1,380 acre-feet. This was only 1.5 percent of the ground water pumped for all purposes in the county in that year.

The use of ground water for public supply in Jackson County has increased substantially. From 1940 to 1963, public-supply pumpage increased from 0.34 mgd, or 385 acre-feet, to 1.23 mgd, or 1,380 acre-feet (Figure 11). The increasing population of cities and towns in the county and modernization of homes is responsible for the increase and has created the need for additional supplies of water. New wells have been drilled to keep up with the increasing demand, and most of the newer municipal wells now in use were drilled within the past 10 to 15 years when the cities had substantial increases in population. The largest yearly increase in water pumpage was in 1963 when about 30 percent more water was pumped than in 1962. Part of this large increase is due to an increase in population and partly to a 10-inch deficiency of rainfall in 1963.

The city of Edna is the largest user of ground water for public supply. In 1963, Edna pumped 819 acre-feet, which is 59 percent of the total ground water used for public supply. In 1940, the city depended on a single well 410 feet deep to supply a population of 2,724. By 1960, the population had increased 85 percent to 5,038 and Edna had drilled its fifth well, 1,318 feet deep, to keep up with the increasing demands for city water.

The city of Ganado is the second largest user of ground water for public supply. In 1963, Ganado pumped 367 acre-feet, which is nearly 27 percent of the total ground water used for public supply. In 1940, the city used a single well 267 feet deep to supply a population of 717. By 1960, the population had increased to 1,626, and two additional wells, each 1,291 feet deep, had been drilled in 1946 and 1953.

The remaining 1.4 percent of the ground water pumped for public supply in Jackson County in 1963 was used primarily by Point Comfort in Calhoun County, the town being supplied by wells in Jackson County, and by the towns of Lolita, Vanderbilt, and La Ward.

Rural Domestic and Livestock Needs

The use of ground water in 1963 for rural domestic and livestock needs in Jackson County was about 0.65 mgd, or 729 acre-feet. This is less than 1 percent of the ground water pumped for all purposes in the county.

Construction of Wells

Proper well construction and operation is becoming more important with the increasing requirements of ground water. There is no universal pattern by

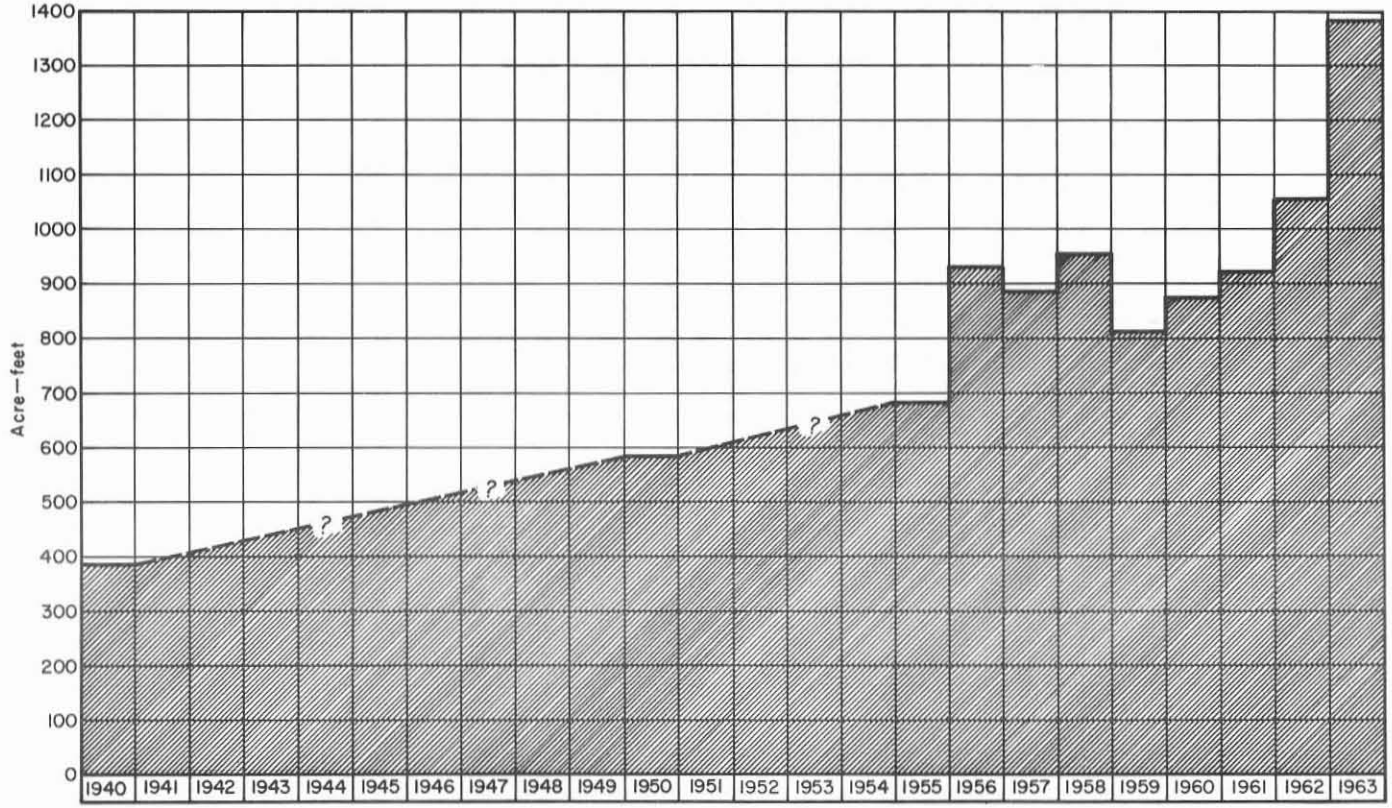

Figure 11

Pumpage of Ground Water for Public Supply in Jackson County, 1940-63

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

which all water wells can be constructed; to be successful, each well must be individually designed for subsurface conditions at the well location.

Most of the modern large-capacity wells in the Gulf Coast aquifer are gravel-packed wells. The gravel pack is used to increase the effective well diameter, thereby reducing the velocity of the incoming water so that the maximum withdrawal of water may be obtained with a minimum of drawdown.

Irrigation wells usually are gravel packed from the land surface to the bottom of the well. Even though all sand beds are not screened, the gravel packing in the well becomes a medium through which water may move between sand beds whether or not a screen is opposite the sand. In Jackson County, the shallow sands generally are under greater pressure than the sands that are screened in the wells; therefore, water from the shallow sands above the screen may move down the gravel pack and eventually enter the well. If the shallow sands above the screen may move down the gravel pack and eventually enter the well. If the shallow sands contain poor quality water, as in some oil-field areas, the well may become contaminated. In the southeastern part of the county where shallow salt-water sands overlie fresh-water sands, sufficient surface casing is set and cement grout is placed between the drilled hole and the casing, the grout extending from the top of the shallowest fresh-water-bearing sand to be screened to the ground surface. In this way, contamination is avoided.

A typical public supply or industrial well, which selectively screens the sands having water of the best quality, generally has a large-diameter surface casing (10 to 16 inches in diameter) which is cemented in place to seal off undesirable water above the producing zone. The hole below the surface casing is underreamed to as much as 30 to 36 inches in the sections that are screened. Small-diameter screen and blank casing (5 to 8 inches in diameter) extend to the bottom of the hole, and the annular space around the screen and blank casing is packed with gravel.

Some of the factors that must be given consideration in proper well construction are:

1. The upper casing should be of sufficient diameter to accommodate a pump capable of producing the required quantity of water, and the casing depth should be sufficient for the expected decline in water level throughout the life of the well.

2. The uppermost screen should be below the expected pumping level so that water will not cascade into the well. The cascading water entraps air which causes a pocket of free air to form at the impellers of the pump. The air, being highly compressible, does not easily pass up through the impellers, thus reducing the efficiency of the pump (Oral communication, J. L. Dickson, Katy Drilling Co., 1964).

3. The casing and screen should meet basic requirements of maximum resistance to corrosion and deterioration, structural strength to resist collapse, and prevention of excessive sand pumpage.

4. The drilled hole should be sufficiently straight to permit the satisfactory operation of a deep well turbine pump.

5. In a gravel-packed well, the size of the gravel and screen openings should be determined from an analysis of the assortment and grain size of the water sands. Sufficient gravel should be used to completely and uniformly pack the casing. Incomplete gravel packs result in excessive sand production which may create cavities in the sand beds and permit overlying clay beds to collapse, partially shutting off production.

6. Test pumping should be continued as long as necessary for adequate development of the well so as to insure the maximum possible production of water with minimum drawdown, resulting in an efficient well.

Most of the pumps on the irrigation wells are equipped with internal combustion engines powered with natural gas, diesel fuel, or a combination of the two. Most public-supply and industrial wells are equipped with electric motors.

EFFECTS OF PUMPING

When ground water is pumped from the Gulf Coast aquifer, a hydraulic gradient or slope in the water-level surface is established toward the well from all directions. This sloping water-level surface surrounding a pumping well assumes the shape of an inverted cone called the cone of depression. Theis (1938, p. 893) considers the cone of depression as "a pirating agent created by the well to produce water for it, first robbing the aquifer of stored water and finally robbing surface water or areas of transpiration in the localities of recharge or natural discharge." Wells drilled close together create cones of depression that may overlap, thereby causing additional lowering of water levels. Overlapping cones of depression resulting from the pumpage of vast quantities of ground water from the many large-capacity wells have caused the water levels to decline throughout Jackson County.

Decline of Water Levels

Figure 12 shows the approximate decline of water levels in the heavily pumped zone in a part of Jackson County and adjacent areas from 1944 to 1964. Relatively small declines are characteristic of the Ganado area; whereas, declines one and a half to two times larger are common elsewhere in the county, especially in the Cordele area and in southeastern Jackson County and western Matagorda County.

The range in water-level declines is due partly to the differences in permeability of the sand and partly to the variations in depth and thickness of the heavily pumped zone. Because of the high permeability and shallow zone of heavy pumpage in the Ganado area, the small declines of about 20 feet partly reflect a dewatering of the aquifer. On the other hand where the heavily pumped zone is relatively deep and permeability somewhat less, the declines reflect, to a larger degree, a decline in water pressure in the aquifer.

Figure 13 shows the approximate decline of water levels in the heavily pumped zone in Jackson County and adjacent areas from 1959 to 1964. The Ganado area, in general, had the least declines in water levels, ranging from 0 in a small area southeast of Ganado to about 6 feet. Declines of less than 2 feet in the southwestern part of the county reflect the small amount of irrigation pumpage in this area. Relatively large declines from 20 to almost 30 feet in the northwestern and northern parts of the county are due mainly to intensive pumping from deep wells. The large declines near Point Comfort represent continuous ground-water withdrawal in the Aluminum Co. of America well field. With the exception of the areas of large declines, most of the remainder of Jackson County and adjacent areas to the east had a smaller average yearly decline from 1959 to 1964 than from 1944 to 1964.

The decline of water levels in wells tapping the heavily pumped zone is shown graphically in Figure 14; Figure 15 shows the decline in water levels in wells tapping shallow sands overlying the heavily pumped zone and the accumulated departure from normal precipitation at Edna beginning in 1934. All wells shown tapping the heavily pumped zone (Figure 14) have net declines in water levels through the period of record, the minor fluctuations from year to year being due to relative amounts of rainfall and related increases or decreases in irrigation pumpage. It is significant, however, that the wells shown tapping the shallow sands overlying the heavily pumped zone (Figure 15) have also had net declines for the period of record even though very little water was pumped from them. Although the trend in water levels generally conforms to the accumulative departure from normal precipitation, in no wells did the water levels in 1959 recover to their previous positions in 1940 when the departure was also almost negligible. For example, in 1940 and 1959 when the accumulated departure from normal was small, the 1959 water levels were from about 10 to almost 25 feet lower than in 1940. It is thus evident that the shallow water sands are recharging the underlying heavily pumped zone by a downward movement of water. The downward movement has been detected by the spinner survey on an irrigation well south of Ganado (Figure 4).

The amount of water drained from the shallow sands by downward movement into the heavily pumped zone differs from place to place in Jackson County and is proportional to the difference in water levels. It is greatest wherever the relative positions of the water levels in the heavily pumped zone and in the overlying sands are the most widely separated. For example in the Cordele area, the water level was about 15 feet higher in 1964 in Well PP-66-51-507 tapping the shallow sand than in Well PP-66-51-505, a nearby well tapping the heavily pumped zone. In the Ganado area in Well PP-66-60-601 tapping a shallow sand and in Well PP-66-60-303 tapping the heavily pumped zone, the difference in water levels in 1964 was about 7.5 feet, or half that in the Cordele area. The net water-level decline from 1943 to 1964 in the shallow Ganado well was about half that in the shallow Cordele well. Thus, about twice as much water is being drained from the shallow sands in the Cordele area than in the Ganado area, assuming the same vertical permeability in both areas.

The drainage of ground water from the shallow sands into the underlying heavily pumped zone has evidently affected the streamflow in the Lavaca River as indicated by the hydrograph of Well PP-66-58-601. The well, which is 76 feet deep, has a surface elevation of 90 feet and is about 0.5 mile from the Lavaca River which has a channel elevation of 45 feet near the well. Prior to 1955, the elevation of the water level was consistently higher than the Lavaca River channel, indicating movement of ground water toward the river and probable discharge into the river, thereby contributing to the base flow of the stream. From 1955 through 1957 and since about 1962, the water level has been several feet below the level of the river, suggesting that the Lavaca River is losing some of its flow to the shallow outcropping sands. If the water levels in the shallow sands continue to decline and remain below the level of the streams in much of Jackson County, a considerable volume of streamflow will eventually be diverted under ground materially reducing the base flow of the streams.

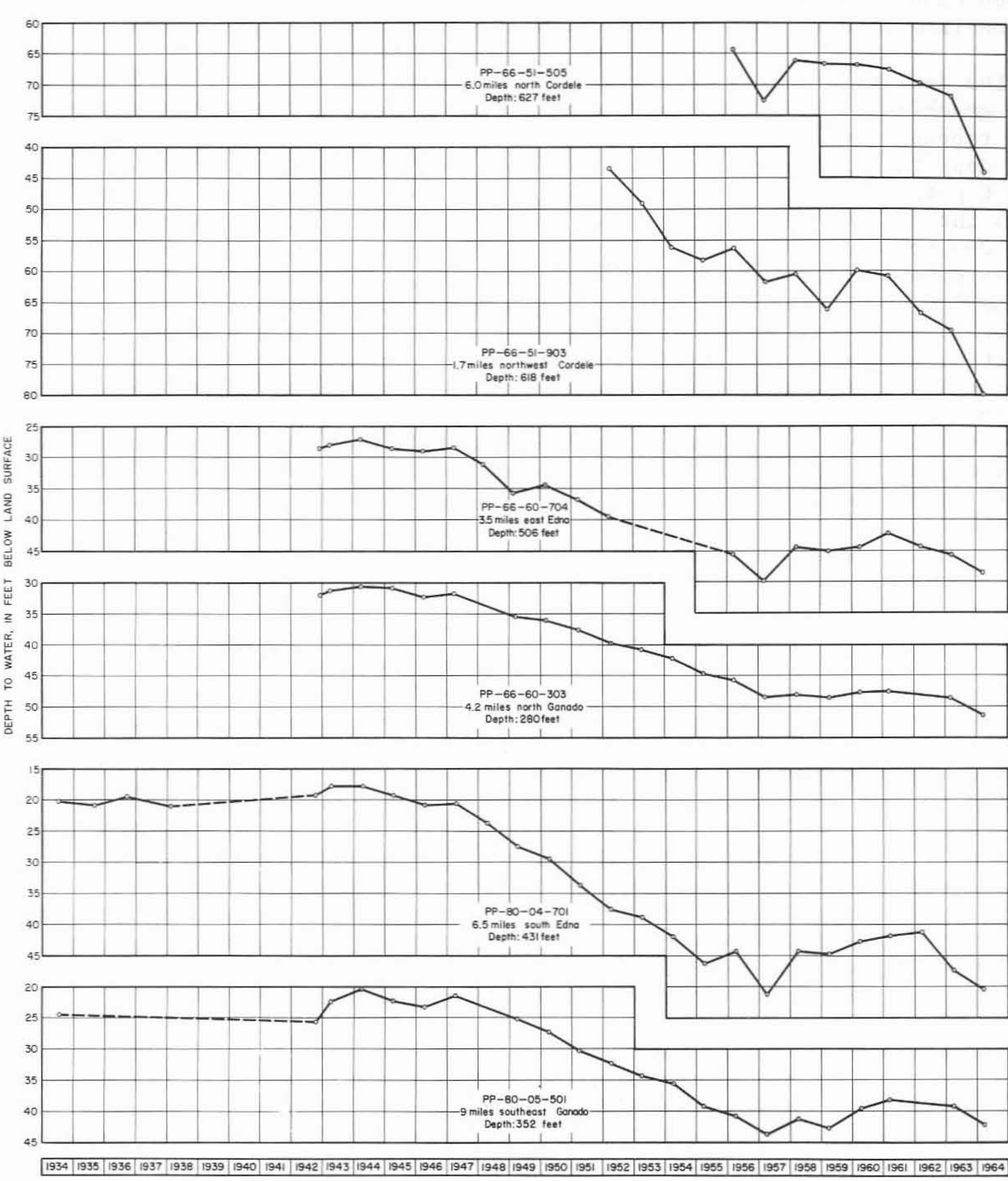

Figure 14

Graphs Showing the Decline of Water Levels in Wells Tapping the Heavily Pumped Zone in Jackson County

U.S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

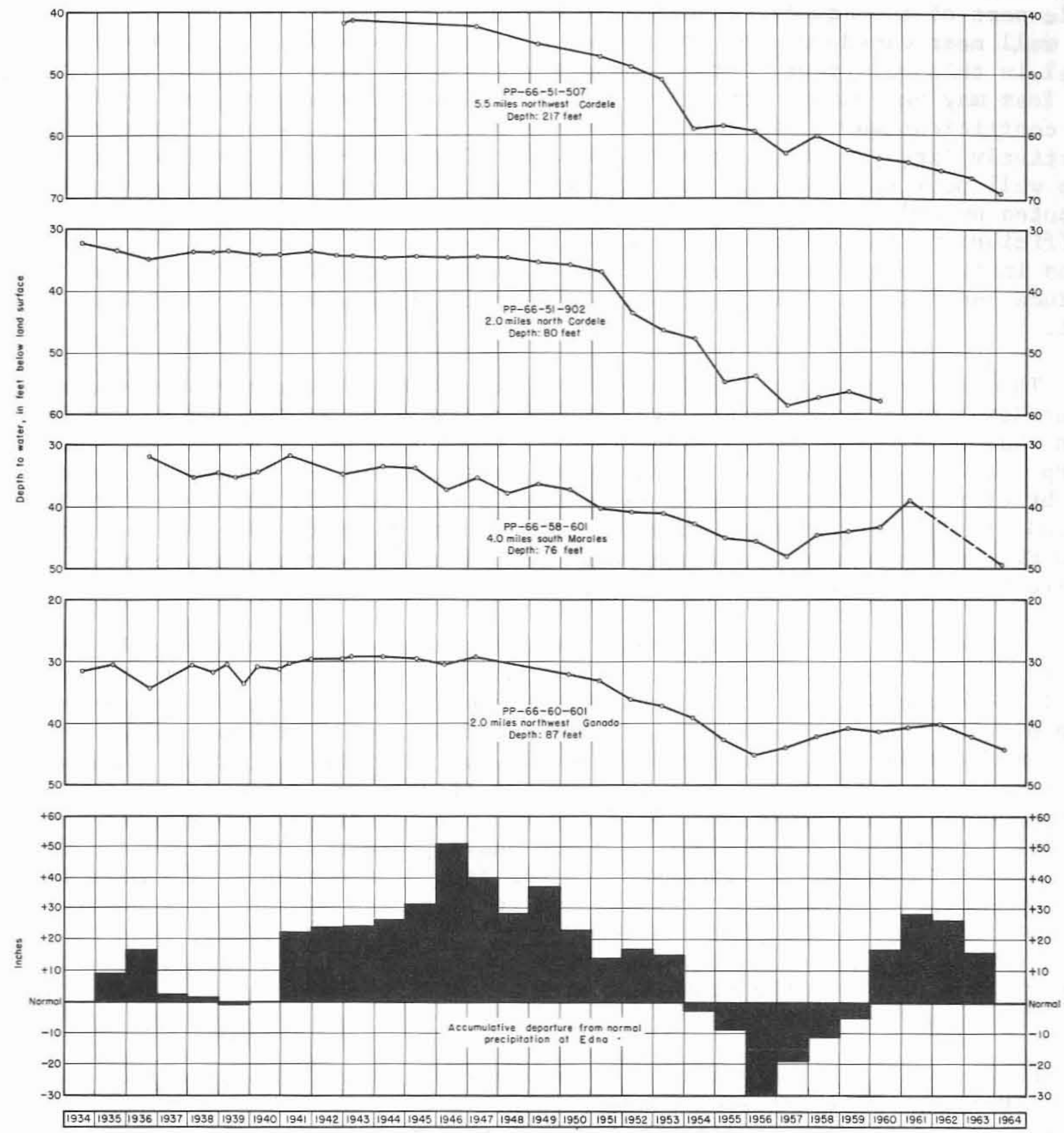

Figure 15

Graphs Showing the Decline of Water Levels in Wells Tapping Shallow Sands Overlying the Heavily Pumped Zone in Jackson County and Accumulated Departure From Normal Precipitation at Edna

U.S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

Figure 16 shows records of fluctuations of water levels in Well PP-66-60-605, 140 feet deep near Ganado, and in Well PP-80-03-101, 590 feet deep near Edna during the period September 1963 through July 1964. The figure illustrates the difference in water-level fluctuations in wells in the water-table part of the aquifer as compared to wells in the artesian part. The shallow well near Ganado may be considered a water-table well. A decline in water level in this well represents a comparatively large loss of water from storage. The loss may be computed by multiplying the decline in water level by the storage coefficient which, in the water-table part of the aquifer, is probably comparatively large, perhaps as much as 0.15. The water-level fluctuations in the deep well near Edna reflect only small changes in storage. The changes may be computed by multiplying the changes in water levels by the artesian storage coefficient which is very small, perhaps about 0.001. The water-level fluctuations in the deep well represent changes in pressure which are necessary to produce the hydraulic gradient required for the movement of water toward the well.

The water-level fluctuations in Well PP-80-03-101 clearly show the annual water-level cycle--the water-level recovery beginning at the end of the irrigation season in October, the highest level being reached in mid-April, and a sharp nearly steady decline in the water level during the irrigation season. The brief rises in the early parts of May, June, and July are due to shut-down periods in a nearby irrigation well. Noteworthy on March 27, 1964 was the Good Friday earthquake in Alaska which was clearly recorded in this well by a 7.6-foot instantaneous fluctuation in the water level.

Future declines of water levels in wells caused by pumping may be predicted for Jackson County. Figure 17 shows the relation of decline in water levels to the distance from the center of pumping for different coefficients of transmissibility. The calculations are based on a well or group of wells pumping 1 mgd (million gallons per day) for 1 year from the Gulf Coast aquifer having coefficients of transmissibility and storage as indicated. For example, if the coefficients of transmissibility and storage are 50,000 gpd per foot and 0.001, respectively, as is common in the heavily pumped zone in Jackson County, the decline of the water level would be 12 feet at a distance of 1 mile from a well or group of wells discharging 1 mgd for 1 year. If the coefficients of transmissibility and storage are 10,000 gpd per foot and 0.0001, respectively, as is common in the relatively deep parts of the aquifer in Jackson County, the same pumping rate for the same time would cause about 48 feet of decline at the same distance.

Figure 18 shows the relation of decline to time and distance from the center of pumping where artesian conditions prevail in Jackson County. It indicates that the rate of decline decreases with time and that the decline caused by pumping is proportional to the time of pumping. For example, if the decline 100 feet from a pumping well is 11 feet after 1 mgd has been pumped for 1 year, the decline would be about 15 feet after 1 mgd had been pumped for 100 years. The total decline at any one place within the cone of depression or influence of several wells would be the sum of the influences of the several wells. The equilibrium curve shows the time-drawdown relation when a line source of recharge is 25 miles from the point of discharge.

Figure 19 shows the relation of decline to time and distance from the center of pumping where water-table conditions prevail in Jackson County. The decline is less than that where artesian conditions prevail because of the

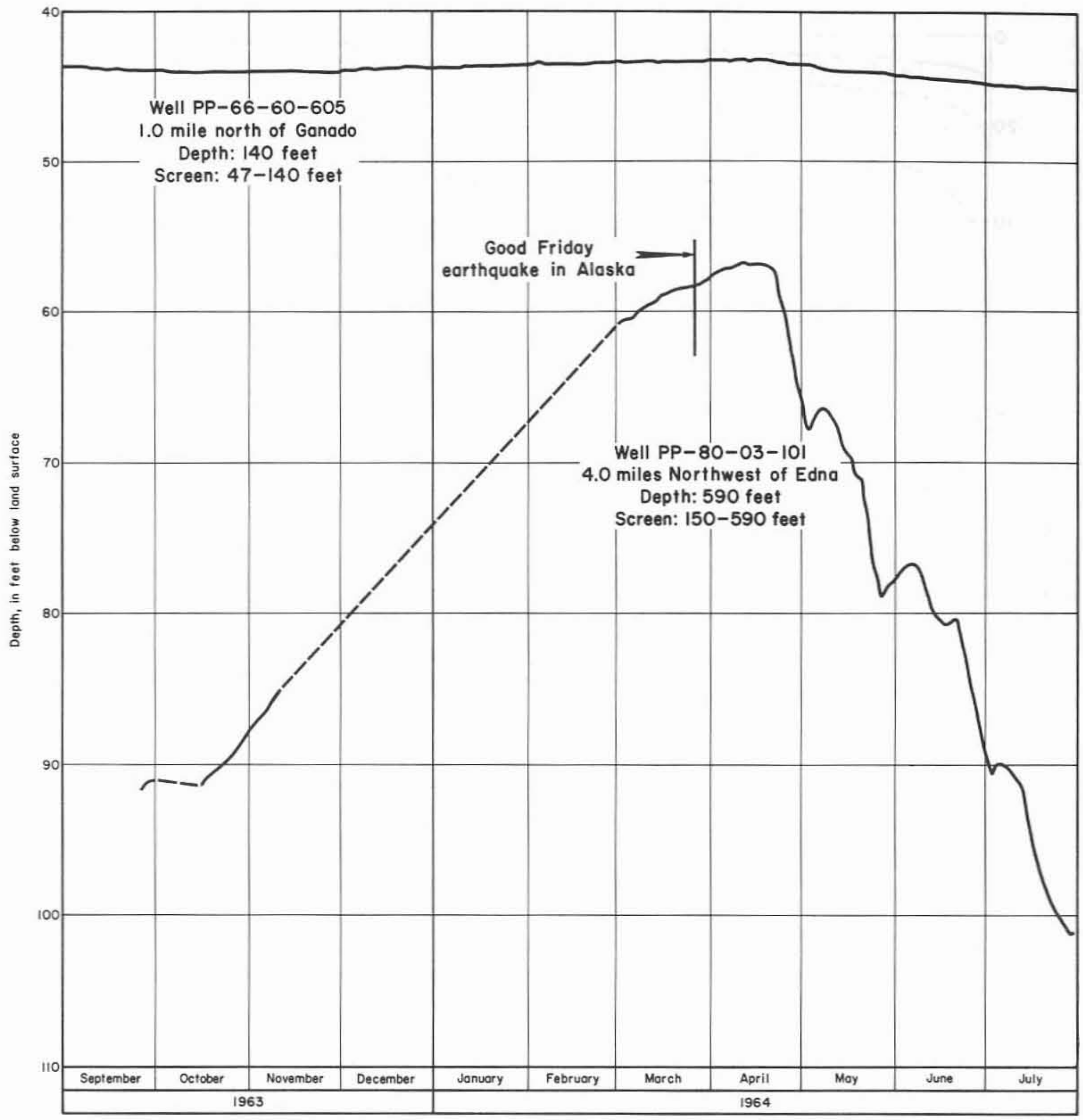

Figure 16

Graphs Showing Fluctuations of Water Levels in Wells PP-66-60-605 and PP-80-03-101 in Jackson County, September 1963 to August 1964

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

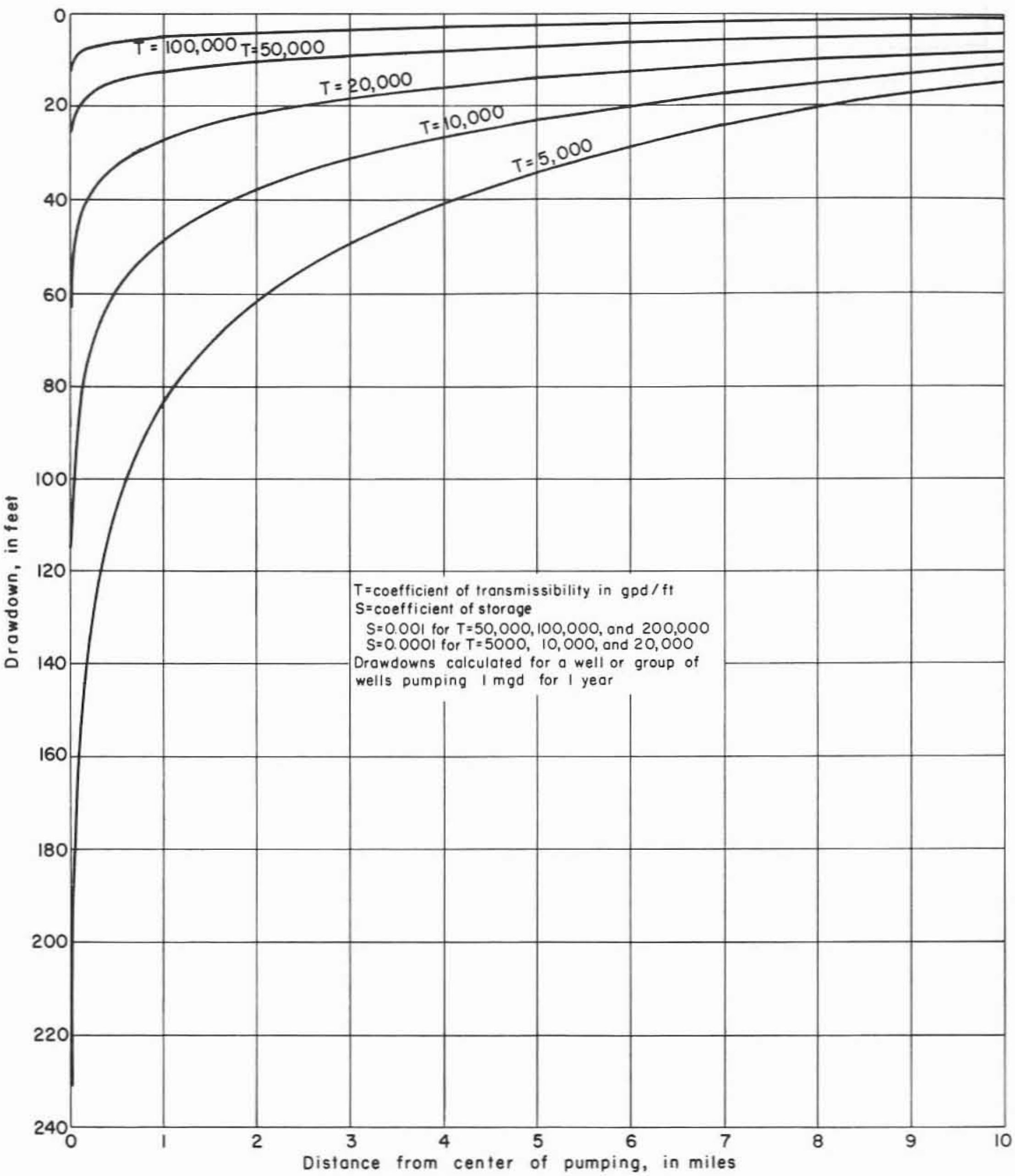

Figure 17

Graph Showing Relation of Decline in Water Levels to Transmissibility and Distance

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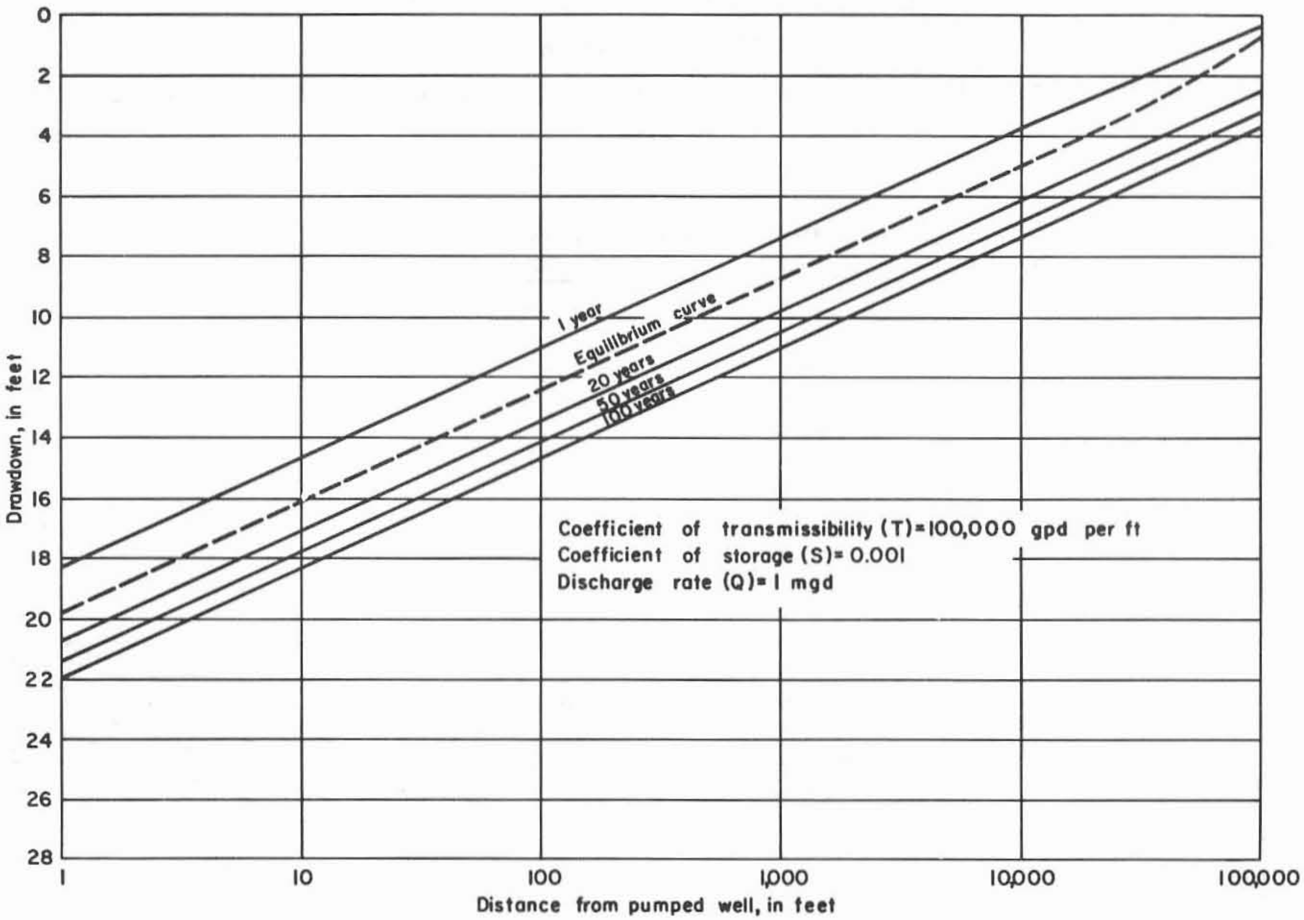

Figure 18

Graph Showing Relation of Decline in Water Levels to Time and Distance as a Result of Pumping Under Artesian Conditions

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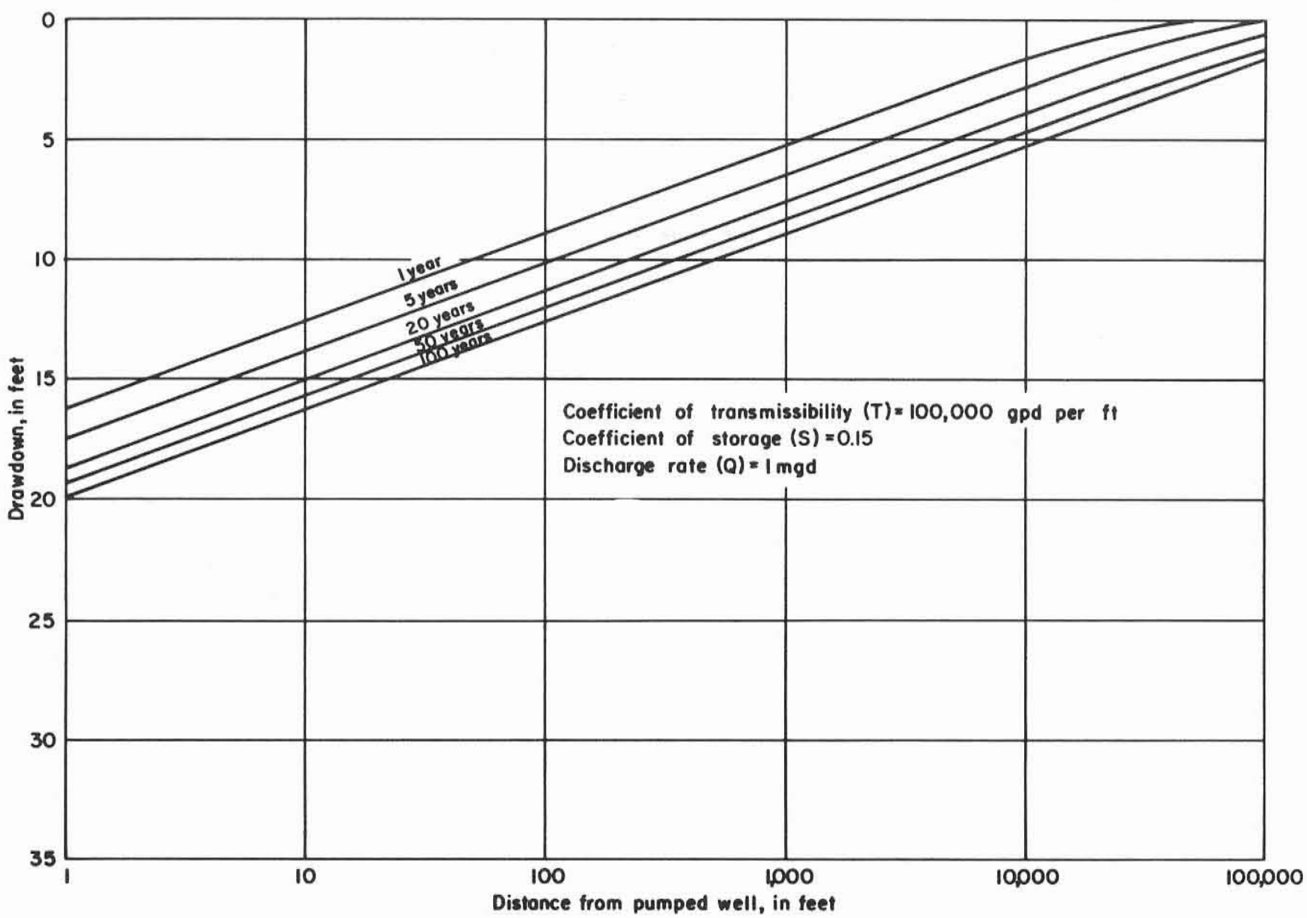

Figure 19

Graph Showing Relation of Decline in Water Levels to Time and Distance as a Result of Pumping Under Water-Table Conditions

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large coefficient of storage, other factors being equal. These curves largely apply to relatively shallow wells in the outcrop area of the aquifer.

Salt-Water Encroachment

Before large-scale withdrawals of ground water began in Jackson County, the salt water-fresh water boundary or "interface" was practically stationary and was south of the county in most of the aquifer. The system was in equilibrium because the hydrostatic pressure on the fresh-water side of the interface balanced the pressure on the salt-water side. The water-level surface sloped gently toward the Gulf of Mexico, indicating that the fresh water was moving in that direction, and nowhere in the county were the water levels below sea level.

The large withdrawals of ground water for irrigation in the county have gradually lowered the water levels, and by 1948 they were beginning to drop below sea level. The concentrated pumping at the Aluminum Co. of America well field 8 miles south of La Ward and at the plant site at Point Comfort has created a trough in the water-level surface extending roughly across the southern end of the county. Irrigation pumpage in western Matagorda County has probably extended the trough into that county (Figure 5). Because the ground water must flow in the direction of the slope of the sides of the trough, salt water must be moving toward the trough from the south. North of the trough, the fresh water is still moving gulfward and will continue to move in that direction as long as the trough is maintained. Thus, the encroachment of salt water laterally in the aquifer from the south is not considered a problem affecting the irrigated area of Jackson County north of the trough.

Another source of salt-water encroachment may be a threat in Jackson County. Figure 27 shows an area in the southern part of the county where saline-water-bearing sands overlie the fresh-water-bearing sands. The figure also shows a belt extending nearly across the south-central part of the county where saline-water-bearing sands are interbedded with fresh-water-bearing sands. When the head is lowered by pumping fresh water in these areas, a vertical hydraulic gradient will be established between the fresh water and the saline water, causing the saline water to move vertically into the fresh-water sands. The amount of salt-water encroachment will depend on the difference in head and on the vertical permeability. Because the vertical permeability is probably much less than the horizontal permeability and, consequently, most of the water pumped will be replaced by lateral movement of water rather than vertical movement, this type of encroachment may not be serious. Nevertheless, a certain amount of deterioration of the quality of the water is to be expected and a program should be set up to observe and measure the amount of deterioration.

Subsidence of the Land Surface

The major cause of subsidence of the land surface in Jackson County is the removal of ground water by pumping and the accompanying decline in water levels or pressure in the Gulf Coast aquifer. Meinzer and Wenzel (1942, p. 458) state that in an artesian aquifer, the water pressure provides a buoyant effect that helps to support the aquifer, and when the water pressure in the sands is lowered the buoyancy is reduced and the aquifer compacts. They also state that most of the compaction takes place in the fine-grained materials such as clays.

In other words, some of the water in the clay beds in the aquifer is forced out of the clay into the sands. The clay becomes compacted, and the land surface subsides.

Evidence of the relation between subsidence of the land surface and decline in water levels is afforded by a comparison of Figures 20 and 12. The subsidence in the county is shown by a comparison of the results of the releveling of a line of bench marks by the U.S. Coast and Geodetic Survey. The line was originally leveled in 1918 and was releveled in 1951. The subsidence increases from west to east or from eastern Victoria County across southern Jackson County into western Matagorda County, and corresponds to the increase in water-level declines from west to east.

The ratio between the subsidence of the land surface and the decline of water levels in Jackson County can be computed only generally because of the overlapping periods of measurements of subsidence (1918-51) and water-level decline (1944-64). However, because large-scale ground-water withdrawals did not begin in southeastern Jackson County and western Matagorda County until about 1941, the subsidence recorded from 1918-51 is believed to have occurred chiefly during the 10-year period from 1941-51. Wells PP-80-22-103 and TA-80-22-301, about 10 miles south of subsidence determinations at Francitas, show declines in water levels from 1941-51 of about 18 and 20 feet, respectively. The relationship of the subsidence of 0.2 foot at Francitas to the water-level declines of about 18 and 20 feet indicates a ratio of 1 foot of subsidence to about 90 to 100 feet of decline. This agrees closely with a ratio of about 1 foot of subsidence to 100 feet of decline determined by Winslow and Doyel (1954, p. 419-420) in the northern part of the Houston-Galveston region where maximum subsidence of several feet has been measured.

General subsidence of the land surface throughout most of Jackson County probably is occurring because of wide distribution of the many wells pumping large quantities of water. On the basis of observed water-level declines and the ratio of subsidence to decline, the maximum land-surface subsidence is believed to be less than 1 foot in any part of the county. The fairly uniform distribution of wells in the county will tend to distribute the subsidence over a large area and minimize the undesirable effects. For this reason, no damaged highways, broken pipelines, drainage problems, and cracked foundations of buildings have occurred or are foreseen in the near future.

An effect of subsidence that may be considered beneficial is that a significant quantity of water is made available to wells by the compaction of clay and other fine sediments as the land surface subsides. This additional amount of water was determined by Winslow and Wood (1959, p. 1034) in the Houston area to be about one-fifth of the total water produced.

CHEMICAL QUALITY OF THE GROUND WATER

The chemical substances in the ground water in Jackson County originate principally from the soil and rocks through which the water has moved. Consequently, the differences in chemical character of the water reflect in a general way the character of the rock formations that have been in contact with the water. The low rate of movement of ground water tends to inhibit mixing and diffusion. Lenses of sediments such as tight sand and clay form local barriers to ground-water movement and prevent uniform dispersion of water throughout the aquifer. As a result of these factors, variation in chemical

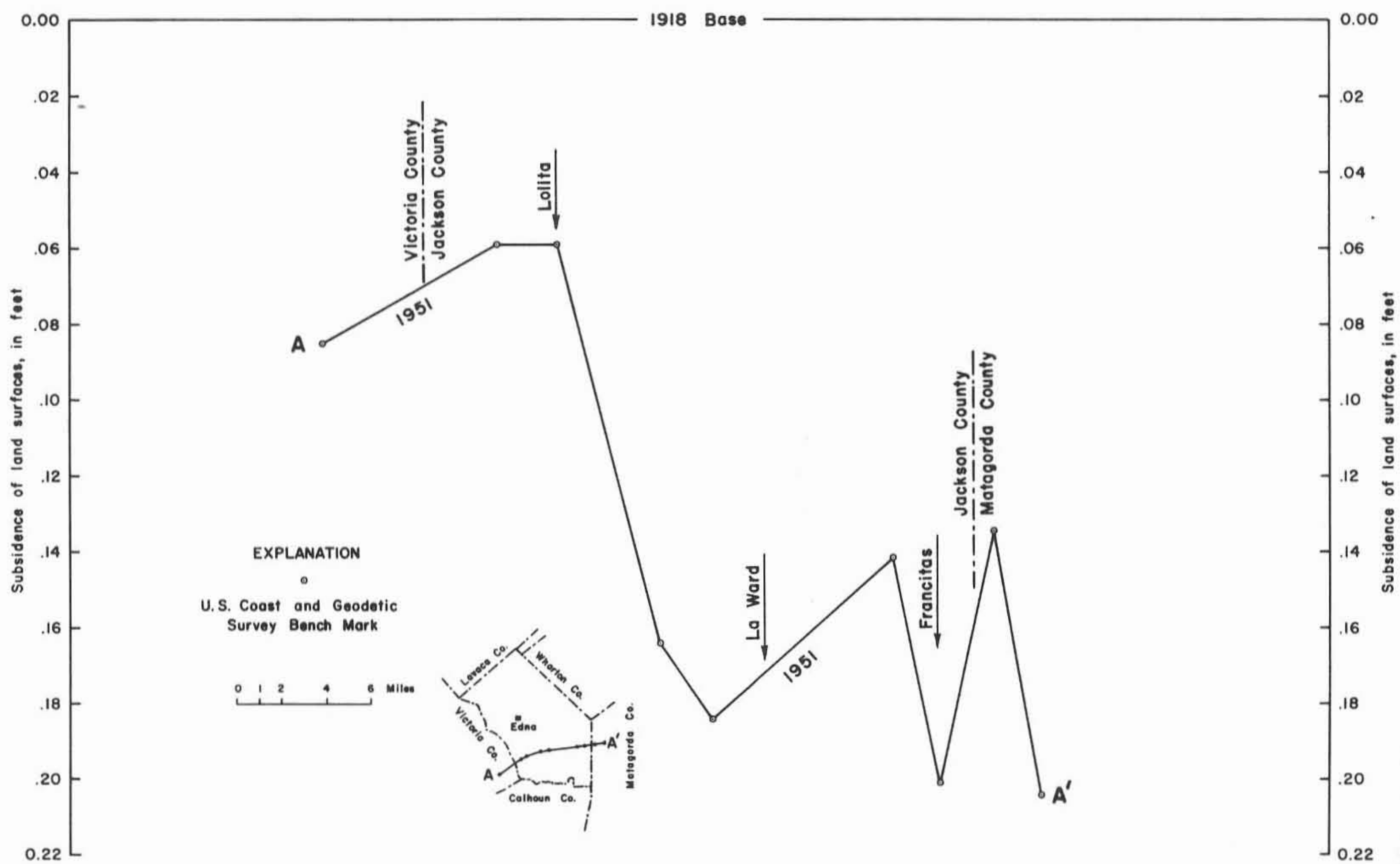

Figure 20

Profile of Land-Surface Subsidence in Southern Jackson County From 1918-51

U. S. Geological Survey in cooperation with the Texas Water Development Board and Jackson County

quality of the water can be expected in various parts of the aquifer. Table 9 shows 158 chemical analyses of water from wells that tap the Gulf Coast aquifer in Jackson County. The wells sampled are identified on Plate 1 by means of bars over the well numbers.

Suitability of the Water for Use

The suitability of a water supply depends upon the chemical quality of the water and the limitations imposed by the contemplated use of the water. Various criteria of water-quality requirements have been developed, including most categories of water quality: bacterial content; physical characteristics, such as turbidity, color, odor, and temperature; chemical substances; and radioactivity. Usually water-quality problems of bacteria and physical characteristics can be alleviated economically, but the removal or neutralization of undesirable chemical constituents can be difficult and expensive.

The dissolved-solids or "total salts" content is a major limitation on the use of the water for many purposes. The classification of water based on dissolved-solids content in ppm (parts per million) as used in this report is as follows (Winslow and Kister, 1956, p. 5):

Description	Dissolved-solids content (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

Irrigation

The suitability of water for irrigation depends on the chemical quality of the water and other factors such as soil texture and composition, types of crops, irrigation practices, and climate. Chemical analyses of irrigation water identify the more important substances that are present and show their concentration. From such analyses, it is possible to classify water in terms of suitability for irrigation and to anticipate with some assurance the effect of the water on crops and soils. The most important chemical characteristics pertinent to the evaluation of water for irrigation are the sodium concentration, an index of the sodium or alkali hazard; total concentration of soluble salts, an index of the salinity hazard; residual sodium carbonate; and concentration of boron.

Much study has been devoted to the determination of the quality requirements for rice irrigation, rice being by far the principal irrigated crop in Jackson County. Young rice is particularly sensitive to high sodium chloride content in the water, but the rice develops resistance as the plant matures.

According to Shutts (1953, p. 871-884), the commonly accepted tolerances of rice to sodium chloride are as follows:

Concentration of salts as sodium chloride (ppm)	Tolerance
600	Tolerable at all stages.
1,300	Rarely harmful and only to seedlings in dry, hard soil.
1,700	Harmful before tillering; tolerable from jointing to heading.
3,400	Harmful before booting; tolerable from booting to heading.
5,100	Harmful at all stages.

The sodium-chloride concentration in water from 51 representative irrigation wells throughout Jackson County ranged from 59 to 1,485 ppm; however, in only 3 wells did it exceed 600 ppm, and in only 6 wells did it exceed 300 ppm. The well having 1,485 ppm sodium chloride has been abandoned because of the high concentration of salt. Thus, in relation to sodium chloride alone, most of the ground water in Jackson County is tolerable to rice at all stages of growth.

Sodium is significant in evaluating quality of irrigation water because of its potential effect on the soil. A high percentage of sodium in water tends to make the soil plastic thus restricting movement of water through it and giving rise to problems of drainage and cultivation. A system of classification commonly used for judging the quality of water for irrigation was proposed in 1954 by the U.S. Salinity Laboratory Staff (1954, p. 69-82). The classification is based on the salinity hazard as measured by the electrical conductivity of the water and the sodium or alkali hazard as measured by the SAR (sodium-adsorption ratio). This classification of irrigation water is diagrammed in Figure 21, and analyses of water from 41 representative irrigation wells are plotted on the diagram.

The diagram indicates that almost 70 percent of the irrigation water is a low-sodium water and can be used on almost all soils with little danger to the soil. Slightly more than 20 percent of the water is a medium-sodium water which may be used without harmful effects to the soil if the soil is coarse textured, organic, and permeable. The remainder of the irrigation water, about 10 percent, is a high to very high sodium water which may have harmful effects on the soil and will require special soil management and irrigation practices. Regarding salinity, the diagram indicates that 80 percent of the water is a high-salinity water which should be used on soils having adequate drainage, plants with good salt tolerance should be selected, and salinity control should be practiced. Almost 20 percent of the water is a medium-salinity water which can be safely used if a moderate amount of leaching occurs.

Wilcox (1955, p. 15) stated that the system of classification used by the U.S. Salinity Laboratory Staff "...is not directly applicable to supplemental waters used in areas of relatively high rainfall." In Jackson County, where rainfall is relatively high, the system may not directly apply to row crops such as cotton, which is irrigated only when rainfall is deficient. Also, the

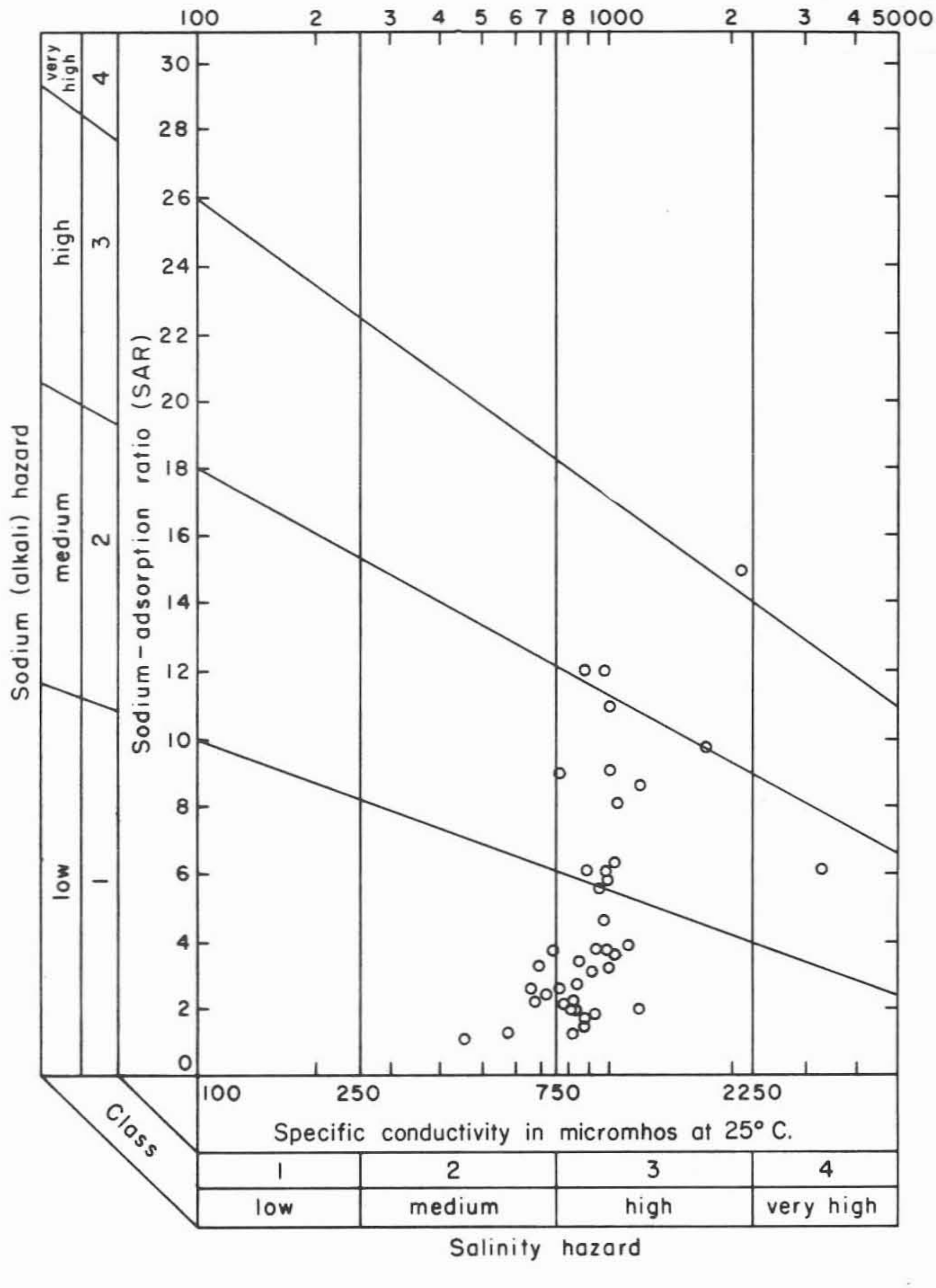

Figure 21

Diagram for the Classification of Irrigation Waters

(After United States Salinity Laboratory Staff, 1954, p. 80)

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restrictions associated with high-salinity water in Jackson County are, for the most part, overcome by the rice-pasture rotation system, which may be considered adequate salinity control primarily because of substantial leaching of the soil from rainfall when rice is not grown.

Irrigation water having the lowest sodium and salinity hazard is in the Ganado and Francitas areas; however, because most of the irrigation water throughout Jackson County is low in sodium and most of the crops grown (rice and cotton) are tolerant to the salt concentrations found in ground water used for irrigation in the county, the overall appraisal of irrigation water in Jackson County with respect to plant growth and soil effects is favorable.

Another factor used in assessing the quality of water for irrigation is the RSC (residual sodium carbonate) in the water. Excessive RSC causes the soil structure to deteriorate, air and water movement through the soil is restricted, soil alkalinity increases, and plant growth diminishes accordingly. The soil may become a grayish black, and the land areas affected are referred to as "black alkali." Wilcox (1955, p. 11) states that laboratory and field studies have concluded that water containing more than 2.6 epm (equivalents per million) RSC is not suitable for irrigation. Water containing from 1.25 to 2.5 epm is marginal, and water containing less than 1.25 epm probably is safe.

RSC was calculated from analyses of water from 33 representative irrigation wells throughout Jackson County. About 50 percent of the water tested contained less than 1.25 epm RSC, about 20 percent contained from 1.25 to 2.5 epm, and about 30 percent contained more than 2.5 epm. The irrigation water having the lowest RSC is in the general area around Ganado. Good irrigation practices make it possible to use the higher RSC water successfully for irrigation. Furthermore, according to Wilcox, Blair, and Bower (1954, p. 265), the degree of leaching will modify the permissible limit to some extent. Thus, in Jackson County where the rice-pasture system allows for substantial leaching of the soil by rainfall and where irrigation for row crops is used only to supplement rainfall, the harmful effects of the high RSC in some irrigation water in the county probably is greatly reduced.

An excessive concentration of boron makes a water unsuitable for irrigation. Boron is found in practically all natural waters, the concentration varying from a trace to several parts per million. It is essential to plant growth, but is exceedingly toxic at concentrations only slightly more than optimum. Scofield (1936, p. 286) indicated that boron concentrations of as much as 1 ppm are permissible for irrigating most boron-sensitive crops, and concentrations as much as 3 ppm are permissible for the more boron-tolerant crops.

The boron concentration in water from 37 representative irrigation wells ranged from 0.05 to 1.0 ppm and averaged 0.22 ppm. The average boron concentration is thus considerably less than the 1 ppm permitted for irrigating even the most boron-sensitive crops. In view of the fact that cotton, and possibly rice, are classed as semitolerant, the irrigation water in Jackson County is rated as satisfactory.

Public Supply

The quality of water required for public supply can be simply stated in general terms--the water furnished to the consumer must be free of harmful chemical substances which adversely affect health; it must be free of turbidity, odor, and color to the extent that it is not objectionable to the user; and must not be excessively corrosive to the water-supply system. To produce such water with practicable treatment, the quality of the raw water prior to treatment must not be below certain standards.

The U.S. Public Health Service has established and periodically revises standards of drinking water to be used on common carriers engaged in interstate commerce. The standards are designed to protect the traveling public and are used to evaluate public water supplies. According to the standards, chemical substances should not be present in a water supply in excess of the listed concentrations whenever more suitable supplies are or can be made available at reasonable cost. These limits apply to the water at a free-flowing outlet of the consumer. The major chemical standards adopted by the U.S. Public Health Service (1962, p. 7-8) are as follows:

Substance	Concentration (ppm)
Chloride	250
Fluoride	0.8*
Iron	.3
Manganese	.05
Nitrate	45
Sulfate	250
Total dissolved solids	500

* Upper limit for Jackson County based on an appropriate annual average of maximum daily air temperature of 79.9°F calculated over 14 complete years from 1944 through 1961 at Maurbro, 5 miles north of La Ward.

Water having a chloride content in excess of 250 ppm is objectionable because with an equivalent amount of sodium it has a salty taste to many people and may be excessively corrosive to the water-supply system. The chloride content of 140 samples in Jackson County ranged from 32 to 1,300 ppm, exceeding 250 ppm in 46 samples. In only two public-supply wells did the chloride content exceed 250 ppm. In many places in the county, water from shallow wells less than 100 feet deep had a higher chloride content than water from a deeper sand. In most of the county, ground water having a chloride content less than 250 ppm can be easily obtained.

Water containing optimum fluoride content reduces the incidence of tooth decay, especially in children, when the water is used during the period of enamel calcification. However, in excessive concentrations, it may cause mottling of the teeth, depending on the age of the child, amount of drinking water consumed, and susceptibility of the individual (Maier, 1950, p. 1120-1132). The optimum fluoride level for a given area depends on climatic conditions because the amount of drinking water (and consequently the amount of fluoride) consumed is influenced primarily by air temperature. Based on the annual average of maximum air temperatures in Jackson County of 79.9°F calculated over 14 complete years from 1944 through 1961 at Maurbro 5 miles north of La Ward, the lower, optimum, and upper control limits of fluoride concentrations established by the U.S. Public Health Service are 0.6, 0.7, and 0.8 ppm, respectively. Presence of fluoride in average concentrations greater than two times the optimum value, or 1.4 ppm for Jackson County would constitute grounds for rejection of the water supply by the Public Health Service. The fluoride content in water from 68 wells ranged from 0 to 2.4 ppm, exceeding 0.8 ppm in 18 wells. In only 6 wells did it exceed 1.4 ppm. The higher fluoride concentrations in Jackson County are associated with the deeper sands, such as those between 1,200-1,400 feet which supply water to Edna, Ganado, and Vanderbilt.

Water containing iron in excess of 0.3 ppm and manganese in excess of 0.05 ppm may cause reddish-brown or dark-gray stains on laundered goods, utensils, and plumbing fixtures, and iron in large amounts imparts an objectionable taste. The total iron content in water from 60 wells ranged from 0.01 to 3.6 ppm, exceeding 0.3 ppm in 21 wells. Areas having a high iron content in ground water are mainly west and southwest of Edna between Arenosa Creek and the Lavaca River, and in the Lolita-Vanderbilt area. The concentration of manganese in the ground water in Jackson County is generally negligible and was less than 0.05 ppm in the wells tested.

Water having a nitrate content in excess of 45 ppm is potentially dangerous for infant feeding and has been related to infant cyanosis or "blue baby" disease (Maxcy, 1950, p. 271). More than several parts per million of nitrate may indicate contamination by sewage (Lohr and Love, 1954, p. 10), decaying organic matter, fertilizers, or nitrates in the soil. The nitrate content in water from 78 wells ranged from 0 to 1.5 ppm. In only 7 wells did it equal or exceed 1.0 ppm. Three of the 7 wells having the higher nitrate content are shallow irrigation wells in the Ganado area. Here the sands are very permeable and the source of the nitrates may be the nitrogen fertilizer applied to the rice fields.

Water having a sulfate content in excess of 250 ppm may have a laxative effect on people not habituated to the use of water high in sulfate. The sulfate content in water from 95 wells ranged from 0 to 155 ppm. There seems to be little relationship between the concentration of sulfate and the depth of the water or the area in Jackson County.

Water having a dissolved-solids content (degree of mineralization or "total salts") in excess of 500 ppm is not recommended for public supply if other less mineralized supplies are or can be made available at reasonable cost. Water in excess of 500 ppm dissolved solids is not always available, and it is recognized that a considerable number of supplies with dissolved solids in excess of the recommended limit are used without any obvious ill effects. Usually, water containing more than 1,000 ppm dissolved solids is unsuitable for many purposes. The dissolved-solids content in water from 91 wells ranged from 212 to 3,020 ppm, exceeding 500 ppm in 68 wells. In only 14 wells did it exceed 1,000 ppm. Fresh water (less than 1,000 ppm dissolved solids) can be obtained in about 97 percent of Jackson County based on a study of electrical logs and chemical analyses.

The hardness of water caused principally by calcium and magnesium is important in a water supply, although no limits of rejection have been established by the U.S. Public Health Service. As the hardness of water increases, the desirability of the water decreases for most household purposes, especially cleaning, because of increased soap consumption, and heating, because of increased formation of scale in hot water heaters and water pipes. Water used for ordinary household purposes does not become particularly objectionable until it reaches the level of 100 ppm or so (Hem, 1959, p. 147). The commonly accepted classification of water hardness is given in the following table:

Hardness range (ppm)	Classification
60 or less	Soft
61 to 120	Moderately hard
121 to 180	Hard
More than 180	Very hard

The hardness of water from 116 wells ranged from 21 to 1,011 ppm, exceeding 60 ppm in 93 wells and exceeding 100 ppm in 84 wells. In most places in Jackson County, the shallow sands contain the hardest water, while the deeper sands contain the softest water. Water in the 1,200 to 1,400-foot sands, which is used by Edna, Ganado, and Vanderbilt, for example, is soft, generally containing much less than 60 ppm hardness.

In summary, ground water that meets the quality standards of the U.S. Public Health Service is available throughout most of Jackson County.

Industrial Use

The quality requirements for industrial water range widely, and almost every industrial application has different standards. Because of the wide variations of chemical-quality standards for industrial water, only facts and interpretations of a general nature that can be further studied by those who have special requirements are discussed.

Ground water used by industry can be classified into three principal categories--cooling, boiler, and process. The quantity used in Jackson County for cooling exceeds that used for all other purposes.

Cooling water usually is selected for its temperature and source of supply, although its chemical quality also is significant. Hardness, iron, and silica may cause scale which adversely affects the heat-exchange surfaces in the cooling process. Corrosiveness is another objectionable feature. Sodium chloride, acids, oxygen, and carbon dioxide are among substances that make water corrosive.

Boiler water for the production of steam must meet rigid chemical-quality requirements. Here the problems of corrosion and encrustation are paramount. The calcium and magnesium content, which causes hardness, greatly affects the industrial value of the water by contributing to the formation of boiler scale. Silica in boiler water also is undesirable because it too forms a hard scale, the scale-forming tendency increasing with pressure in the boiler (Moore, 1940, p. 263). Very little ground water is used in boilers in Jackson County.

Process water, that is incorporated into the manufactured product, usually is subject to rigid quality requirements. Quality approaching that of distilled water is required for processes such as the manufacture of textiles, high-grade paper, beverages, pharmaceuticals, and the like, where impurities in the water would seriously affect the quality of the product. Water that is low in dissolved solids and contains little or no iron and manganese which cause staining is highly desirable for use as process water.

In general, temperature and chemical quality of water are the most significant factors in judging the suitability of a water for most industrial uses. In Jackson County, the temperature of ground water increases about 1°F for every 100 feet of depth; the temperature of water in shallow sands near the land surface is about 70°F.

Silica, one of the substances that causes scale, ranged in concentration from 6.2 to 42 ppm in 76 wells, exceeding 20 ppm in 33 wells. Most of the ground water having the lowest silica content is in the southern half of the county.

Most of the ground water of Jackson County is alkaline. The pH of water from 99 wells ranged from 6.7, which is only slightly acidic, to 8.5, which is alkaline, and exceeded 7.0, which is neutral, in 86 wells. Alkalinity in ground water in the county increases with increasing depth.

Hydrogen sulfide gas (H_2S) which, in excessive amounts, renders water unsuitable for some industrial uses, is particularly noticeable (a strong odor is imparted by less than 1 ppm of H_2S, the characteristic ingredient in "sulfur water") in water from many wells in the northwest quarter of the county.

Other factors significant for many industrial uses, such as concentrations of iron, manganese, dissolved solids, and degree of hardness, in ground water in Jackson County have been discussed in the section on suitability for public supply.

In summary, ground water in many places in Jackson County will meet the quality requirements for many industrial uses, and with treatment, it is technically possible to make the water satisfactory for any special use.

Changes in Chemical Quality

Maintenance of the chemical quality of ground water produced by a well is desirable and, in many cases, necessary if quality limits related to the use of the water are not to be exceeded. One of the principal advantages of using ground water is its uniformity of quality; however, the withdrawal of ground water imposes new conditions on the aquifer and under certain circumstances causes changes in the chemical quality of the water.

Changes in the chloride content of water pumped from several wells tapping the Gulf Coast aquifer in Jackson and Calhoun Counties are shown graphically in Figure 22. The largest percentage increase was in Well PP-80-21-201 where the chloride content increased from 69 ppm in 1949 to 92 ppm in 1956, an increase of 33 percent or slightly more than 3 ppm per year. Since 1956, the

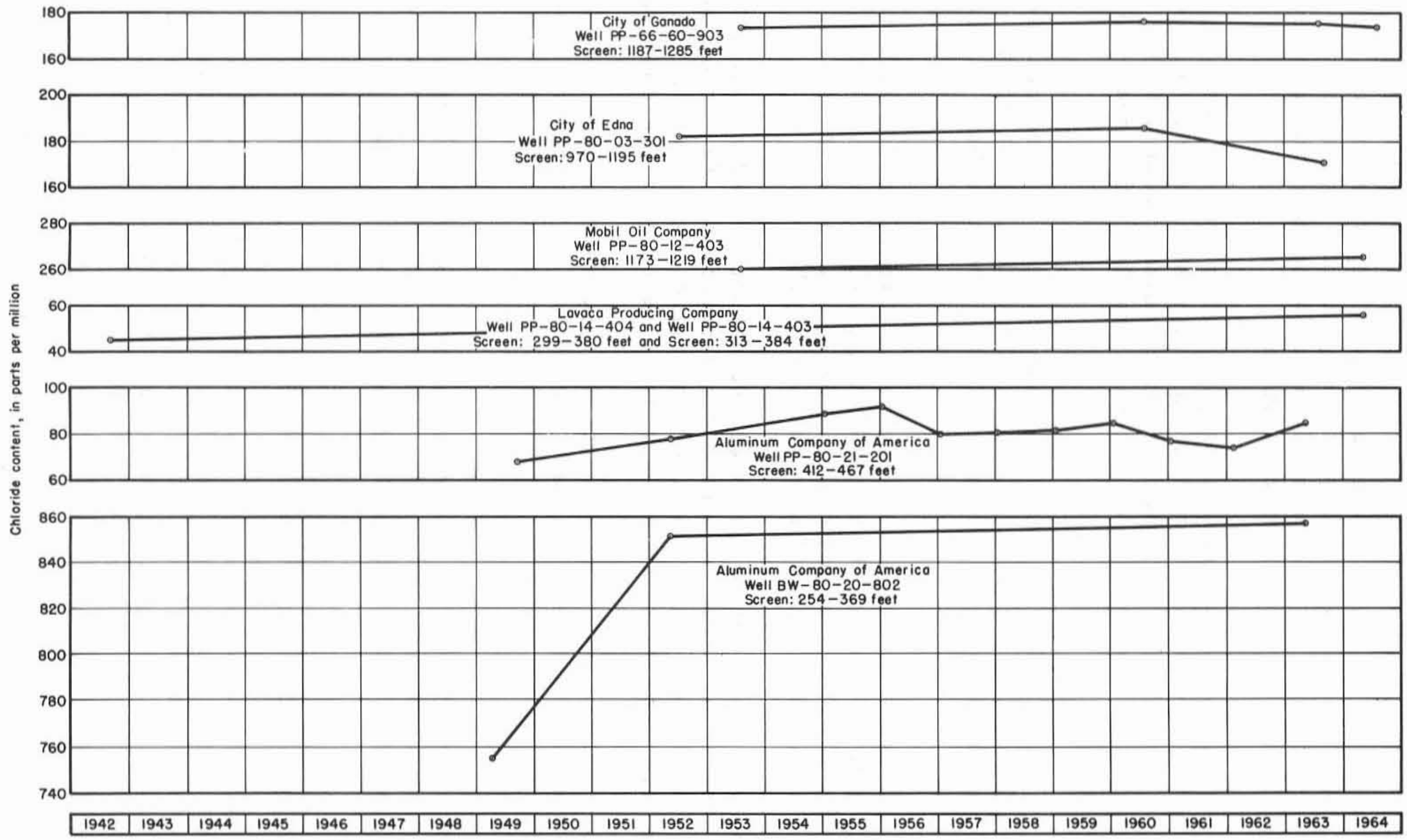

Figure 22

Graph Showing Changes in the Chloride Content of Water From Wells in Jackson and Calhoun Counties

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chloride content has decreased, and in 1963 it was 85 ppm. The changes in chloride in the water from this well, however, are somewhat insignificant because of the relatively low chloride level. An increase in chloride of 24 percent was observed in Wells PP-80-14-403 and PP-80-14-404, less than 1,000 feet apart. From 1942 to 1964, the chloride content increased from 45 ppm to 56 ppm in these wells, the rate of increase being about 0.5 ppm per year, and again somewhat insignificant because of the low chloride level. In Calhoun County, the water from Well BW-80-20-802 had an increase of 13 percent in chloride from 755 ppm in 1949 to 856 ppm in 1963. Almost all of the increase was within 3 years after the well began pumping. This slightly saline water well is near the fresh water-salt water boundary, and additional withdrawals of water will probably increase the chloride content. The increase in chloride in the water from Well PP-80-12-403, tapping a deep fresh-water sand near Vanderbilt, is, for the most part, negligible, the chloride having increased only 5 ppm since 1953. The changes in chloride content in the water from city of Ganado Well PP-66-60-903 were insignificant from 1953 to 1964, and in Well PP-80-03-301 at Edna, the chloride content has decreased slightly.

The chemical quality and temperature of water pumped from wells screened opposite a series of sand beds usually change during a relatively brief interval of time after the pumping begins. These changes are significant because they indicate chemical and pressure relations in the aquifer. The changes are particularly evident in irrigation wells which are generally screened or slotted opposite as many sand beds as practical. Results of chloride and temperature surveys of various irrigation wells in Jackson County are shown graphically in Figures 23, 24, and 25.

Figure 23 indicates that the chloride content in water pumped from irrigation wells in Jackson County either increases or decreases after the wells start discharging. Of the five wells surveyed, four had decreases in chlorides; only Well PP-80-03-202 had an increase. The relative amount of increase or decrease is partly dependent upon the length of time the well was idle prior to the survey; the wells having the longest periods of shutdown had the largest increase or decrease. For example, Wells PP-80-13-901, PP-80-03-202, and PP-80-06-102, idle for several weeks prior to the survey, had maximum recorded changes in chloride of 29, 66, and 72 ppm, respectively, while Wells PP-80-14-401 and PP-66-59-303, shut down for about 1 hour prior to the surveys, had maximum recorded changes in chlorides of 7 and 18 ppm, respectively. After most wells have been pumping about 30 to 60 minutes, the chloride content changes very little. The time since pumping started is thus important when periodically sampling a multiscreened well for quality comparison.

Figure 24 indicates that the chloride content of water changes with the temperature of the water pumped from irrigation wells in Jackson County. Therefore, because of a direct relation between temperature and depth, the relative depth of the water of better quality in the aquifer can be determined. The chloride-temperature surveys also are useful in locating the source of contamination in wells. For example, the surveys in Wells PP-80-03-202 and PP-80-14-401 indicate that the relatively shallow sands contribute water of better quality than the deeper sands; conversely, surveys in Wells PP-80-13-901, PP-66-59-303, and PP-80-06-102 indicate that the relatively deep sands contribute water of better quality than the shallower sands. These surveys and many chemical analyses of water reveal that within the heavily-pumped zone the relatively shallow sands generally contain water which is more mineralized than that from the deeper sands.

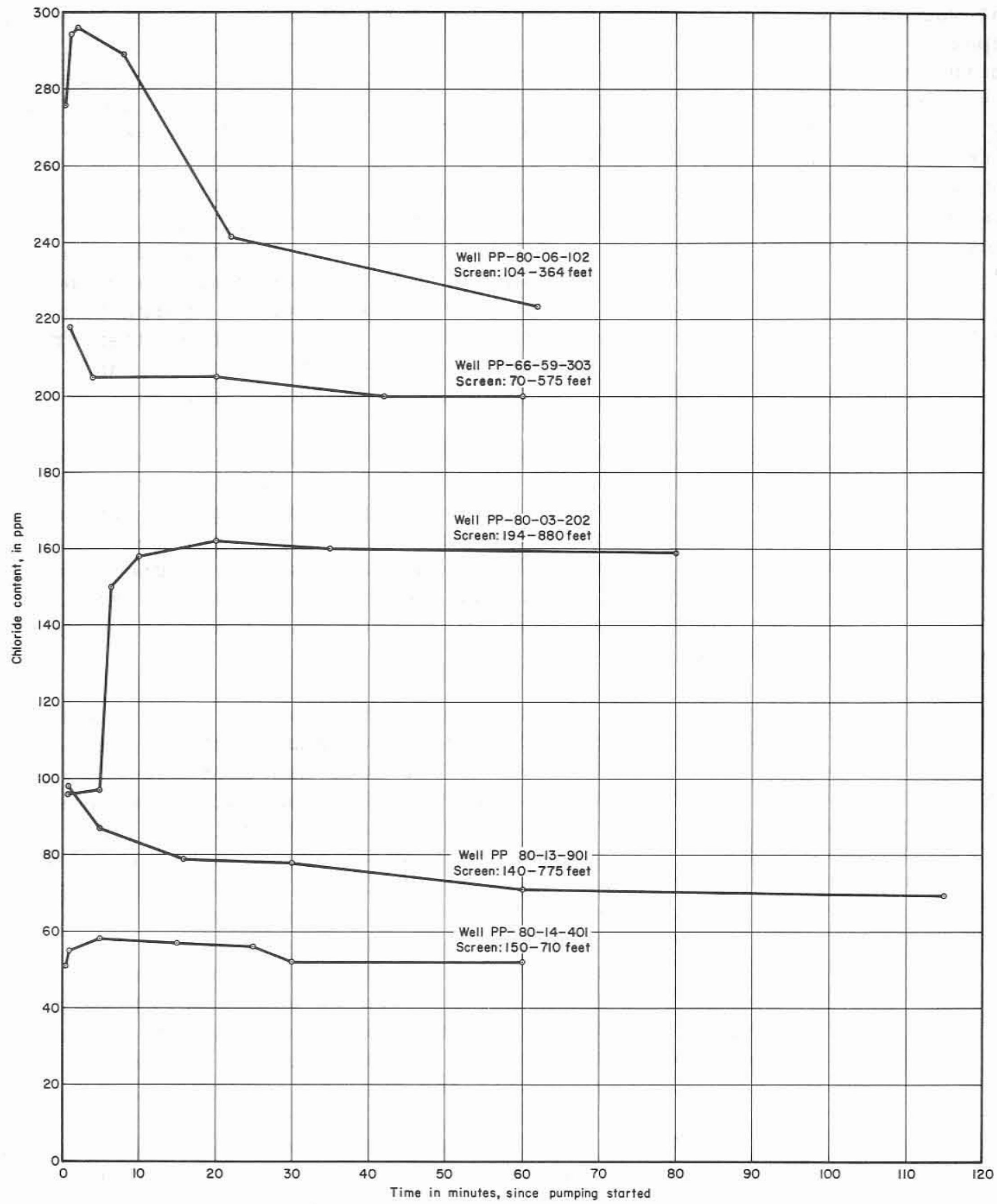

Figure 23

Graph Showing Changes in the Chloride Content of Water With Pumping Time in Irrigation Wells in Jackson County

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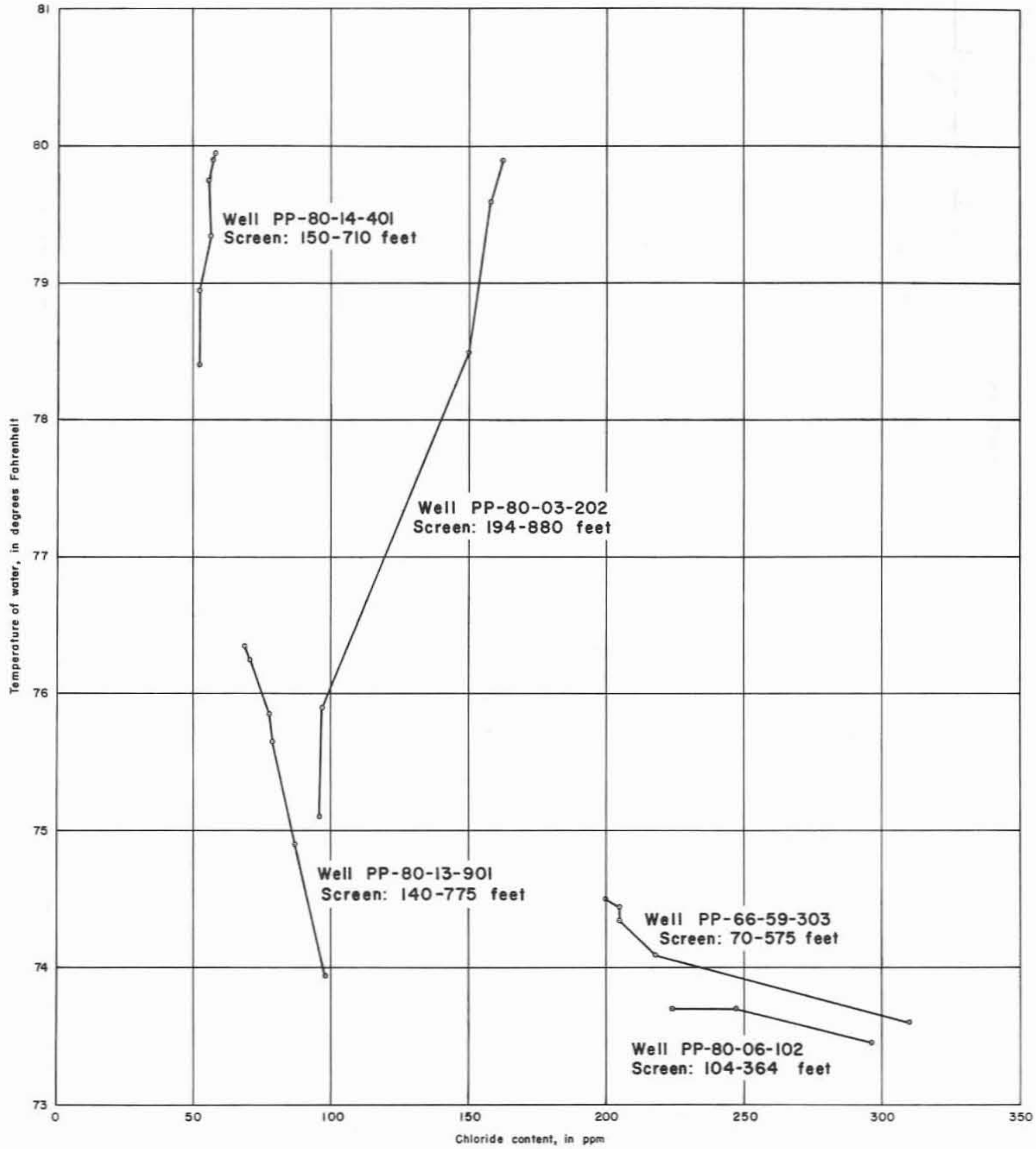

Figure 24

Graph Showing the Relation of the Chloride Content to the Temperature of Water From Selected Irrigation Wells in Jackson County

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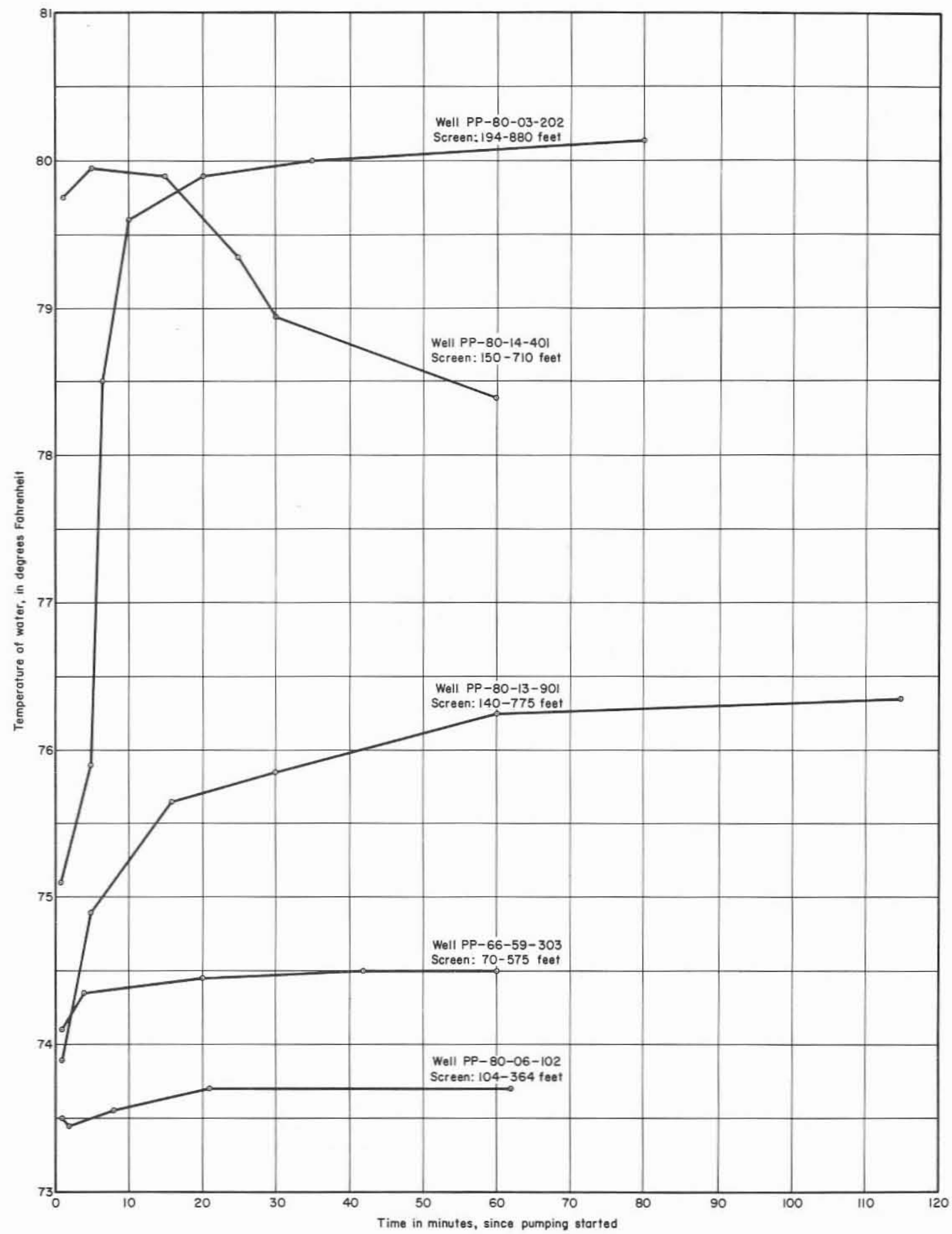

Figure 25

Graph Showing Changes in the Temperature of Water With Pumping Time in Irrigation Wells in Jackson County

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Figure 25 indicates that the temperature of water pumped from irrigation wells in Jackson County either increases or decreases after the wells start discharging water. In the 5 wells surveyed, the water from 4 increased in temperature; only in Well PP-80-14-401 did it decrease. The amount of increase or decrease is mostly dependent on the depth of the well and the vertical separation of the screens. For example, Well PP-80-06-102, screened from 104 to 364 feet, had a maximum recorded temperature increase of only 0.25°F; whereas Well PP-80-03-202, screened from 194 to 880 feet, had a maximum recorded temperature increase of slightly more than 5°F.

The temperature-time surveys are useful in detecting the direction of vertical movement or interchange of water from sands under relatively high pressure into sands under lower pressure which occurs while the well is idle. In Well PP-80-03-202, for example, one can surmise from the graphical plot of the temperature-time data that while the well was shut down or idle, cooler water from relatively shallow sands was moving down the well casing and entering or recharging deeper sands normally containing warmer water. The cooler water displaced the warmer native water and spread out into the aquifer. This process probably continued until the well pump was started. As the pump began drawing water from the sands, the initial water discharged at the surface was consequently the return flow of the cooler water from the various deeper sands that it had previously entered, plus cool water directly from the shallower sands. As pumping continued, the cooler water that had entered the various deeper sands was gradually removed, and a progressively larger amount of normal warmer water was being discharged at the surface. After about 20 to 30 minutes of pumping, equilibrium was almost attained, the temperature of the pumped water was nearly stable, and all sands were, for the most part, contributing their proportionate amounts of native water to the well. Thus, evidence of recharge to and discharge from individual sands within the aquifer was detected by the temperature-time survey. Similar information was obtained by the spinner survey in Well PP-80-05-401, 7 miles south of Ganado (Figure 4).

GROUND-WATER PROBLEMS

Rapid Decline of Water Levels

Large withdrawals of ground water from wells concentrated in relatively small areas in Jackson County have caused rapid declines of water levels. The areas most seriously affected include the northern one-third of the county, particularly the northwestern part where the rate of decline is most acute and the extreme southern part south of La Ward (Figure 13).

The relatively low permeability of the sand, mostly less than 200 gpd per square foot in the northern one-third of the county, together with the heavy pumpage is largely responsible for the rapid decline of water levels. Because of the low permeability, many large-capacity wells are necessary for supplying adequate supplies of water for rice irrigation in this area; consequently, the interference among wells is considerably greater than in other areas.

Pumpage in excess of about 5,000 acre-feet per year from about 12 wells within a relatively small area in northwestern Jackson County, southwestern Lavaca County, and northeastern Victoria County has caused about 28 feet of decline of water levels during the period 1959-64, a rate of almost 6 feet per year. The relatively low permeability of the sand in this area also has been a significant cause of the rapid declines.

Concentrated pumping in the Aluminum Co. of America well field 8 miles south of La Ward has caused a rapid decline of water levels. From 1949, when the first well was drilled in the 30-acre field, to 1964, the water levels have declined 90 to 100 feet, a rate of 6 to 7 feet per year. Four wells now in operation pumped slightly more than 5,000 acre-feet in 1963. The relatively high permeability of the producing sands, about 450 gpd per square foot, has offset to some extent the interference which might have been expected between the wells. A combination of closely spaced wells and continuous pumping throughout the year is responsible for the rapidly declining water levels.

The consequences of the rapidly declining water levels are mainly economic. Frequent lowering of pumps, drilling new wells to accommodate deeper pump settings, and increased fuel consumption from progressively higher lifts are costly and reduce profits. Most irrigation wells in northern Jackson County have pump settings between 200 and 300 feet, and the pumps require large engines. In contrast, most irrigation wells in the Ganado area have pump settings between 100 and 150 feet, requiring relatively small engines. Power tests reveal that about 2 to 5 times as much fuel is being used to pump a unit of water in the northern part of the county than in the Edna and Ganado areas where water levels are much higher.

Contamination of Ground Water in Areas of Oil and Gas-Field Operations

Disposal of Salt Water

The Railroad Commission of Texas recognized 160 oil and gas fields (including multiple pay zones) in Jackson County in 1961. According to a salt-water disposal inventory (Texas Water Commission and Texas Water Pollution Control Board, 1963), 38,514,242 barrels, or nearly 5,000 acre-feet, of salt water was produced in 1961 in the county. The methods of disposal related to the number of fields and quantity disposed are shown in Table 5.

Table 5.--Methods and quantity of salt water disposed in 1961 in Jackson County

Methods of disposal	Number of fields	Quantity disposed		Percent
		Barrels	Acre-feet	
Disposal wells	64	28,482,198	3,671.30	74.0
Surface-water course	10	6,496,972	837.45	16.9
Open surface pits	100	3,490,204	449.88	9.1
Miscellaneous	1	32,168	4.15	.1
Unknown	1	12,700	1.64	.0
	Totals.....	38,514,242	4,964.42	

At least part of the salt water (about 450 acre-feet in 1961) disposed in open surface pits in Jackson County seeps into the ground and in places probably has contaminated the shallow fresh-water-bearing sands. For this reason, this method of salt-water disposal is the most hazardous. The average yearly evaporation rate of about 60 inches cannot be depended upon to evaporate the salt water being placed continuously in the pits. Even if the water were evaporated, the salt would be left in the pits and would eventually be washed into the underlying material. Many of the pits are constructed so that the first shallow sand, in places from 10 to 30 feet below the land surface, is exposed in the bottom. Because the first shallow sand is generally above the water table, it serves as an effective conduit for rapid disposal of much of the salt water. When the salt water percolates downward to the water table, it is diluted somewhat as it would be in a surface stream. However, because ground-water movement is laminar, a slug of salt water reaching the water table usually moves in a well-defined streamline with a minimum of lateral or vertical diffusion and dilution (California State Water Pollution Control Board, 1952, p. 47).

The low rate of movement of ground water, about 20 feet per year, in places in Jackson County causes two significant conditions in the aquifer. First, the salt water that is being absorbed by the ground at one point may not affect the quality of the water in nearby wells for many years; consequently, no complaints may be registered and no one may be aware of the damage being done. Second, when the quality of the water supply begins to deteriorate and the contamination is finally detected, the damage cannot be immediately remedied merely by stopping the contamination at its source, because purification by leaching and dilution will require a longer time than the period of original contamination.

Some open surface pits in the Stewart, Ganado, Mauritz, North La Ward, Texana, and Lolita fields have presumably contaminated shallow fresh-water-bearing sands in places in these fields. Presumption of contamination in these fields is based partly on chemical analyses of water that reveal mineralization in excess of the normal chemical quality, partly on the reported history of the wells, and partly upon construction of the surface pits. The presumption of contamination of shallow ground-water sands is not necessarily restricted to the above-named fields, and contamination is possible in 20 to 30 other oil and gas fields in the county.

The best method of disposal of salt water is through the use of disposal wells. In 1961, almost 3,700 acre-feet of salt water (74 percent of the total amount produced) was disposed in this manner in Jackson County. All of the disposal wells were injecting into salt-water sands from 300 to 4,800 feet below the base of the slightly saline water, and, providing the disposal wells are properly constructed, no contamination of the fresh or slightly saline water is likely.

More than 800 acre-feet of salt water was disposed by dumping into surface-water courses in 1961. Because of the proximity of the fields using this method to Lavaca and Carancahua Bays, little or no contamination of ground water is likely.

Improperly Cased Wells

Another possible source of salt-water contamination is through improperly cased oil and gas wells. These wells normally penetrate not only the fresh-water-bearing sands but also saline-water-bearing sands before reaching the oil or gas producing horizons. If the salt water is under greater pressure than the fresh water, the salt water may move up the well bore and invade the fresh-water sands. In order to combat the threat of this source of contamination, the Railroad Commission of Texas requires that fresh-water strata be protected by casing and cement in oil and gas wells drilled in the State. The Oil and Gas Division of the Railroad Commission is responsible for seeing that oil and gas wells are properly constructed, and in the last few years, the Texas Water Commission [function concentrated in the Texas Water Development Board September 1, 1965] has furnished ground-water data to oil operators and to the Railroad Commission in order that all fresh- and slightly saline-water bearing sands may be protected.

Figure 26 illustrates the approximate depth to the base of the slightly saline-water sands in some of the oil and gas fields in Jackson County, and the amount of cemented casing required, according to published field rules of the Railroad Commission. No cases have been definitely determined where salt-water contamination has resulted from inadequately cased oil wells in the county. Such contamination is possible, however, in many places, as two-thirds of the fields listed in Figure 26 do not require adequate cemented casing to fully protect the fresh to slightly saline-water sands.

AVAILABILITY OF GROUND WATER

Distribution and Quantity of Water in the Aquifer

Fresh Water

Fresh ground water containing less than 1,000 ppm dissolved solids is available everywhere in Jackson County except in an area of about 25 square miles along the Lavaca River Valley extending from Lavaca Bay northward to about the confluence of the Lavaca and Navidad Rivers.

The base of the fresh water ranges in depth from about sea level (indicated by the zero contour line) to at least 1,815 feet below sea level near Ganado (Figure 27). The deepest areas of fresh water are aligned in a trough-like depression trending southwestward from Ganado and passing slightly south of Edna. Northwestward from the trough, the depth to the base of the fresh water decreases to less than 400 feet just north of Jackson County in Victoria and Lavaca Counties. Southeastward from the trough, the deeper water becomes saline, causing the base of the fresh water to be shifted vertically upward, the shift exceeding 1,200 feet in places. This causes a drastic thinning of the fresh-water section. South of the line of vertical shift, the depth to the base of the fresh water increases toward the east. In an area of about 115 square miles in the southern half of the county sands containing water in excess of 1,000 ppm dissolved solids overlie the base of the fresh water. In other words, the fresh-water sands in this area are both overlain and underlain by saline-water sands. This is illustrated in Figure 27 and in the geologic

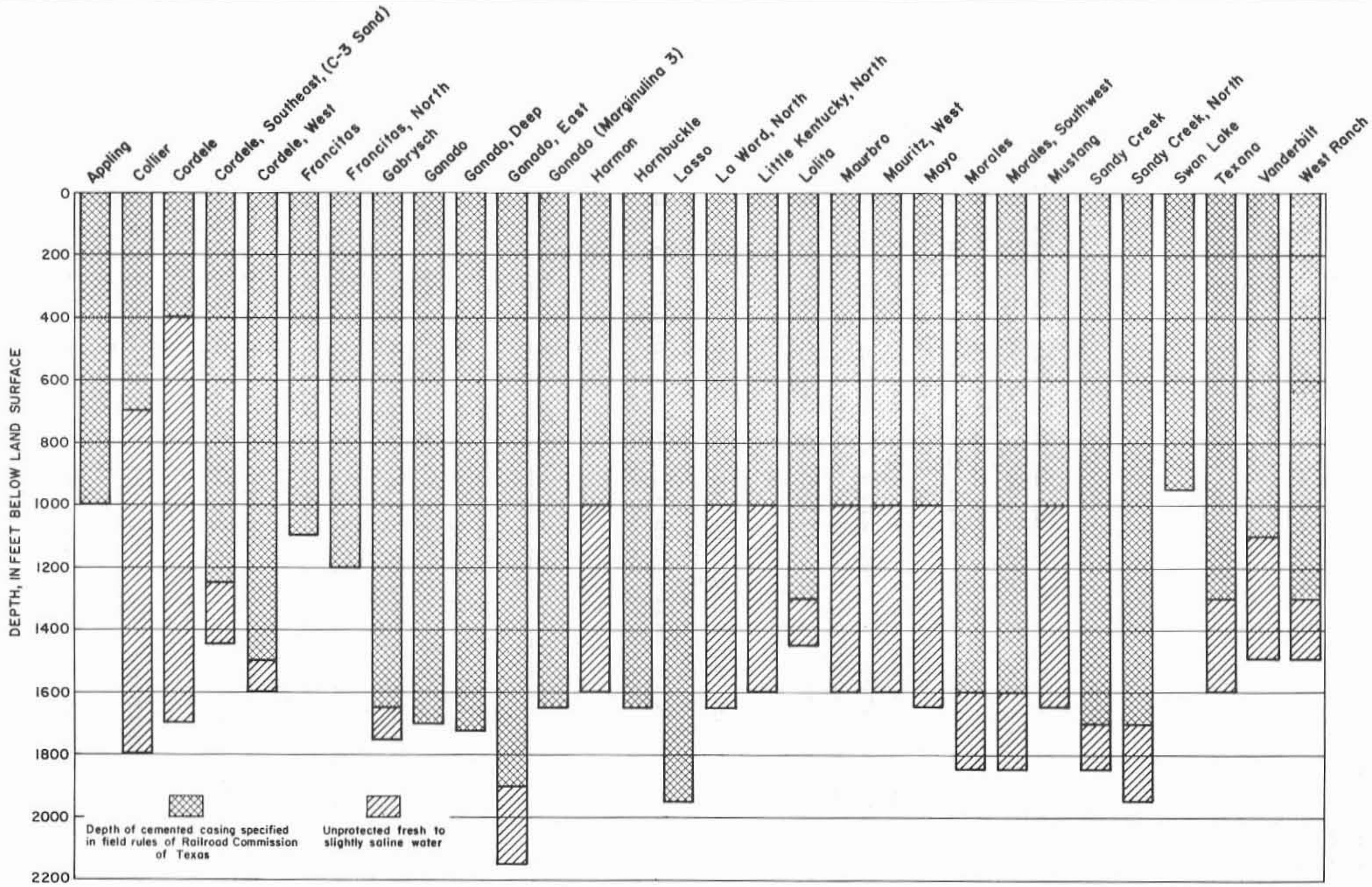

Figure 26

Comparison Between Depth to the Base of the Fresh to Slightly Saline Water Sands and Amount of Surface Casing Required in Oil and Gas Fields in Jackson County

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sections shown in Plates 2, 3, and 4. The sections were prepared from electric logs of wells from which the quality of the water can be estimated by a study of the deflection of the curves.

About 95 million acre-feet of fresh ground water is in storage in the Gulf Coast aquifer in Jackson County; however, only a part of this water is recoverable and available for development. The approximate thickness of the fresh-water sands in the county is shown in Figure 28. The area in which the sands are thickest is along a line trending southwestward from Ganado and passing slightly south of Edna, the greatest thickness of more than 1,200 feet being in the Ganado area. The amount of sand thins progressively northwestward and southeastward from this line.

Slightly Saline Water

Slightly saline ground water containing from 1,000 to 3,000 ppm dissolved solids is available everywhere in Jackson County and underlies the fresh water. The depth below sea level to the base of the slightly saline water ranges from less than 300 feet between Lolita and La Ward to at least 2,340 feet near Ganado (Figure 29). The configuration of the base of the slightly saline water is similar to that of the fresh water and is generally several hundred feet below the base of the fresh water. In an area of about 120 square miles in the southern half of the county, sands containing water in excess of 3,000 ppm dissolved solids overlie the base of the slightly saline water (Plates 2-4 and Figure 29).

About 35 million acre-feet of slightly saline water is in storage in Jackson County; however, only a part of this water is recoverable and available for development. The approximate thickness of sand containing fresh and slightly saline water in the county is shown in Figure 30.

Quantity of Fresh Ground Water Available for Development

Various methods have been used in different parts of the Gulf Coast region of Texas to evaluate the Gulf Coast aquifer in terms of the quantity of ground water that could be developed. Some workers have used as an index of the availability of water the amount of water in storage in the aquifer. However, most of our ground-water resources are only renewable over long periods of time, and if the aquifers were to be depleted, it would require probably centuries to refill them. As stated above, about 95 million acre-feet of fresh ground water is in storage in Jackson County; however, most of this is not available for development because of the great depth at which most of the water occurs, and because of the fact that a large fraction of the water cannot be drained from the sands.

Another method of determining the availability of ground water is by a determination of the transmission capacity of the aquifer which is the amount of water that any given segment of the aquifer will transmit under any given hydraulic gradient. Estimates using this method are based on many assumptions of which probably only a few are valid in the Jackson County area.

Perhaps the best way to estimate the availability of ground water in Jackson County would be to compare the area with another area in which a large development has already taken place. The Jackson County area is very similar

Developing and utilizing ground water for optimum efficiency require adequate planning. Exploration by test drilling and test pumping, including chemical analysis of the water at various levels in the aquifer, is desirable before permanent locations are selected for any large-scale development. Such preliminary data can be used to determine the optimum pumping rate, the most efficient pump setting, and well spacing, and the feasibility of drilling additional wells.

The periodic collection of basic data such as the inventory of pumpage, observation of water levels, and collection of water samples for quality studies should be continued in Jackson County as ground-water development increases. The collection of water samples at regular intervals will provide information on the status of salt-water encroachment and contamination. Sampling should be principally near the Jackson-Calhoun county line where the threat of salt-water encroachment is greatest. The proper spacing of wells to avoid mutual interference is particularly important in this area near the salt water, so that water-level declines can be minimized. A network of 27 observation wells has already been established throughout Jackson County and water levels in these wells are measured and recorded annually by the Texas Water Development Board.

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Table 6.--Records of wells in Jackson and adjacent counties

All wells are drilled unless otherwise noted in Remarks column.

Water level : Reported water levels given in feet; measured water levels given in feet and tenths.

Method of lift and type of power: C, cylinder; E, electric; G, gasoline, butane, or Diesel engine; J, jet; N, none; Ng, natural gas; T, turbine; W, windmill. Number indicates horsepower.

Use of water : D, domestic; Ind, industrial; Irr, irrigation; N, none; P, public supply; S, stock.

Well	Owner	Driller	Date completed	Depth of well (ft)	Diameter of well (in.)	Altitude of land surface (ft)	Water level: Below land-surface datum (ft)	Water level: Date of measurement	Method of lift	Use of water	Remarks
						Jackson County					
PP-66-43-904	Wady Nichols	Crowell Bros.	1950	633	13	139	--	--	T,Ng, 200	Irr	Cased to bottom.
* 50-801	Paschall & Utz	Katy Drilling Co.	1955	886	20, 12	128	61.3 131.9 79.1	Mar. 23, 1960 Aug. 6, 1963 Mar. 10, 1964	T,Ng, 200	Irr	Casing: 20-in. to 321 ft, 12-in. from 321 to bottom. Slotted from 229 ft to bottom. Pumping level 189.62 ft while discharging 1,040 gpm for 14 days. Water level recovered 42.34 ft after 1-hour shutdown. Large amount of natural gas in water. Temp. 78°F. 1/ 4/
51-202	J. W. Brisbois	Henry Cleveland	1951	720	20, 12	142	100.5	Mar. 5, 1964	T,Ng, 120	Irr	Casing: 20-in. to 250 ft, 12-in. from 250 ft to bottom. Slotted from 100 ft to bottom. Measured discharge 1,230 gpm on Aug. 23, 1963. Pump set at 220 ft. Temp. 75°F.
203	do	--	1951	106	4	139	63.9	Aug. 27, 1963	J,E, 1	D,S	Pump set at 78 ft.
301	Maurice Hicks	H. L. Powell	1949	625	20, 12	129	99.2	Oct. 22, 1960	N	N	Casing: 20-in. to 160 ft, 12-in. from 160 ft to bottom. Abandoned.
302	Morton Bros.	Katy Drilling Co.	1959	631	20, 12	139	--	--	T,Ng, 150	Irr	Casing: 20-in. to 320 ft, 12-in. from 320 ft to bottom. Slotted from 150 ft to bottom. 1/
303	Maurice Hicks	Crowell Bros.	1958	630	20, 12	133	--	--	T,Ng, 50	Irr	Casing: 20-in. to 287 ft, 12-in. from 287 ft to bottom. Slotted from 214 ft to bottom. Drilled to 819 ft, plugged back to 630 ft. Measured discharge 1,350 gpm on Aug. 21, 1963. Temp. 76°F. 2/
304	Peck Bros.	H. L. Powell & Layne-Texas Co.	1953	612	24	129	--	--	T,Ng, 190	Irr	Casing slotted from 200 ft to bottom. Pump set at 250 ft. Measured discharge 1,120 gpm on Aug. 21, 1963. Temp. 76°F.
* 305	Maurice Hicks	Crowell Bros.	1963	1,010	18, 14, 12, 10	131	185.9	Aug. 28, 1963	T,Ng, 225	Irr	Casing: 18-in. to 300 ft; 14-in. from 300 ft to 328 ft, 12-in. from 328 ft to 655 ft, and 10-in. from 655 ft to bottom. Slotted from 225-425, 540-650, 680-700, 760-780, and 830-1,010 ft. Measured discharge 1,650 gpm on Sept. 12, 1963. Drilled to 1,048 ft, plugged back to 1,010 ft. Pump set at 230 ft. Temp. 79°F.

See footnotes at end of table.

Table 6.--Records of wells in Jackson and adjacent counties--Continued

Well	Owner	Driller	Date completed	Depth of well (ft)	Diameter of well (in.)	Altitude of land surface (ft)	Water level: Below land-surface datum (ft)	Water level: Date of measurement	Method of lift	Use of water	Remarks
PP-66-51-401	Alfred Hunt	Henry Cleveland	1951	400	16	137	120	Dec. 1960	T,Ng, 130	Irr	Cased to bottom. Slotted from 100 ft to bottom.
402	do	do	1953	700	20, 16	133	120	do	T,Ng, 250	Irr	Casing: 20-in. to 200 ft, 16-in. from 200 ft to bottom. Measured discharge 1,540 gpm on Aug. 27, 1963. Pump set at 250 ft.
503	Peck Bros.	H. L. Powell	1948	600	20, 12	137	--	--	T,Ng, 120	Irr	Casing: 20-in. to 160 ft, 12-in. from 160 ft to bottom. Slotted from 200 ft to bottom. Measured discharge 490 gpm on Aug. 27, 1963. Temp. 76°F.
504	do	Katy Drilling Co.	1953	710	20, 12	136	--	--	T,Ng, 190	Irr	Casing: 20-in. to 318 ft, 12-in. from 318 ft to bottom. Slotted from 105 ft to bottom. Measured discharge 1,110 gpm on Aug. 27, 1963. Drilled to 845 ft, plugged back to 710 ft. Temp. 75°F. 1/
505	Don Fenner	H. L. Powell	1948	627	20, 12	128	63.5 67.0 91.0	Mar. 20, 1956 Mar. 22, 1960 Mar. 5, 1964	N	N	Casing: 20-in. to 197 ft, 12-in. from 197 ft to bottom. Slotted from 300 ft to bottom. Measured discharge 1,200 gpm on July 6, 1955. Liner from 197 to 202 ft. Used as observation well. Temp. 77°F. Discontinued as irrigation well.
506	do	Henry Cleveland	1951	505	20	129	90.1	Mar. 5, 1964	T,Ng, 200	Irr	Cased to bottom. Slotted from 200 ft to bottom. Drilled to 830 ft, plugged back to 505 ft. Measured pumping level 230.85 ft while discharging 710 gpm on Aug. 27, 1963. Pump set at 250 ft. Temp. 76°F. 2/
507	do	O. E. Mickelson	1942	217	12	126	41.2 63.8 68.7	Dec. 15, 1942 Mar. 22, 1960 Mar. 5, 1964	T,Ng, 38	Irr	Casing slotted from 72 ft to bottom. Used as observation well. Well 304 in 1943 Jackson County report. 1/
508	do	do	1942	210	12	129	43.3 62.4	Dec. 15, 1942 Apr. 2, 1959	T,Ng, 33	Irr	Cased to bottom. Slotted from 65 ft to 100 ft, 108 to 122, 134 to 144, and 156 to 210 ft. Measured discharge 490 gpm on Aug. 27, 1963. Pump set at 150 ft. Drilled to 302 ft, plugged back to 210 ft. Formerly used as observation well. Well 305 in 1943 Jackson County report. 1/
* 509	do	Katy Drilling Co.	1963	729	20, 12	130	204.9	Aug. 21, 1963	T,Ng, 225	Irr	Casing: 20-in. to 399 ft, 12-in. from 399 ft to bottom. Slotted from 268 ft to bottom. Drilled to 1,016 ft, plugged back to 729 ft. Measured pumping level 270 ft after discharging 2,380 gpm for 18 days on Aug. 21, 1963. Pump set at 270 ft. Temp. 78°F. 2/
601	M. G. Johnson	H. L. Powell	1950?	600?	--	126	150.8	Aug. 14, 1963	N	Irr	

See footnotes at end of table.

Table 6.--Records of wells in Jackson and adjacent counties--Continued

Well	Owner	Driller	Date com-plet-ed	Depth of well (ft)	Diam-eter of well (in.)	Altitude of land surface (ft)	Water level: Below land-surface datum (ft)	Water level: Date of measurement	Method of lift	Use of water	Remarks
PP-66-51-602	Charles Shefcik	H. L. Powell	--	530	20, 14	119	70	Apr. 1959	T,G, 156	Irr	Casing: 20-in. to 180 ft, 14-in. from 180 ft to bottom.
* 603	Jackson County	--	--	75	4	123	33.1 38.4	July 17, 1934 Mar. 21, 1950	N	N	Bored well. Well 5 in 1943 Jackson County report. Formerly used as observation well. Abandoned. Temp. 73°F.
604	Keith Cox	Crowell Bros.	1957	663	20, 16, 12	124	63.7 195.0 62.0	Mar. 22, 1960 Aug. 14, 1963 Mar. 20, 1964	T,Ng, 180	Irr	Casing: 20-in. to 119 ft, 16-in. from 119 ft to 302 ft, 12-in. from 302 ft to 663 ft. Slotted from 240 to 663 ft. Pump set at 260 ft. Measured discharge 1,380 gpm on Aug. 17, 1963. Drilled to 815 ft, plugged back to 663 ft. 2/
701	C. H. Greer	Chas. Chase	1959	220	4	103	--	--	T,E, 2	Irr	Reported discharge 60 gpm. Reported irrigates 17 acres of pasture.
801	Paschall & Utz	Henry Cleveland	1953	616	20, 16	117	88.3	Aug. 6, 1963	T,G, 109	Irr	Casing: 20-in. to 245 ft, 16-in. from 245 ft to bottom. Slotted from 100 ft to bottom. Well blocked at 320 ft; 100 ft of sand between 100 and 316 ft. No water coming through the blockage. Measured pumping level 162.00 ft after 1 hour pumping at 505 gpm, Aug. 7, 1963. Casing collapsed at 320 ft. Temp. 73°F.
802	do	do	1951	620	20, 18	115	39.2 63.9 105.9	Apr. 3, 1951 Mar. 22, 1960 Aug. 6, 1963	N	N	Casing: 20-in. to 240 ft, 18-in. from 240 ft to bottom. Slotted from 100 to 620 ft. Casing reported collapsed at 350 ft. Dis-continued irrigation well. Formerly used as observation well. Abandoned.
803	Roy Budd	Katy Drilling Co.	1954	865	20, 12	114	--	--	T,Ng, 50	Irr	Casing: 20-in. to 317 ft, 12-in. from 317 ft to bottom. Slotted from 193 ft to bottom. 1/
804	Dean and Gayle Morton	do	1953	785	20, 12	112	--	--	T,Ng	Irr	Casing: 20-in. to 318 ft, 12-in. to bottom. Slotted from 200 ft to bottom. 1/
805	Walter and Travis Morton	Henry Cleveland	1950	804	20, 16	113	57.9	Mar. 22, 1960	T,Ng, 145	Irr	Casing: 20-in. to 200 ft, 16-in. from 200 ft to 600 ft. Slotted from 190 to 250 ft. 2/
806	Koop Bros.	Leonard Mickelson	1951	768	18, 16, 12	106	--	--	T,Ng	Irr	Casing: 18-in. to 199 ft, 16-in. from 199 to 310 ft, 12-in. from 310 ft to bottom. Slot-ted from 140 ft to bottom.
807	do	do	1951	675	18, 16, 12	104	--	--	T,Ng, 160	Irr	Casing: 18-in. to 196 ft, 16-in. from 196 to 299 ft, 12-in. from 299 ft to bottom.

See footnotes at end of table.